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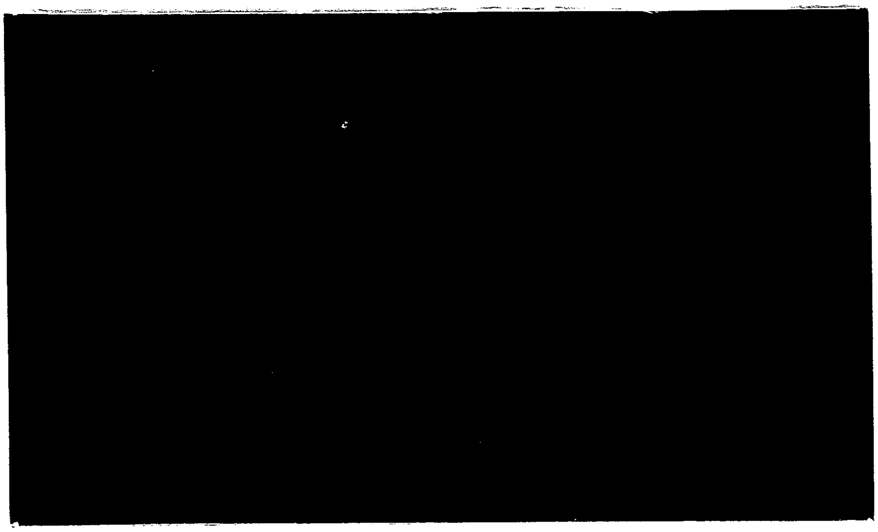

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HYDROCARBON MIGRATION WITHIN SANDSTONES OF THE LATROBE GROUP FROM VEILFIN-1 AND SAWBELLY-1, GIPPSLAND BASIN

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FHA

Fluid History Analysis

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ABSTRACT

- *A fluid inclusion study designed to develop an understanding of the migration and entrapment of liquid hydrocarbons in Latrobe Group reservoir sandstones has been completed for six samples from Veilfin-1 and a single sample from Sawbelly-1.*

- *Frequencies of oil bearing fluid inclusions (GOI) range from 0 to 2.0% which is comparable in magnitude to samples from beneath the OWC in known oilfields and is consistent with migration of oil under conditions of low oil saturation.*

- *Samples from Veilfin-1, with the exception of the 2030-35 m sample, come from presently gas saturated sands indicating the presence of intact seal. The low GOI values infer either limited oil charge, possibly due to low permeability or the absence of a valid trap during oil migration.*

- *In Veilfin-1 oil inclusions exhibit different fluorescence colours reflecting derivation from source rocks at different levels of maturity. The orange fluorescing oil inclusions, interpreted to be of low maturity, may represent oil generated in situ. The blue fluorescing oil inclusions seen in samples at 3770-75 m and 3405-10 m and interpreted to contain high maturity oil, are too mature to have been locally generated which indicates there are migration paths in these sands.*

- *In the single sample from Sawbelly-1 blue and white fluorescing oil inclusions indicate intersection with migration paths for mainly high maturity oil.*

- *The oil inclusions in all samples occur solely on fractures in detrital quartz and provide no direct constraint to the timing of oil migration. However, oil migration in Veilfin-1 is likely to have been restricted by low permeabilities which are the result of extensive early formed dolomite and mixed layer clay.*

HYDROCARBON MIGRATION WITHIN SANDSTONES OF THE LATROBE GROUP FROM VEILFIN-1 AND SAWBELLY-1, GIPPSLAND BASIN

M. Lisk

1 INTRODUCTION

An investigation of the oil migration history in sandstones from Veilfin-1 has been carried out using fluid inclusion techniques. The samples are ditch cuttings from the Eocene to Early Cretaceous section of the Latrobe Group. The location of samples and a summary of the data collected is shown in Table 1.

Table 1: Description of Samples

Depth (m kb)	CSIRO Sample Number	Borehole	Sample Type	Analysis
2030-35	122162	Veilfin-1	cuttings	hydrocarbon petrography
3185-90	122163	Veilfin-1	cuttings	hydrocarbon petrography
3210-15	122164	Veilfin-1	cuttings	hydrocarbon petrography
3225-30	122165	Veilfin-1	cuttings	hydrocarbon petrography
3370-75	122166	Veilfin-1	cuttings	hydrocarbon petrography
3405-10	122167	Veilfin-1	cuttings	hydrocarbon petrography
2890	122168	Sawbelly-1	cuttings	hydrocarbon petrography

This report presents observational information on the occurrence and frequency of oil bearing fluid inclusions. The objectives of the study are to assess the palaeo-saturation of these sands with respect to oil and to provide information on the timing of oil migration relative to the degradation of reservoir quality due to diagenesis. Sample depths are given as metres below the rotary kelly bushing (mkb).

The petrographic observations and fluid inclusion measurements are presented in Tables 1 and 2 and Figures 1 to 4. All premises used in the interpretations are stated so they can be evaluated with any data not available during this investigation.

1.1 Sample Preparation

The ditch cuttings were soaked overnight in dilute H_2O_2, washed in water and air dried at 40°C. Lithic fragments were removed by hand-picking with the resultant quartz concentrate prepared directly as a doubly polished fluid inclusion thin section.

2 PETROGRAPHY OF SAMPLES INVESTIGATED

With the exception of the sample at 2030-35 m which contains only solitary detrital quartz grains, these ditch cuttings contain sandstone chips made up of aggregates of quartz grains allowing the identification of diagenetic cements. These sandstone chips can be divided into two broad groups, one dominated by pore occluding carbonate cements (Fig. 1A), the other by clay cement. Authigenic clay minerals are dominated by mixed layer llite smectite type clays (Fig. 1B). These appear to be derived from widespread dissolution of labile grains and probably developed relatively early in the burial history. Kaolinite and illite (Fig. 2A)

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are also present although their distribution is more variable. The illite probably represents conversion of precursor mixed layer clays and could represent a late stage product of diagenesis as suggested for the Gippsland Basin by Bodard et al (1992). Quartz overgrowths occur in most samples although these are rare and are generally only developed where early cements are absent (Fig. 2B).

The second group of sandstone chips are carbonate cemented. Aggregates of quartz grains are enclosed in either fine grained amorphous carbonate cement or a more crystalline carbonate cement (dolomite and calcite ?). In the 3210-15 m and 3225-30 m sample a carbonate cement comprising small high relief rhombic crystals (clearly dolomite) is locally significant as a cementing phase. The presence of unaltered feldspars enclosed by carbonate cement (Fig. 1A) would suggest development of these phases was an early diagenetic event.

3 HYDROCARBON PETROGRAPHY

3.1 Overview

Fluid inclusions are small volumes of pore fluid encapsulated in crystallising cement. In diagenetic minerals they commonly range in size from 5 to 40 microns and are investigated by petrological microscope. Framework silicates and carbonate minerals such as quartz, feldspar and calcite may contain fluid inclusions. Evidence for changes in the nature of pore fluids can be derived from observations made on fluid inclusions within different cements together with recognition of primary and secondary inclusions within individual cements. This gives a relative, though not absolute, time scale for fluid migration during diagenesis. Primary diagenetic inclusions are those formed during crystallisation of the diagenetic host mineral. In quartz overgrowths they occur with a circumferential distribution at the boundary of the detrital grain and diagenetic overgrowth and also within the overgrowth. Secondary diagenetic inclusions decorate the trace of healed fractures that cut across a pre-existing diagenetic mineral. Inclusions formed during diagenesis may occur decorating fractures in detrital minerals repaired by mineral growth but these do not contribute information about time and sequence unless they clearly post-date a diagenetic phase. The migration of hydrocarbons through reservoir rocks is recorded by the entrapment of oil and gas within fluid inclusions (i.e. Burruss, 1981 & 1992; Horsefield & McLimans, 1984, Narr & Burruss, 1984). These can occur either within pore occluding diagenetic cements, which are time specific, or in cemented fractures that form throughout most of the burial history. The distribution of oil inclusions relative to the sequence of diagenetic cements allows the relative timing of oil migration to be addressed. The aromatic fraction of the oil fluoresces under UV excitation in a range of colours which can be used to distinguish different oil charges. The colours are indicative of maturity (Li & Mai, 1992, McLimans, 1987) and probably reflect changing API as the maturity of the oil increases (Hagemann & Hollerbach, 1986). Oil filled fluid inclusions were identified using dark field fluorescence microscopy utilising violet and ultra-violet fluorescence excitation. Gas rich inclusions were identified by their high percent vapour and a characteristic low refractive index. The distribution of oil inclusions reflects the impelling forces for oil migration, which comprise capillary pressure, buoyancy, and hydrodynamic force. In siliciclastic rocks the proportion of grains containing hydrocarbon inclusions rises with the relative saturation of oil. Accumulation of a stable oil column can be differentiated from continuous migration. The parameter used is the number of quartz grains containing oil inclusions which is a qualitative indication of the number of adjacent pore spaces that contained oil. Palaeo-oil columns can be identified on the basis of hydrocarbons trapped within fluid inclusions even where rocks are currently water wet or gas saturated.

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A computer assisted microscope was utilised to collect quantitative counts of the number of quartz grains containing oil inclusions in these samples. All thin section samples were petrographically screened to identify oil inclusions with a record made of the number of quartz grains containing oil inclusions, the fluorescence colour under dark field UV illumination and the location of oil inclusions relative to diagenetic cements. The number of quartz grains with oil inclusions is expressed as a percentage of the total number of grains in each sample, termed GOI (Lisk & Eadington, 1994). The total number of quartz grains in these sections was estimated by extrapolating counts of the number of quartz grains in twenty, randomly selected, fields of view.

3.2 Results

Oil filled fluid inclusions are present in all samples investigated with the exception of the 3225-30 m sample. GOI values of between 0 and 2.04 % (Table 2). The oil bearing inclusions exhibit blue, white and orange fluorescence colours. The oil inclusions occur exclusively on fractures in detrital quartz.

Table 2 - Results of Hydrocarbon Petrography, Veilfin-1 & Sawbelly-1

Borehole	Depth (m kb)	GOI (total)	Total Grains	Total Grains with oil incls	Blue	White	Yellow	Orange
Veilfin-1	2030-35	1.62	864	14	0	7	0	7
Veilfin-1	3185-90	0.56	1798	10	0	4	0	6
Veilfin-1	3210-15	0.02	13291	3	2	0	0	1
Veilfin-1	3225-30	0	nr	0	0	0	0	0
Veilfin-1	3370-75	0.75	3488	26	24	0	0	2
Veilfin-1	3405-10	2.04	1174	24	24	0	0	0
Sawbelly-1	2890	0.14	3586	5	3	2	0	0

nr = not recorded

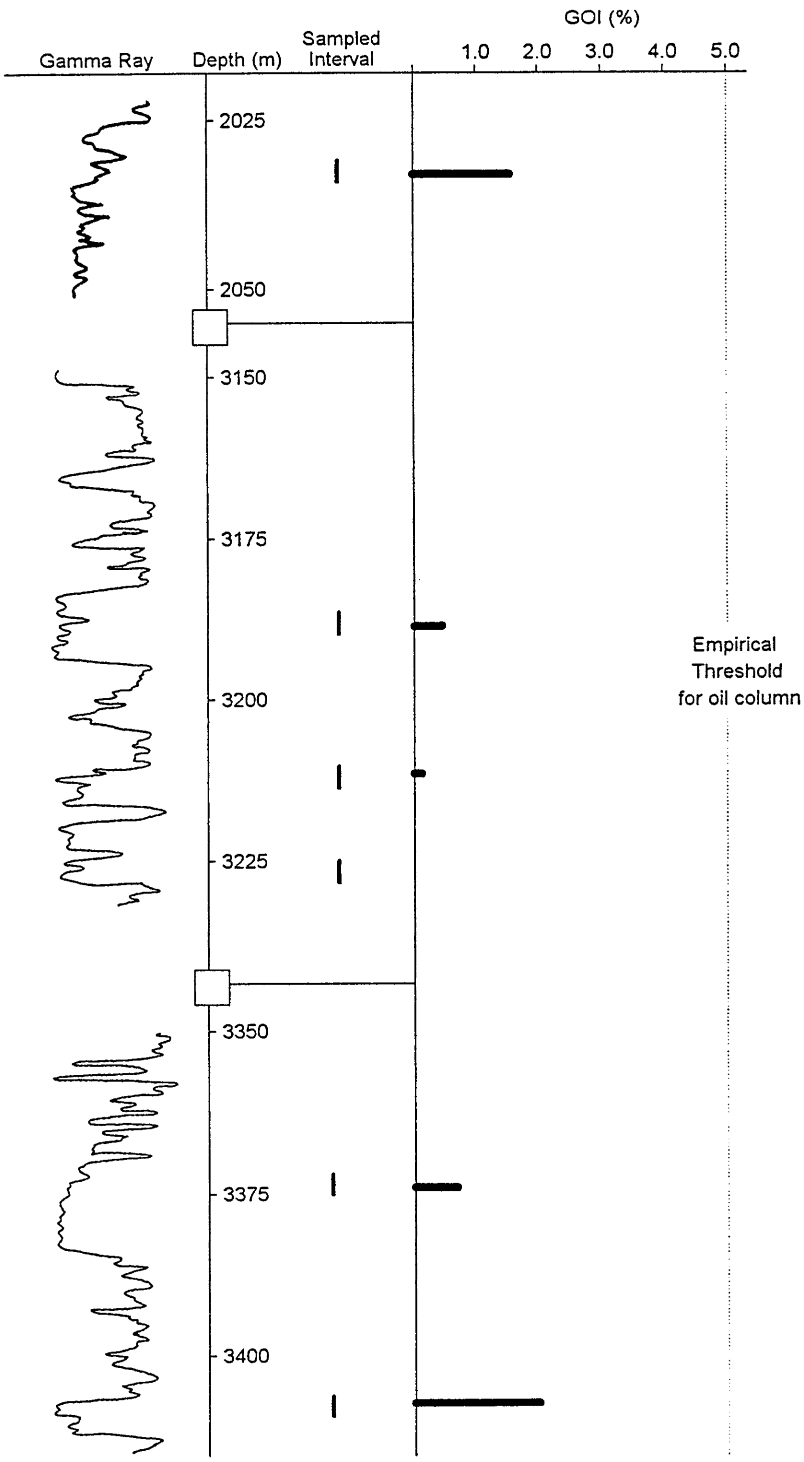
4 DISCUSSION

4.1 Palaeo-Oil Saturation from Fluid Inclusion Petrography

Migrating oil that enters a heterogeneous sand flows preferentially through the largest pore throats due to differential capillary pressure (Appendix 1). If there is no barrier to flow then capillary pressure will confine the oil to the largest interconnected pore network and only a relatively small number of pores will be exposed to oil. As a consequence only a small number of grains which intersect the migration stringer trap oil inclusions. The high oil pressures achieved within an oil column overcome capillary pressure opposing oil flow into the smaller pore throats and the oil saturation increases. Under conditions of high oil saturation, which accompany the presence of a stable oil column, most pores are exposed to oil and correspondingly a high proportion of grains trap oil inclusions.

The number of quartz grains which contain oil inclusions as a percentage of the total number of quartz grains in these samples (GOI) ranges from 0 to 2.0% (Table 2, Fig. 3). These low GOI values are consistent with migration of oil under conditions of low oil saturation and are similar to GOI values recorded beneath the OWC in present day oil fields or from boreholes with limited hydrocarbon indications (c.f. Lisk & Eadington, 1994 and unpublished CSIRO database). By comparison, GOI values recorded in current day oil fields range between about 5 and 50% (c.f. Lisk & Eadington, 1994 and unpublished CSIRO database).

Figure 3 - Location of samples & results of Hydrocarbon Petrography, Veilfin-1

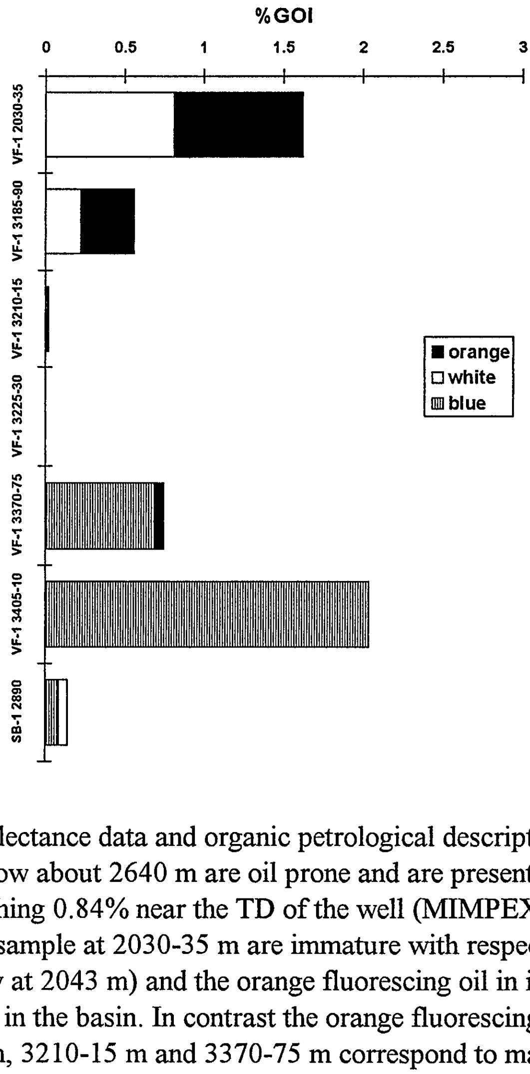


These sands are presently gas saturated beneath about 3090 m indicating the presence of an intact seal. The low palaeo-oil saturation denoted by the low GOI values suggests that either the oil migration prior to gas emplacement was insufficient to charge the reservoir or that their was no valid trap at the time of oil migration. Where aggregates of grains are cemented they exhibit very low visual porosity and oil migration may have been restricted due to very low permeabilities.

4.2 Maturity of Oil in Fluid Inclusions

The differences in fluorescence colour observed in oil bearing fluid inclusions in samples from Veilfin-1 (Table 2, Fig. 4) represent oils of varying maturity. The orange fluorescing oil within inclusions (Fig. 5A) is interpreted to represent oil generated at the onset of oil generation while the inclusions which exhibit blue fluorescence (Figs. 5B & 6) represent oil generated from source rocks under conditions of peak oil generation (Li & Mai, 1992, McLimans, 1987; Appendix 2). The white fluorescing oil inclusions (Fig. 7) are more difficult to place on a relative maturity scale on the basis of published literature. An unpublished CSIRO geochemical study of oil within fluid inclusions from the North West Shelf showed that inclusions exhibiting white fluorescence had a similar maturity to inclusion exhibiting blue fluorescence which have measured Methyl Phenanthrene Index (MPI) values of about 0.94 to 1.0% Rv equivalent. However, the maturity of oil exhibiting white fluorescence cannot be confidently predicted and may be affected by a mix of source and maturity parameters.

Figure 4 - GOI results, Veilfin-1 and Sawbelly-1



Available vitrinite reflectance data and organic petrological descriptions suggest source rocks in Veilfin-1 below about 2640 m are oil prone and are presently within the oil window with Rv reaching 0.84% near the TD of the well (MIMPEX database). Source rocks adjacent to the sample at 2030-35 m are immature with respect to hydrocarbon generation (0.41% Rv at 2043 m) and the orange fluorescing oil in inclusions must have migrated from deeper in the basin. In contrast the orange fluorescing oil inclusions seen in samples at 3185-90 m, 3210-15 m and 3370-75 m correspond to mature source rocks (0.79% Rv at 3158.3 m & 0.84% Rv at 3432 m, MIMPEX database) and may have been

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generated in situ. In the lower samples oil inclusions exhibit predominantly blue fluorescence colours and the oil is probably too mature to have been generated in situ. Therefore despite the low visual porosity exhibited by these samples and the low permeability (O.14 md) recorded during a production test these results appear to support some migration of high maturity oil through this location.

In the single sample from Sawbelly-1 blue and white fluorescing oil inclusions are consistent with trapping of high maturity oil. Tmax values are low (<435) for samples down to about 3000 m (MIMPEX database) suggesting source rocks are presently immature for local generation and that the high maturity oil seen in inclusions represents migrated oil.

4.3 Timing of Oil Migration Relative to Diagenesis

In these samples oil bearing fluid inclusions are hosted exclusively on fractures in detrital quartz and provide no direct constraint on the timing of oil migration. Most samples investigated comprise aggregates of quartz grains which are well cemented by either pore filling clay minerals or pore occluding carbonate minerals. These appear to largely represent products of early diagenesis and reservoir quality appears to have been severely degraded prior to the main phase of oil migration. Despite this, the creation of secondary porosity, primarily through dissolution of dolomite cement and generation of microporosity due to feldspar alteration has been previously documented for the Gippsland Basin (Bodard et al, 1984). However, the disaggregated nature of these cuttings samples limits the reconstruction of the original rock fabric, and the development of secondary porosity cannot be assessed without petrographic examination of available SWCs. However, without significant dissolution of dolomite cement then these sands are unlikely to represent producible oil reservoirs although they may have retained the potential to produce gas.

5 CONCLUSIONS

- Frequencies of oil bearing fluid inclusions (GOI) ranging from 0 to 2.0% indicate the presence of oil under conditions of low oil saturation.

- Samples from Veilfin-1 generally come from presently gas saturated sands indicating the presence of intact seal. The low GOI values infer either restricted oil charge or the absence of a valid trap during oil migration.

- Oil of variable maturity has been trapped by oil inclusions in Veilfin-1. The orange fluorescing oil inclusions are interpreted to be of low maturity and could represent oil generated in situ while the high maturity blue fluorescing oil inclusions seen in deeper samples must have migrated from deeper rocks. The single sample from Sawbelly-1 contains only high maturity oil within inclusions and migration of oil can be inferred.

- The oil inclusions in all samples occur solely on fractures in detrital quartz and provide no direct constraint to the timing of oil migration. However, oil migration in Veilfin-1 is likely to have been restricted by low permeabilities which are the result of extensive early formed dolomite and mixed layer clay.

6 ACKNOWLEDGEMENTS

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Appendix 1

Oil Migration and Fluid History Analysis

Oil in fluid inclusions offers opportunities to evaluate oil migration through time. Oil migration can be investigated by considering the fluid dynamics that control oil flow through rocks and therefore the distribution of oil inclusions.

Oil migrates in a direction of decreasing hydraulic potential (head) and the forces controlling oil flow are primarily related to the effects of capillary pressure and buoyancy (Bethke et. al., 1991).

CAPILLARY EFFECTS

Capillary force is has an effect on the distribution of oil (and oil inclusions in minerals) because reservoir rocks and carrier beds are heterogeneous.

$$P_c = 2g[\frac{1}{r_t} - \frac{1}{r_p}]$$

where g is the surface tension between oil (or gas) and water, r_p is the radius of the occupied pore, and r_t is the radius of the pore throat that must be entered for continued migration. If $r_t < r_p$ then the capillary pressure is positive and the capillary force opposes migration.

Interfacial tension, g, is related to surface tension, s which is a function of the curvature on the interface between the fluids.

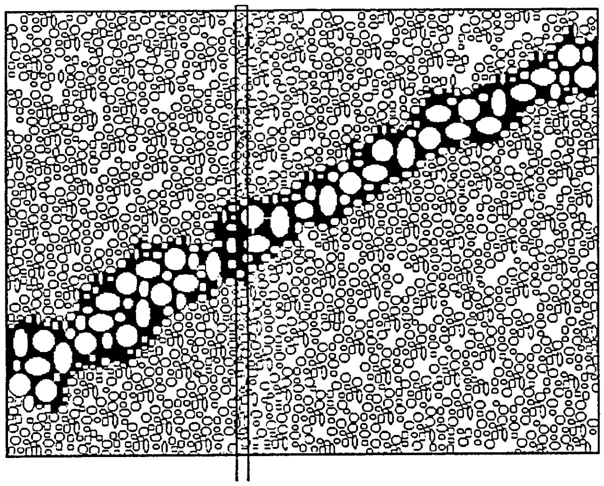
	Surface tension (against air) σ	Interfacial tension (against water)
methane	0 Nm^{-1}	70.10^{-3} Nm^{-1}
light crude	25.10^{-3}	30.10^{-3}
heavy crude	35.10^{-3}	15.10^{-3}
water	75.10^{-3}	0
brine	80.10^{-3}	near 0

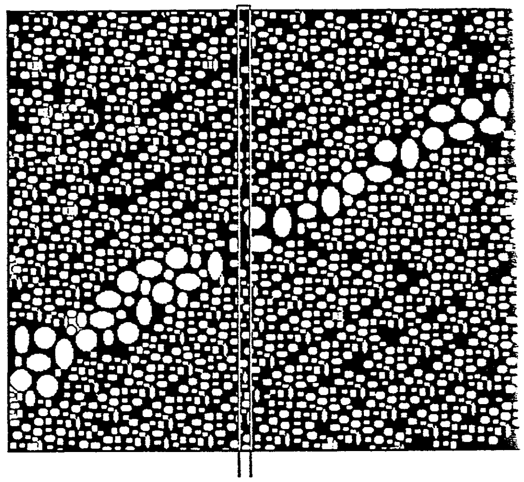
For hydrocarbons within a water saturated rock capillary force is highest for gas, and lowest in the largest pore openings.

An important consequence of capillary pressure is the relative oil saturation that will be achieved under conditions of confinement. The distribution of oil inclusions in a thin section of reservoir rock indicates which grains have been exposed to oil and can be used to infer the relative saturation of the rock with oil.

Migrating oil entering a heterogeneous sand flows preferentially through the largest rconnected pores due to capillary pressure.
Increasing hydrocarbon pressure due to buoyancy will increase the flow rate but is probably not sufficient to overcome high capillary pressures.

High oil pressure is required to overcome capillary pressure and allow oil to enter the smaller pores. In the presence of an adequate seal oil will progressively fill smaller pore spaces as the pressure exerted by the oil exceeds the capillary pressure of these smaller pores.

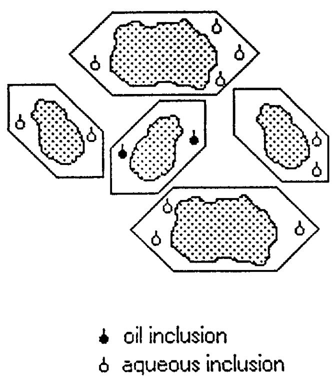




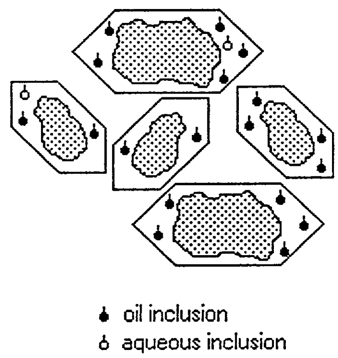
Under conditions of high oil saturation most pores are exposed to oil and correspondingly most grains trap oil inclusions.

If there is no barrier to flow then rising hydrocarbon pressure due to buoyancy will result in continuous migration of oil with only a relatively small number of pores being exposed to oil and correspondingly only a small number of grains trapping oil inclusions (see above and below).

Migration Pathway



Oil Column



Because of the capillary effect it can be inferred that there was an oil column in the rock to provide the pressure necessary to enter the range of pore spaces.

A consequence of capillary pressure is that coarse grained lenses make the best sampling positions for determining hydrocarbon migration history. If hydrocarbons have migrated through the rocks then these parts of the rock will be the migration pathway.

Buoyancy Effects

Buoyancy forces arise out of the different density of water and hydrocarbons.

Oil and gas have different buoyancy forces, however, because the forces act vertically upwards then in a hydrostatic groundwater regime the migration directions for oil and gas will be the same, the maximum slope on the top of the carrier bed.

An important consequence of buoyancy for Fluid History Analysis is that oil migrating laterally with confinement under a regional seal will leave fluorescing oil inclusions in minerals within a few metres below the seal or below the oil water contact.

The observation of oils with the same fluorescence colour over hundreds of metres vertical distance below the seal or oil water contact is evidence for upwards migration of oil in faults or stacked sand bodies.

By sampling directly beneath the regional seal or oil water contact and at several intervals well below the regional seal the likelihood of lateral vs upwards migration can be evaluated.

Appendix 2

The Fluorescence Colours of Oil Bearing Fluid Inclusions as an Indication of Maturity

Fluorescence from oil originates in compounds with extended conjugated bonds, e.g. polycyclic aromatic compounds and NSO compounds. Aliphatic hydrocarbons don't fluorescence. The fluorescence emission of the polycyclic aromatic compounds ranges from red for pentacence (5 rings) through blue for phenanthrene (3 rings) to ultraviolet (not visible) for benzene.

With increasing maturity of oil there is a shift from yellow fluorescence through yellow - orange and shades of cream-white towards blue (McLimans, 1987; Hagemann & Hollerbach, 1985; Li & Mai, 1992). For example, condensate inclusions often have a large vapour bubble with a rim of blue fluorescing liquid. Low maturity oils have yellow or yellow-orange fluorescence. This shift in fluorescence colours appears to comprise initially a shift towards red wavelengths then a shift towards blue. This sequence of colours is consistent with reactions involving fusion of polycyclic aromatic compounds which increase in size until they become insoluble and form a residue. Increasing size of these molecules increases the amount of red emission giving a shift to yellow-orange then cream-white. Precipitation of a residue leaves small stable aromatic compounds with blue fluorescence.

Fluorescence colour is subject to multiple controlling factors. Changing fluorescence colours due to increasing maturity appears to be ubiquitously observed but must be modified to an unknown extent by the nature of organic matter in the source rocks which determines the initial composition of the oil.

McClimans (1987) presents fluorescence spectra of oil. He concluded there is an increase in the fluorescence emission of blue wavelengths from oils with increasing maturity. The most noticeable changes are in the blue and ultra violet region of the spectrum, however, there are also subtle changes across all of the visible region.

Increasing "Maturity" of Oil →

Sequence of Fluorescence Colours

Yellow / Orange - Yellow / Cream White / Cream - Blue / Blue

Increasing Intensity Red Wavelengths → Increasing Intensity Blue Wavelengths →

Similar studies by Hagemann and Hollerbach (1985) showed that with increasing maturation a continuous shift from a maximum wavelength of 550 nm (green-yellow) to 440 nm (blue) occurred.