THE POTENTIAL EFFECT OF SOLUTION SEAMS ON RESERVOIR PERFORMANCE IN A SANDSTONE RESERVOIR

A case study from an Ashgillan (Late Ordovician) reservoir in North Africa

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INTRODUCTION

Stylolites are diagenetic features that occur in many carbonate reservoirs, and more rarely in some sandstone ones (Koepnick et al. 1987& Corwin. et al 1997). They are seams of insoluble residue that record the removal of rock by pressure dissolution. These geological features occur with various amplitudes. In the reservoir under study, inspection of recovered cores reveals that the stylolites occur as low amplitude solution seams (SS). These geological features might affect vertical transmissibility as barriers and baffles, and consequently water flood performance for this reservoir.

This paper introduces the detailed geological, petrophyiscal, and engineering approaches that have been applied in order to estimate the effect of SS on reservoir performance.

GEOLOGICAL APPROACHES

Close inspection of the core reveals that the SS distribution is quite regular in this reservoir (varying from 1 to 2 per foot) in all cored intervals. Several scales of laboratory geological characterisation were carried out in order to estimate the impact of these geological features on the reservoir performance (i.e fluid flow properties).

1. Environmental Scanning Electron microscopy (ESEM, Fig.1a).
2. Thin section analysis (Fig.1b).

PETROPHYSICAL APPROACHES

Three main approaches were followed:

1. Small-scale probe-permeametry profiles (profile A& B, Fig.2) along the solution seam. The average of the probe readings within each profile represents the permeability of the solution seam (ks).
2. Core plug data (both kh, kv) to measure the permeability of the SS. Two techniques were used:
   The first method (CP1) used the harmonic average equation by knowing the values of the permeability of matrix (k1, k2) in (Fig.3) from local plug kh and their thickness one can obtained the SS permeability, ks.
   In the second method (CP2) the arithmetic and harmonic average equations have been solved simultaneously by which, one can estimate the thin solution seam permeability, this technique developed by Natalya Williams (personal communication).
3. Hydraulic Unit Delineation (HU), (Amaefule et al, 1993) has also been used to characterise this reservoir. As can be seen (Fig.4) the sandstone reservoir can be classified into a several HU based on pore geometry. Interestingly, the relatively rare core plugs in HU7 represent the SS, which are quite common feature in this reservoir.

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ENGINEERING APPROACHES

From the engineering point of view, the SS could have a serious impact on vertical transmissibility by holding-up water. Therefore a careful reservoir simulation study was carried out, in order to model the effects of vertical transmissibility barriers and baffles on the reservoir performance.

Upscaling the probe and core plug permeability data to be used in the model.

The previously measured probe and plug permeability data have to be upscaled, in order to be used in the reservoir model. To perform that, two deterministic models have been used using a spreadsheet.

Three different types of rocks (different kh and kv/kh ratios) based on the rock texture and HU concept have been used in the models. These two models have been used to upscale the probe kh, and plug kv by using the arithmetic and harmonic average respectively.

Reservoir Simulation models

Two different reservoir simulation proposed scenarios were put forward as following:

- Optimistic model (SS were set parallel to the reservoir bedding, SS Case).
- Pessimistic model (SS cross the bedding fabric, TSS Case).

The two scenarios are compared with the base case (no SS incorporated in the model)

2D simple model

Using the above mentioned upscaled permeability a two-dimensional model of the reservoir (Fig.5) was built with two wells (an injector & producer). This model assumed that the reservoir was represented only by HU1 which, clean sandstone (kv/kh =1, Base case), this assumption were put forward in order to evaluate the gravity segregation effect on the sweep efficiency in a clean sandstone reservoir. In the other two models, the solution seams were incorporated into the models (SS & TSS Case) respectively. These models represented by HU1& HU7, which is SS dominated unit.

RESULTS AND DISCUSSION

From the probe-permeametry measurements, it is clear that the permeability value at the location of SS drops by an order of magnitude. The results of ks measurements from both probe and plug compare well (Fig.2 and Table 1). These show a low ks (1-6mD) in what is otherwise a high permeability reservoir (100-1000mD).

Method	Probe-permeametry	CP1	CP2
Solution seam profile (A), k mD	5	5.2	5
Solution seam profile (B), k mD	2.17	1.2	1.3

Table 1: Permeability of solution seam determined by various methods.

The upscaling results reveal that the effective kh is not as affected by the presence of SS. However the effective kv dropped by an order of magnitude, which is a significant effect.
As can be seen in (Fig.5a) the water slumps because of gravity segregation, but this effect clearly has been reduced by the SS (SS Case), because they act as horizontals baffles and lead to more piston-like sweep (Fig.5b). This results in later break-through of water (Fig.6a) than in the previous case. Oil recovery, oil flow rate and reservoir pressure was quite similar for both cases (Fig.6b,d&c). That might be because of the high k in the base case, which made the viscous forces play a significant role in the sweep efficiency.
In TSS Case (Fig.5c) we observed much earlier break through (Fig.6a), and poorer recovery because of the trapped oil than in the previous cases (Fig.6b). The production rate in this case is also lower than the other cases, whereas the reservoir pressure was well conserved compared with the other two cases (Fig.6c).

CONCLUSION

1. Solution seams are important features in the sandstone reservoir, forming horizontal baffles which reduce the gravity segregation, and delay the water break through, consequently improving the oil recovery.
2. The HU approach is a powerful approach for reservoir description, if a careful handling and sampling scheme for the core can be achieved.
3. Solution seams are a common feature in this reservoir, therefore a full-field simulation model considering more accurate spatial distribution of solution seams (outcrop analogue) is crucial

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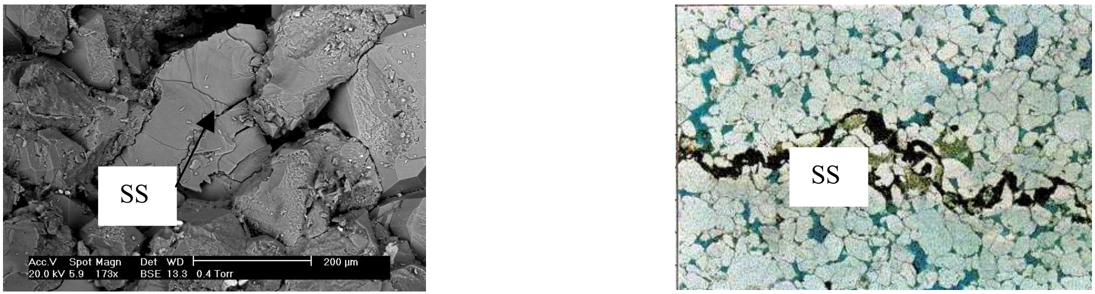

a. ESEM image. b. Thin section.

Figure 1: ESEM and thin section in which the solution seams can be clearly seen at the pore scale.

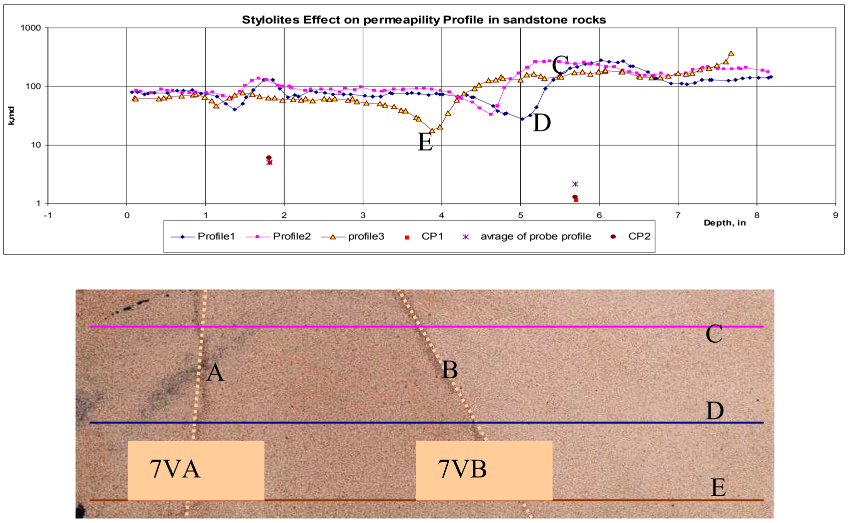

Figure 2: Small-scale probe-permeametry and the plug (7VA&7VB) determined solution seam permeability measurements.

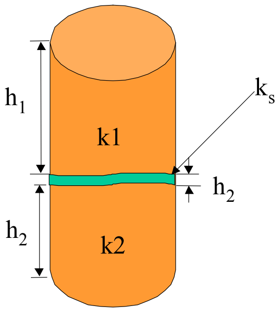

Figure 3: Schematic diagram of a core plug with solution seam

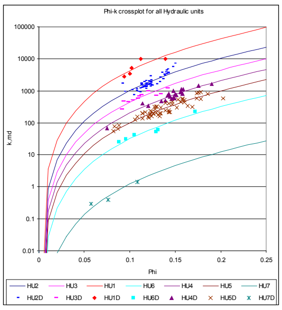

Figure 4: Improved k-phi classification using HU approach.

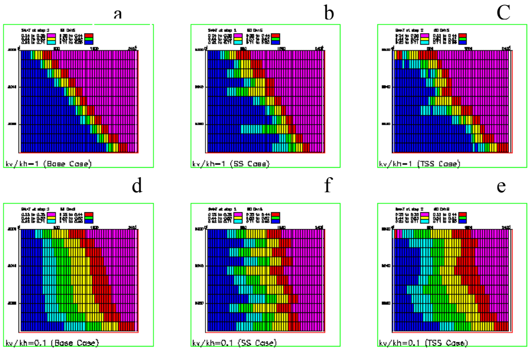

Figure 5: Water saturation front vs. distance. For the base case (a), SS case (b), T SS case (c) (kv/kh=1). It is clear that the anisotropy (kv/kh=0.1) reduces gravitational effects and make the displacement more piston like (d, e& f).

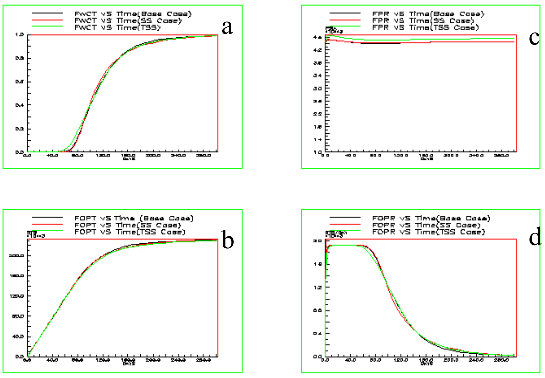

Figure 6: Field water cut(FWCT), oil production total(FOPT), pressure(FPR) & oil production rate (FOPR) for the three cases.

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