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KEROGEN FACIES IN THE MAJOR JURASSIC MUDROCK FORMATIONS OF SOUTHERN ENGLAND AND THE IMPLICATION ON THE DEPOSITIONAL ENVIRONMENTS OF THEIR PRECURSORS

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Kerogen types and their hydrocarbon-generating potentials in three main mudrock units in the Jurassic of Southern England — the Lower Lias, the Oxford Clay and the Kimmeridge Clay — have been investigated using elemental analysis, transmitted-light microscopy, density fractionation and pyrolysis-gas chromatography. The results show that, as with the lithology, the three formations display variations in their kerogen composition. The kerogen facies range from the chemical Type II to Type IV in the Lower Lias and the Oxford Clay, whereas only Types II to III are identified in the Kimmeridge Clay. Amorphous organic material constitutes the most abundant fraction of all the kerogen samples. All the identified kerogen types show a potential for generating both oil and gas.

The fluctuating oxic-anoxic depositional bottom conditions during the Jurassic is suggested to have been the major factor controlling the distribution of kerogen facies in the three formations.

INTRODUCTION

The Jurassic System of Southern England contains three major mudrock formations, namely: the Lower Lias, the Oxford Clay and the Kimmeridge Clay. Rocks of these formations occur both in outcrop sections and in the subsurface at various depths across the area (Figs. 1 and 2). It is deduced from the lithologic character, sedimentary environments and contained fauna of the three formations that they were deposited in marine conditions below the wave base (Arkell, 1933, 1947; Melville and Freshney, 1982; Selley, *pers. comm.*). These three formations have been known to contain organic-rich black shale sequences (Hallam, 1960; Bitterli, 1963; Gallois, 1976; Morris, 1980). The Lower Lias and the Kimmeridge Clay Formations display a wide range of lithologic types — from shales through mudstones and marls, to micritic limestones (both laminated and non-laminated).

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Alterations of their various lithologies occur at various stratigraphic levels in these two formations (Hallam, 1960; Sellwood, 1970, 1972; Gallois, 1976, 1978; Tyson *et al.*, 1979; Ebukanson, 1984) (Fig. 3). By contrast, the Oxford Clay Formation shows a restricted lithologic range — consisting mainly of shales in the lower part and mudstones in the middle and upper parts (Arkell, 1947; Callomon and Cope, 1971; Morris 1980; Ebukanson, 1984) (Fig. 4).

Some relationship has been noted between the lithologies of these formations and their organic matter content/richness. The laminated mudrocks (shales and laminated limestones), which represent oxygen-deficient depositional bottom conditions with low benthic faunal activity, have been found to be very organic-rich; while the non-laminated varieties (mudstones, marls and normal limestones), which it is deduced were deposited in oxic environments, are generally poorer in organic content (Hallam, 1960; Gallois, 1976, 1978; Tyson *et al.*, 1979; Ebukanson, 1984). The variations in the lithology and the organic matter richness of the three Jurassic mudrock formations have been attributed by these Authors to varying depositional environmental conditions, including depth of sea floor and oxic-anoxic bottom conditions.

The present work is mainly an investigation of the kerogen types in the various lithologies of the three formations, their hydrocarbon potentials, and the influence of environmental factors in the kerogen facies distribution.

SAMPLING

Both outcrop and borehole samples of the three formations were investigated. Fresh outcrop samples were collected in the Dorset coastal area: the Lower Lias was sampled at Charmouth and Lyme Regis; the Oxford Clay was sampled at Shortlake and in the Chickerell area (from brickpits); and the Kimmeridge Clay was sampled in the Ringstead Bay and Kimmeridge Bay—Chapman's Pool areas. Stratigraphic sampling of the outcrop sections by ammonite zonation was carried out for the Oxford Clay and for the Kimmeridge Clay (only in the Kimmeridge Bay — Chapman's Pool area).

Rock samples from ten boreholes were collected for this study. The boreholes are Marchwood; Warlingham; Winterborne Kingston; Cranborne No. 1; Burton Row; Arreton No. 2; Cooles Farm No. 1: Winchester No. 1; Henfield; and Penshurst (see Fig. 1). The present depths of the three sampled formations in these boreholes are shown in Fig. 5. The samples from Arreston No. 2, Cooles Farm No. 1, Cranborne No. 1 and the Lower Lias of Penshurst Wells were ditch cuttings, whereas those from the other wells and the Oxford and Kimmeridge Clay Formations of the Penshurst Well were conventional core materials. The samples from each of the three formations were collected and labelled in order of depth.

ANALYTICAL TECHNIQUES

Five-50g of each rock sample selected, previously crushed to 1-mm grain size, were subjected to a maceration procedure adapted from that described by Barss and William (1973) for palynological preparations. This involved placing the crushed sample in a 600-ml plastic beaker and subsequent treatment with 100-ml portions of 10% hydrochloric acid (HCl, technical grade) in order to eliminate any carbonates. The HCl-treatment was continued until the reaction and evolution of carbon dioxide ceased to be observable. The residue was washed in distilled water to neutrality, in an attempt to remove all the calcium ions. The residue was allowed sufficient time to settle before the clear water was decanted. The concentrate was acidified with a few millilitres of 5% HCl, and then treated with two 50-ml portions of concentrated hydrofluoric acid (60% HF, technical grade) to digest completely the silicate minerals. The HF-treatment was carried out over a period of 48 hours. Care was taken to avoid any form of heating or oxidation of the organic matter. The
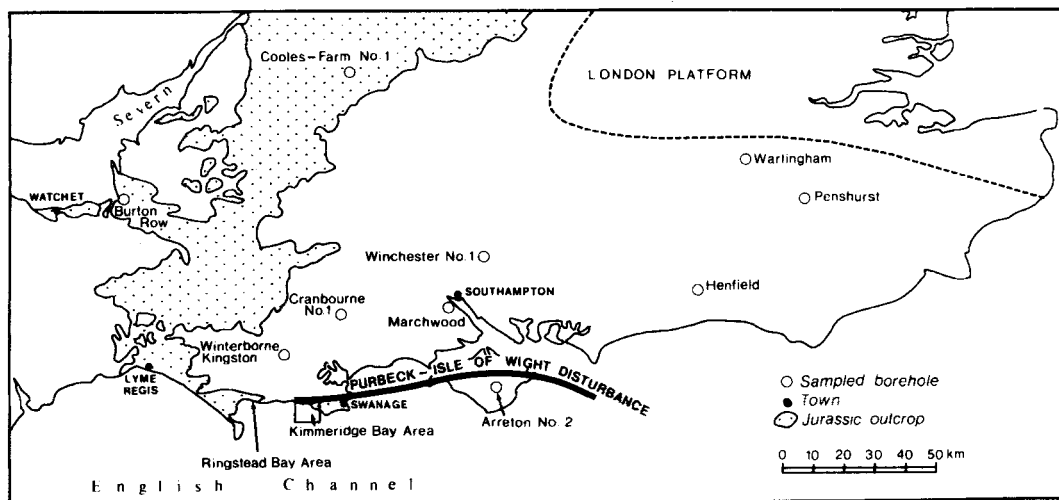
Fig. 1. Part of Southern England showing Jurassic outcrop and positions of sample boreholes.

STAGES				LITHOLOGICAL DIVISIONS	SEDIMENTARY FACIES
JURASSIC	UPPER	Portlandian		Purbeck Beds	Continental/Paralic
				Portland Beds	Marine Carbonates & Clastics
		Kimmeridgian		Kimmeridge Clay	Marine Sub-Wave Base Mud
		Oxfordian		Corallian Beds	Paralic & Marine Shoal Carbonates & Clastics
	MIDDLE	Callovian		Oxford Clay	Marine Sub-Wave Base Mud
		Bathonian		Kellaway Beds	Marine Shoal Carbonates, Sands & Mud
				Cornbrash Great Oolite	
		Bajocian Aalenian		Inferior Oolite	
	LIASSIC	Upper Lias	Toarsian	Bridport Sands	Sporadic Sub-Shoal Sands & Sub-Wave Base Mud
		Middle Lias	Pliensbachian	Downcliff Clay	
				Thorncombe & Downcliff Sands	
	LOWER LIAS	Lower Lias	Sinemurian	Calcilutites Marls & Shales	
			Hettangian		

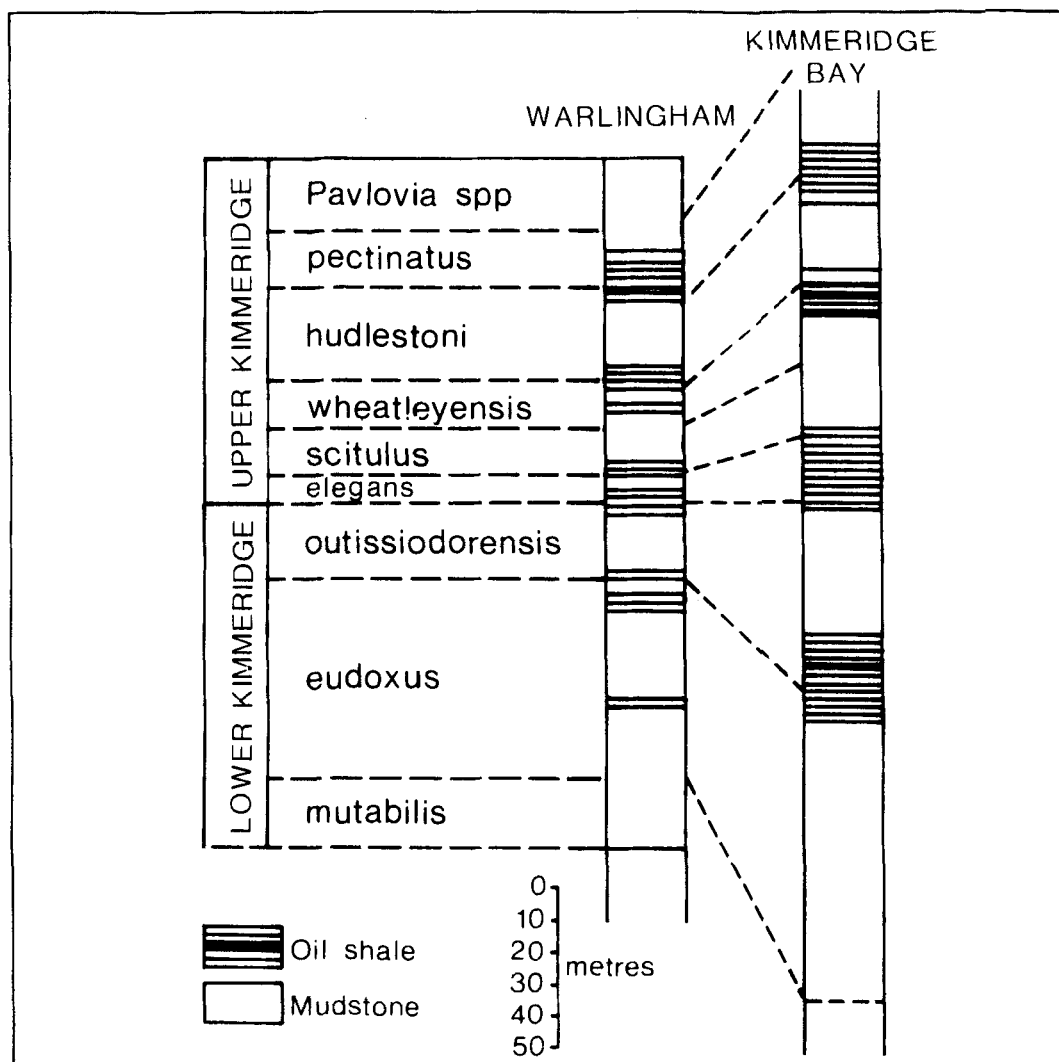**Fig. 2. Summary of Jurassic stratigraphic column in Southern England.**

Fig. 3. Stratigraphic subdivisions and correlation of the Kimmeridge Clay between Kimmeridge Bay (Dorset) and the Warlingham Well (Adapted from Morris, 1980).

acidification of the residue with 5% HCl prior to HF treatment was to prevent any calcium ions that may have been present from forming fluoride complexes (Saxby, 1970; Bostick and Alpern, 1977). The HCl/HF acid insoluble residue was washed to neutrality with distilled water.

The insoluble organic matter was then subjected to a fractionation procedure similar to that described by Kinghorn and Rahman (1980, 1983) using zinc bromide solutions with specific gravities of 2.2, 1.65, 1.53 and 1.45 (see Fig. 6). A portion of the washed "float" fraction of the initial separation by centrifugation in zinc bromide solution of specific gravity 2.2 (washing in 1% HCl and then in distilled water) was oven-dried at 40° ± 2°C in a nitrogen atmosphere until a fairly constant weight was reached. The dried organic matter was ground in an agate mortar and then rinsed with dichloromethane (boiling point: 38°C) in order to remove any bitumen left in the insoluble organic matter after the HCl/HF treatment (Peters *et al.*, 1983). The kerogen was dried again under the same conditions as above for a day, and then stored in a stoppered glass tube in a desiccator. The remaining
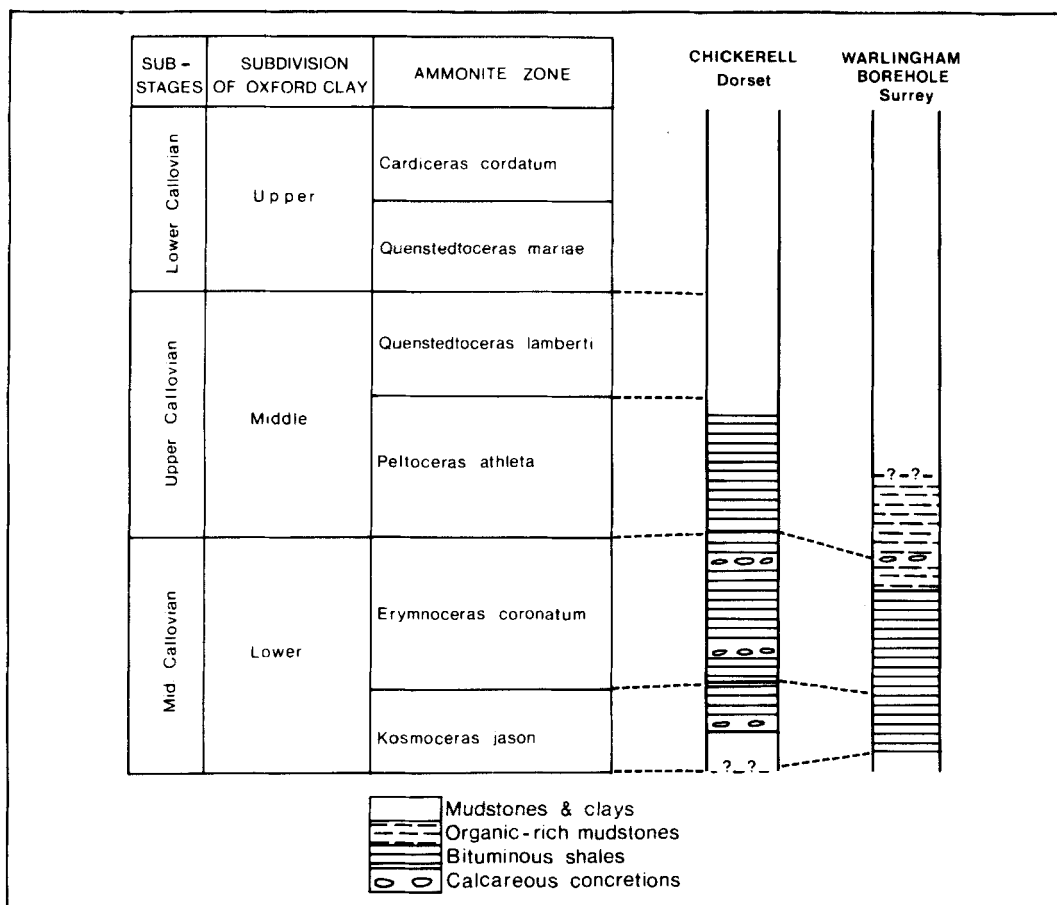
SUB - STAGES	SUBDIVISION OF OXFORD CLAY	AMMONITE ZONE	CHICKERELL Dorset	WARLINGHAM BOREHOLE Surrey
Lower Callovian	Upper	Cardiceras cordatum		
		Quenstedtoceras mariae		
Upper Callovian	Middle	Quenstedtoceras lamberti		
		Peltoceras athleta		
Mid Callovian	Lower	Erymnoceras coronatum		
		Kosmoceras jason		

Mudstones & clays
Organic - rich mudstones
Bituminous shales
Calcareous concretions

Fig. 4. Stratigraphic sub-divisions of the Oxford Clay formation and its general lithologic trend in Southern England.

"float" fraction of the initial density fractionation (in zinc bromide of specific gravity 2.2) was then density-fractionated successively into four fractions (Fig. 6) of densities: less than 1.45; 1.45-1.53; 1.53-1.65; and 1.65-2.2 respectively). The separated fractions were washed and allowed to settle in distilled water in graduated centrifuge tubes for a period of 24 hours. The percentage separations of the four fractions were then estimated volumetrically. A representative sample from each of the density fractions, as well as one from the total organic matter, were mounted in glycerine jelly on standard glass slides for transmitted-light microscopic examination.

A *Perkin Elmer Model 240* Elemental Analyzer was used to determine the total organic carbon content of the rock samples, and also to analyse the dried kerogen samples for their carbon (C), hydrogen (H) and oxygen (O) contents.

A programmed-temperature pyrolysis-gas chromatographic apparatus was used to analyse some of the kerogen samples. The set-up employed essentially a *Perkin Elmer Model F30* Gas Chromatograph, in which the injector had been replaced with a programmable stainless steel furnace. The furnace was controlled via a transformer by a muffle-furnace temperature controller. The gas chromatograph detector (FID) response was displayed via an amplifier unit by a chart recorder operated at a speed of 5 mm/minute. 0.5−2 mg kerogen sample was rapidly pyrolysed from 150°-550°C (in helium carrier gas) in 9 minutes, and the pyrolysis products were then analysed by gas chromatography. The gas
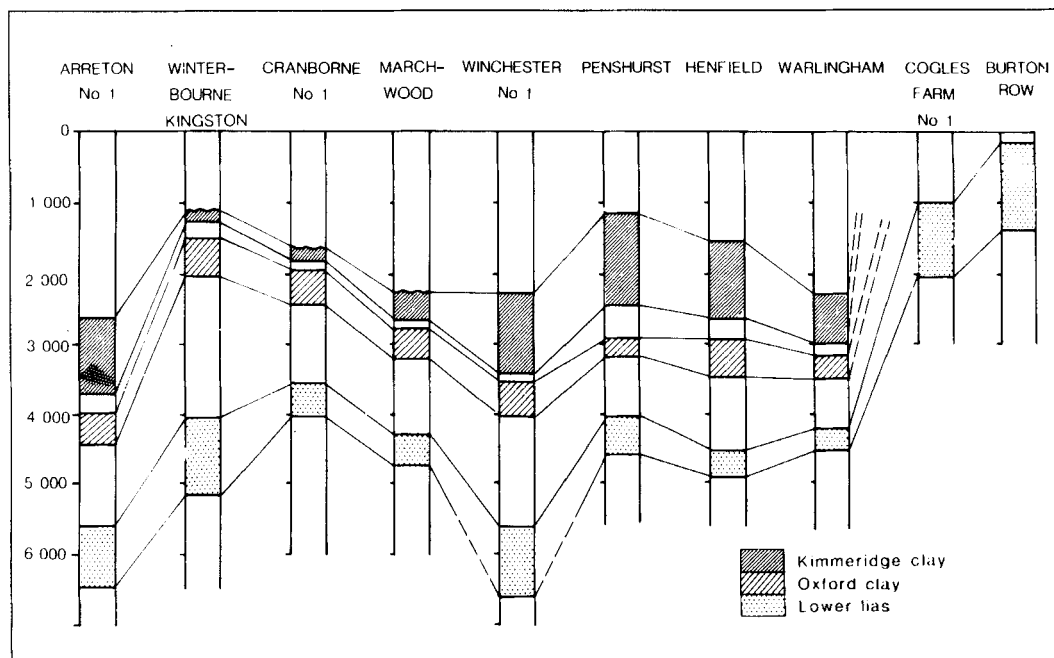
Fig. 5. Correlation of the Lower Lias, the Oxford Clay and the Kimmeridge Clay Formations in the sampled boreholes.

chromatograph temperature programme involved a 3-minute purge, and a temperature rise from 80°-270°C at the rate of 4°C/min. Identification of the normal alkane components of the pyrolysates was achieved by comparison of their retention times with those of authentic compounds in a standard mixture gas-chromatographed (after disconnecting the pyrolysis furnace) using the same procedure as for the pyrolysates.

RESULTS AND DISCUSSIONS

Kerogen types and their variation in the Lower Lias, the Oxford Clay and the Kimmeridge Clay

Following the work of Van Krevelen (1961) on the thermal evolution of coal macerals based on elemental composition (C,H,O) and employing cross-plots of the atomic H/C and O/C ratios, Tissot *et al.*(1974) defined the first three types of kerogen (i.e. Types I, II, and III). More recently, on the same basis, a fourth type has been identified and described as residual organic matter or Type IV kerogen (Bostick, 1979; Tissot *et al.*,1980; Brooks, 1981; Kinghorn, 1983) (Fig. 7). Types I and II kerogens, with high initial hydrogen contents but low oxygen contents, are believed to be derived from algal material, the remains of micro-organisms (like bacteria and fungi) as well as lipid-rich residues of terrestrial spores, pollens and cuticles deposited in reducing environments. They are regarded as having great generating potential for both oil and gas (Tissot and Welte, 1978; Bailey, 1981).

By contrast, Type III kerogen, with a relatively low initial hydrogen content but a high oxygen content, is believed to be derived mainly from allochthonous terrestrial higher plant material, and is often described as gas-prone with the least potential for oil generation. Tissot *et al.* (1980) attribute the presence of Type III kerogen in marine sediments largely to the transport of terrestrial organic matter into an ocean basin where an oxic water column
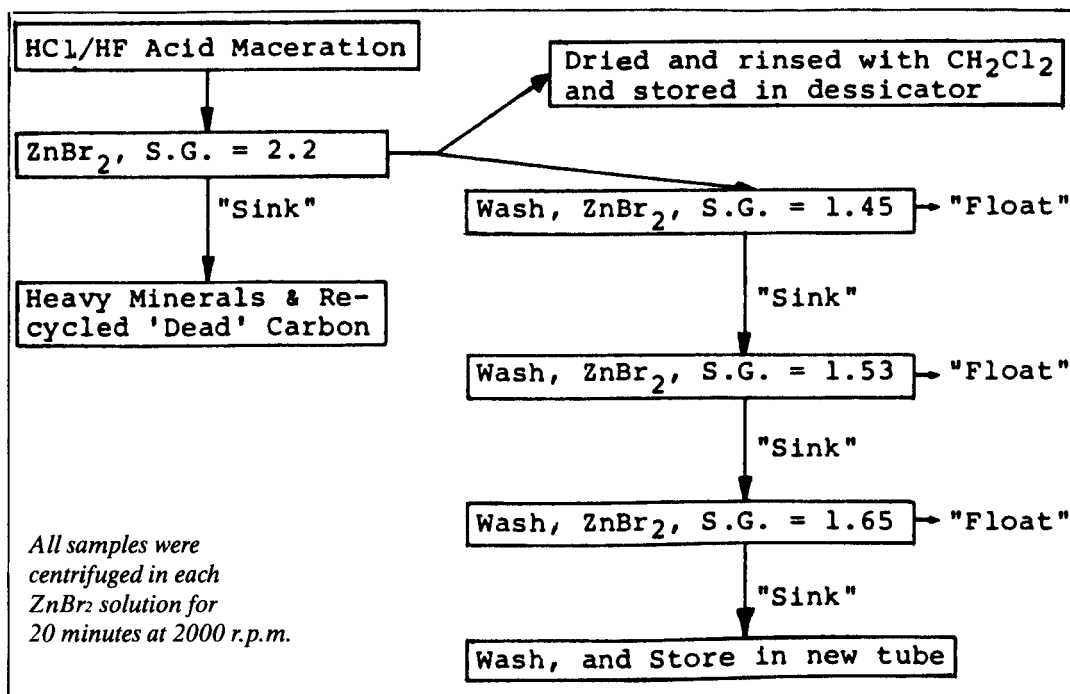
Fig. 6. Method for fractionating acid-insoluble organic matter.

prevents the deposition of the planktonic remains. Such conditions, they pointed out, lead to comparatively enhanced preservation of the more resistant, hydrogen-poor, terrestrial organic matter whereas the marine planktonic input is preferentially biodegraded.

Type IV kerogen has been described as consisting mostly of residual organic matter derived from highly oxidised/altered material (like charcoal), or high rank material recycled from older sediments. Regarded as inertinitic, Type IV kerogen is often considered as "dead carbon" with very little or no potential at all for hydrocarbon generation (Tisot *et al.,* 1980; Bostick, 1979; Kinghorn, 1983).

The atomic ratios of the kerogen concentrates from the Kimmeridge Clay (KC), the Oxford Clay (OC) and the Lower Lias (LL) samples from outcrops in Dorset (OSD) and from Henfield (HN), Warlingham (WM) and Cranborne-1 (CN) wells are presented in Table 1 (p. 453), and the Van Krevelen diagrams for the kerogen samples are shown in Fig. 8. Also presented in Table 1 are the lithologies and total organic carbon (TOC) values of the whole rock samples, as well as the associated kerogen types (based on the Van Krevelen diagrams in Fig. 8). Analytical results of samples from the few localities are presented because they illustrate fully the general characters of the three Jurassic formations in terms of lithology, organic matter content and composition.

As noted from Table 1 and Fig. 8, the kerogens show wide variations in their elemental composition, and they have been classified into four groups or Types. These are Types II, mixed II/III, III and IV. The mixed Type II/III is considered as those which plot between the fields of Type II and Type III. The formation of this intermediate or mixed type could be due to massive terrestrial organic matter input into anoxic marine basins where lipid-rich marine planktons also accumulate (Tissot *et al.,*1980), and can also be produced by partial biodegradation of Type II kerogen precursors deposited in bottom waters which are not completely anoxic (Ebukanson, 1984).

Kerogen Types II, II/III and III are identified in the samples from the Lower Lias, the Oxford Clay and the Kimmeridge Clay. Type IV kerogens are identified in the Lower Lias

(samples WM/LL.4 and WM/LL.5 from the Warlingham well) and in the Upper Oxford Clay (sample CN/OC.1 from the Cranborne-1 well) but not in the Kimmeridge Clay. Thus, vertical/stratigraphic variations in the kerogen types do occur in each of these three formations.

In the Lower Lias and Kimmeridge Clay, just like the lithologic variations, no single trend in the kerogen type variation with stratigraphy is noticed. Rather, alterations of the identified types tend to occur at various stratigraphic levels. By contrast, a single stratigraphic trend is observed in the kerogen-type variations in the Oxford Clay Formation throughout Southern England. Wherever the complete Oxford Clay Formation occurs, the following vertical trend in the kerogen types is generally noticed from the base to the top of the formation: Type II — mixed Type II/III — Type III — Type IV. Such a vertical kerogen-type variation seems to imply either a single directional variation in the position of the oxic — anoxic boundary of the bottom waters, or a uniform variation in the organic input or both during the deposition of the Oxford Clay sediments.

Characterization of the identified kerogen types by transmitted-light microscopy and density fractionation

Table 2 shows the results of the transmitted-light microscopic assessment of the kerogen samples, as well as the density separation ranges for the amorphous and the humic fractions of these kerogens. The chemical kerogen type is indicated for each sample on the table for ease of compositional comparison between the various types.

As indicated in Table 2, the organic constituents of the Jurassic kerogens are classified into four easily-recognizable categories of sedimentary organic matter by transmitted-light microscopy. These categories are: amorphous (described as sapropelic or fine-grained); palynomorphs (including pollens, spores, dinoflagellates and acritarchs); humic matter (brown to opaque woody and coaly fragments); and "cuticles" (any thin, translucent, tissue-like fragments, not necessarily the waxy coating of leaf or stem epidermis), (Masran and Pocock, 1981). The relative abundances of these four organic groups were estimated visually.

Contrary to the notion which, previously, was generally held, Powell *et al.* (1982) and Kinghorn and Rahman (1983) pointed out that not all amorphous organic matter is lipid-rich. They identified both the hydrogen-rich (or oil-prone) and the hydrogen-lean (or gas-prone) varieties. Hydrogen-rich amorphous matter is believed to be derived from algal material deposited in reducing environments (and is therefore sapropelic), whereas the hydrogen-lean variety is regarded as the result of microbial degradation of marine- or terrestrially-derived organic materials. At low levels of organic maturation, the sapropelic, oil-prone amorphous material (classified as kerogen Type I or II) has been shown to occur commonly as unorganized fluffy to semi-coherent masses; whereas the gas-prone amorphous material (classified as Type III kerogen) tends to be finely dispersed in texture (Kinghorn and Rahman, 1983).

Based on the findings of Fenely (1971) and Stach *et al.*, (1975) — that maceral components of the various types of sedimentary organic matter (i.e. exinites, vitrinites, inertinites, etc.) each have a characteristic density — Kinghorn and Rahman (1980, 1983) characterized the various kerogen materials (particularly the amorphous kinds) in terms of their type and maturity, using the method of density separation in heavy liquid (zinc bromide). They have shown that the hydrogen-rich amorphous type is characteristically light, with a specific gravity range of less than 1.45 to 1.65; whereas the hydrogen-lean amorphous type is heavy, with a specific gravities range of 1.53-2.2. In both cases, the specific gravities have been shown to increase with increasing maturity. They associated the humic fragments (i.e. vitrinites and inertinites) with the same specific gravity range as the gas-prone amorphous material.
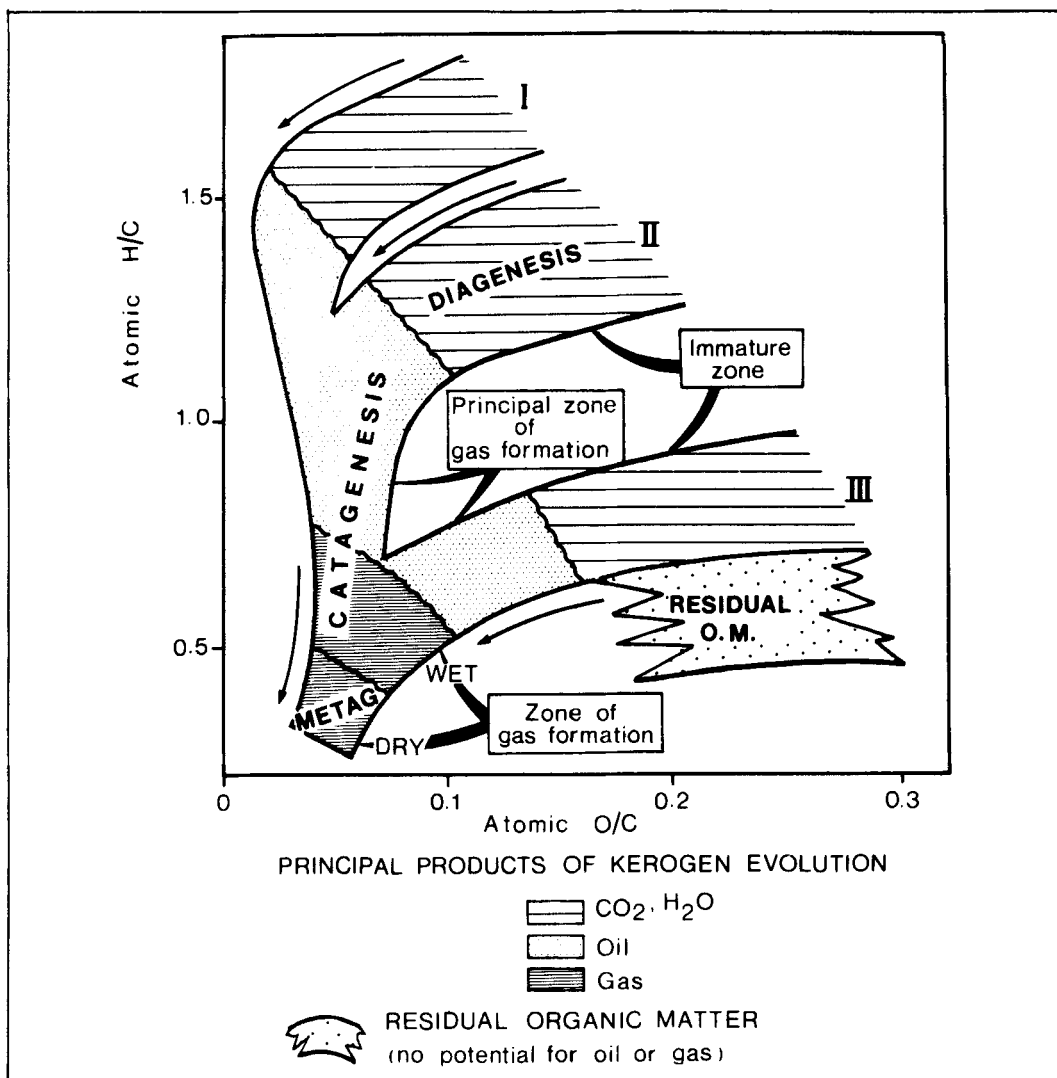
Fig. 7. Elementary composition of kerogens showing main types and principal products generated during thermal evolution (After Tissot *et al.*, 1980).

Significant differences are observed in the composition of the four identified kerogen-types in the Jurassic of Southern England (i.e. Types II, mixed II/III, III and IV). In the Type II group, the most abundant material is yellow to pale-brown, sapropelic and amorphous; this has a specific gravity mostly in the range of less than 1.45 to 1.65, and is therefore regarded as light (see Plate 1a). However, a few Type II kerogen samples at low maturity levels contain a mixture of sapropelic and finely dispersed amorphous material (see Plate 1c). This is probably indicative of early, arrested biodegradation of the deposited marine plankton, with a possible accumulation of the bacterial and fungal biomass. Also noted is the fact that the sapropelic amorphous matter of some samples have specific gravities ranging up to 2.2. The heaviness is most probably explained by the unique abundance of opaque particles — most likely pyrite — in the fluffy masses (Plate 1d). Tiny "cuticular" fragments tend to be quite common (5-49%) in these Type II kerogens, whereas the humic fragments are rare to minor (i.e. less than 20%) in content. Palynomorphs
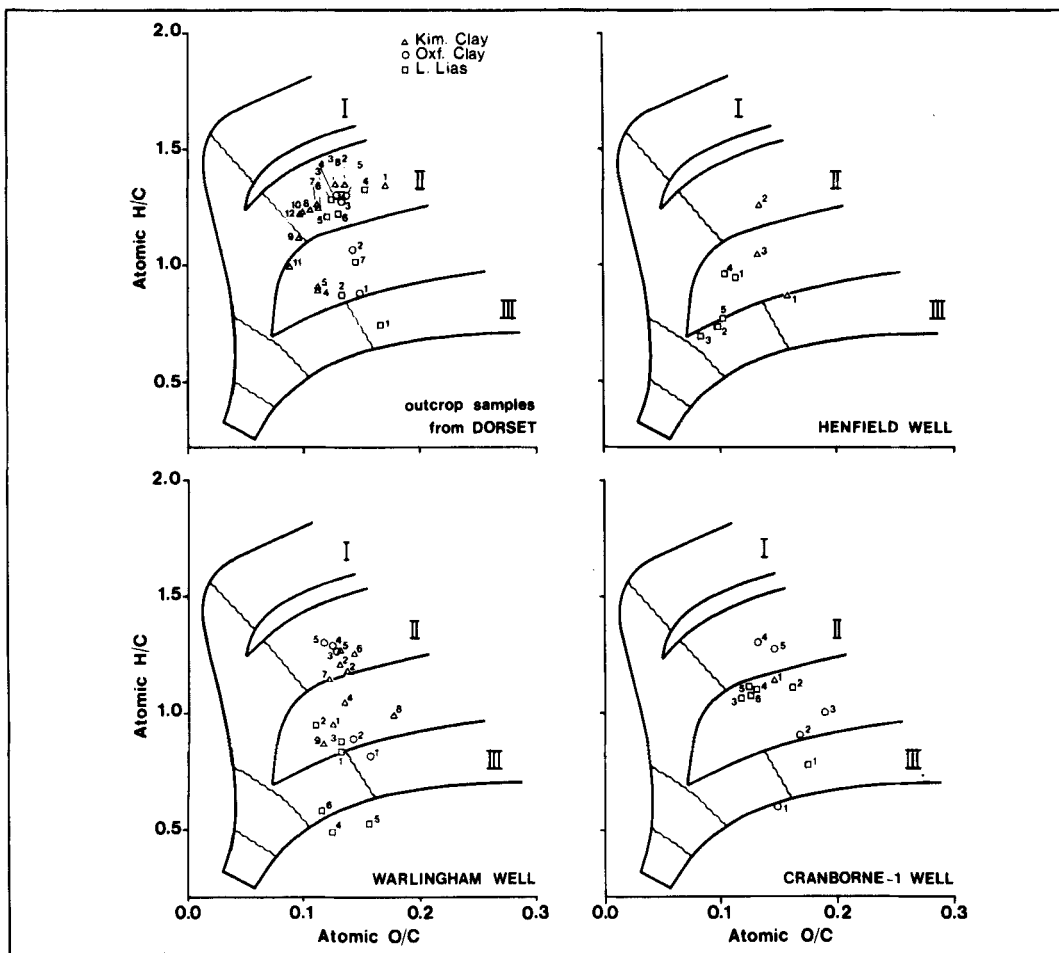
Fig. 8. Van Krevelen diagrams: (a) outcrop samples; (b) Henfield well; (c) Warlingham Well; (d) Cranborne-1 Well.

constitute less than 35% in all Type II kerogens. The humic fragments in this Jurassic kerogen group tend to be very light (specific gravity range: less than 1.45 to 1.65) compared to the heavy vitrinite and inertinites with specific gravities greater than 1.65 reported by Kinghorn and Rahman (1980). This may be interpreted as indicating that light inertinitic materials like charcoal are the major constitutents of the humic matter of the identified Jurassic Type II kerogens.

By using reflected-light microscopy, Douglas and Williams (1981) reported that the particulate sedimentary organic matter in the Kimmeridge oil-shale samples from outcrops and shallow boreholes in England are mainly composed of structureless, very low reflecting amorphous sapropel (bituminite), while recognisable coal macerals are not generally abundant. And of these, inertinite was observed to be predominant, with secondary and primary vitrinites being subordinare and locally rare. This finding by Douglas and Williams agrees very well with the composition of the Type II kerogens in the three Jurassic formations described above, based on transmitted light microscopy and density fractionation.

In the Type III kerogen samples, the amorphous material is again the most abundant organic constituent (greater than 50%) but here, it is the heavy, hydrogen-lean, fine-grained

Fig. 9. Typical pyro-chromatograms of the immature Type II kerogens: (a) (above) Sample OSD/KC.7 from the Kimmeridge Clay Formation; (b) (below) Sample OSD/OC.4 from the Oxford Clay Formation.
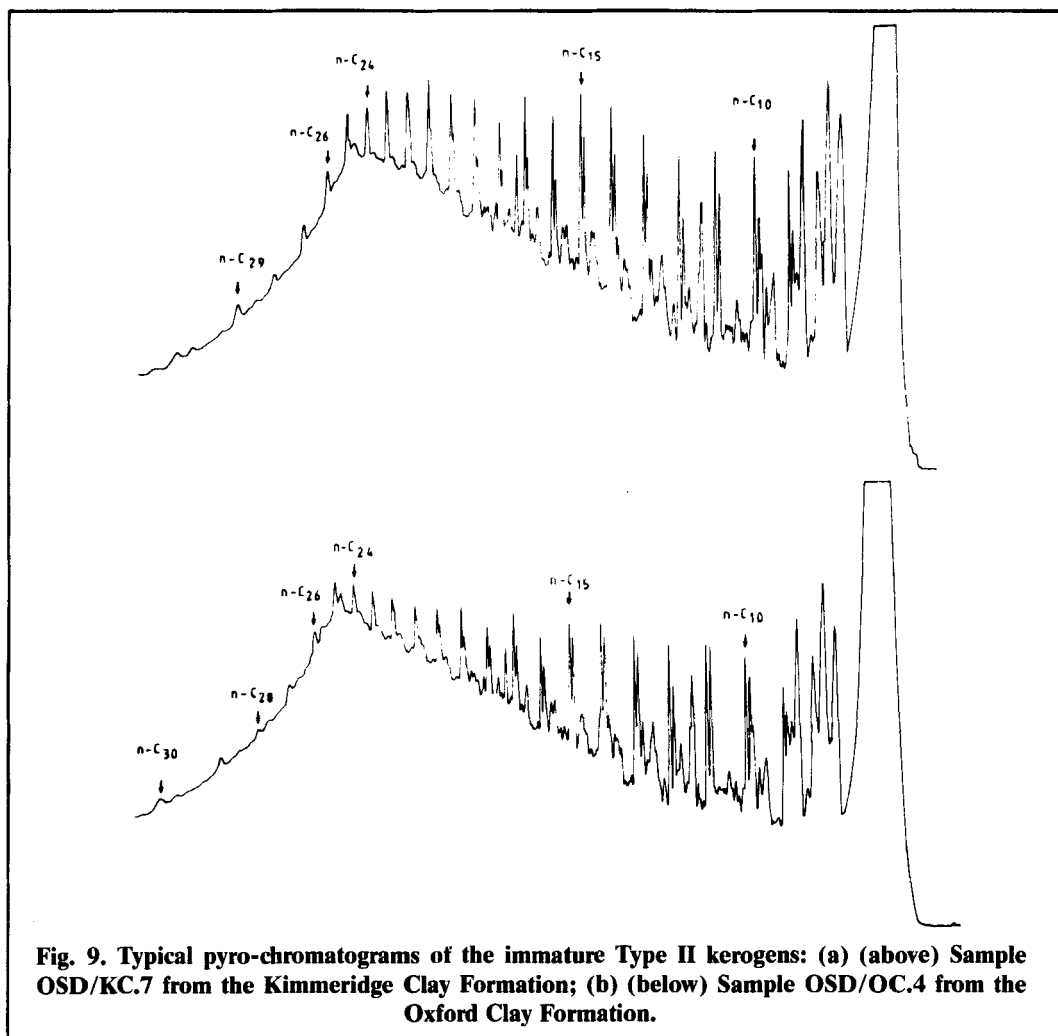
type described by Kinghorn and Rahman (1983) (Plate 2). It is commonly greyish to greyish-brown in colour. The humic fragments of wide density range (specific gravity: less than 1.45 to 2.2) constitute the next most abundant material in this kerogen group, and make up 20-49% in most samples. This indicates a relatively high terrestrial influence compared to the Type II situation, with the inclusion of a wide variety of humic material ranging from the very light fusinitic ones (like charcoal) to the very heavy, high rank, recycled ones. The palynomorphs constitute less than 20% in all the Type III samples whereas the "cuticles" are rare (less than 5%) to common (i.e. 20-34%) in abundance.

The mixed Type II/III kerogens occupy an intermediate position between Types II and III with regard to the relative abundance and form of the four organic matter categories. The amorphous material is the most abundant, being either wholly finely dispersed or made up of relatively few sapropelic masses in a fine-grained groundmass. In many Type II/III samples, the humic particles of wide density range (less than 1.45 to 2.2) constitute the next most abundant material, and form 5-49% of all samples in this group.

In the Type IV kerogen group, the heavy, fine-grained, greyish amorphous material constitutes over 50% of the total concentrate, and is again the most abundant component. As with Type III, the humic fragments (specific gravity: less than 1.45 to 2.2) are next in

abundance, forming 35 to 49% in all the samples. Both the palynomorphs and the "cuticles" are rare to minor in content (see Plate 3).

On the basis of their somewhat fibrous nature, some organic fragments, described as "cuticles" in Types II and mixed II/III particularly, are likely to be incompletely altered algal and fungal fragments (Batten, 1983) (Plate 1b).
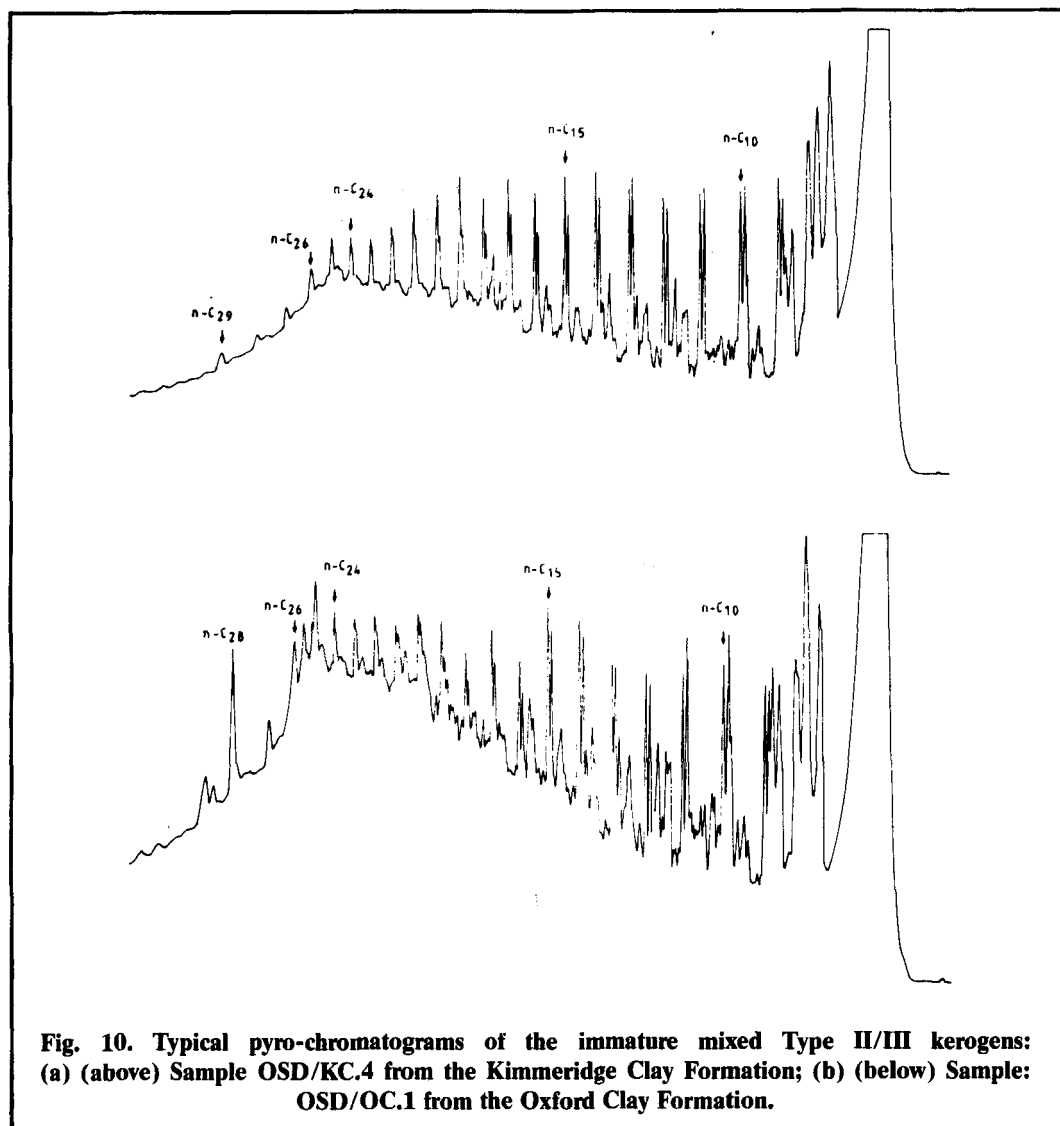
PYROLYSIS-GAS CHROMATOGRAPHIC ANALYSIS OF THE IDENTIFIED KEROGEN TYPES AND THEIR OIL AND GAS GENERATING POTENTIALS

Recently, gas chromatograms of kerogen pyrolysates have been used by a number of workers to assess both the type and hydrocarbon potential of insoluble sedimentary organic matter (Larter and Douglas, 1978; 1980; Van de Meent et al., 1980; Bailey, 1981; Dembicki et al., 1983). According to Bailey (1981), a kerogen sample is judged not to be oil-prone if its pyrolysate consists almost exclusively of materials lighter than approximately C_{15}, due to the fact that about half of a typical crude oil consists of the missing C_{15+} fraction.

The kerogen pyrolysis — gas chromatographic analysis was carried out as part of this investigation to characterize further the various kerogen types identified in the three Jurassic mudrock-formations in Southern England in terms of their chemical nature and hydrocarbon-generating capabilities. Fig. 9 shows typical chromatograms of pyrolysates from immature Jurassic Type II kerogens — consisting mainly of the sapropelic, hydrogen-rich amorphous material. As indicated by the chromatograms, the pyrolysates consist mainly of normal alkene — alkane doublets in the C_{9+} range with a high doublet peak-to-background ratio. The background components represent contributions from branched and cyclic alkenes and alkanes as well as aromatic compounds. The chemical nature of these Jurassic Type II kerogens, as portrayed by the pyrolysate chromatograms in Fig. 9, is at variance with the results of similar analyses of kerogen concentrates (believed to be Type II) from the Kimmeridge Clay, sampled in Kimmeridge Bay, Dorset, by Williams and Douglas (1980). These analyses showed the pyrolysates to consist mostly of aromatic hydrocarbons. The presence of components extending into the C_{24+} range (including waxes) in the pyrolysates of presently-identified Type II kerogens confirms the oil-prone nature of this kerogen type, and indicates some contributions of terrestrially-derived herbaceous materials to the kerogen composition (Van de Meent et al.,1980; Bailey, 1981). Thus, some waxiness in the oils sourced by this kerogen type in Southern England may not be unexpected.

Typical chromatograms of the mixed Type II/III kerogen pyrolysates are shown in Fig. 10. They appear similar to the kerogen Type II pyrolysate-chromatograms, with a slightly lower aliphatic hydrocarbon doublet peak-to-background ratio in some cases. This probably reflects the higher humic matter content, as well as the partially oxidised nature of the amorphous material in this mixed kerogen facies, compared to the pure Type II.

Fig. 11 is a Lower Lias Type III kerogen pyrolysate-chromatogram, showing that the aliphatic hydrocarbons constitute a significant proportion of the pyrolysis yield; components are noted to extend to the heavy end (i.e. C_{24+}) with an increased peak-strength in the C_{24}-C_{26} range. Also noted are the higher contributions of the background components in the C_{9+} fraction compared to the first two kerogen groups. Based on the pyro-chromatograms (e.g. Fig. 10), it may be argued that the Jurassic Type III kerogens identified in the present investigation consist mainly of the greyish hydrogen-lean amorphous material with some admixtures of humic and herbaceous organic matter, and that they have both gas- and oil-generating capabilities. Of particular interest is the chromatogram of a Lower Lias Type IV kerogen pyrolysate shown in Fig. 12. Normal alkene — alkane doublets, as well as other organic compounds, are present up to C_{30}. The result of this analysis thus shows that the Type IV samples identified in the Jurassic of Southern England do have some potential for gaseous and oil-range hydrocarbon generation. This finding appears contradictory to the general notion that hydrogen-lean inertinitic materials have no

Fig. 10. Typical pyro-chromatograms of the immature mixed Type II/III kerogens: (a) (above) Sample OSD/KC.4 from the Kimmeridge Clay Formation; (b) (below) Sample: OSD/OC.1 from the Oxford Clay Formation.

potential for hydrocarbon generation. Although this study has proved that very hydrogen-poor kerogen may have some hydrocarbon-generating potential, it should be noted that, in order to function as a commercial oil-source, a relatively high concentration of this kerogen type material is required to be present in a source rock. This is suggested by the comparatively large quantity of this kerogen sample that was required to generate the chromatogram shown in Fig. 12.

Recently, Smyth (1983) proposed that the dispersed inertinite in the Gidgealpa Group sediments is one of the sources for liquid and gaseous hydrocarbons in the Cooper Basin of Australia, based on the results of organic petrographic analysis and mass balance calculations. The results of the present organic geochemical investigation of Jurassic mudrocks in Southern England seems to support Smyth's suggestion, that inertinites should be considered as a source or potential source material for liquid hydrocarbons.

KEROGEN TYPE VARIATIONS AND THEIR IMPLICATION ON THE DEPOSITIONAL CONDITIONS OF THE MAJOR JURASSIC MUDROCK-FORMATIONS IN S. ENGLAND

Based on the transmitted-light microscopic study, it is noted that the main differences in the four identified Jurassic kerogen types generally lie in the nature and relative abundance of two categories of organic matter: the amorphous and the humic types. The association of sapropelic, hydrogen-rich amorphous material with mainly relatively-light, humic matter in Type II kerogens seems to indicate that the precursors of this kerogen group in the Jurassic were deposited in deep-water conditions, far removed from the shoreline, where the environment was reducing and quiet; only very light land-derived organic matter (humic and herbaceous) could be transported to these deep deposits.

By contrast, compositions of Type II/III, Type III and Type IV kerogens tend to reflect (in that order) increasingly shallower depositional conditions, where the bottom waters were more oxidising and less quiet, and, being shallow, were in closer proximity to the shoreline. Hence the incorporation of larger amounts of terrestrially-derived organic matter of wide density range.

A careful study of Table 1 shows that there is no simple relationship between kerogen types and the associated lithologies. The various kerogen types occur in both argillaceous and carbonate rocks. Shales and other argillaceous rocks are normally considered in a sedimentary sequence to suggest deeper water phases, while the limestones should indicate periods of shallower and clearer water (Perkins, 1977; Selley, 1978). But there seems to be a relationship between the kerogen types and the organic richness of the rock samples. It is noted that kerogen Type II is mainly associated with the very organic-rich samples of each section, whereas other kerogen types occur in rock samples with moderate-to-low total organic carbon contents. Table 1 shows that the laminated mudrocks (i.e. shales, laminated marls and limestones) are the most organic-rich lithologic types in the three Jurassic formations. Since these lithologies are normally considered to represent quiet, anoxic depositional bottom environments (Tyson *et al.*, 1979; Morris, 1980), it thus implies that the Jurassic Type II kerogen precursors in S. England were mainly deposited and preserved in oxygen-deficient bottom waters. It may be suggested that these conditions, unfavourable for the benthic fauna and flora, resulted in the increased preservation of the marine phytoplankton deposited (Tissot and Welte, 1978; Coleman *et al.*,1979; Demaison and Moore, 1980). It thus seems that the nature or compositions of the mixed Type II/III, Type III and Type IV kerogens, as well as the relatively low TOC values of their mainly non-laminated lithologies, are due to the oxidising nature of their depositional environments, and are not necessarily the outcome of the organic input. Oxic bottom conditions would have favoured significant destruction of the deposited organic matter, and in particular, the preferential degradation of the phytoplanktons with a resulting increase in the relative contents of the more resistant humic materials (Tissot *et al.*, 1980; Meyers *et al.*, 1984) as noted in this investigation.

The fluctuating anoxic-oxic depositional conditions during the Jurassic therefore appear to have been the major factor controlling both the distribution of the kerogen facies, and the organic matter richness of the associated lithologies in the Lower Lias, the Oxford Clay and the Kimmeridge Clay Formations. This assertion is supported by the observations by Melville and Freshney (1982) that these major Jurassic fine-grained rock units were probably laid down in water of practically the same, if moderate, depth and sluggish circulation; and that the variation in the facies of these formations were produced by the enhanced importance of quite small depth-fluctuations of the generally shallow Jurassic Sea in response to continent-wide, small-scale, epeirogenic movements (of amplitudes generally less than 30 m or 98 ft.) of the time.
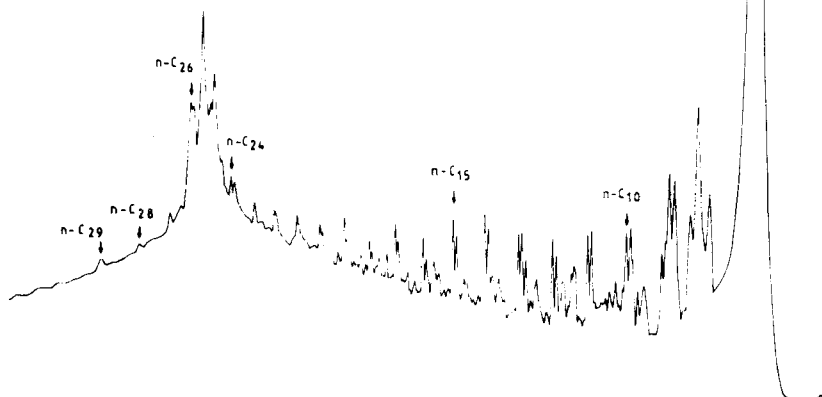
Fig 11 (above). Pyro-chromatogram of a kerogen Type III sample, OSD/LL.1, from the Lower Lias Formation.
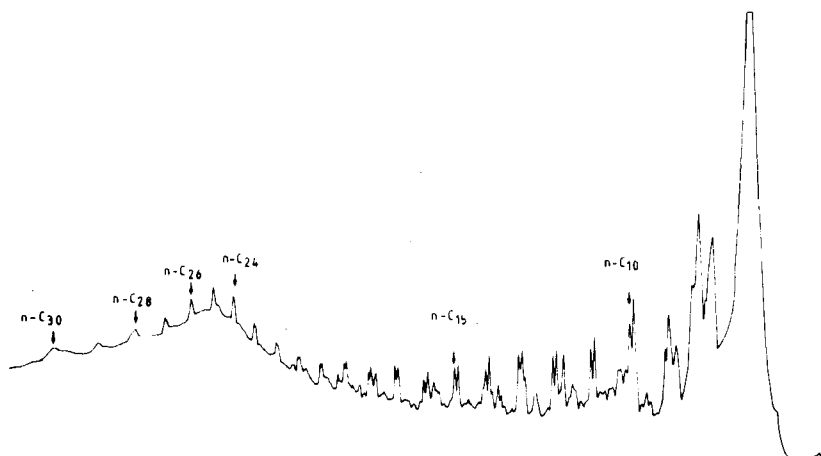
Fig. 12 (below). Pyro-chromatogram of a kerogen Type IV sample, WM/LL.5, from the Lower Lias Formation.

SUMMARY AND CONCLUSIONS

Wide variations in kerogen elemental composition occur in samples from each of the three Jurassic formations. The kerogen facies range from Type II, through the mixed Type II/III and Type III, to Type IV in the Lower Lias and the Oxford Clay, whereas only the first three types are identified in the Kimmeridge Clay. Amorphous organic material constitutes the most abundant fraction of all the kerogen types identified. The herbaceous and humic matter constitute relatively minor components. The amorphous matter in Type II kerogens is mostly sapropelic and light (density) in nature, whereas the amorphous components in the other kerogen types are heavy, biodegraded varieties.

The pyrolysis — gas chromatographic analysis shows that the kerogen Types II, II/III and III identified have the potential for oil and gas generation. Though Type IV kerogens show the potential for liquid as well as gaseous hydrocarbon generation, it is doubtful if they can source commercial accumulations in Southern England.

PLATE TITLES

Plate 1.
(a). A Type II kerogen concentrate, consisting mainly of yellowish sapropelic masses and some "cuticular fragments" (x 45). (Sample: WM/OC.5).

(b). A magnified portion of Plate 1(a) showing "cuticular" fragments. Their fibrous nature is suggestive of incompletely altered algal or fungal material (Batten, 1983) (x 180).

(c). A Type II kerogen concentrate consisting mainly of dark greyish brown sapropelic masses and dark greyish brown amorphous fines (Sample: WM/KC.3) (x 45).

(d). Very heavy, hydrogen-rich, sapropelic amorphous matter (specific gravity: 1.65-2.2) shown to be infested with opaque, heavy mineral grains — most probably pyrite. This highest-density fraction accounted for about 75% by volume of a Type II kerogen concentrate from a Burton Row Well sample. A similar situation is noted with Sample CN/OC.5 of Cranborne-1 Well (x 45).

Plate 2. A typical Type III kerogen concentrate consisting mainly of greyish, granular amorphous and humic fragments. (x 45).

Plate 3. A typical Type IV kerogen concentrate consisting mainly of fine-grained amorphous matter and humic fragments (x 45).
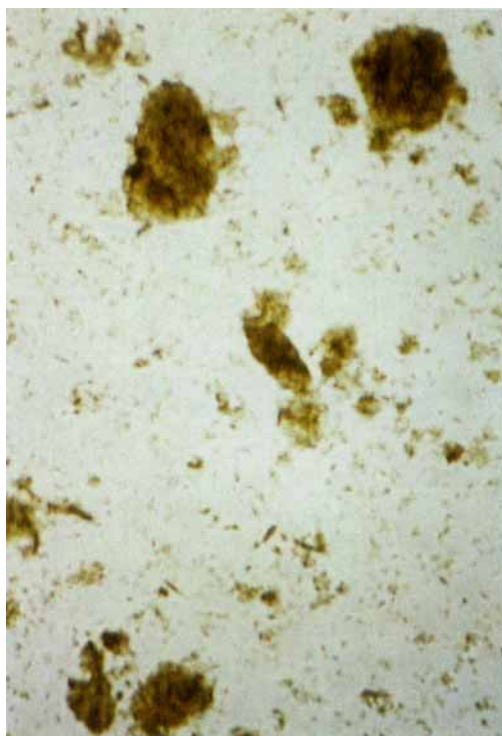
Plate 1(a)   **Plate 1(b)**
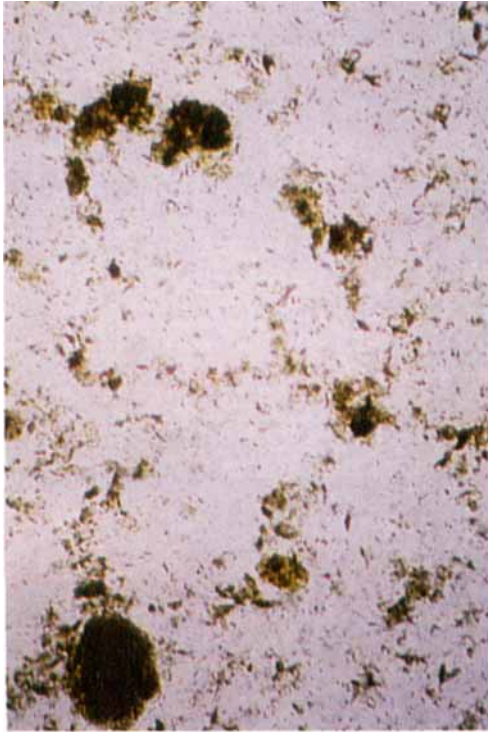
Plate 1(c)
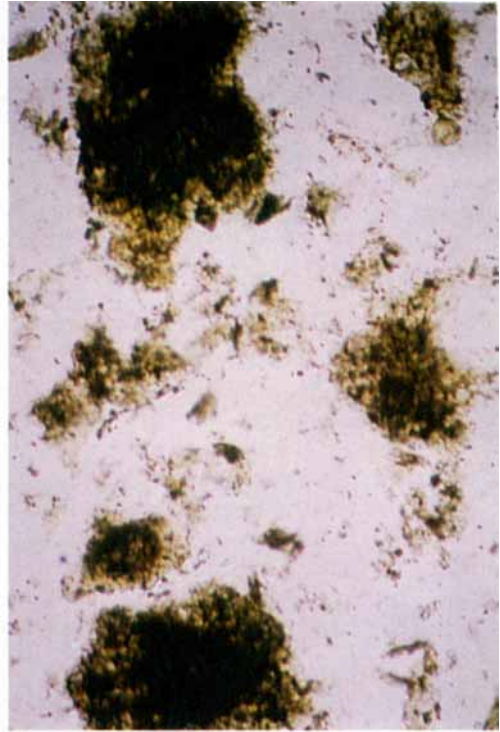
Plate 1(d)
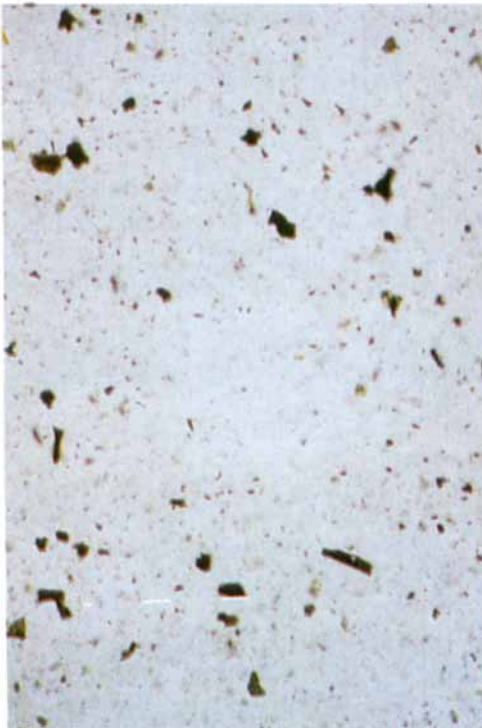
Plate 2
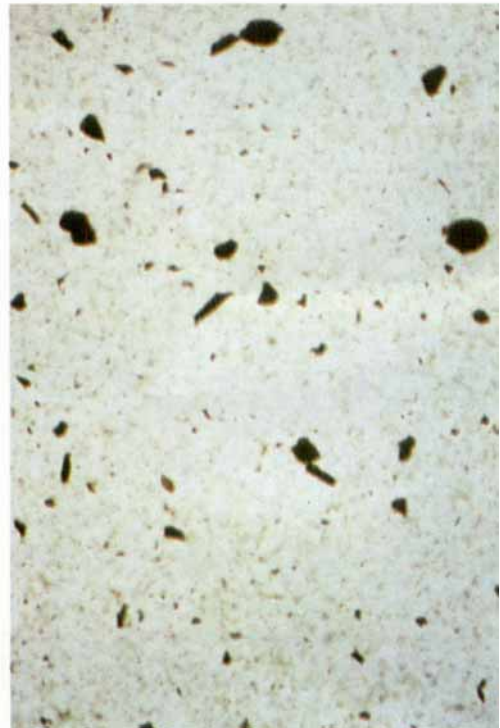
Plate 3

The various kerogen types are noted to occur in both argillaceous and carbonate rocks. There appears to be a relationship between kerogen type and the organic richness of the containing rock sample: kerogen Type II is mostly associated with very organic-rich laminated rock samples, whereas other kerogen types are associated with mainly non-laminated rock samples with moderate-to-low organic carbon contents. It is suggested that the fluctuating anoxic-oxic depositional bottom conditions during the Jurassic were the major factor controlling both the organic richness of the sedimentary facies, and the distribution of the kerogen facies in the Lower Lias, the Oxford Clay and the Kimmeridge Clay.

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TABLE 1. KEROGEN ATOMIC RATIOS, KEROGEN TYPES AND TOTAL ORGANIC CARBON CONTENTS (TOC) OF ASSOCIATED LITHOLOGIES

(a) Outcrop Samples:

Locality	Sample No.	Formation	Ammonite Zone	Lithology	TOC (Wt%)	Kerogen Atomic Ratios H/C	O/C	Kerogen Type
Ringstead Bay Area (Dorset)	OSD/KC.1	Kimm. Clay	—	Coccolith Limestone	2.95	1.35	0.172	II
	OSD/KC.2	,,	—	Shale	16.34	1.35	0.135	II
	OSD/KC.3	,,	—	,,	10.59	1.35	0.128	II
Kimmeridge Bay	OSD/KC.4	,,	*Rotunda*	Mudstone	1.76	0.90	0.115	Mixed II/III
Chapman's	OSD/KC.5	,,	*Pallasioides*	,,	1.62	0.92	0.114	Mixed II/III
Poole Area (Dorset)	OSD/KC.6	,,	*Pectinatus*	Shale	6.81	1.25	0.109	II
	OSD/KC.7	,,	*Hudlestoni*	,,	16.37	1.26	0.112	II
	OSD/KC.8	,,	*Wheatleyensis*	,,	20.48	1.24	0.106	II
	OSD/KC.9	,,	,,	Mudstone	3.26	1.12	0.095	II
	OSD/KC.10	,,	*Elegans*	Shale	8.44	1.24	0.100	II
	OSD/KC.11	,,	*Autissiodorensis*	Shale	2.50	1.08	0.089	Mixed II/III
	OSD/KC.12	,,	*Euxodus*	Shale	6.16	1.22	0.096	II
Short Lake (Dorset)	OSD/OC.1	Oxford Clay	*Cordatum*	Mudstone	1.73	0.88	0.147	Mixed II/III
Chickerell (Dorset)	OSD/OC.2	,,	*Athleta*	Shale	1.50	1.07	0.139	Mixed II/III
	OSD/OC.3	,,	,,	,,	12.36	1.29	0.130	II
	OSD/OC.4	,,	*Coronatum*	,,	8.14	1.30	0.128	II
	OSD/OC.5	,,	,,	,,	5.63	1.29	0.131	II
Charmouth (Dorset)	OSD/LL.1	Lower Lias	Black-Ven Marls	Limestone	0.51	0.76	0.164	III
	OSD/LL.2	,,	,, ,, ,,	,,	0.70	0.87	0.133	Mixed II/III
	OSD/LL.3	,,	Shales-with-Beef	Laminated Marl	6.18	1.29	0.125	II
	OSD/LL.4	,,	,, ,, ,,	Laminated Limestone	2.86	1.33	0.151	II
Lyme Regis (Dorset)	OSD/LL.5	,,	,, ,, ,,	Shale	7.36	1.21	0.120	II
	OSD/LL.6	,,	,, ,, ,,	Shale	6.74	1.22	0.128	II
	OSD/LL.7	,,	Blue Lias	Limestone	0.63	1.01	0.142	Mixed II/III
	OSD/LL.8	,,	,, ,,	Shale	5.98	1.30	0.130	II

(b) Henfield Well.

Sample No.	Depth (ft.)	Formation	Lithology	TOC (Wt%)	H/C	Kerogen Atomic Ratios O/C	Kerogen Type
HN/KC.1	1585–1587	Kimm. Clay	Calcareous Mudstone	1.47	0.87	0.159	III
HN/KC.2	2092–2094	,,	Black Shale	10.02	1.25	0.133	II
HN/KC.3	2102	,,	Black Limestone	1.05	1.04	0.133	Mixed II/III
HN/LL.1	4416	Lower Lias	Calcareous Mudstone	2.50	0.94	0.114	Mixed II/III
HN/LL.2	2698	,,	,, ,,	1.09	0.74	0.099	III
HN/LL.3	4707	,,	,, ,,	1.30	0.69	0.086	III
HN/LL.4	4838	,,	Mudstone	1.27	0.96	0.104	Mixed II/III
HN/LL.5	4843.5	,,	Calcareous Mudstone	0.78	0.78	0.102	III

(c) Warlingham Well.

Sample No.	Depth (ft.)	Formation	Lithology	TOC (Wt%)	H/C	Kerogen Atomic Ratios O/C	Kerogen Type
WM/KC.1	2279.5	Kimm. Clay	Marl	1.45	0.96	0.125	Mixed II/III
WM/KC.2	2379.5	,,	Poorly laminated mudstone	4.95	1.18	0.137	II
WM/KC.3	2480.5	,,	Laminated Marl	3.84	1.21	0.132	II
WM/KC.4	2520	,,	Limestone	2.20	1.05	0.135	Mixed II/III
WM/KC.5	2580	,,	Laminated Marl	3.61	1.27	0.130	II
WM/KC.6	2680	,,	Marl	1.20	1.26	0.143	II
WM/KC.7	2779.5	,,	Calcareous Mudstone	2.74	1.15	0.122	II
WM/KC.8	2880	,,	,, ,,	1.42	0.99	0.176	Mixed II/III
WM/KC.9	2982	,,	,, ,,	0.99	0.87	0.117	Mixed II/III
WM/OC.1	3162.5	Oxford Clay	,, ,,	1.03	0.82	0.157	III
WM/OC.2	3202	,,	,, ,,	1.22	0.90	0.142	Mixed II/III
WM/OC.3	3400.3	,,	Shale	3.41	1.27	0.126	II
WM/OC.4	3430	,,	,,	2.27	1.28	0.124	II
WM/OC.5	3466	,,	,,	5.89	1.30	0.118	II
WM/LL.1	4200	Lower Lias	Mudstone	1.06	0.84	0.133	III
WM/LL.2	4300	,,	,,	1.32	0.95	0.110	Mixed II/III
WM/LL.3	4350	,,	Limestone	0.26	0.88	0.132	Mixed II/III
WM/LL.4	4400	,,	Mudstone	0.72	0.50	0.125	IV
WM/LL.5	4460	,,	,,	0.73	0.53	0.153	IV
WM/LL.6	4480	,,	,,	1.15	0.59	0.116	III

(d) Cranborne-1 Well.

Sample No.	Depth (ft.)	Formation	Lithology	Kerogen Atomic Ratios		Kerogen Type
				H/C	O/C	
CN/KC.1	1718.7	Kimm. Clay	n.d. (cuttings) *	1.15	0.143	Mixed II/III
CN/OC.1	1974.6	Oxford Clay	,, ,,	0.65	0.147	IV
CN/OC.2	2105.8-2112.3	,, ,,	,, ,,	0.92	0.165	Mixed II/III
CN/OC.3	2230.4-2243.5	,, ,,	,, ,,	1.02	0.185	Mixed II/III
CN/OC.4	2361.6-2374.7	,, ,,	,, ,,	1.31	0.126	II
CN/OC.5	2466.6	,, ,,	,, ,,	1.28	0.142	II
CN/LL.1	3568.6-3575	Lower Lias	,, ,,	0.79	0.171	III
CN/LL.2	3673.6-3680	,, ,,	,, ,,	1.12	0.158	Mixed II/III
CN/LL.3	3739.2-3745.8	,, ,,	,, ,,	1.07	0.114	Mixed II/III
CN/LL.4	3804.8-3832.5	,, ,,	,, ,,	1.11	0.126	Mixed II/III
CN/LL.5	3936-3941.1	,, ,,	,, ,,	1.12	0.121	Mixed II/III
CN/LL.6	4001.6-4014.7	,, ,,	,, ,,	1.08	0.121	Mixed II/III

*n.d. — not determined

TABLE 2a. OPTICAL ASSESSMENT AND DENSITY FRACTIONATION DATA FOR THE JURASSIC KEROGENS

Locality / Borehole	Sample Number	Kerogen Type	Composition of Insoluble Organic Matter				Density Separation Specific gravity range		Spore/Pollen Colour	Thermal Alteration Index (TAI)	Estimated Vitrinite Reflectance (Ro%)
			Amorphous	Palyno-morphs	Humic	"Cuticles"	amorphous matter	The humic fragments			
Ringstead Bay, Dorset	OSD/KC.1	II	◆ (s)	▲	▲	▲	1.45-2.2*	1.53-2.2	Pale yellow	2.00	0.30
"	OSD/KC.2	II	● (s)	x	▲	□	1.45-1.53	1.45-2.2	"	2.15	0.36
"	OSD/KC.3	II	● (s)	▲	▲	□	1.45-2.2*	1.45-1.53	"	"	0.36
Kimmeridge Bay —	OSD/KC.4	Mixed II/III	● (FG)	▲	▲	□	1.53-1.65	1.45-2.2	"	2.33	0.43
Chapman's Pool, Dorset	OSD/KC.5	"	◆ (FG)	▲	▲	▲	1.65-2.2	1.45-1.65	"	"	0.43
"	OSD/KC.6	II	● (s)	▲	▲	□	1.45-1.65	1.45-1.53	"	2.35	0.44
"	OSD/KC.7	II	● (s)	x	x	□	<1.45-1.53	1.53-1.65	"	"	0.44
"	OSD/KC.8	II	● (s)	x	▲	□	1.45-1.53	1.53-1.65	"	2.38	0.45
"	OSD/KC.9	II	● (S+FG)	▲	▲	□	1.45-2.2	1.45-1.65	"	"	0.45
"	OSD/KC.10	II	● (s)	▲	▲	□	1.45-1.53	1.53-1.65	"	2.40	0.46
"	OSD/KC.11	Mixed II/III	● (s+FG)	▲	▲	□	1.53-1.65	1.45-2.2	"	2.42	0.47
"	OSD/KC.12	II	● (s+FG)	□	▲	□	1.45-1.65	1.45-1.65	Yellow	2.45	0.48
Short Lake Dorset	OSD/OC.1	Mixed II/III	● (FG)	□	□	▲	1.65-2.2	1.45-2.2	Pale yellow	2.25	0.40

(a) - Outcrop Samples

◆ = Dominant (>75%);   ● = Abundant (50-75%);   □ = Common (35-49%);   ■ = Very Common (20-34%);

▲ = Minor (5-19%);   x = Rare (5%);   * = Presence of Pyrite;   S = Sapropelic;   FG = Fine Grained

TABLE 2a (cont.). OPTICAL ASSESSMENT AND DENSITY FRACTIONATION DATA FOR THE JURASSIC KEROGENS

| Locality /Borehole | Sample Number | Kerogen Type | Composition of Insoluble Organic Matter | | | | Density Separation Specific gravity range | | Spore/Pollen Colour | Thermal Alteration Index (TAI) | Estimated Vitrinite Reflectance (Ro%) |
			Amorphous	Palyno-morphs	Humic	"Cuticles"	amorphous matter	The humic fragments			
Chickerell, Dorset	OSD/OC.2	Mixed II/III	● (FG+S)	◀	□	□	1.65 - 2.2	1.53 - 2.2	Pale yellow	2.30	0.42
"	OSD/OC.3	II	● (S)	◀	×	□	1.45 - 1.65	1.53 - 1.65	"	"	0.42
"	OSD/OC.4	II	● (8)	◀	◀	□	1.45 - 1.65	1.53 - 1.65	"	2.35	0.44
"	OSD/OC.5	II	● (S+FG)	◀	×	■	1.53 - 1.65	1.53 - 2.2	"	"	0.44
Charmouth, Dorset	OSD/LL.1	III	● (FG)	◀	■	◀	1.65 - 2.2	<1.45 - 2.2	"	2.12	0.35
"	OSD/LL.2	Mixed II/III	● (FG)	◀	□	◀	1.53 - 2.2	1.45 - 2.2	"	"	0.35
"	OSD/LL.3	II	● (S)	×	×	□	1.53 - 1.65	1.53 - 1.65	"	2.15	0.36
"	OSD/LL.4	II	● (S)	◀	×	□	1.45 - 1.65	1.65 - 2.2	"	2.10	0.34
"	OSD/LL.5	II	● (S)	×	◀	■	1.45 - 2.2*	1.45 - 1.65	"	2.15	0.36
"	OSD/LL.6	II	● (S)	×	×	■	1.45 - 2.2*	1.45 - 1.65	"	"	0.36
Lyme Regis, Dorset	OSD/LL.7	Mixed II/III	◆ (FG)	◀	◀	×	1.65 - 2.2	<1.45 - 2.2	"	2.05	0.32
"	OSD/LL.8	II	● (S)	×	◀	■	1.53 - 2.2*	<1.45 - 1.65	"	"	0.32

TABLE 2b. CRANBORNE-1 WELL.
OPTICAL ASSESSMENT AND DENSITY FRACTIONATION DATA FOR THE JURASSIC KEROGENS

Locality /Borehole	Sample Number	Kerogen Type	Composition of Insoluble Organic Matter				Density Separation Specific gravity range		Spore/Pollen Colour	Thermal Alteration Index (TAI)	Estimated Vitrinite Reflectance (Ro%)
			Amorphous	Palynomorphs	Humic	"Cuticles"	amorphous matter	The humic fragments			
Cranbourne No. 1 Well	CN/KC.1	Mixed II/III	● (FG+S)	◄	◄	□	1.53 – 1.65	1.45 – 2.2	Pale Yellow	2.15	0.36
	CN/OC.1	IV	● (FG)	◄	■	◄	1.65 – 2.2	<1.45 – 2.2	"	2.20	0.38
	CN/OC.2	Mixed II/III	● (FG)	□	□	◄	1.65 – 2.2	1.45 – 2.2	"	"	0.38
	CN/OC.3	"	● (FG)	◄	◄	□	1.65 – 2.2	1.45 – 2.2	"	2.25	0.40
	CN/OC.4	II	● (S+FG)	◄	×	■	1.45 – 1.53	1.53 – 1.65	"	"	0.40
	CN/OC.5	II	● (S)	◄	◄	■	1.53 – 2.2*	1.45 – 1.65	"	2.30	0.42
	CN/LL.1	III	◆ (FG)	◄	◄	◄	1.65 – 2.2	<1.45 – 1.65	"	2.38	0.45
	CN/LL.2	Mixed II/III	◆ (FG+S)	◄	◄	◄	1.65 – 2.2	1.45 – 1.65	"	"	0.45
	CN/LL.3	"	● (FG+S)	◄	◄	□	1.65 – 2.2	1.45 – 1.65	"	2.40	0.46
	CN/LL.4	"	● (FG+S)	◄	◄	□	1.65 – 2.2	1.45 – 1.65	"	"	0.46
	CN/LL.5	"	● (FG+S)	◄	◄	□	1.65 – 2.2	1.45 – 1.65	Yellow	2.45	0.48
	CN/LL.6	"	● (FG+S)	◄	◄	□	1.65 – 2.2	1.45 – 1.65	"	"	0.48

TABLE 2c. WARLINGHAM WELL.
OPTICAL ASSESSMENT AND DENSITY FRACTIONATION DATA FOR THE JURASSIC KEROGENS

Locality /Borehole	Sample Number	Kerogen Type	Composition of Insoluble Organic Matter				Density Separation — Specific gravity range		Spore/Pollen Colour	Thermal Alteration Index (TAI)	Estimated Vitrinite Reflectance (Ro%)
			Amorphous	Palyno-morphs	Humic	"Cuticles"	amorphous matter	The humic fragments			
Warlingham Well	WM/KC.1	Mixed II/III	● (FG+S)	◄	□	◄	1.53 - 2.2	1.45 - 1.65	Pale Yellow	2.12	0.35
	WM/KC.2	II	● (S+FG)	◄	◄	■	1.53 - 1.65	1.53 - 1.65	"	2.15	0.36
	WM/KC.3	II	● (S+FG)	×	◄	□	1.53 - 1.65	1.65 - 2.2	"	"	0.36
	WM/KC.4	Mixed II/III	● (FG+S)	◄	□	×	1.65 - 2.2	1.45 - 2.2	"	2.17	0.37
	WM/KC.5	II	● (S)	◄	◄	□	1.53 - 1.65	1.45 - 1.65	"	"	0.37
	WM/KC.6	II	◆ (S+FG)	◄	◄	×	1.45 - 1.65	1.53 - 1.65	"	2.20	0.38
	WM/KC.7	II	● (S+FG)	◄	□	□	1.53 - 2.2	1.45 - 2.2	"	"	0.38
	WM/KC.8	Mixed II/III	◆ (FG)	◄	◄	◄	1.65 - 2.2	< 1.45 - 1.65	"	2.25	0.40
	WM/KC.9	"	● (FG)	◄	■	×	1.65 - 2.2	< 1.45 - 2.2	"	"	0.40
	WM/OC.1	III	● (FG)	◄	□	◄	1.65 - 2.2	1.45 - 2.2	"	2.30	0.42
	WM/OC.2	Mixed II/III	● (FG+S)	◄	□	◄	1.65 - 2.2	1.45 - 2.2	"	"	0.42
	WM/OC.3	II	● (S)	◄	◄	□	1.53 - 1.65	1.45 - 1.65	"	2.35	0.44
	WM/OC.4	II	● (FG+S)	◄	◄	□	1.53 - 1.65	< 1.45 - 1.53	"	"	0.44

TABLE 2d. HENFIELD WELL.
OPTICAL ASSESSMENT AND DENSITY FRACTIONATION DATA FOR THE JURASSIC KEROGENS

Locality /Borehole	Sample Number	Kerogen Type	Composition of Insoluble Organic Matter				Density Separation — Specific gravity range		Spore/Pollen Colour	Thermal Alteration Index (TAI)	Estimated Vitrinite Reflectance (Ro%)
			Amorphous	Palyno-morphs	Humic	"Cuticles"	amorphous matter	The humic fragments			
Henfield Well	HN/KC.1	III	● (FG)	▲	▲	▲	1.53 – 2.2	1.45 – 1.53	Pale yellow	2.15	0.36
	HN/KC.2	II	● (S+FG)	▲	x	□	1.45 – 1.65	1.53 – 1.65	"	2.25	0.40
	HN/KC.3	Mixed II/III	● (FG)	▲	▲	▲	1.65 – 2.2	1.45 – 1.65	"	2.25	0.40
	HN/LL.1	"	● (FG+S)	▲	▲	□	1.53 – 2.2	1.45 – 1.65	Yellow	2.55	0.55
	HN/LL.2	III	● (FG)	▲	□	□	1.65 – 2.2	<1.45 – 1.65	"	2.58	0.58
	HN/LL.3	III	● (FG)	▲	□	▲	1.65 – 2.2	<1.45 – 2.2	"	2.60	0.60
	HN/LL.4	Mixed II/III	● (FG+S)	x	▲	□	1.53 – 2.2	1.45 – 2.2	"	2.62	0.62
	HN/LL.5	III	● (FG)	▲	□	▲	1.65 – 2.2	1.45 – 2.2	"	"	0.62