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GEOLOGICAL DESCRIPTION AND FLOW CHARACTERIZATION OF A NORTH SEA CHALK CONTAINING STYLOLITES AND A GOUGE-FILLED FRACTURE

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ABSTRACT

A geological description and fluid displacement experiment have been conducted on a core sample containing both stylolites and a gouge-filled fracture to investigate their effect on fluid flow and their fluid retention characteristics. Magnetic Resonance Imaging (MRI) was utilized during the displacement experiment to monitor fluid movement within the core sample.

Scanning electron microscope (SEM) and MRI analyses indicated that both the grain and pore size within the gouge-filled fracture had been reduced with respect to the adjacent chalk matrix. This reduction resulted from the mechanical breakdown of the coccolith fragments that made up the bulk of the chalk matrix into their constituent, submicron size platelets, as opposed to the crushing of individual calcite crystals. The reduction in pore size contributed to an increased degree of capillarity within the gouge-filled fracture, as was evidenced in MRI images during the displacement experiment.

During the gas displacement experiment, the core sample, containing decane and residual water, was progressively desaturated by the injection of nitrogen. MRI analyses were performed at each level of desaturation. The gouge-filled fracture was observed to exhibit a displacement pressure that was greater than that of the adjacent bulk matrix. MRI analyses also indicated that the effect of the stylolite on fluid flow was negligible. The final distribution of the residual fluids upon desaturation indicated that the stylolites and the gouge-filled fracture did not act as an impediment to fluid movement.

INTRODUCTION

Core descriptions of Shetland Group chalks from naturally fractured reservoirs in the Greater Ekofisk area of the Central Graben, North Sea indicate that the reservoirs contain a number of discontinuities. Open natural fractures are the major factor enhancing permeability in these reservoirs; however other features such as gouge-filled fractures and stylolites are also present in large numbers. Gas displacement experiments were designed to assess the potential influence of these features on the flow of hydrocarbons. Gouge-filled fractures are perhaps the most obvious visual features in core samples. The morphology of this type of fracture is varied, but they most commonly appear as braided networks of fine dark brown lines that stand out in relief on the outside of the cores. In hand samples they are harder than the adjacent chalk matrix. The healed fracture networks occur in allochthonous chalk facies and are thought to result from several episodes of syn- to post-depositional deformation that occurred before diagenetic processes had fully lithified the chalk matrix.

MICROSTRUCTURE

Although the gouge-filled fractures are strikingly visible on the cores, once hydrocarbons have been extracted from the samples for thin section and SEM analysis, the features are very difficult to see. A gouge-filled fracture that traversed the entire diameter of a core was selected for study. Its microstructure was examined petrographically and by SEM imaging using both secondary electron images of a rough sample and back-scattered electron images of a polished thin section. In thin section the gouge-filled fracture was observed to be slightly oil stained in spite of sample cleaning. There was also minor alignment of elongate grains within the zone which indicate shear across the zone.

Using SEM secondary electron imaging, the texture of the gouge-filled fractures were almost indistinguishable from that of the adjacent chalk matrix. Figure 1 is an example of the undeformed bulk matrix which is composed primarily of coccolithophorid platelets and rings of platelets termed coccoliths. By contrast, the grains of the gouge-filled fracture are mostly platelets and broken coccoliths and appeared to be smaller and more closely packed than in the adjacent undeformed material (Figure 2). Thus, shear across the zone, which was indicated by the alignment of elongate grains, has produced cataclasis.

The porosity reduction within the gouge-filled fracture has been documented using histogram segregation of a series of images taken in sequence across the fracture. Porosity reduction within the gouge-filled fracture (Figure 3) was accompanied by a reduction in both average grain and pore size.

DESCRIPTION OF DISPLACEMENT EXPERIMENT

The whole core, 6.6 cm in diameter, containing stylolites and a gouge-filled fracture, was subjected to a gas displacement, porous membrane experiment to investigate the effect of these features on fluid flow. The objectives of the experiment were to attempt to define the displacement pressure of the bulk matrix and of the gouge-filled fracture, monitor the fluid distribution throughout the displacement process, and identify any locations of fluid 'trapping' due to a lack of flow conductivity and/or capillary continuity.

The displacement experiment utilized decane as the hydrocarbon phase, deuterium oxide (heavy water) as the water phase, and nitrogen as the gas phase. There were two primary reasons for the selection of decane and deuterium oxide as the liquid phases. First, with these fluids, solvent cleaning of the core sample after the experiment was not required. Mere drying of the core in a vacuum oven at 200 degrees F evaporated the fluids without leaving any residue. This preserved the character of the core sample without risk of mechanical degradation or altering the wettability state of the sample. The second reason is that the hydrogen nuclei of decane were detectable by the MRI, while the deuterium oxide will not produce a signal. In this two-phase system, MRI interpretation was simplified because areas containing hydrocarbon appeared as bright areas, while the areas containing the water phase appeared dark. The MRI intensity is proportional to the concentration of hydrogen nuclei, thus decane saturation.

The core sample, 6.6 cm in diameter and 14 cm in length, was assembled in a Hassler-type cell that utilized nylon endpieces. The core assembly was subjected to a confining pressure of 1500 psi for the duration of the experiment. Pressures across the core were initially low and were progressively increased throughout the course of the experiment. The core was initially oil saturated with a residual water present of 18 percent pore volume. MRI imaging indicated that the initial hydrocarbon distribution throughout the core was uniform. MRI also clearly defined the position of the stylolites and gouge-filled fracture within the core, as well as other characteristic features.

The initial pressure exerted across the core sample was 5 psi and no hydrocarbon production was observed. The pressure was increased to 10 psi and still no production was observed. The pressure was increased to 20 psi and the decane began to flow from the core sample. This indicated that the displacement pressure for the bulk matrix was between 10 and 20 psi. This pressure was maintained until a flow rate of approximately 0.2 cc/day was achieved and the experiment was then suspended. The MRI images indicated that the bulk matrix of the core had a lower intensity, indicative of the hydrocarbon being replaced by the nitrogen, while the region of the gouge-filled fracture had not significantly changed from its original hydrocarbon saturation. The core assembly was loaded into the test cell and the test continued. Additional pressures investigated were 35 psi, 50 psi, and 75 psi. MRI imaging was conducted at each of these pressures to monitor the change in fluid distribution and the saturation levels within the core. A summary of the oil production data observed is presented in Figure 4. The majority of the production was early in the experiment; however, oil production was observed to continue, albeit at a very low rate.

Figure 5, images (a) through (e), illustrates a comparison of the residual fluid saturation within the core sample throughout the different segments of the experiment.

Image 5(a) is the baseline fluid distribution prior to any gas injection. The hydrocarbon phase, decane, appeared very bright due to its high initial saturation. The two dominant stylolites, running diagonally from lower-and-mid left to the upper-right, and the primary gouge-filled fracture, running diagonally from the middle left to the lower right of the image, both appear darker than the bulk of the matrix material. This is attributable to the reduced porosity, hence less fluid saturation, associated with these features.

After exposure to a pressure differential of 20 psi, image 5(b) was produced. The bulk matrix appears less bright than the baseline image. This is due to the reduction of hydrocarbon present within the system. The stylolites and the gouge-filled fracture appear brighter than the bulk matrix due to their retention of the residual hydrocarbon phase. The 20 psi pressure differential, while sufficient to displace the decane from the bulk matrix, was not sufficient to displace the fluid within the primary gouge-filled fracture. This is indicative of a higher displacement pressure for the fracture than what was observed for the bulk matrix.

In the subsequent images, (c) through (d), the intensity changes very little. The residual oil for these cases changes from 39 percent to 35 percent of total pore volume. The bulk matrix intensity demonstrates a very slight darkening which is representative of the reduction of hydrocarbon presence due to further production at the increased pressure differentials.

The stylolites appear to be constant in intensity throughout the experiment. The primary gouge-filled fracture appears to exhibit a slight reduction in size and intensity as the pressure differential had been increased. However, this feature still retained the majority of its original hydrocarbon saturation. Again, this is indicative that even at a differential pressure of 75 psi, the gouge-filled fracture's displacement pressure had not yet been attained.

DESCRIPTION OF NUCLEAR MAGNETIC RESONANCE IMAGER

All NMR images (also known as Magnetic Resonance Images, MRI) were obtained with a SISco 85/310 NMR imager. It has a 31 cm bore 2 Tesla magnet and operates at 85.55 MHz for hydrogen protons. A 9 cm internal diameter saddle coil was used as both transmitting and receiving coil. Signals from hydrogen protons were obtained with a spin-echo Hahn sequence. An echo time of 6.2 ms and a recovery time of 2500 ms were used. Five slices, each 2.3 mm in thickness, were obtained parallel to the cylindrical axis of the core. This orientation produced rectangular images. One set of images were obtained perpendicular to the cylindrical axis and appear as a series of circles. The former were used to follow flow, since it was along the cylindrical axis, while the latter were used to verify the location of the fractures. The field of view was 16 by 8 cm with each pixel 0.556 by 0.625 mm. The images consist of 255 levels of gray in a 256 by 256 display. The intensities of individual pictures were adjusted to give a presentable visual display. For quantitative determinations the absolute intensities were used. The stainless steel endpieces used in the Hassler assembly had to be removed prior to imaging the cores due to image distortion that was generated by the metallic mass. Nylon endpieces were used in the last tests in order to minimize the potential damage to the core system caused by the removal and subsequent replacement of the standard metallic endpieces. The nylon endpieces permitted imaging of the intact core assembly at various levels of desaturation. This allowed a profile of the desaturation of the core as a function of time, as opposed to the previous experiments in which only the initial and final saturation distributions could be examined.

CONCLUSIONS

Several conclusions can be drawn from the flow experiments. First, there was no apparent diversion of fluid flow attributable to the presence of the stylolites or the gouge-filled fracture. No evidence was found to indicate fluid holdup or bypass at either of these features. This observation for the stylolites is consistent with previous research reported in the literature (Reference 1). No previous work investigating the affect of gouge-filled fractures on fluid flow were identified. Total hydrocarbon production from the core sample was comparable with clean, fairly homogeneous North Sea samples.

Second, the gouge-filled fracture did not release the fluids contained within it under any of the differential pressures investigated, while the bulk matrix initially produced fluid between 10 and 20 psi. This indicates that the gouge-filled fracture exhibited higher capillary characteristics than that of the bulk matrix. This concept is consistent with the geological analyses of this feature.

A second displacement experiment was conducted on the same core under similar circumstances; however, a constant differential pressure of 75 psi was maintained throughout the experiment. This was done to investigate if the phenomena of the gouge-filled fracture retaining its fluids could have been attributable to the interrupted flow process. However, when the second test was completed, MRI analysis indicated that the gouge-filled fracture still retained the fluid as before, again most likely attributable to an increase in capillary forces due to the reduction in pore size within this feature.

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REFERENCES

1. Lind, I., Nykaer, Ol, Priisholm, S., and Springer, N., "Permeability of Stylolite-Bearing Chalk," SPE Paper 26019, *JPT*, November 1994, 986-993.

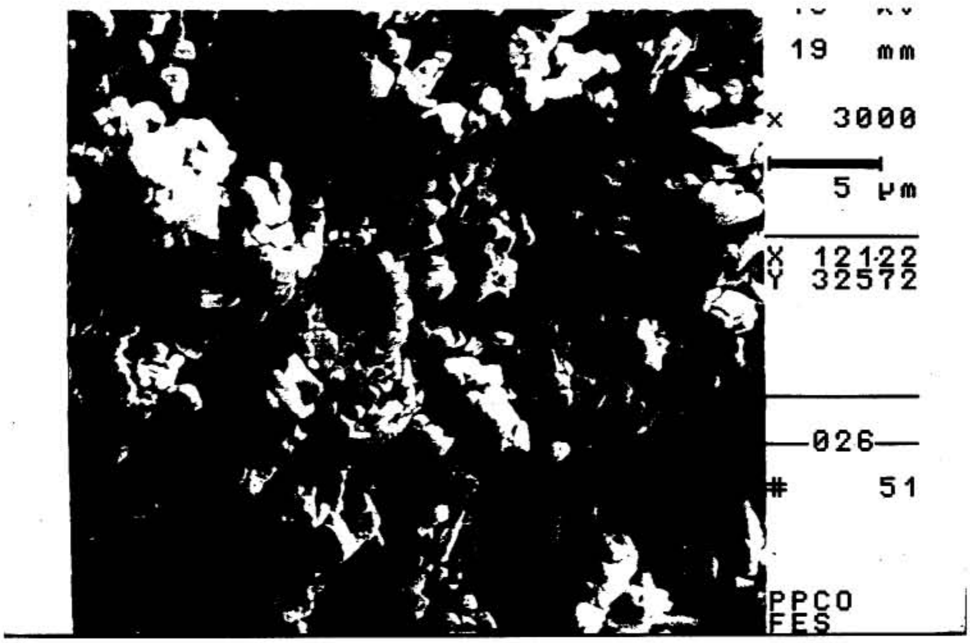


Figure 1 – SEM photograph of undeformed bulk matrix of a North Sea chalk sample.

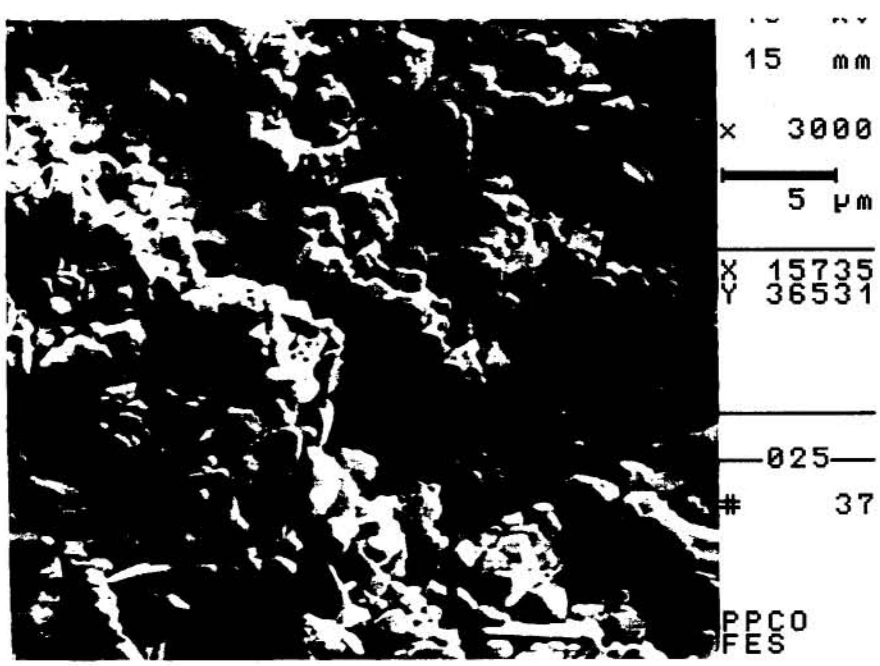


Figure 2 – SEM photograph of the gouge-filled fracture region of a North Sea chalk sample.

Figure 3: Porosity reduction across a gouge-filled fracture in a North Sea chalk sample

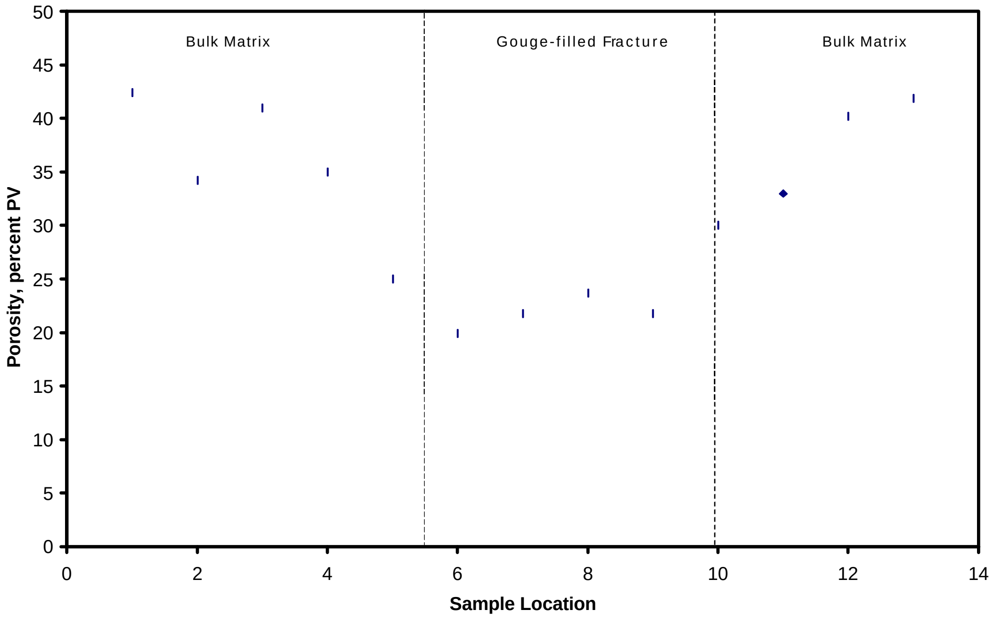
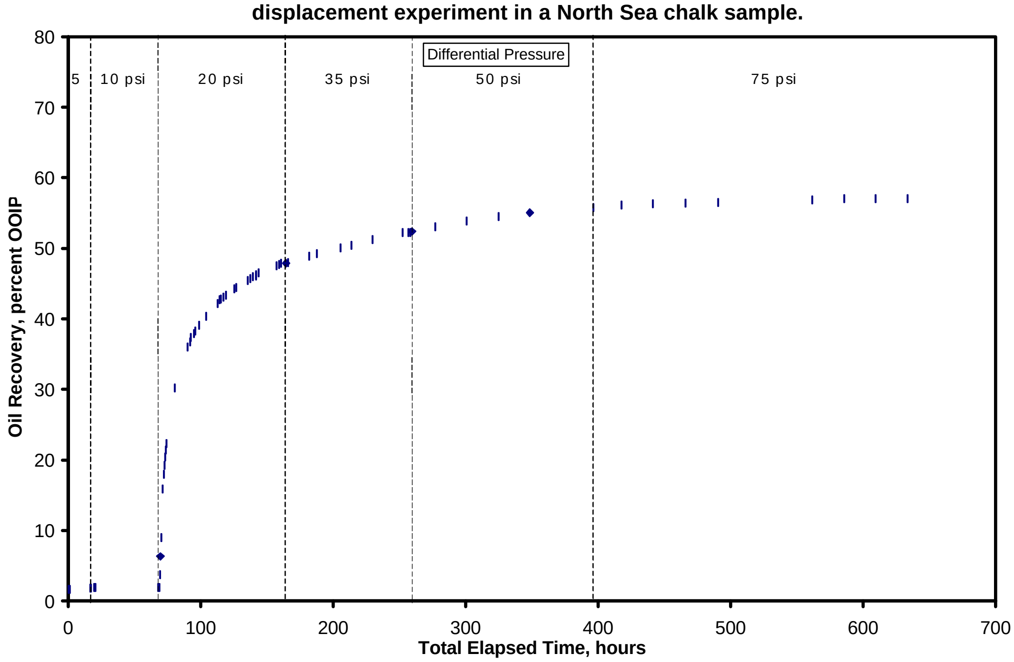
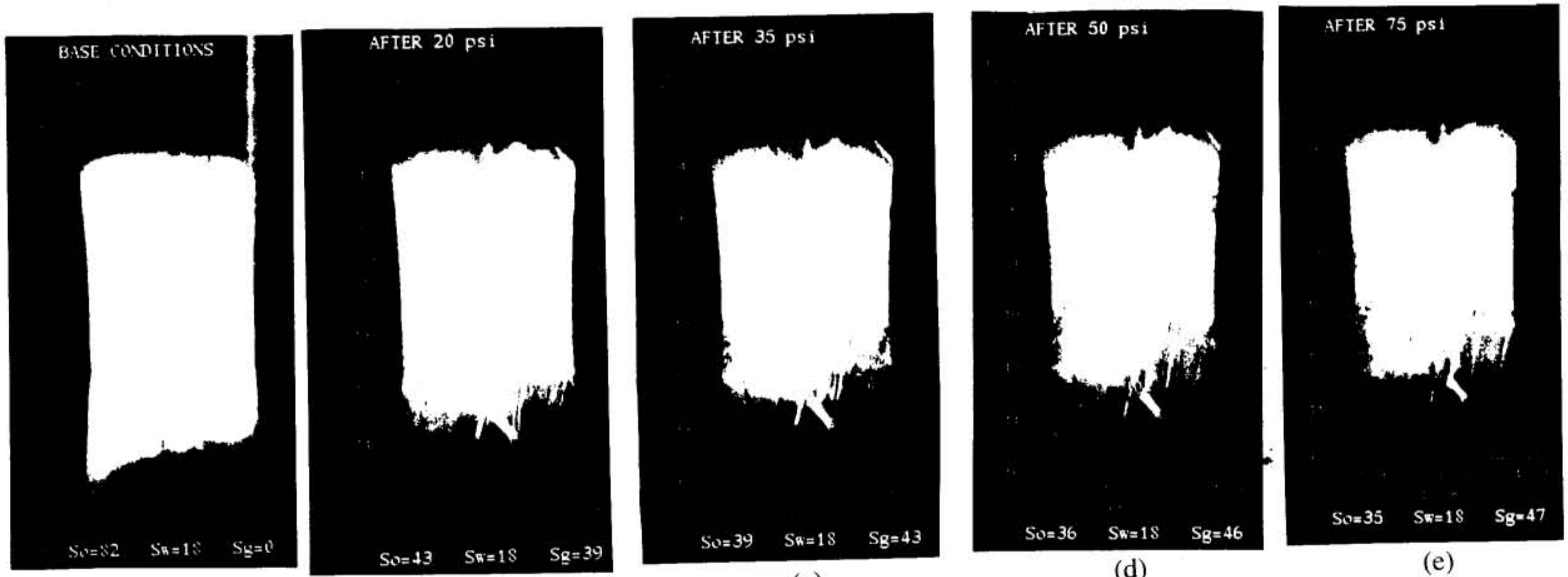


Figure 4: Oil recovery as a function of time and pressure differential for the gas displacement experiment in a North Sea chalk sample.





(a) (b) (c) (d) (e)

Figure 5 – Comparison of residual fluid distributions throughout a gas displacement experiment.