

## Using Biomarkers to Investigate the Roles Played by Faults in the Variation in Crude Oil Distribution in the Wessex Basin, UK

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### ABSTRACT

In this research, I examined the Wessex Basin, southern England geochemically, I investigated Potential hydrocarbon migration pathways from the hanging wall of the Purbeck fault into Sherwood Sandstone reservoir at Wytch Farm using geochemical characterisation of oils extracted from core materials from the Wessex Basin. These revealed oils found at Stoborough and Waddock Cross are less mature than oils at Wytch Farm, which likely indicates spillage from the top of the reservoir at Wytch Farm due to regional tilting and faulting. In addition, the geochemical data from the core materials also show probable migration paths for oils found at Chickerell controlled by the two main faults in the Wessex Basin.

**Keywords:** Biomakers, Source maturity, Crude oil maturity, Faults, Basin inversion

### INTRODUCTION

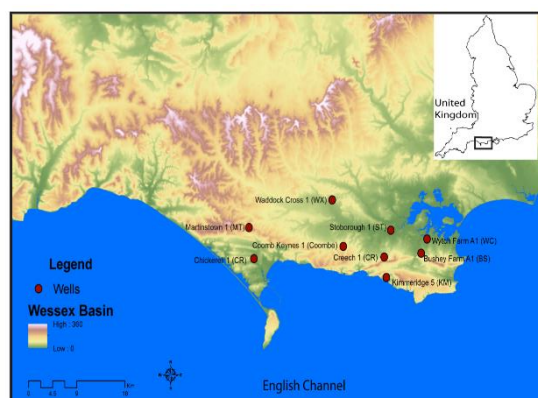
The Wessex Basin lies in Southern England (Fig. 1) and comprises a series of linked intra-cratonic basins that formed in the Jurassic and Early Cretaceous by extensional collapse of deep-seated Late Carboniferous Variscan thrusts. The complex structural and stratigraphic evolution of the Wessex Basin runs from Permian to Tertiary times. The Wessex Basin is one of the largest oil fields in Europe with a billion barrel<sup>+</sup> of crude already extracted from the 70s to the present (Hawkes *et al.*, 1998). The basin is believed to have originated during the Permo-Triassic rifting events that affected most of north western Europe (Hawkes *et al.*, 1998) and its history is characterized by four major tectonic events; 1) Early Atlantic plate sequence (Late Permian-Triassic), 2) Atlantic plate sequence (Early Jurassic-Late Jurassic), 3) Biscay plate sequence (Late Jurassic-Late Cretaceous) and 4) Alpine plate sequence (Late Cretaceous-Tertiary). Although, the basin has been studied extensively, no attention was paid to the roles played the two main faults: The Abbotsbury Ridgeway and the Purbeck Disturbance.

### Hydrocarbon generation and the Tertiary Inversion in the Wessex Basin

The Late Cretaceous-Tertiary inversion of the pre-existing east-west trending extensional faults has been identified

throughout the Wessex Basin (Beeley and Norton, 1998; Bray *et al.*, 1998; Chadwick, 1993; Drummond, 1970; Lake and Karner, 1987; Law, 1998; Lott *et al.*, 1982; McMahon and Turner, 1998; Smith and Hatton, 1998; Stoneley, 1982; Underhill and Paterson, 1998) and there is evidence that suggests the inversion might have started as early as the Campanian (Drummond, 1970; Westhead and Woods, 1994). Plint (1982) reported significant uplift and erosion in the basin during the Eocene, but the most extensive inversion movement is argued to have occurred during the Miocene (Butler and Pullan, 1990; Chadwick, 1993).

Furthermore, it is generally thought among workers that maturation and generation of hydrocarbons occurred uniquely on the hanging wall of the Abbotsbury-Ridgeway and the Purbeck-Isle of Wight fault systems during Late Cretaceous maximum burial prior to the Tertiary inversion, event. Hydrocarbons have likely migrated northwards into the footwall, either vertically along fault planes (e.g., Ebukanson and Kinghorn, 1986; Penn *et al.*, 1986; Underhill and Stoneley, 1998) or laterally across the fault plane where sand-sand juxtaposition occurred



**Figure 1:** Map of Wessex Basin with location of the 9 sampled wells.

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However, others believe there was at least some maturation of the Lias mudstones at Wytch Farm, even though that might not have resulted in any significant generation of hydrocarbons ( Stoneley and Selley, 1986, Bray *et al.*, 1998; McMahon and Turner, 1998;).

The generation of hydrocarbons in the Wessex and other adjacent basins in southern England was frozen by

inversion events that took place at various intervals. Figure 2 shows areas affected by the uplift in the Wessex Basin. It can clearly be seen that the main axis of the inversion lies south of the Purbeck disturbance, in the Portland-South Wight Basin but the inversion was not restricted to this area. Localised and even major inversion axes are visible north of the Abbotsbury Ridgeway Fault and the Purbeck Disturbance.

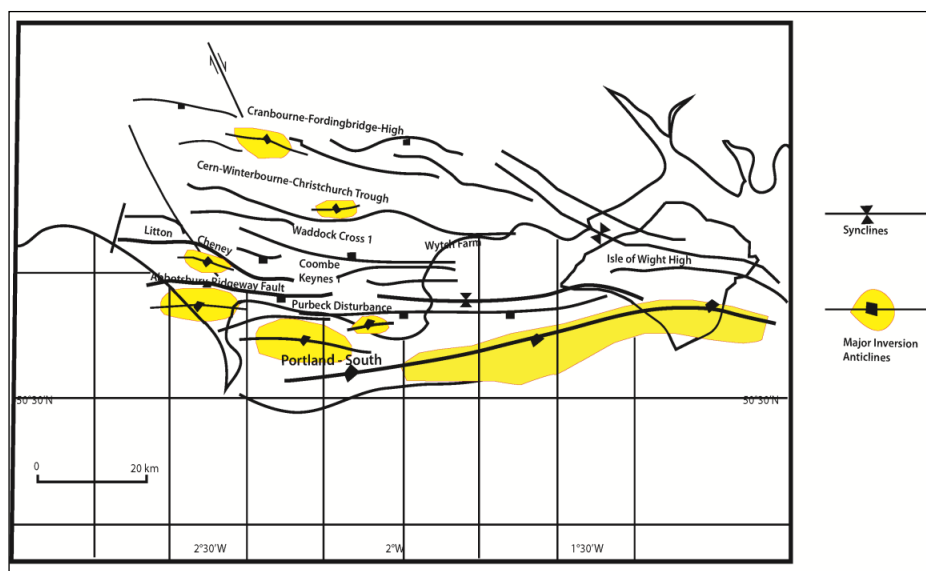


Figure 2: Map showing the Tertiary inversion elements in the Wessex Basin. Modified from Butler (1998).

## SAMPLING AND METHODS

### Sampling

Well cores from British Geological Survey (BGS) core store at Keyworth, England, were also sampled. Cores were sampled from nine wells (Table 1) and the sampling was restricted to Bridport Sandstone and the Inferior Oolite formations of the Upper Lias, which represent the reservoir rock and cap rock respectively (Hawkes *et al.*, 1998). Forty-five samples were collected in total for geochemical characterization. Sampling for this geochemical experimentation was done based on evidence of visible oil stains, i.e., only the core intervals that appear to have visible oil stain were sampled.

### Column Chromatography

Column chromatography is used to extract extractible organic matter (EOM) from samples by progressively adding various solvents that will elute the various fractions of EOM present in samples. A gram of the samples was fed into test tubes and a non-polar (pentane) solvent was gently added.

The test tubes containing the samples and the solvent were then placed on a mixer until the solvent and the sediment were thoroughly mixed and then placed in a beaker containing some water and placed in a sonicator for about five minutes; this was to enhance a full dissolution of the EOM by the solvent. The test tubes were then centrifuged

at 2500 rpm for 5 minutes and the supernatants were carefully collected with a pipette into clean test tubes. This procedure was repeated until the mixture was clear and the collected EOM was blown down slowly using nitrogen. Secondly, alumina ( $Al_2O_3$ ) was activated by heating it in an oven at 150 °C for about an hour and fed into a rinsed pipette plugged with quartz wool. DCM was then ran through the pipette for further rinsing. A small amount of the activated alumina was added into collected EOM and allowed to dry then gently fed into the pipette. Ten millilitres of hexane was run through the pipette to collect the aliphatic fractions followed by 10 ml of DCM to collect the aromatic fraction. The collected fractions were stored in labelled clean vials.

### Gas Chromatography Mass Spectroscopy (GC-MS)

The various fractions were analysed by GC-MS with an Agilent Technologies 6890 gas chromatograph coupled to a 5973 mass spectrometer. The gas chromatograph injector was held at 200 °C and operated in split mode (35:1) with a column flow rate of 2 ml min<sup>-1</sup>. Separation was performed on a J&W GS-Q PLOT column (30 m · 0.32 mm). The gas chromatograph oven was held for 5 minutes at 35 °C and then ramped at a rate of 10 °C min<sup>-1</sup> to 200 °C, where it was held for 4 min. Compounds present in the samples were identified based on elution order and mass spectrometric fragmentation patterns.

**Table 1:** Well-core samples analysed during this study, showing sample depths, formation and lithology

Sample Name	Sample code	Depth (ft.)	Formation	Lithology
Bushey Fm SSK27620	BS1	3464	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27621	BS2	3468	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27622	BS3	3477.3	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27623	BS4	3485.1	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27624	BS5	3486	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27625	BS6	3504	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27626	BS7	3504.8	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27627	BS8	3518.1	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27628	BS9	3524	Bridport Sandstone Fm	Sandstone
Bushey Fm SSK27629	BS10	3526	Bridport Sandstone Fm	Sandstone
Coombe K. SSK35431	COOMB1	3443	Bridport Sandstone Fm	Sandstone
Coombe K. SSK35432	COOMB2	3475	Bridport Sandstone Fm	Sandstone
Coombe K. SSK36413	COOMB3	3498.75	Bridport Sandstone Fm	Sandstone
Coombe K. SSK36414	COOMB4	3522.9	Bridport Sandstone Fm	Sandstone
Martinstown 1 SSK35425	MT1	1514.6	Bridport Sandstone Fm	Sandstone
Martinstown 1 SSK35426	MT2	1534.12	Bridport Sandstone Fm	Sandstone
Martinstown 1 SSK35427	MT3	1516.83	Bridport Sandstone Fm	Sandstone
Martinstown 1 SSK35428	MT4	1534.12	Bridport Sandstone Fm	Sandstone
Stoborough 2 SSK36416	ST1	3536.75	Bridport Sandstone Fm	Sandstone
Stoborough 2 SSK36417	ST2	3561.3	Bridport Sandstone Fm	Sandstone
Stoborough 2 SSK36418	ST3	3562	Bridport Sandstone Fm	Sandstone
Stoborough 2 SSK36419	ST4	3569.23	Bridport Sandstone Fm	Sandstone
Waddock Cross SSK36415	WX1	2197.1	Bridport Sandstone Fm	Sandstone
Waddock Cross SSK35430	WX2	2203	Bridport Sandstone Fm	Sandstone
Waddock Cross SSK36415	WX3	2285	Bridport Sandstone Fm	Sandstone
Chickerell SSK27638	CH1	860.89	Bridport Sandstone Fm	Sandstone
Chickerell SSK27639	CH2	863.85	Bridport Sandstone Fm	Sandstone
Chickerell SSK27640	CH3	874.84	Bridport Sandstone Fm	Sandstone
Chickerell SSK27641	CH4	876.64	Bridport Sandstone Fm	Sandstone
Chickerell SSK27642	CH5	879.76	Bridport Sandstone Fm	Sandstone
Chickerell SSK27648	CH6	900.26	Bridport Sandstone Fm	Sandstone
Chickerell SSK27649	CH7	905.2	Bridport Sandstone Fm	Sandstone
Creech SSK27629	CR1	3451.4	Inferior Oolite Fm	Limestone
Creech SSK27630	CR2	3456	Inferior Oolite Fm	Limestone
Creech SSK27631	CR3	3452.76	Inferior Oolite Fm	Limestone
Creech SSK27632	CR4	3456.04	Bridport Sandstone Fm	Sandstone
Creech SSK27633	CR5	3456.92	Bridport Sandstone Fm	Sandstone
Creech SSK27634	CR6	3463.75	Bridport Sandstone Fm	Sandstone
Creech SSK27635	CR7	3470	Bridport Sandstone Fm	Sandstone
Kimmeridge SSK27636	KM1	2828.08	Bridport Sandstone Fm	Sandstone
Kimmeridge SSK27637	KM2	2854.66	Bridport Sandstone Fm	Sandstone
Kimmeridge SSK27643	KM3	2861.71	Bridport Sandstone Fm	Sandstone
Kimmeridge SSK27644	KM4	2870.57	Bridport Sandstone Fm	Sandstone
Wytych Fm SSK27645	WC1	2996	Bridport Sandstone Fm	Sandstone
Wytych Fm SSK27646	WC2	2997.25	Bridport Sandstone Fm	Sandstone
Wytych Fm SSK27647	WC3	2998.15	Bridport Sandstone Fm	Sandstone

**RESULT**

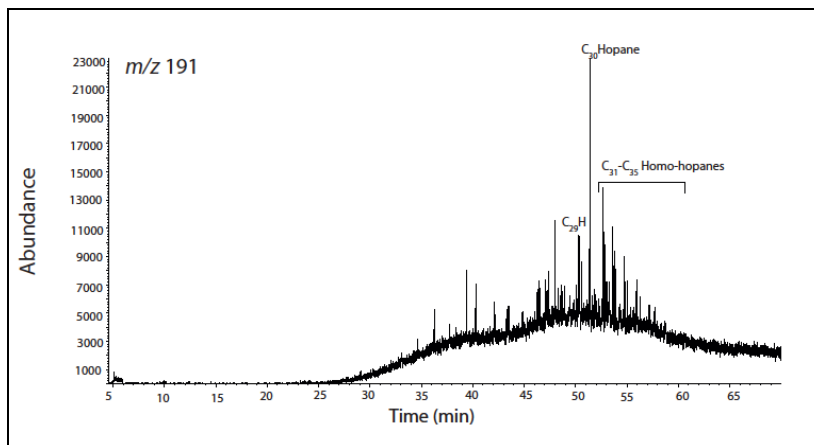
The following biomarkers were used to investigate the various maturity levels of crude oil maturity across the two main fault lines (Abbotsbury Ridgeway And Purbeck disturbance).

**17 $\alpha$ -Diahopane/ 18 $\alpha$ -30-norneohopane (C<sub>30</sub>/C<sub>29</sub>Ts)**

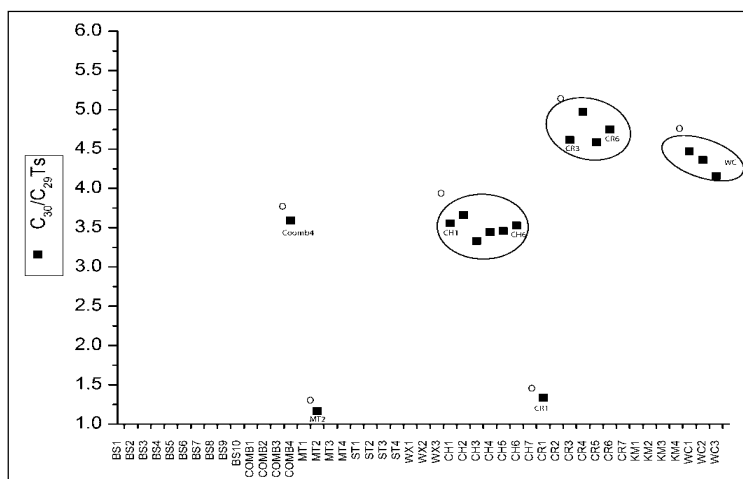
The C<sub>30</sub>H/C<sub>29</sub>Ts ratio was plotted to investigate a probable relationship between C<sub>30</sub> hopane and oxic-suboxic/clay depositional environments. It was measured using the m/z 191 ion. A plot of C<sub>30</sub> H/C<sub>29</sub> Ts is presented in Figure 4. Two main groups can be seen: Coomb4 and the CH samples plot around 3.5 whereas CR and WC samples plot within the 4.0-5.0 range. The C<sub>30</sub> H/C<sub>29</sub> averages for all

the wells are plotted on a map and seem to show some structural control over the distribution of this biomarker; wells situated on or close to Abbotsbury Ridgeway and Purbeck faults have  $C_{30}H/C_{29}Ts$  values  $>0$ , whereas wells located away from faults show a total absence of the biomarker except for Wytch Farm (Fig. 5.). Additionally

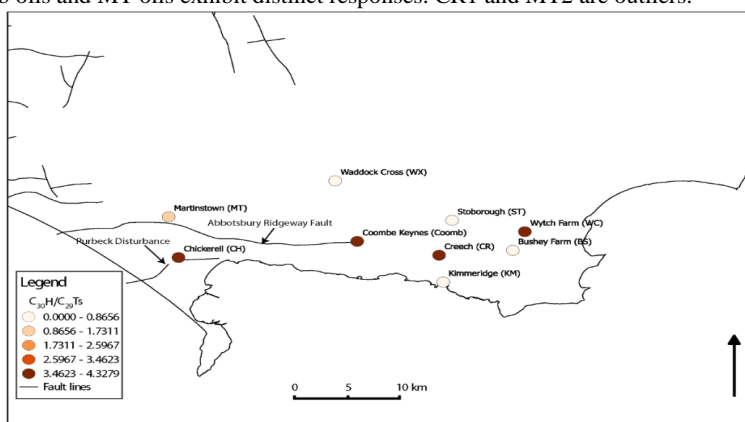
a plot of  $C_{29}Ts / (C_{29}H + C_{29}Ts)$  can be used due to its abundance in crude oils as an oil maturity biomarker. A plot of  $C_{29}Ts / (C_{29}H + C_{29}Ts)$  is shown in Figure 6, in which the samples plot in two distinct groups (Peters *et al.*, 2005); the CR and the WC samples plot between 0.5-0.55 whereas all the CH samples had values  $>0.55$  (Fig. 6).



**Figure 3:** An example of the  $m/z$  191 chromatogram from CR3 sample.  $C_{29}$  &  $C_{30}$  hopanes, as well as the  $C_{31}$ - $C_{35}$  homo-hopanes are visible.



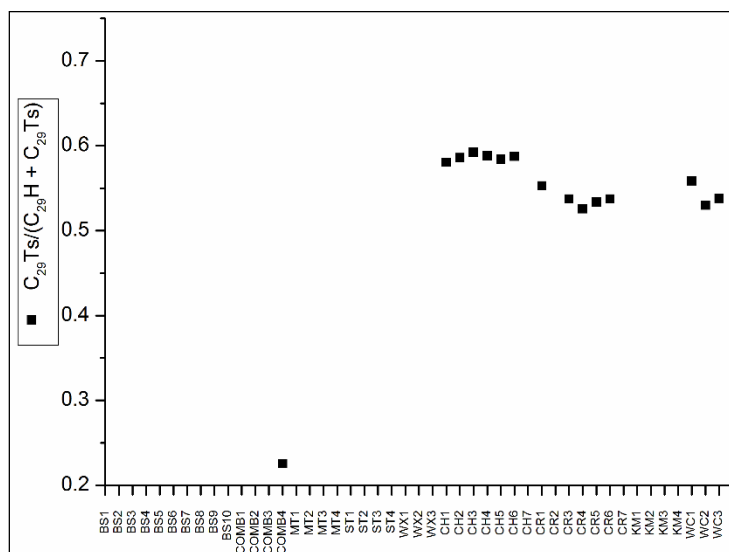
**Figure 4:** A plot of  $C_{30}/C_{29}Ts$  showing two distinct groups of oils; Coomb1 and the CH oils in one group, and CR and WC oils in another. Comb oils and MT oils exhibit distinct responses. CR1 and MT2 are outliers.



**Figure 5:** The distribution of well average values for  $C_{30}/C_{29}Ts$ , showing the biomarker mainly distributed along the main fault line of the study area.

The  $C_{29}Ts/(C_{29}H + C_{29}Ts)$  average values for each of the wells was also plotted on a map of the study area and high values are evident on or near the Abbotsbury Ridgeway

and Purbeck-Isle of Wight faults which display higher concentrations  $C_{29}Ts/(C_{29}H + C_{29}Ts)$  except for Martinstown (Fig. 7).



**Figure 6:** A plot of  $C_{29}Ts/(C_{29}H + C_{29}Ts)$  with the CH oils plotting differently from CR and WC. Values  $> 1$  indicate carbonate/evaporite source. Low Coomb4 values could be instrument error.



**Figure 7:** The distribution of well average values for  $C_{29}Ts/(C_{29}H + C_{29}Ts)$ , showing the biomarker mainly distributed linearly along the main fault line of the study area.

### Homohopanes indices ( $C_{31}-C_{35}$ )

The homohopanes are used as indicators for redox potential of the oil source rock during the time of deposition. They are usually visualised using the  $m/z$  191 ion. Figure 8 shows a plot of  $C_{35}H/(C_{31}H - C_{35}H)$ . Samples BS9, ST4, CR3-CR6 and all the WC samples plotted between 0.2-0.35 while WX1 and WX3 have ratios  $> 0.45$ . The  $C_{35}H/(C_{31}H - C_{35}H)$  well averages plotted on a map show  $C_{35}H/(C_{31}H - C_{35}H)$  on the eastern part of the

study area, with concentrations declining from Waddock Cross south-eastwards (Fig. 9). In addition, a plot of the ratio of  $C_{35}/C_{34}$  and  $C_{29}/C_{30}$ , plotted in tandem (Fig. 10), can be used to investigate the source facies of oil (Peters and Moldowan, 1991). The  $C_{35}/C_{34}$  parameter on the y axis shows variation among the samples, with values ranging from 0.35-0.7, whereas  $C_{29}/C_{30}$  was more or less constant at  $\sim 0.3$  (Fig. 10).

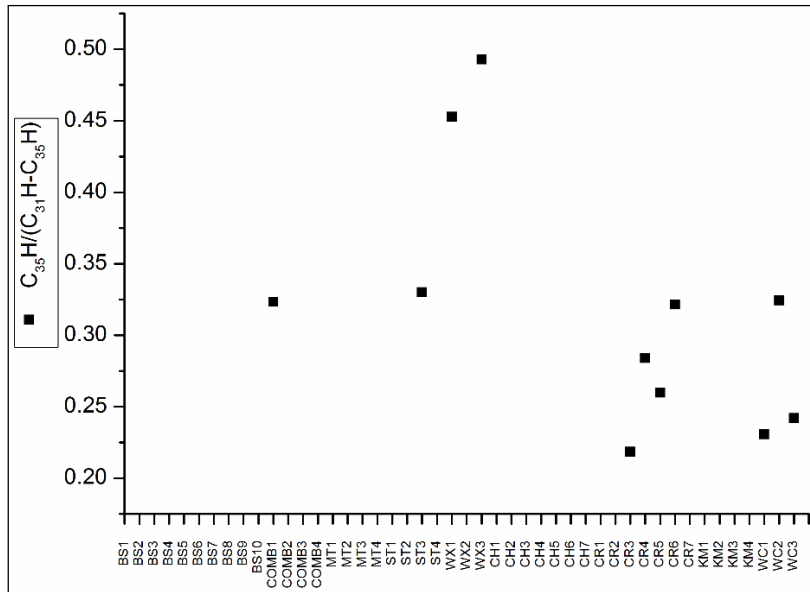


Figure 8: A plot of  $C_{35}H/(C_{31}H - C_{35}H)$  showing the WX samples plotting separate from the rest of the samples.

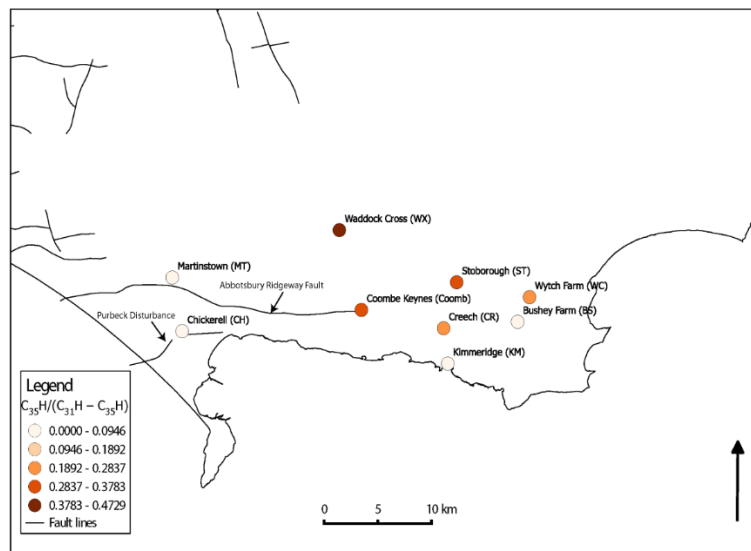


Figure 9: The distribution of well average values for  $C_{35}H/(C_{31}H - C_{35}H)$ , showing the biomarker mainly distributed on the eastern section of the study area with concentration getting less from Waddock Cross south-eastwards.

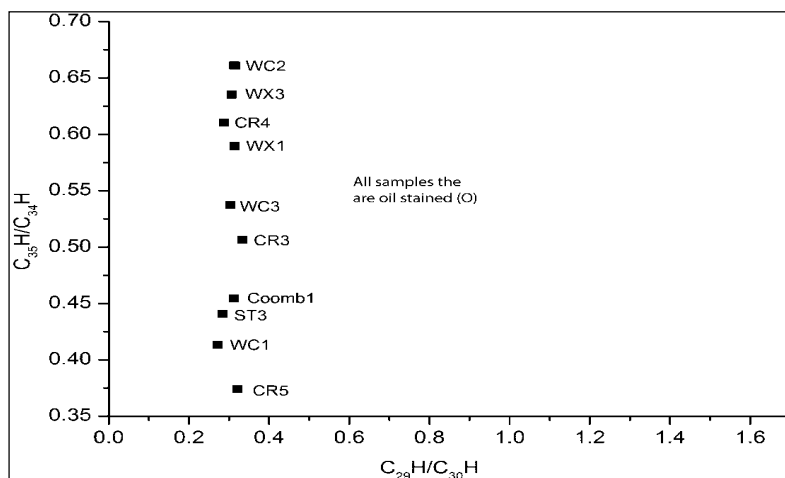
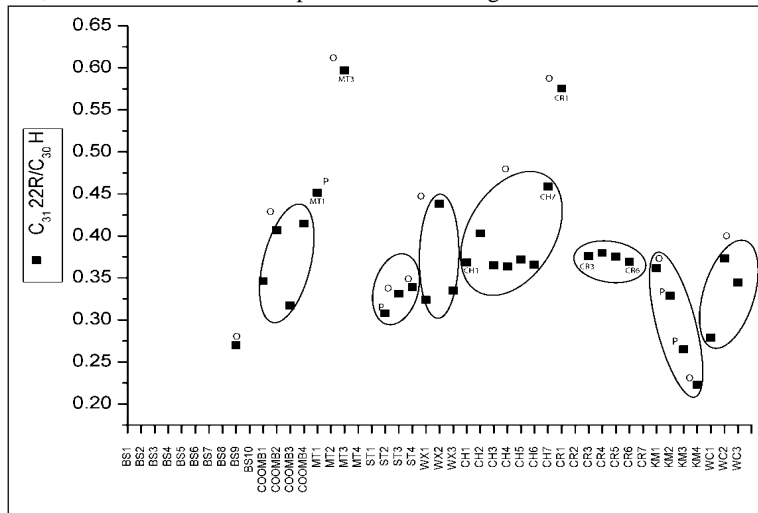


Figure 10: A plot  $C_{35}H/C_{34}H$  showing no distinct groupings from the different oil samples.

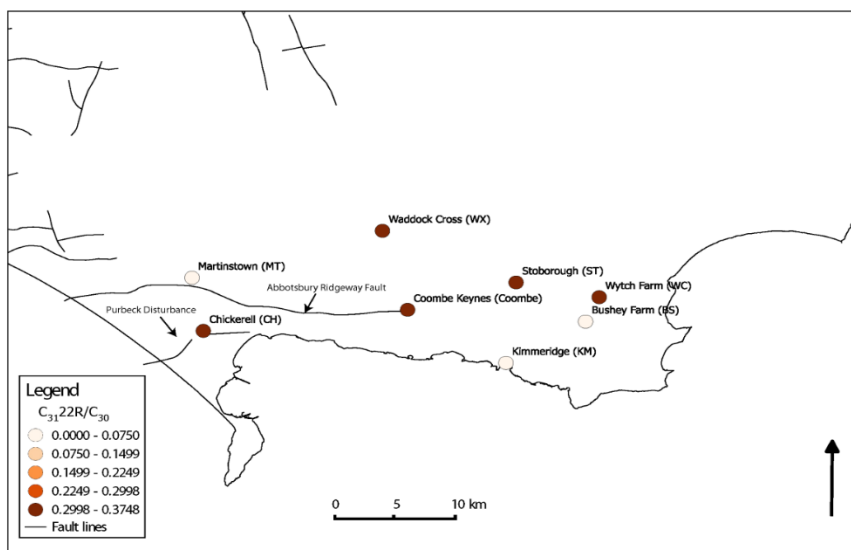
### C<sub>31</sub>/C<sub>30</sub>hopanes

A plot of the ratios of C<sub>31</sub>/C<sub>30</sub>hopanes is used to separate oils of marine from those of lacustrine deposited source rocks and is presented here in Figure 11, with most of the samples plotting between 0.3-0.45 and displaying some grouping; with CH, CR and WC samples mostly having similar values around 0.36, whereas ST and WX samples

have ~0.33 (Fig. 11). The presence of C<sub>31</sub>H is generally in any crude sample is generally regarded as an indication for marine source (Peters *et al.*, 2005). A plot on map of the well average (Table 5.3a) values for C<sub>31</sub>/C<sub>30</sub> biomarker is shown in Figure 12, with no apparent pattern to the average distribution of the biomarker between the wells.



**Figure 11:** A plot of C<sub>31</sub> 22R/C<sub>30</sub> H showing ST and WX grouped on one hand, and CH, CR and WC on the other. Cycles indicate grouping of Os and Ps.



**Figure 12:** The distribution of well average values for C<sub>31</sub> 22R/C<sub>30</sub> H biomarker, showing no particular pattern of distribution.

### DISCUSSION

C<sub>30</sub>/C<sub>29</sub>Ts hopane ratios plotted to investigate source type and environment of deposition (Moldowan *et al.*, 1985) shows source rocks that generated the Creech oils were deposited in an oxic-suboxic environment, Wytch Farm in suboxic-dysoxic environment and while Chickerell and Coombe Keynes oils in dysoxic-anoxic environment (Fig. 4), with some sort of lineament observed in the distribution of the biomarker, along the Abbotsbury Ridgeway-Purbeck faults (Fig. 5). However, Kolaczowska *et al.* (1990) and Peters *et al.* (2005) argued that this ratio is also affected by oil maturity. Peters *et al.* (2005) suggest that the C<sub>30</sub> hopane is thermally more stable

than C<sub>29</sub> Ts and the C<sub>30</sub>/C<sub>29</sub>Ts ratio could not be solely relied upon.

In contrast, the C<sub>29</sub>Ts/(C<sub>29</sub>H + C<sub>29</sub>Ts) shows all the oils present had slightly varying maturity levels, with oils from Creech and Wytch Farm being slightly more mature than the Chickerell oils (Moldowan *et al.*, 1985) (Fig. 6) and a similar distribution of the biomarker along the Abbotsbury Ridgeway and Purbeck-Isle of Wight fault lines (Fig. 7). Furthermore, the homohopanes (C<sub>31</sub> – C<sub>35</sub>hopanes) contained in the samples analysed indicate that the source rocks that generated Wytch Farm and Creech samples were deposited in oxic-suboxic environment (Fig. 8) (Krooss *et al.*, 1991), this agrees with the C<sub>30</sub>/C<sub>29</sub>Ts ratios

above (Fig. 4), while the Stoborough oils were sourced from rocks deposited in anoxic environments. In addition, Peters and Moldowan (1991) considered the presence of C<sub>35</sub>hopanes in any oil sample as an indication that the source rocks were deposited in a highly reducing (-Eh) marine environment.

The C<sub>35</sub>/C<sub>34</sub>homohopane ratios for the oils measured had values less than the predicted for oils derived from marine shales (>0.6), but most of the samples measured had values <0.6, this is indicative of oils sourced from coal/resin materials (Fig. 10). However, this ratio is also reported to be affected by oil maturity, e.g., Peters and Moldowan (1991) found values of <0.6 in oils from Monterey Formation, California, which was neither sourced from coal nor resins.

The C<sub>31</sub>/C<sub>30</sub>homohopane ratios are highly specific for distinguishing marine from lacustrine depositional conditions; samples measured in this study using this ratio had values > 0.25 (Fig. 11). This reaffirms the source rock for these oils was deposited in a marine environment (Johnson, 2006), with the biomarker fairly distributed around the study area (Fig. 12).

## CONCLUSION

There is no evidence to suggest, based on the biomarker analysis carried out on the aliphatic fractions of the oil samples that they were not from a common source rock, i.e., all oils analysed in this study probably had the same source rock. However, variations observed in some of the environment of deposition biomarkers, e.g., the C<sub>35</sub>homohopane ) might be due differences in oil thermal maturity, biodegradation or there were variations in conditions, during the deposition of the Lias. The deposition of the Lias took millions of years (Hawkes *et al.*, 1998), and it is probably incorrect to assume conditions were the constant throughout. There is strong evidence to suggest oil maturity varies across the sampled wells. Oil samples from Kimmeridge are mature than samples from Creech, with both being more mature than samples from Waddock Cross, but less mature Wytch Farm samples. Therefore, It is possible to argue, based on biomarker analyses, that oils found at different locations in Wessex Basin may have accumulated from various charge points, instead of a series of spill-chains as currently thought (Hawkes *et al.*, 1998). These various charge points are controlled by the two major faults in the study area, that serve as conduit petroleum migration.

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