A REAPPRAISAL OF THE EVIDENCE FOR DAMAGE CAUSED BY OVEN DRYING OF HYDROCARBON ZONE CORE

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ABSTRACT

Seminal work published in the early 1980's raised awareness of the problem of potential damage to reservoir rock caused by oven drying. A driving force behind this early research was the need to explain differences between well-test and conventional core analysis data. The main focus of this and subsequent work was the determination of permeability in both the dried state and fully water saturated state of water zone samples containing various quantities of clay minerals, since clay was suspected as the causal agent with regard to permeability alteration.

New work performed chiefly on hydrocarbon zone core presented here confirms significant differences between brine and Klinkenberg permeability but demonstrates compatibility between permeability in the dried state and at connate water saturation. These new data lead to the conclusion that alteration to clay morphology in hydrocarbon zone samples is caused by resaturating largely oil-filled samples with brine and not by oven drying.

Data from a plurality of fields are presented demonstrating close agreement in permeability in both the dried state and at connate water saturation for oil zone core samples. The authors hypothesize that susceptibility to alteration of clay morphology from the original state by drying is a function of the history of interfacial forces experienced by reservoir rock samples, and thus of height above free water level. Data for a suite of clay-rich samples tested from a single well extending from the water zone through to the oil zone, covering a vertical depth range of some 150 metres, are strongly supportive of this hypothesis.

INTRODUCTION

The issue of potential alteration to delicate mineral structures contained within reservoir rock samples by oven drying started to achieve widespread recognition some twenty years ago. The interfacial forces experienced by fibrous clay minerals during drying were shown to cause damage to these structures.

Early work performed around this time concentrated upon gas / brine permeability ratios to provide a quantitative measure of damage, an approach which is now well established. Sample selection was also heavily biased in favour of water zones. Effective permeability to gas or oil at connate water saturation was rarely reported.

However, observations made by the authors during the course of normal special core analysis field studies on hydrocarbon zone core led to the recognition that gas-to-brine

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permeability ratios cannot be used in isolation in this regard, and do not in fact necessarily relate to damage during oven drying at all. Comparisons of effective oil permeability, brine permeability and gas permeability showed unequivocal compatibility between gas and oil permeability, with brine permeability being invariably lower. This suggests that introduction of brine to the samples resulted in loss of permeability, rather than oven drying causing an increase in permeability.

All of the early commentators on the subject observed much larger differences between brine and gas permeability in the water zones compared with hydrocarbon zones. de Waal and co-workers [1] speculated that delicate illite formation post-dated hydrocarbon emplacement in their field, as did Heaviside et al [2] despite their being no difference in overall clay content or type with depth in the Magnus field.

It is surprising that capillary pressure measurements have not been more extensively used in view of the causality attributed to interfacial forces in the alteration of clay structures. This paper contains new capillary pressure and permeability data in addition to data culled from the literature in support of a new theory relating to all of these observations.

A NEW HYPOTHESIS

The authors propose that the magnitude of capillary forces experienced by reservoir rock at a given point in a continuous hydrocarbon accumulation is a primary agent governing the in-situ morphological structure of clays and thus susceptibility to irreversible change of these components by subsequent oven drying in the laboratory.

This hypothesis would predict that samples originating from above some critical height in an hydrocarbon accumulation would be immune to damage by oven drying. It is also a consequence of this theory that samples from a water zone would be naturally vulnerable to damage by interfacial forces. They could potentially suffer permanent alteration to their properties even during recovery from the reservoir thus limiting their value for subsequent laboratory studies. A number of experiments were devised and carried out to test the new hypothesis. These are described below.

EXPERIMENTAL DETAILS

Permeability Studies

A total of 21 preserved samples originating from the oil zones of seven wells in three separate fields in the West of Shetland province were selected for study. The selected samples were miscible flush cleaned prior to being miscibly displaced to brine. Permeability to brine was then determined. At this point they were desaturated with gas in an ambient porous plate vessel at a drainage pressure of 128 psi. Upon reaching equilibrium, the samples were removed from the pot and saturated with kerosene. Effective permeability to oil was then determined. Whilst flowing with oil, care was taken to maintain the differential pressure below 40 psi. The samples were then miscibly displaced to methanol and oven dried in a dry oven at 95°C.

CAPILLARY PRESSURE STUDIES

A total of 11 preserved samples originating from a Central North Sea Triassic gas reservoir were selected for study. The samples came from the gas and transition zones. The samples were known to contain significant quantities of diagenetic illite and chlorite. Offcuts of each sample were soxhlet cleaned and dried and subjected to high pressure mercury intrusion to give an indication of the proportion of porosity comprised of clay-related microporosity. The samples were miscible cleaned without initial drying and miscibly displaced to brine. At this point they were desaturated with gas at a suite of drainage capillary pressures up to 128 psi in a porous plate pot. At the end of this cycle, they were flushed with methanol and dried in a dry oven at 95°C. After determination of Klinkenberg [3] permeability they were resaturated with brine and subjected to a repeat series of desaturation pressures up to 64 psi. Klinkenberg permeability was then determined at connate water saturation. Care was taken to ensure that the differential gas pressure during these permeability determinations did not exceed the ultimate drainage pressure.

RESULTS AND DISCUSSION

PERMEABILITY TRENDS

The brine, Klinkenberg and effective permeability to oil data for the West of Shetland samples are presented in Table 1. The data have been cross-plotted in Figure 1. The oil and Klinkenberg permeabilites are strikingly compatible despite the fact the samples had never been dried prior to effective oil permeability determination. This indicates that the brine permeabilities were in fact reduced by some mechanism and that the Klinkenberg permeabilities have not been enhanced by drying. The authors' hypothesis would suggest that the brine permeabilities were reduced by the expansion of otherwise constrained flexible components due to the absence of capillary forces in a 100% brine system.

Similar data were discovered in a publication by Mikkelsen et al [4] who studied both oil and water zone material. A range of different procedures were used to acquire initial water saturations, which may have introduced some uncertainties. Nonetheless, the work is of interest since both oil and water zone samples are included and despite the fact that

Mikklesen did not analyse his own data in the manner that the authors of this paper have done.

A cross-plot for oil zone samples is shown in Figure 2. These data appear compatible with the data generated by the current authors. Water zone samples are presented in Figure 3. A number of these samples show a very large increase in gas permeability over effective oil permeability, which may relate to some damage mechanism. The big difference in behaviour between the oil and water zones as predicted by the authors' hypothesis is noteworthy.

CAPILLARY PRESSURE DATA

Drainage capillary pressure curves were compared for each sample in the preserved state and after oven drying. In order to make a comparison, the difference in water saturation at 64 psi between the two cycles was calculated. The water saturation at 64 psi was interpolated using a simple power function for the preserved cycle. These data are presented in Table 2 together with the Klinkenberg permeability data in the dried state and the subsequent measurement at connate water saturation. Figures 4 and 5 display comparison plots for two of the samples, one from the gas zone and one close to the free water level.

The ratios of Klinkenberg permeability in the dried state to that at connate water saturation are plotted as a function of height above free water level in Figure 6. The ratio appears to increase markedly towards the free water level, but is very close to unity for samples more than 76 m above the free water level. Many of these samples more remote from the free water level nonetheless contain copious amounts of microporosity, just as the more transitional samples do. This may be observed in the pore frequency distribution functions presented in Figure 7.

The ratios of gas saturation at 64 psi (ratio of post-drying : preserved) are plotted as a function of height above free water level in Figure 8. The same group of samples with Klinkenberg ratios of unity also have hydrocarbon saturation ratios close to unity. The samples closest to the free water level present higher measured hydrocarbon saturations at 64 psi after drying, which seems to relate to an irreversible damage mechanism caused by the intermediate drying. The high Klinkenberg ratios exhibited by these samples, indicates recovery of clay morphology after resaturation. However, the saturation data reveal that this recovery is only partial, suggesting that the permeability ratios would have been higher still for these samples were they to have fully recovered their original pore morphology.

CONCLUSIONS

1. Differences between brine permeability in the preserved state and gas permeability after drying are insufficient grounds in isolation to deduce damage to delicate structures caused by oven drying.

2. The experimental work executed to date is supportive of the authors' hypothesis relating susceptibility to damage by oven drying to height above free water level.

3. Clay-rich samples originating from transition or water zones could suffer permanent alteration of clay structures during drainage capillary pressure tests regardless of the preparation methods used.

4. Comparison between drainage capillary pressure tests before and after oven drying can be used to assess the quantitative impact of damage caused by drying. Such a criterion could be used to screen existing dried core for damage to assess usefulness for further analyses.

5. Further work is required to elucidate some minimum height in a hydrocarbon zone, corresponding to a critical in-situ drainage capillary pressure, above which the clay structures are sufficiently robust to withstand normal oven drying without sustaining damage.

NOMENCLATURE

H_{FWL}	Height above Free Water Level
K_w	Brine Permeability
K_{eo}	Effective Oil Permeability
K_g	Gas Permeability
K_L	Klinkenberg Corrected Permeability
P_c	Capillary Pressure
S_w	Water Saturation

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[2] Heaviside, J., Langley, G.O., and Pallatt, N.: "Permeability Characterisitics of Magnus Reservoir Rock", *8th European Formation Evaluation Symposium*, (1983), 1-29.

[3] Klinkenberg, L.J.: "The Permeability of Porous Media to Liquids and Gases", *API Drilling and Production Practices,* (1941) **200**.

[4] Mikkelsen, M., Scheie, A., and de Boer, E.T.: "Abnormal Permeability Behaviour of a North Sea Sandstone Reservoir", *66th SPE Annual Technical Conference and Exhibition*, (1991), SPE 22600.

Table 1: UK West of Shetland Permeability Data

Well	**Sample**	**K_L**	**K_w**	**K_{eo}**
		mD	**mD**	**mD**
WOS1	1	730	321	528
WOS1	2	550	294	421
W0S2	3	1350	666	1026
WOS2	4	118	61	110
WOS3	5	990	281	883
WOS3	6	870	262	619
WOS4	7	930	274	746
WOS4	8	230	52	129
WOS4	9	520	118	383
WOS4	10	500	158	385
WOS5	11	267	165	284
WOS5	12	308	190	329
WOS5	13	176	84	176
WOS6	14	730	380	730
WOS6	15	800	390	780
WOS6	16	550	240	494
WOS6	17	651	268	603
WOS7	18	115	58	101
WOS7	19	233	118	206
WOS7	20	214	134	189
WOS7	21	248	131	217

Table 2: UK Central North Sea Capillary Pressure Data

Sample	**H_{FWL}**	**S_w @ 64 psi**		**K_L**	**K_L**
		preserved	**post-drying**	**dried**	**at S_{wi}**
	m			**mD**	**mD**
A	150.55	0.373	0.362	288	281
B	141.16	0.363	0.354	310	304
C	135.94	0.199	0.205	127	124
D	120.81	0.439	0.437	183	174
E	99.13	0.394	0.386	93	91
F	76.58	0.259	0.244	908	954
G	46.94	0.651	0.600	6.5	4.1
H	45.86	0.537	0.489	25.1	16.1
I	35.25	0.656	0.625	2.3	0.9
J	23.29	0.537	0.511	9.0	6.7
K	9.96	0.759	0.698	2.3	0.091

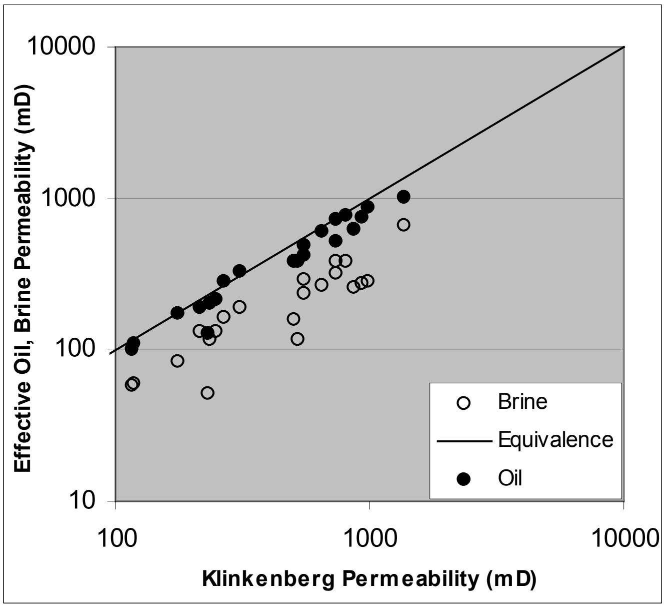

Figure 1: WOS Hydrocarbon Zone Permeability Trends

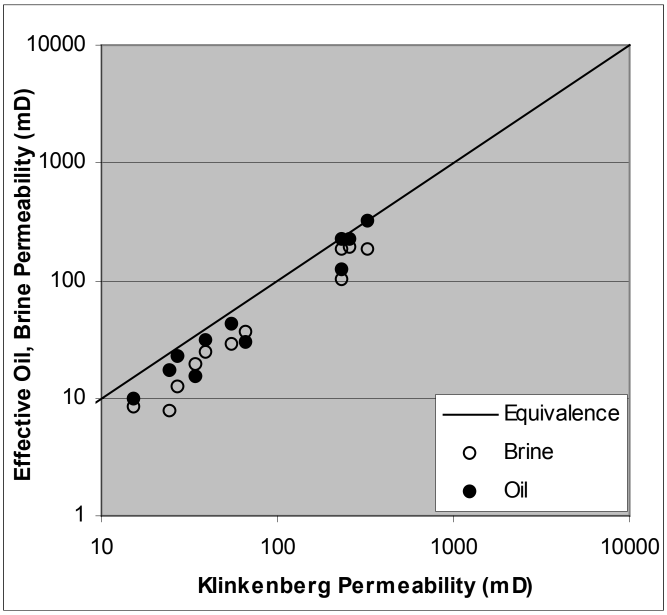

Figure 2: Hydrocarbon Zone Permeability Trends (from Mikkelsen et al.)

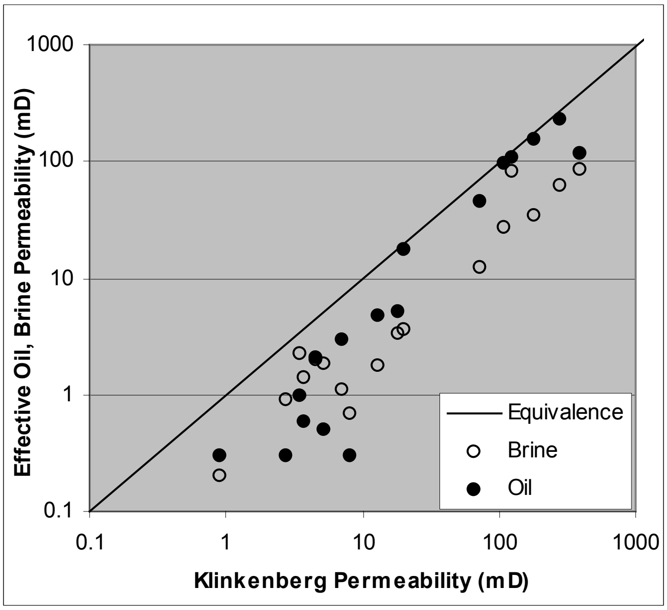

Figure 3: Water Zone Permeability Trends (from Mikkelsen et al.)

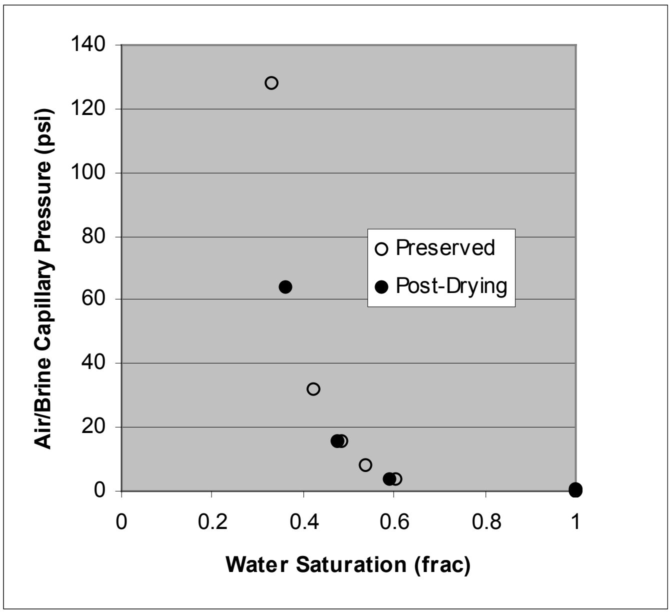

Figure 4: Capillary Pressure Comparison Hydrocarbon Zone (Sample A)

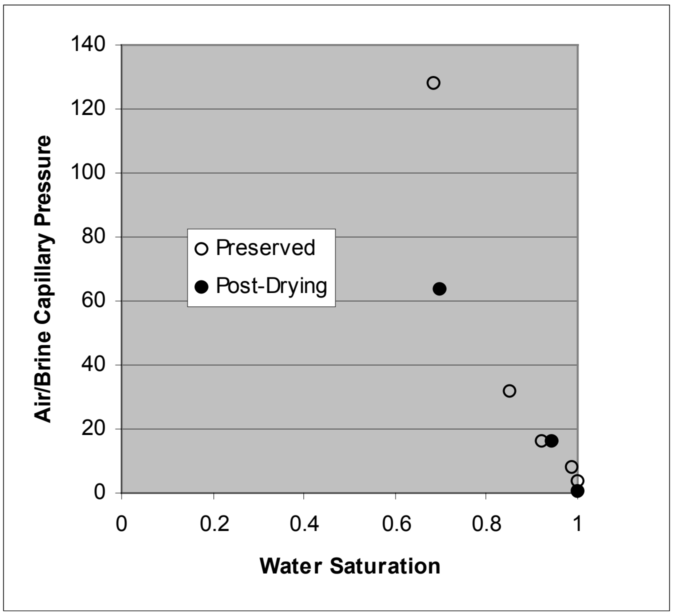

Figure 5: Capillary Pressure Comparison Transition Zone (Sample K)

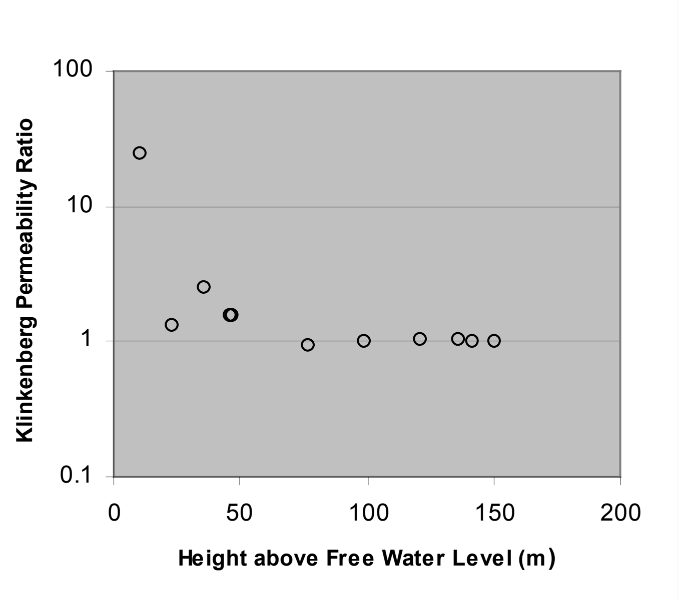

Figure 6: Klinkenberg Ratio (Dried : at Swi) versus Height above FWL

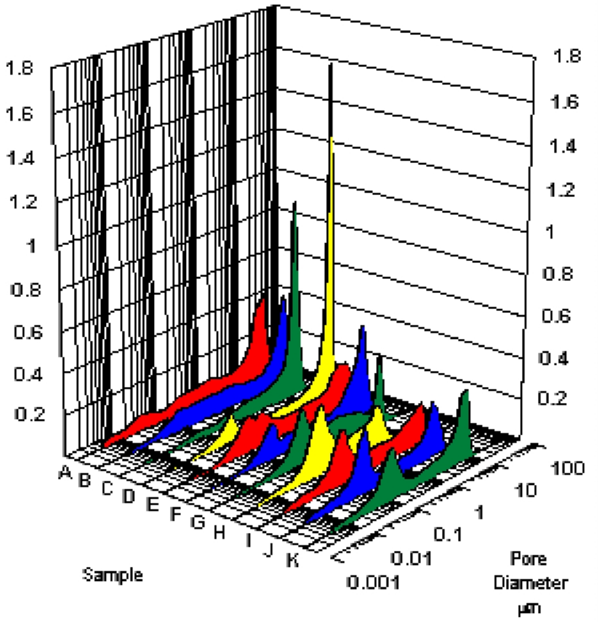

Figure 7: Pore Frequency Distributions for Central North Sea Gas Field Samples

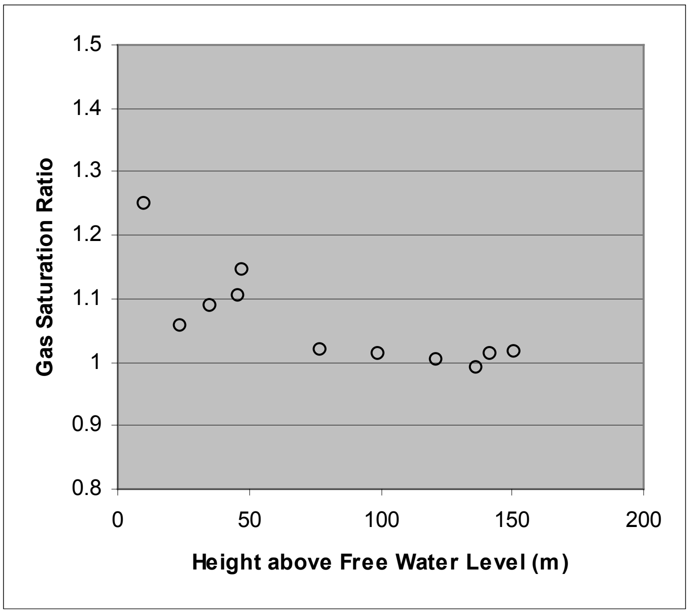

Figure 8: Gas Saturation Ratio (Post-Drying: Preserved) versus Height above FWL

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