

OIL AND GAS ACCUMULATIONS AND THEIR POSSIBLE SOURCE ROCKS IN SOUTHERN ENGLAND

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A number of commercial hydrocarbon accumulations, which include oil and gas, are now known in southern England. Investigations into the organic maturity and hydrocarbon potentials of sedimentary rocks in the area suggest that the Jurassic Lias, Oxford Clay and Kimmeridge Clay units are the most probable sources for these hydrocarbon accumulations. The Lias on the southern side of the Purbeck-Isle of Wight Disturbance appears to be the main source of the Dorset oils (Wytch Farm and Kimmeridge Bay) on the bases of adequate maturity, n-alkane distribution, alkane ratios and stable carbon and hydrogen isotope ratios. On the basis of organic maturity, the oil accumulations in the Weald and the adjacent Hampshire areas are considered to be composed of varying contributions of bitumen generated from the three Jurassic source formations.

Application of the modified Lopatin method of basin modelling suggests the Lias in the Weald as the probable source for the natural gas deposit at Godley Bridge in Surrey and predicts a possible Liassic sourced wet-gas field in the Dorset-Isle of Wight area.

INTRODUCTION

A number of commercial hydrocarbon accumulations are now known in southern England. These include the *Wytch Farm* and *Kimmeridge Bay* oilfields in Dorset; the oilfields at *Humbly Grove*, and *Horndean* five miles NW of Winchester in Hampshire; the gasfield at *Godley Bridge* near Chiddingfold in Surrey, and the oilfield at *Palmer's Wood* also in Surrey (Fig. 1). However, despite the increasing number of discoveries, a very limited quantity of established facts are available on possible source rocks for these oil and gas deposits.

The organic-rich mudrocks of both the Devonian and Carboniferous periods in South England were deformed to metamorphic grade by the Variscan Orogeny, and this is evidenced by the occurrence of Westphalian anthracite coal in East Kent (Bennison and Wright, 1969; Edmonds *et al.*, 1975; Cornford, 1984). During this tectonic episode, vast

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amounts of gas and possibly oil must have been generated, but they were rapidly lost during uplift and erosion (Cornford, 1984). Southern England experienced arid climatic conditions during the Permian and most of the Triassic, and red continental facies were deposited at this time (Edmonds *et al.*, 1975; Rayner, 1981). Reddish rocks are known to be indicative of highly-oxidising depositional environments, which are not conducive to organic matter preservation (Pettijohn, 1975). Much of Southern England came under the influence of marine transgression from the Tethys Sea towards the close of the Triassic in Rhaetic times. It is possible that the Rhaetic rocks of Southern England (the Penarth Group) which consist of black shales, sandstones and limestones (Warrington *et al.*, 1980) may have locally developed in an oil- and gas-prone facies (Cornford, 1984), but the volume of the unit is small: it is only about 70 ft (21 m) thick in the *Wytch Farm* oilfield (Colter and Havard, 1981). In contrast, the Jurassic contains three major organic-rich mudrock formations (the Lower Lias, the Oxford Clay and the Kimmeridge Clay), each with both oil- and gas-prone kerogens (Ebukanson and Kinghorn, 1985). The Lower Lias is about 600 ft thick in the proposed type sectional area between Pinhay Bay in Devon and Seaton in Dorset (Palmer, 1972) while a thickness of 550 ft is recorded in the Penshurst well in West Kent. From a maximum thickness of 550 ft in Dorset (Bennison and Wright, 1969), the Oxford Clay thins to 320 ft in the Warlingham borehole in Surrey (Worssam and Ivimey-Cook, 1971) and 249 ft in the Penshurst Well in Kent (Fig. 1). The Kimmeridge Clay is about 1,650 ft thick in the Kimmeridge Bay area in Dorset (Arkell, 1947; Gallois, 1978) and 1,242 ft thick in the Penshurst Well. Although the organic matter in these formations is immature on outcrop sections, they are noted to be mature in the subsurface in parts of the area (Ebukanson and Kinghorn, 1986) (see Fig. 1). According to Cornford (1984), the deltaic Wealden facies of the Lower Cretaceous, as displayed on the south coast of England, is in gas-prone facies with thin lignite seams and stringers, and carbonaceous shales. The fact that even the Jurassic is organically immature in many parts of Southern England (Ebukanson and Kinghorn, 1986) shows that the gas potential of the Wealden Beds is unlikely to be realised at the present time.

All the above observations suggest these three major Jurassic mudrock formations as the most probable source rocks of the oil and gas accumulations in the area. Most of the hydrocarbon accumulations and prospects occur in structures within the Jurassic System (Colter and Havard, 1981; Sinclair, 1983), and these structures are believed to have been emplaced by the important Mid-Cretaceous tectonic movements which occurred between Aptian and Albian times, and possibly also by the Alpine orogenic movements from the Latest Cretaceous to the Miocene (Brunstrom, 1963; Ebukanson and Kinghorn, 1986). Each of the three major Jurassic potential hydrocarbon source formations is succeeded stratigraphically by marine shoal/paralic sands, which are in turn overlain by shallow marine carbonates consisting of skeletal and oolitic packstones and grainstones (Ebukanson and Kinghorn, 1985) (Fig. 2). Both the sands and the limestones, though generally of rather low porosity and permeability, act as petroleum reservoir rocks in Southern England. However, in the *Wytch Farm* field, the Triassic Sherwood Sandstone Group constitute one of the major oil reservoir rocks.

Colter and Havard (1981) suggested the Lias, the Oxford Clay and the Kimmeridge Clay in the locality of the Arreton No. 2 Well as the possible sources for the *Wytch Farm* oils, although no oil-source correlation was attempted. The present study is an attempt to associate the various known and unknown oil and gas deposits in Southern England with possible Jurassic source units or horizons using preliminary correlation techniques.

EXPERIMENTAL

Samples

The sampling of the Lower Lias, the Oxford Clay and the Kimmeridge Clay on outcrops as well as in boreholes was described in Ebukanson and Kinghorn (1985). The oil samples

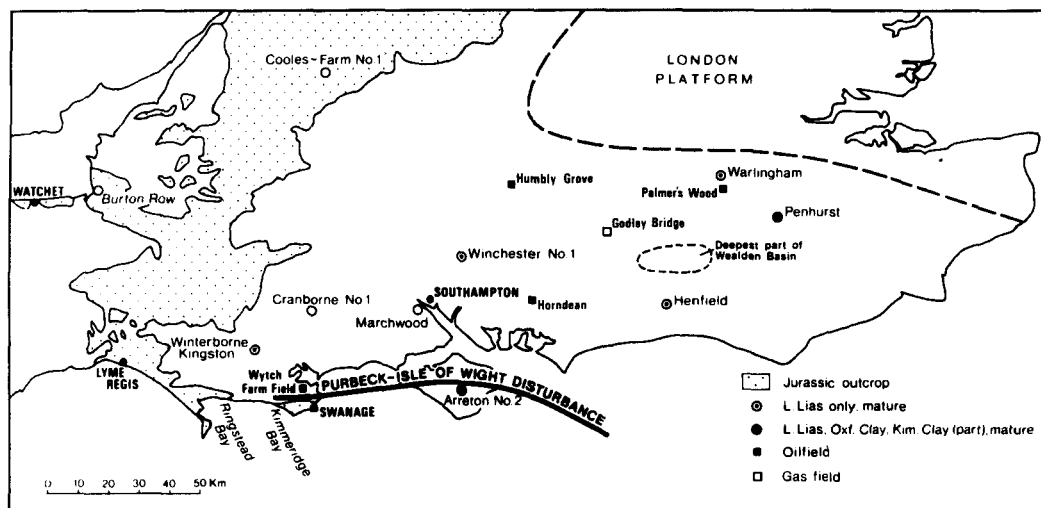


Fig. 1. Location map of commercial oil and gasfields in Southern England and associated localities where Jurassic organic matter is in the catagenesis stage (based on Ebukanson, 1984; and Ebukanson and Kinghorn, 1986).

analysed in the present study were produced from the three main reservoir rocks in Dorset. They are:— the oil from the fractured Middle Jurassic Cornbrash limestone obtained from the Kimmeridge No. 1 Well at *Kimmeridge Bay* (depth: 1,791 ft), and the two oils from *Wytch Farm* produced respectively from the shallower Upper Liassic Bridport Sands (depth: 3,038–3,225 ft) and the deeper Triassic Sherwood Sandstone Group (depth: 5,156–5,594 ft). The three oils are referred to, in this report, as the *Kimmeridge Bay*, the *Bridport* and the *Sherwood* oils respectively. The oils were topped at 40° + 2°C for 24 hours and stored in stoppered glass tubes in a nitrogen atmosphere at room temperature prior to analyses.

Bitumen extraction and fractionation of oils and extracts

Bitumen extraction from rock samples and subsequent fractionation by HPLC was described in Ebukanson and Kinghorn (1986). The oils were de-asphalted using *n*-heptane, and then fractionated into Saturates, Aromatics and Resins using an HPLC system which employed both UV (*Cecil Instrument CE515*) and refractive index (*Model 1107 Refracto-Monitor*) detectors. *n*-Heptane was used to elute first the saturates and then aromatics followed by a mixture of dichloromethane (75%) and isopropanol (25%) to elute the resins.

Gas Chromatography

The gas chromatographic technique used for the analysis of the hydrocarbon fractions of both the extracts and the oils was described in Ebukanson and Kinghorn (1986).

Stable carbon and hydrogen isotope measurements

4–6 mg of organic matter sample (either whole oil or extract) was oxidised in an evacuated quartz tube containing about 0.5 g of copper oxide at 800°C for 2 hours. A small roll of silver wool was added to the mixture to help in the removal of any traces of sulphur during the reaction. The oxidation products — CO₂ and H₂O — were extracted from the quartz reaction tube using extraction lines operated by a high vacuum system. The CO₂ was

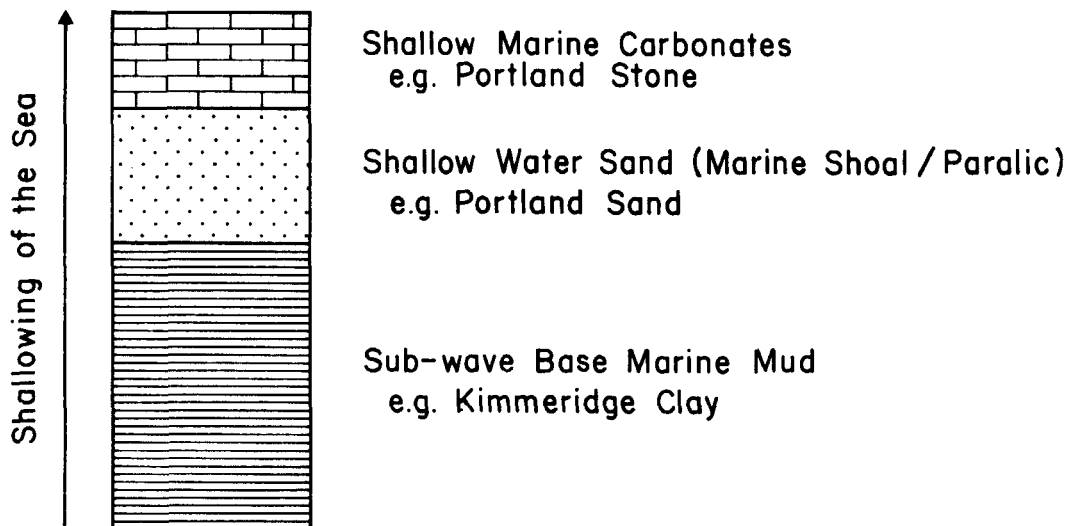


Fig. 2. A typical Jurassic sedimentary cycle.

analysed for carbon isotopes using a triple-collector mass spectrometer. The collected water was first reduced to hydrogen gas by reaction with zinc at 430°C for about one hour. A double-collector mass spectrometer was used for the hydrogen isotope analysis. The isotope data obtained from the analyses were, after correction, expressed in the usual δ -notation and related to the Peedee Belemnite Standard for carbon ($\delta^{13}\text{C}_{\text{PDB}}$) and Standard Mean Ocean Water for hydrogen ($\delta\text{D}_{\text{SMOW}}$). The extraction method of this analysis was checked by using the international reference MBS 22 with $\delta^{13}\text{C}_{\text{PDB}} = -29.8\text{‰}$ and $\delta\text{D}_{\text{SMOW}} = -119.2\text{‰}$ (Schoell *et al.*, 1983). Reproducibilities of lower than 0.2‰ for δD were obtained from duplicate analyses.

ISLE OF WIGHT — DORSET AREA

Oils

Commercial oil accumulations in this area are known in Dorset at *Wytch Farm* and *Kimmeridge Bay* (Colter and Havard, 1981). Table 1 shows some of the properties of three Dorset reservoir oils: the *Kimmeridge Bay* oil, and the *Wytch Farm* Bridport and Sherwood oils. The three oils are shown to be high in saturated hydrocarbons and low in asphaltenes, but they are noted to vary in their saturates-to-aromatics ratios, with the *Kimmeridge Bay* oil showing the highest value (8.5), followed by the Sherwood oil (with a ratio of 5.9), and then the Bridport oil with the lowest value of 3.1. The three oils thus appear different on a compositional basis. Genetically related oils can vary in their compositions as a result of numerous factors, including source-bed variation and maturity, degree of hydrocarbon expulsion from the source bed, migration, and thermal and microbial alteration (Connan *et al.*, 1975; Fuex, 1977; Kinghorn, 1983; Cornford *et al.*, 1983; Sofer, 1984; Leythaeuser *et al.*, 1984). Migration and thermal evolution are known to improve oil quality by reducing the concentration of polar as well as high molecular weight compounds, with a resultant increase in the saturates/aromatics ratio. The depths of occurrences of the three oils range from 1,791-5,594 ft (546-1,705 m), and based on the estimated present-day regional average geothermal gradient of about 30°C/km in Southern England (J. Wheildon, *pers. comm.*), the temperature range of the reservoirs is 25-61°C, with the *Kimmeridge Bay* oil being at the lowest temperature. No significant differential thermal alterations of the reservoir crude oils are feasible at such a temperature interval.

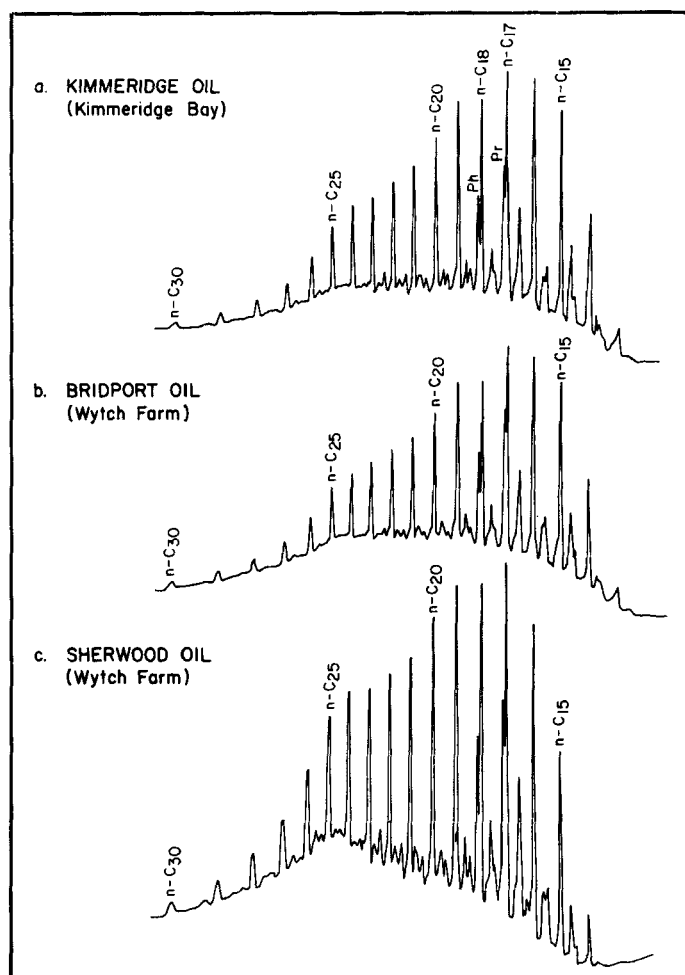


Fig. 3. Gas chromatograms of the hydrocarbons of the three Dorset oils.

Fig. 3 shows the gas chromatograms of the hydrocarbon fractions of the oils. The presence of the full range of *n*-alkanes in the C_{15} - C_{30} range with very similar distributions suggests that none of the oils has suffered biodegradation as well as a significant differential thermal alteration (William and Winters, 1969; Evans *et al.*, 1971; Bailey *et al.*, 1973; Connan *et al.*, 1975).

All the oils show very similar alkane ratios (Table 1), with CPI values of about 1.0. Their Pristane/Phytane (Pr/Ph) ratios are in the range of 1.30-1.45, which suggests that the oils have been mainly sourced by organic matter deposited in a slightly oxidising environment (Brooks *et al.*, 1969; Didyk *et al.*, 1978). That the oils are dominantly marine in origin is indicated by the high $(C_{21}+C_{22})/(C_{28}+C_{29})$ *n*-paraffin ratios of 3.54 to 4.21, within the 1.5-5.0 range obtained by Philippi (1974) for marine oils.

The $\delta^{13}C_{PDB}$ and δD_{SMOW} values of the topped oils are also presented in Table 1. $\delta^{13}C$ values show a narrow range of -28.5 to -29.8‰ for the three oils with a spread of 1.3‰ . According to Sofer (1984), such a spread is quite acceptable for genetically related oils, taking into account the fact that isotopic variations in the source beds can result in isotopic variations in the oils of a magnitude larger than 2‰ . The $\delta^{13}C$ values for the oils are noticed to vary very consistently with their saturate/aromatic ratios: the Kimmeridge oil with the

highest ratio of 8.5 is isotopically the lightest ($\delta^{13}\text{C} = -29.8\text{‰}$) and the Bridport oil with the lowest ratio of 3:1 is isotopically the heaviest ($\delta^{13}\text{C} = -28.5\text{‰}$). The above results are consistent with the fact that the aromatic hydrocarbon fraction in petroleum is isotopically heavier with respect to carbon than their associated saturated hydrocarbon fractions (Stahl, 1977; Sofer, 1984). The hydrogen isotope ratios (δD) for the oils show a rather wide range as well as a trend contrasting to that of the $\delta^{13}\text{C}$ values: the Kimmeridge Bay oil is the heaviest, with δD value of -68‰ , while the Bridport is the lightest with δD value of -133‰ . No clear distinction seems to have been made yet between the hydrogen isotopic compositions of the saturated and aromatic hydrocarbon fractions of crude oils (Yeh and Epstein, 1981).

On the bases of very similar *n*-paraffin distributions and the alkane ratios as well as the very narrow range of topped oil $\delta^{13}\text{C}$ values (Fuex, 1977; Ross, 1980; Sofer, 1984), it may be concluded that the three Dorset oils have been derived from the same source, or very similar source rocks. The higher API gravity and Gas/Oil Ratio (GOR) data for the Sherwood oil compared to those of the Bridport oil (Table 1) tend to suggest varying source-bed maturity as the main factor responsible for the trend in saturates/aromatics ratios for the three Dorset oils, since the migration pathways are not envisaged to have been much different for the oil deposits (Cornford, 1983; Cooper and Cornford, 1984). This would imply that the Kimmeridge Bay oil represents the highest source-bed maturity and the Bridport oil the lowest. This deduction appears consistent with the observation that the Sherwood oil is relatively more waxy than the less mature Bridport oil (Colter and Havard, 1981), probably due to the fact that hydrocarbons expelled from the early mature argillaceous source beds are lower in the high molecular weight *n*-alkanes, possibly due to geochromatography, compared to those expelled at higher maturity when there is increased generation of bitumen (Leythaeuser *et al.*, 1984).

PRELIMINARY OIL-SOURCE CORRELATION

The properties of the Dorset oils shown in Table 1 are very similar to the North Sea oils sourced from mid to late mature horizons of the Kimmeridge Clay Formation at 0.6-1.1% vitrinite reflectivity, equivalent to a spore colour index (SCI) of 5-7.5 (Cornford, 1983; Cooper and Cornford, 1984). Ebukanson and Kinghorn (1986) showed that on the basis of spore colour and alkane distribution, Jurassic kerogens in the Dorset-Isle of Wight area are in the catagenesis stage in the Winterborne Kingston and Arreton No. 2 Wells. In the Winterborne Kingston Well, the Base Lias was shown to be at an organic maturity of about 0.56% R_o ($<0.6\%$), and is therefore only marginally mature. Such a maturity level represents relatively small hydrocarbon generation, with little or no expulsion from the rocks, since the main phase of oil generation has not been achieved (Dow, 1977; Waples, 1980). The average total organic carbon content of the basal Lias in this well is about 1%, and the kerogen varies between chemical Types II and III (Ebukanson, 1984). The Lower Kimmeridge Clay and the Oxford Clay samples from the Arreton No. 2 Well were also noted to be at marginal maturity, and only the Lower Lias was found to be fully mature (at estimated R_o of 0.7 to 0.9%). A slightly higher maturity ($0.98 < R_o < 1.0\%$) was, however, indicated for the Base Lias by the Lopatin integrated time/temperature modelling technique.

Figs. 4a-c are the gas chromatograms of hydrocarbon fractions from a basal Kimmeridge Clay sample and two Lower Lias samples from Arreton No. 2 Well showing the distribution of *n*-alkanes and the isoprenoids, pristane and phytane. Table 2 shows alkane ratios for the three samples, as well as carbon and hydrogen isotope data for some Lower Lias bitumen samples. The *n*-alkane distributions and the alkane ratios of the Lower Lias samples show good correlations with the three Dorset oils (see Table 1 and Fig. 3). Alexander *et al.* (1981) suggested that for good oil-source correlation the alkane ratios of the correlated source-rock extract should be within the following limits of the oil: Pr/Ph ratio ± 0.6 ; Pr/*n*-C₁₇ ± 0.8 ;

Sample	Depth of Reservoir (ft.)	API* Gravity	De-asphalting & HPLC					Alkane Ratios						Isotope Ratios			
			Sat. %	Arom. %	Resins %	Asph. %	Sat. / Arom.	Pr/Phy	n-C ₁₇ / n-C ₁₈	Phy / n-C ₁₈	$\frac{(n-C_{17} + n-C_{18})}{(Pr + Ph)}$	$\frac{(n-C_{17} + n-C_{18})}{(n-C_{17} + n-C_{18})}$	$\frac{(n-C_{17} + n-C_{18})}{(n-C_{17} + n-C_{18})}$	CPI (n-C ₃₀)	δ ¹³ C _{org} (‰)	δD _{org} (‰)	Gas Oil Ratios Sjt' /bbl
Cornbrash Oil (Kimmeridge Bay)	1791	-	82.2	9.7	6.7	1.5	8.5	1.41	0.58	0.49	0.54	0.54	4.15	1.02	-29.8	-68	-
Bridport Oil (Wytch Farm Field)	3038-3225	35-37°	56.6	18.1	23.2	2.1	3.1	1.45	0.69	0.56	0.63	0.63	3.54	1.04	-28.5	-133	150
Sherwood Oil (Wytch Farm Field)	5156-5594	38-42°	67.5	11.4	17.8	3.3	5.9	1.30	0.61	0.52	0.56	0.56	4.21	0.98	-29.5	-108	300

* Gas Oil Ratios & API gravity data from Colter and Havard, 1981

Table 1. Organic Geochemical analyses of the Dorset Crude Oils.

Sample	Depth (ft.)	Formation	Pr/Ph	Pr/n-C ₁₇	Ph/n-C ₁₈	(Pr + Ph) (n-C ₁₇ + n-C ₁₈)	CPI (n-C ₁₇ -C ₂₀)	δ ¹³ C _{org} (‰)	δD _{org} (‰)
AR/NC.8	3400-3500	Kimm. Clay	1.21	1.44	1.20	1.32	1.35	n.d.	n.d.
AR/LL.2	5600-5700	Lower Lias	n.d.	n.d.	n.d.	n.d.	n.d.	-29.6	-96
AR/LL.4	5800-5900	"	n.d.	n.d.	n.d.	n.d.	n.d.	-30.5	-93
AR/LL.6	6000-6100	"	1.21	0.65	0.57	0.61	1.21	n.d.	n.d.
AR/LL.8	6200-6300	"	1.20	0.79	0.80	0.80	0.95	-28.9	-103

n.d. = not determined

Table 2. Geochemical properties of source Jurassic Bitumen sample from Arreton No. 2 Well (Isle of Wight).

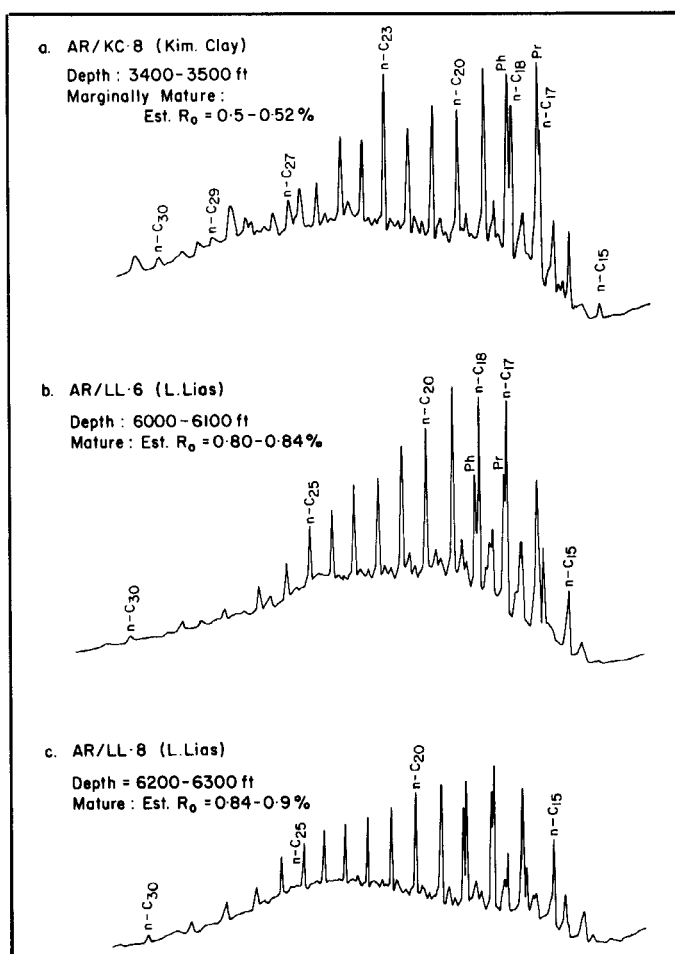


Fig. 4. Gas chromatograms of the hydrocarbon fraction of some Jurassic bitumen samples from the Arreton No. 2 well.

$\text{Ph}/n\text{-C}_{18} \pm 0.8$; $(\text{Pr} + \text{Ph})/(n\text{-C}_{17} - \text{C}_{18}) \pm 0.6$ and $\text{CPI} \pm 0.05$. The Lower Lias samples are noted to satisfy most of these conditions. The isotope data, particularly the $\delta^{13}\text{C}$ values, of the selected Lower Lias bitumen (Table 2) compare very well with those of the Dorset oil. The hypothesis of crude oil — source rock extract correlation by stable isotopic measurements is based on the assumption that genetically-related organic materials should be isotopically similar, since there are no significant hydrogen and carbon isotope fractionations during petroleum migration and maturation processes (Stahl, 1977; Fuex, 1977; Yeh and Epstein, 1981; Sofer, 1984). According to the existing theoretical consideration on the kinetics of petroleum generation, a crude oil should be, with respect to carbon, similar to or isotopically lighter than its source-rock extract, and the extract isotopically lighter than the kerogen if the crude oil and the organic matter of the rock believed to be the source are genetically related. However, some exceptions from this rule have been noted (Welte *et al.*, 1975; Stahl, 1976).

Thus on the bases of adequate maturity, and the comparable *n*-alkane distributions, alkane ratios and isotope data, it may be concluded that the mature Lower Lias Formation to the south of the Purbeck-Isle of Wight Disturbance such as in the locality of Arreton No. 2 Well is the main source of the three Dorset oils.

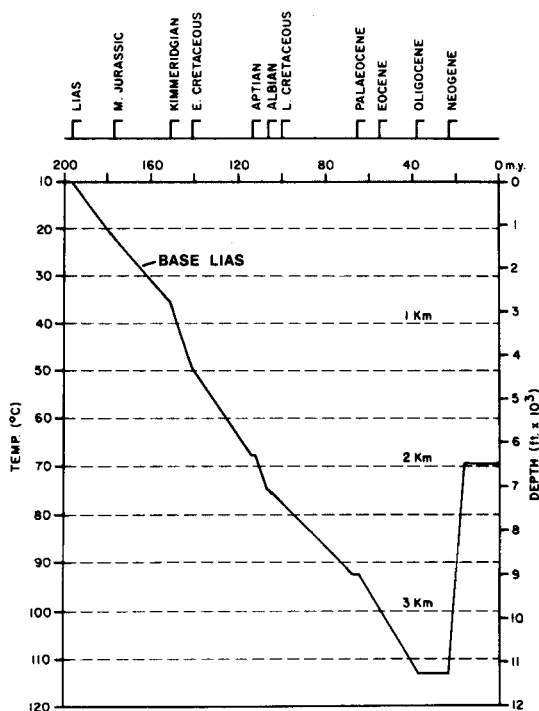


Fig. 5. Geologic model for the Base Lias in the Jurassic depocentre of the Isle of Wight-Dorset Area. The thickness of the Jurassic is assumed to be 4,800 ft.

Table 3. Calculation of present TTI values for the geologic model in Fig. 5 (Jurassic depocentre of Isle of Wight-Dorset area).

Temperature Interval (°C)	r^n	Time (m.y.)	Interval TTI	Total TTI
10-20	2^{-9}	12.30	0.02	0.02
20-30	2^{-8}	12.30	0.05	0.07
30-40	2^{-7}	12.30	0.10	0.17
40-50	2^{-6}	12.30	0.19	0.36
50-60	2^{-5}	14.60	0.46	0.82
60-70	2^{-4}	15.20	0.95	1.77
70-80	2^{-3}	12.00	1.50	3.27
80-90	2^{-2}	22.00	5.50	8.77
90-100	2^{-1}	22.20	11.10	19.87
100-110	2^0	13.20	13.20	33.07
110-120	2^1	27.20	54.40	87.82
110-100	2^0	1.35	1.35	88.82
100-90	2^{-1}	1.35	0.67	89.49
90-80	2^{-2}	1.35	0.34	89.83
80-70	2^{-3}	1.35	0.17	90.00
70-60	2^{-4}	15.00	0.94	90.94

PROSPECTS FOR GAS IN THE ISLE OF WIGHT — DORSET AREA

Both the spore colouration study and the application of the Lopatin method to the Jurassic section in the locality of Arreton-2 Well showed that the Base Lias has not yet attained the peak oil generation stage (i.e. 1.0% R_o) although it is very close to it. According to Vassoevich *et al.*, (1974) and Dow (1977), even though the principal zone of thermal dry gas generation is in the organic maturity range of about 2.0-4.0% R_o , formation actually commences at about 1.20% R_o , while most wet gas generation occurs in a maturity range of 1.0-2.0% R_o . The Jurassic isopach maps of Southern England in Terris and Bullerwell (1965) and Rayner (1981) suggest a Jurassic depocentre of the Dorset — Isle of Wight area was situated between Swanage and the Isle of Wight Disturbance (Colter and Havard, 1981), with a Jurassic thickness of nearly 500 ft greater than in the locality of Arreton-2 Well (Fig. 1). The thickness of the Jurassic in the latter locality is 4,226 ft (Ebukanson and Kinghorn, 1986). Assuming the thickness of the Jurassic rocks at the depocentre to be about 4,800 ft, and using the Cretaceous and Tertiary stratigraphic data in the locality of the Arreton-2 Well (Ebukanson and Kinghorn, 1986), Fig. 5 shows an approximate burial history curve for the Base Lias at the depocentre. Application of the Lopatin method (Waples, 1980) using the estimated regional average present geothermal gradient of 30°C/km (Ebukanson and Kinghorn, 1986), the calculation of TTI values for the Base Lias (Table 3) shows that at maximum burial in the Oligo-Miocene, prior to the Miocene Alpine tectonic inversion, an organic maturity of about 1.05% R_o (TTI of 87.47) was attained, while a predicted present maturity of about 1.06% R_o (TTI of 90.04) is indicated for this Jurassic horizon. Thus, some gas prospect is indicated for the Dorset — Isle of Wight area. As noted from Fig. 4, the Lower Liassic kerogens in the area of thick Jurassic development tend to be mainly Type II, and this oil-prone kerogen has been shown to have more gas-generating potential than the hydrogen-lean Type III (Bailey, 1981). Mainly wet gas generation is envisaged from the Lias in this area, even with Tissot's (1984) suggested modification of the Lopatin method which involves multiplication of the organic reaction rates by 4 to 10 instead of 2 for each 10°C rise in temperature at peak oil generation (i.e. 1.0% R_o) and higher maturity levels.

Therefore, a discovery of a Liassic-sourced, possibly commercial, wet gas accumulation in the Dorset — Isle of Wight area may not be unexpected. It is also possible that at least the Lower Oxford Clay, which is marginally mature in the Arreton-2 Well (Ebukanson and Kinghorn 1986), is locally in the main oil-generation stage in this Jurassic depocentre.

THE WEALD — HAMPSHIRE AREA

Fig. 1 shows the pattern of the oil- and gasfields distributed around the deepest part of the Mesozoic Wealden Basin where the Jurassic is in excess of 5,000 ft (Gallois, 1965; Terris and Bullerwell, 1965; Rayner, 1981). Also shown are associated localities where Jurassic organic matter has entered the catagenesis stage: the Lower Lias in the Henfield, Winchester No. 1 and Penshurst Wells, as well as the Oxford Clay and the Lower Kimmeridge Clay in the Penshurst Well, are in the main phase of oil generation (maturity range of 0.6-0.9% R_o) (Ebukanson and Kinghorn, 1986). On the basis of the indicated maturity levels and trend for the three Jurassic potential source formations in this area, a suggestion is here offered that the oil accumulations in this area are composed of varying contributions of generated and migrated bitumen from these Jurassic formations: the oil deposits in the outer circles of the area being mainly sourced by the Lower Lias, while the contributions from the Oxford Clay and the Kimmeridge Clay increase progressively towards the Jurassic depocentre of the area.

To investigate the possibility of a Jurassic source for the recently-discovered natural gas deposit at *Godley Bridge* in SW Surrey by Conoco (UK) (Sinclair, 1983), a geologic reconstruction of the Base Lias (Waples, 1980) is attempted in the deepest part of the

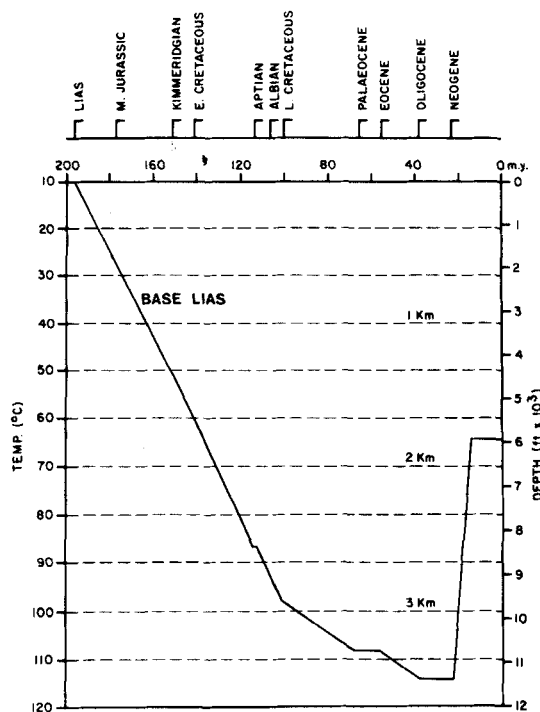


Fig. 6. Geologic model for the Base Lias in the deepest part of the Mesozoic Wealden Basin (NW Sussex—Southern Surrey).

Temperature Interval (°C)	r^u	Time (m. y.)	Interval TTI	Total TTI
Base Lias				
10-20	2^{-9}	11.00	0.02	0.02
20-30	2^{-8}	11.00	0.04	0.06
30-40	2^{-7}	11.00	0.09	0.15
40-50	2^{-6}	11.00	0.17	0.32
50-60	2^{-5}	11.00	0.34	0.66
60-70	2^{-4}	10.5	0.66	1.32
70-80	2^{-3}	10.5	1.31	2.63
80-90	2^{-2}	11.8	2.95	5.58
90-100	2^{-1}	15.0	7.50	13.08
100-110	2^0	44.8	44.80	57.88
110-120	2^1	27.4	54.80	112.68
110-100	2^0	1.5	1.50	114.18
100-90	2^{-1}	1.5	0.75	114.93
90-80	2^{-2}	1.5	0.38	115.31
80-70	2^{-3}	1.5	0.19	115.50
70-60	2^{-4}	15.0	0.94	116.44

Table 4. Calculation of present TTI values for the geologic model in Fig. 6 (Northern W. Sussex-Southern Surrey).

Mesozoic Wealden Basin which is in the NW Sussex — Southern Surrey area. Assuming the thickness of the Jurassic to be 5,400 ft (1,646.3 m), and using the same Cretaceous and Tertiary stratigraphic data as in the locality of the Penshurst Well (Ebukanson and Kinghorn, 1986), a constructed burial curve for the Base Lias is shown in Fig. 6. The calculation of the present TTI values shown in Table 4 suggest that organic maturity levels of 0.60% R_o (TTI of 10) and close to 1.2% R_o , (TTI of 112.68) (Waples, 1980) were attained by the Base Lias in this Jurassic depocentre in the Late Albian (Early Cretaceous) and in Oligocene — Early Miocene times respectively. On the basis of the suggested modification of the Lopatin method by Tissot (1984), it follows that the thermal maturity of the Base Lias in the deepest part of the Mesozoic Wealden basin must have been much higher than the predicted level of about 1.20% R_o at maximum burial prior to the Miocene tectonic inversion, and this could have been enough to result in a significant generation of natural gas in the locality (Vassoevich *et al.*, 1974; Dow, 1977). The close association of the discovered gas deposit with this region of thickest Jurassic development in the Weald appears to support the Liassic source for the gas (see Fig. 1). As noted in the Penshurst Well, the Lower Lias kerogens in the deep central parts of the Wealden Basin belong mainly to the oil-prone Type II chemical group (Ebukanson, 1984). Thus, if the maximum thermal maturity attained by the Lias in the depocentre did not exceed the known oil preservation deadline of about 2.0% R_o (Waples, 1980), then accumulations of some of the generated oil would still be possible in this area. This would therefore imply the formation of the discovered gasfield by the differential migration of the liquid and gaseous hydrocarbons (Magara, 1977; Leythaeuser *et al.*, 1982; Tissot, 1984).

OIL MIGRATION IN SOUTHERN ENGLAND

In spite of the great thicknesses of the fine-grained Jurassic hydrocarbon source-formations in Southern England (i.e. the Lower Lias, the Oxford Clay and the Kimmeridge Clay), there has been no report of any incidence of overpressuring encountered during exploratory or production drillings in the area. Only localised suspected evidence of past overpressuring has been noted in the area — namely, the calcitic cone structure of the Lower Liassic “Shales-with-Beef” in Dorset (Stoneley, 1983). The structural evolution of the Mesozoic Basins in S. England was reviewed in Ebukanson and Kinghorn (1986). It was shown that the rifting episode associated with the basin formation as well as the Mid-Cretaceous tectonic movements and the Miocene Alpine Orogenic phase resulted in the extensive fracturing/faulting and folding of the Mesozoic rocks in the region. We suggest that the early and efficient dewatering of the thick mudrock formations was enhanced to a great extent by the multiple fracturing of the Jurassic by the tectonic movements, and the drainage of generated bitumen out of these formations may have been similarly effected by along-fault discharges. Today, surface oil seepage sand-impregnations can be seen, sometimes associated with fractures, along the Dorset Coast between Weymouth and Swanage in the Upper Jurassic rocks of the Corallian and Purbeck Beds and in the Lower Cretaceous Wealden Sands. In the Weald, surface oil indications occur in the faulted Purbeck inliers and in the Wealden Sands at Chilley near Pevensey (Lees and Cox, 1937). These localised surface oil shows support the suggestion that vertical, mainly oil-phase, migration along faults must have been the major oil-transporting mechanism between the source and the reservoir rocks in southern England.

The preliminary oil-source correlation in the Isle of Wight — Dorset area discussed in the previous section, as well as the above deduction, are in favour of the migration model for the *Wytch Farm* oils earlier suggested by Colter and Havard (1981) which considers the oils to have migrated from the deep mature Jurassic source rocks in the downthrown, southern block across the Purbeck—Isle of Wight fault-zone into the Triassic and Jurassic reservoir rocks in the upthrown northern block. The oilfield in *Kimmeridge Bay* seems to represent an

accumulation of the latest migrated bitumen from the late mature Lower Lias horizons (along the listric normal fault zone) in a roll-over anticlinal structure (Stoneley, 1982) whose closure was enhanced by the Miocene Alpine North-South compressive movements.

CONCLUSIONS

(1) The deeply-buried Lias (prior to the Miocene Alpine tectonic inversion) on the southern side of the Purbeck-Isle of Wight Disturbance is suggested to be the main source of the Dorset reservoir crude oils on the bases of adequate organic maturity, *n*-alkane distribution, alkane ratios and stable carbon and hydrogen isotope ratios.

(2) On the basis of maturity, all the three potential Jurassic hydrocarbon source formations (the Lias, the Oxford Clay and the Kimmeridge Clay) are judged to have contributed in sourcing the oil accumulations in the Weald and adjacent Hampshire area.

(3) The application of the modified Lopatin method of organic maturity calculation suggests the Lias in the Weald as the possible source for the natural gas deposit at *Godley Bridge* in Surrey, and it also predicts a Liassic-sourced, possible wet gas accumulation in the Dorset—Isle of Wight area.

(4) Vertical oil-phase migration along faults is being suggested as the main oil-transporting mechanism between the Jurassic source rocks and the hydrocarbon reservoir rocks in S. England.

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