Appendix A: Estimation of the total in-place oil resource in Jurassic shales in the Weald area, southern Britain

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1. Aim

The aim of this study is to estimate the P90-P50-P10[1] range of potential **total oil-in-place volumes** for the main Jurassic shale units across the Weald area of southern Britain.

This analysis forms an appendix to the main Weald report, which provides the detailed geological background to this shale oil play. This specific study applies a Monte Carlo simulation to a suite of input parameters, some of which come from the geology-based methodology described in the main report, and others which are based on information from published analogues.

2. Introduction

In the case of the Weald Basin, the paucity of geochemical data precludes a full understanding of free oil contents that should be necessary to estimate in-place resources. However, with regards to the use of S1 to estimate oil-in-place, it is reasonable to model two end members:

1. Use Jarvie (2012b) and as '(S1/TOC) x 100' is less than 100, assume that most/all of the measured S1 is associated with kerogen. In this scenario, the free oil density will be negligible.
2. Assume that the sorbed oil is restricted to S2 and that all the S1 is free oil. It is then possible to correct the S1 for evaporative loss (see Michael *et al.* 2013) and use this as the free oil density.

3. Equations[2]

This report converts the S1 data from Rock-Eval analyses to an estimation of free oil yield to determine oil in-place (see Section 9.2), using Michael *et al*.'s (2013) equation:

> Oil in-place (bbls/acre-ft) = corrected S1 (mgHC/gRock) x rock density (g/cm^3) ÷ oil density (g/cm^3) x unit conversion factor

The unit conversion factor to convert from cm^3/m^3 to bbl/acre-ft = 7.758

[1] P10, P50 and P90 correspond to the 10%, 50% or 90% probability of more than that amount being present. In the case of P10, there is a 10% probability that the actual result will be higher, or a 90% chance the result will be lower.

[2] In this project, metric units have been used throughout the calculation stages, with the conversion to imperial units only given for the presentation of the output (Table 2a and 2b and Figure 1).

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4. Values used

Net mature shale volume has been calculated from the 3D model. It is the gross rock volume truncated by the R_o = 0.6% isomaturity cut-off. Two potential maturity gradients have been used – one which provides a cut-off at 7,000 ft (2,130 m) maximum burial depth and the other at 8,000 ft (2,440 m); this is due to the ambiguous nature of the vitrinite reflectance data (see Section 3.8 of the main report).

The 'accessible/viable' net shale volume incorporates data that has been truncated upwards at 3,300 ft (1,000 m) and 5,000 ft (1,500 m). See Section 3.10 of the main report for details of these criteria.

The proportion of potentially productive shale within each shale unit is based on data derived from geophysical logs (see Appendix D) and data from samples analysed for TOC. This figure is the percentage of the seismically mapped volume that comprises organic-rich shale (TOC >=2%).

Present day S1 values are taken from Rock-Eval analyses in organic-rich shales (see Table 7 of the main report). The S1 values used are restricted to those wells within the 'core mature area' (Figure 26 of main report). This 'free oil density' is the amount of the original S1 that is considered to represent extractable oil. The minimum case is that none of the S1 oil is free oil (it is all bound within the kerogen). The most-likely and maximum cases assume that all the S1 will be 'free oil', but in the analyses has been reduced by evaporative loss.

The evaporative loss of S1 from the samples over time may have been considerable, especially if more volatile oils are concerned. For a selection of source rock types and basins, Michael *et al*. (2013) propose the equation:

$$\% \, C_{15} \text{ minus lost} = (\text{oil API} - 20.799)/0.412$$

For API = 35°, loss is 34.5%; API = 40°, loss is 46.4%; API = 45°, loss is 58.7%. The corresponding correction factors are 1.53, 1.87 and 2.42 respectively.

Other authors consider that evaporative loss can be a more significant issue, with correction factors up to 4.0 or even 5.0 suggested by Jarvie *et al*. (2012). There is no evidence of high API oils in the Weald area which are most likely to require such large corrections.

Published shale densities are in the range 2.4 – 2.8 g/cm³. This study has used 2.55 – 2.6 – 2.65 g/cm³ as a range of values for calcareous shale. This is supported by downhole geophysical well logs in the study area.

Oil density or specific gravity (g/cm³) = 141.5/(131.5 + oil API) (American Petroleum Institute definition). The range used in this report is for 35°, 40° and 45° API oil. The gravities of oils in the conventional fields of the Weald area fall in the range 35-42° API (Butler & Pullan 1990). Hydrocarbon inclusions in cements in the Great Oolite indicate a range from 19-30° API in the south-west, increasing to 33-40° API towards the basin centre and up to 48° API close to the depocentre (Sellwood *et al*. 1993).

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5. Monte Carlo input parameters

R_o = 0.6% at 7,000 ft	Accessible/viable$ volume of net mature shale (x10^9 m³)				Net organic-rich and potentially productive shale (%)			Free oil content (mgHC/gRock)			Correction for evaporative loss			Shale density (g/cm³)			Oil density (g/cm³)		
	Lower cut-off	3,300 ft cut-off	5,000 ft cut-off	Upper cut-off	min	ml	max	min	ml	max	min	ml	max	min	ml	max	min	ml	max
Kimmeridge	4.3	5.3	220.4	242.5	52	63	70	0	1.21	1.35	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Corallian	39.5	49.4	201.5	222.6	20	27	35	0	0.60	0.70	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Oxford	77.6	97.0	214.8	236.3	22	30	39	0	1.16	1.30	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Upper Lias	65.9	82.4	137.2	150.9	15	20	28	0	1.07	1.20	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Mid Lias	106.3	132.9	195.0	214.5	9	20	37	0	0.88	1.00	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85

Table 1a. Input parameters for the Monte Carlo simulation used to determine the total oil in place in the five main Jurassic shale units, Weald area, southern Britain using a maturity cut-off at 7,000 ft (2,130 m) maximum, pre-uplift burial depth. $ = volume of shale below various depth cut-offs.

R_o = 0.6% at 8,000 ft	Accessible/viable$ volume of net mature shale (x10^9m³)				Net organic-rich and potentially productive shale (%)			Free oil content (mgHC/gRock)			Correction for evaporative loss			Shale density (g/cm³)			Oil density (g/cm³)		
	Lower cut-off	3,300 ft cut-off	5,000 ft cut-off	Upper cut-off	min	ml	max	min	ml	max	min	ml	max	min	ml	max	min	ml	max
Kimmeridge	0.5	0.6	66.8	73.5	52	63	70	0	1.21	1.35	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Corallian	22.9	28.6	118.3	130.1	20	27	35	0	0.60	0.70	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Oxford	52.9	66.1	148.3	163.1	22	30	39	0	1.16	1.30	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Upper Lias	54.1	67.6	109.7	120.7	15	20	28	0	1.07	1.20	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85
Mid Lias	85.3	106.6	156.8	172.5	9	20	37	0	0.88	1.00	1.53	1.87	2.42	2.55	2.6	2.65	0.8	0.825	0.85

Table 1b. Input parameters for the Monte Carlo simulation used to determine the total oil in place in the five main Jurassic shale units, Weald area, southern Britain using a maturity cut-off at 8,000 ft (2,440 m) maximum, pre-uplift burial depth. $ = volume of shale below various depth cut-offs.

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6. Monte Carlo results

(i) Metric	Total oil in-place estimates (million tonnes)		
R_o = 0.6% at 7,000 ft	Low (P90)	Central (P50)	High (P10)
Kimmeridge	55	271	636
Corallian	27	69	139
Oxford	79	185	328
Upper Lias	37	84	140
Mid Lias	44	105	191
Combined	**477**	**755**	**1,143**

(ii) Imperial	Total oil in-place estimates (billion bbl)		
R_o = 0.6% at 7,000 ft	Low (P90)	Central (P50)	High (P10)
Kimmeridge	0.41	2.03	4.77
Corallian	0.20	0.52	1.04
Oxford	0.59	1.39	2.46
Upper Lias	0.28	0.63	1.05
Mid Lias	0.33	0.79	1.43
Combined	**3.58**	**5.66**	**8.57**

Table 2a. Results of a Monte Carlo simulation (50,000 iterations) to determine the total in-place oil resource in the main Jurassic shales of the Weald area, southern Britain, using a maturity cut-off at 7,000 ft (2,130 m) maximum burial depth. The results are given in (i) metric and (ii) imperial units.

(i) Metric	Total oil in-place estimates (million tonnes)		
R_o = 0.6% at 8,000 ft	Low (P90)	Central (P50)	High (P10)
Kimmeridge	15	81	192
Corallian	15	40	81
Oxford	55	128	227
Upper Lias	29	69	113
Mid Lias	36	85	153
Combined	**293**	**428**	**587**

(ii) Imperial	Total oil in-place estimates (billion bbl)		
R_o = 0.6% at 8,000 ft	Low (P90)	Central (P50)	High (P10)
Kimmeridge	0.11	0.61	1.44
Corallian	0.11	0.30	0.61
Oxford	0.41	0.96	1.70
Upper Lias	0.22	0.52	0.85
Mid Lias	0.27	0.64	1.15
Combined	**2.20**	**3.21**	**4.40**

Table 2b. Results of a Monte Carlo simulation (50,000 iterations) to determine the total in-place oil resource in the main Jurassic shales of the Weald area, southern Britain, using a maturity cut-off at 8,000 ft (2,440 m) maximum burial depth. The results are given in (i) metric and (ii) imperial units.

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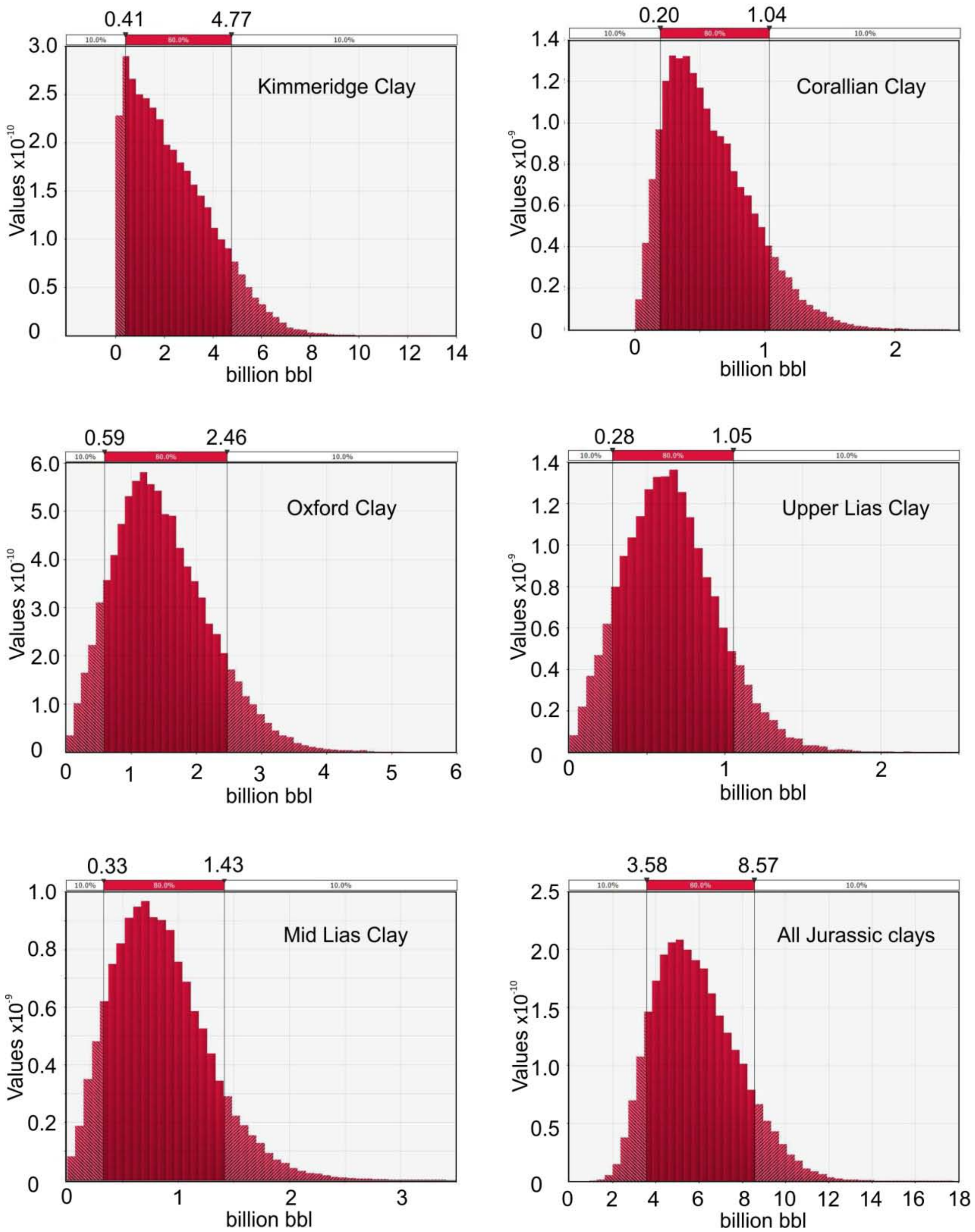

Figure 1. Probabilistic distributions representing the results of a Monte Carlo analysis for the in-place resource estimation of shale oil in the five Jurassic shale units (separate and lastly combined), using a maturity cut-off at 7,000 ft (2,130 m) maximum burial depth.

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7. Key variables and their effect on the estimated oil volume

Variable	Uncertainty
Gross rock volume/3D geological model	The 2D seismic data interpreted in the study area is of variable quality, but is generally moderate to good, reducing to poor in the Lias.
Shallow depth cut-off	The use of 3,300 ft and 5,000 ft is based on USEIA and USGS global screening criteria. If this were deeper, this would reduce the estimated in-place oil volume especially in the shallower shale units.
Definition of prospective shale	The definition of net prospective shale used in this report is significant. Given that the TOC of the two Lias shales is about 2%, any slight deviation from this definition could increase or decrease the amount included as prospective shale.
Free oil density	Oil yields are controlled by kerogen type, percentage of free or extractable oil and the amount of evaporative loss affecting S1 peaks. If there is little or no producible oil in the shales (as suggested by one interpretation of the S1 and TOC data), then any of the estimates presented here would be optimistic. If the oil measured by S1 is essentially all moveable and the samples have undergone higher evaporative loss than predicted, then the estimates could be low.
Definition of oil maturity	The use of R_o = 0.6% as the top of the oil window is standard practice. It could be 0.7% which would reduce the estimated oil volume, or 0.5% which would increase it.
Depth to oil window	The geochemical data do not allow for an accurate assessment of the depth to the oil window relative to the maximum, pre-uplift burial depth. The estimation of Cenozoic uplift is another factor which controls the present-day depth of the oil window. The broad agreement in the amount of uplift obtained from two separate methodologies (see Section 3.5.4 of the main report) gives some confidence that the values used are reasonable. Two possible gradients are modelled in this report. A marginally steeper gradient than these (excluded due to assumed vitrinite suppression) would effectively rule out any shale oil potential, whereas a shallower gradient (excluded due to assumed reworked kerogen) could potentially place the deeper units in the gas window.
Bulk density	The average density of 2.6 g/cm^3 is a robust estimate. If the density is higher this will increase the estimated gas volume (and vice versa if lower).

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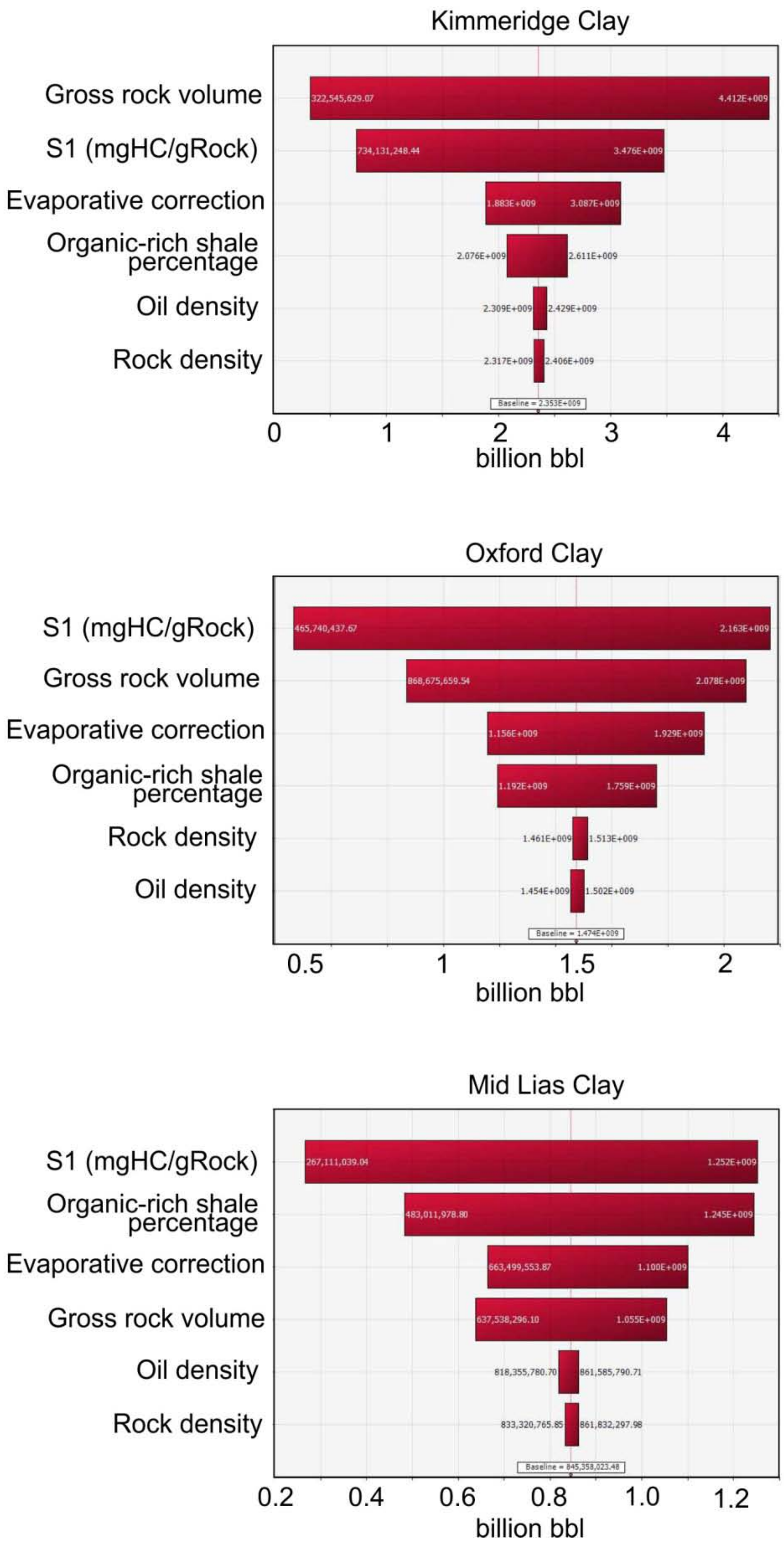

Figure 3. Tornado diagram representing the result of a Monte Carlo analysis for the in-place resource estimation of shale oil in Kimmeridge Clay, Oxford Clay and the Mid Lias Clay using a maturity cut-off at 7,000 ft (2,130 m) maximum burial depth.

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8. Conclusion

This study estimates that the **total in-place oil resource** for the Jurassic shales across the Weald area, southern Britain is 2.2 – 4.4 – 8.6 billion bbl (0.29 – 0.59 – 1.14 billion tonnes) (P90 – P50 – P10).

In order of significance, the Kimmeridge Clay contributes the largest in-place resource in this model, followed by the Oxford Clay, Mid Lias Clay, Upper Lias Clay and finally the Corallian Clay. However, as rock volumes at shallower levels are excluded by using a more cautious maturation gradient or a shallower accessibility/viability cut-off, the Kimmeridge Clay falls to second or even third place.

It should be emphasised that this figure is an in-place resource estimate. The amount that could be recovered depends on factors outwith the scope of this report, and could very likely be a small percentage.

9. Discussion of oil in-place calculation methods

Calculations to establish the volume of oil retained within a mature source rock that can be extracted without retorting/heating, i.e. the in-place shale oil resource, fall into two broad categories. Both involve calculating the 'free oil density' i.e. the volume of free oil per unit volume (say m^3/m^3 or bbl/acre-ft) and then scaling it up to basin dimensions.

8.1. TOC-based methods

The long-standing calculation of a drainage basin's 'petroleum charge' (e.g. White & Gehman 1979, Goff 1982, Lewan *et al.* 2002, Magoon *et al*. 2007) uses a material-balance approach to assess the amount of hydrocarbons that has been generated and has migrated into the conventional hydrocarbon system. A similar methodology can be used to determine the amount of hydrocarbons which are retained in the shale.

A generic equation is:

Oil in-place (volume) = BRV x TOC_o x %GOC x (1 – TR%) x VF% x 'a unit convertor'

The key input parameters are as follows (those that can be derived from Rock-Eval analyses are shown in red):

Bulk rock volume (BRV) = the net volume of organic-rich shale (e.g. TOC > 2%).

TOC_o = the total amount of organic carbon in the immature rock. As a rock matures, organic carbon will be converted to hydrocarbons. TOC_o includes some organic carbon that will generate hydrocarbons and some that won't (see below).

Generative organic carbon (%GOC) (wt %) = the proportion of organic carbon responsible for generating hydrocarbons. At high thermal maturity, all that will remain will be non-generative organic carbon.

Transformation ratio (TR%) = the proportion of organic matter which has been transformed into hydrocarbons during maturation. That is the amount of carbon expelled as petroleum as a

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proportion of the original total organic carbon. It increases with increasing maturity. In a system which is marginally mature for oil generation, Goff (1982) showed a transformation ratio of 20-30%, leaving 70-80% in the source rock and available as a shale oil resource.

Volume factor (VF%) = percentage increase in volume when converting mass (g) to volume (cm^3) during oil generation and using relevant rock and oil densities.

The major draw-back of this method is that the proportion of the hydrocarbons that is expulsed vs. retained is not factored into this equation, with very little to base this parameter on.

Monticone *et al*. (2011) uses 'initial' TOC (although there is no indication how this is calculated from TOC_{pd}) and hydrogen index (HI_o) to calculate a maximum S2 yield in the Paris Basin. The maximum potential hydrocarbon volume is then reduced by a 'transformation ratio' (TR) and divided between remaining and expulsed hydrocarbons. This has the same draw-back as above, with no explanation how they estimated retained petroleum. The remaining (residual) hydrocarbon fraction is their shale oil resource.

Discussion

The lack of an expulsion/retention factor in these equations is crucial. A shale oil resource calculation is concerned with oil retained, which is commonly assumed to be controlled by the ability of kerogen to sorb oil. This assumption is based on analytical (Rock-Eval and solvent extraction) data which show a strong relationship between S1 (or Total Sediment Extract) and TOC. If S1 can be equated to "oil" or "bitumen", this suggests that much of the oil is associated with solid phase organic matter. Note that the relationship is not 1:1 so it is simply implying that much of the oil is associated with kerogen. So, the data imply that as the source rock matures, oil is generated but is not expelled until the kerogen "sponge" is saturated. After that, oil continues to be generated but most is expelled. There is no doubt that some oil is retained very locally in larger pores and/or fractures, but the implication of the S1 data in the Weald area is that the amounts are typically small.

Rock-Eval, solvent extract data and experimental data suggest that 50-100mg HC can be sorbed per gram of organic C (Sandvik *et al*. 1992). This is the heart of Jarvie's simple "oil crossover" plots which he uses as a very simple tool to indicate rocks which might contain some oil that is not physically associated with kerogen, and which might therefore be more readily producible. Below are two examples from his 2012 paper from the Bakken and the Eagle Ford. The upper and lower Bakken are classic source rocks and give the roughly linear scatter of blue points, well below the 100mg/g line. The points near the origin are middle Bakken and Three Forks, which are really reservoir rocks, but juxtaposed with the two sources. They have low TOC, but contain oil – seen on Rock-Eval as S1.

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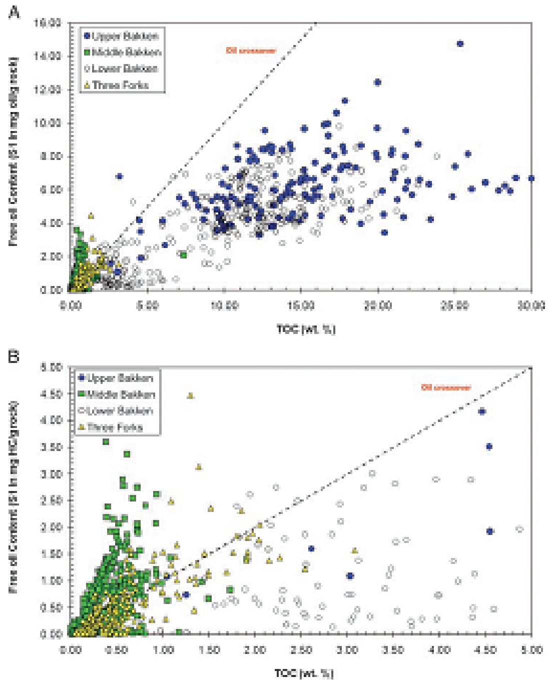

FIGURE 6. (A, B) Geochemical database of total organic carbon (TOC) and Rock-Eval analyses from the North Dakota Geological Survey (2008). A plot of free oil contents versus TOC illustrates the oil crossover effect of the upper Bakken Shale, Middle Member of the Bakken Formation, lower Bakken Shale, and Three Forks: (A) all data with up to 30% TOC, and (B) reduced scale emphasizing the Middle Member of the Bakken Formation and Three Forks data. S1 = Rock-Eval measured oil contents.

Figure 6 of Jarvie (2012b).

The Eagle Ford is really a carbonate, but with some layers richer in clay and organic matter, and some purer limestones. The idea is that there is some micromigration into the limestones, which may be the best reservoirs (perhaps more free oil, perhaps to do with fractures, perhaps to do with pore systems).

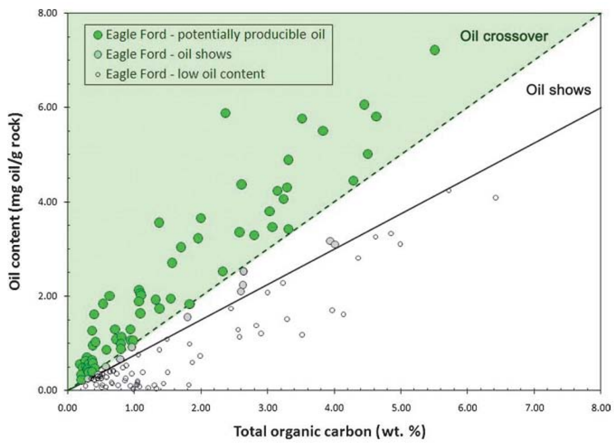

FIGURE 10. Geochemical database of Eagle Ford Shale showing the oil crossover effect.

Figure 10 of Jarvie (2012b). The pale green area = very high oil saturation indicative of potentially producible oil.

8.2. Rock-Eval S1-based methods

The S1 peak derived from Rock-Eval analyses should in theory provide a quick estimate of the amount of free oil retained in a shale sample. The S1 peak refers to the amount of hydrocarbons already generated and present within the rock sample. These are the free hydrocarbons (oil and gas) present in the sample, and distilled during the initial heating of the sample to a temperature of 350°C.

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However, 'evaporative losses' occur and these can seriously downgrade its usefulness in basins with a high proportion of light hydrocarbons (see below).

Jarvie *et al*. (2007) quotes data from the Barnett Shale. Figures for 'oil in rock from S1 (bbl oil per acre-ft)' use a conversion of S1 x 21.89.

Oil in-rock (bbls/acre-ft) = S1 x 21.89 [*with assumed rock and oil densities unknown*]

Downey *et al*. (2011) describe a quick-look method for calculating shale oil resources. This uses the raw S1 (free hydrocarbon) peak data from Rock-Eval pyrolysis in wells, scaled up to basin dimensions.

Michael *et al*. (2013) also use S1 from Rock-Eval to determine oil in-place, but add a correction for oil (mostly less than C_{15}) lost during core recovery and a method to derive oil density from core extracts.

Oil in-place (bbls/acre-ft) = $S1_c$ x rock density ÷ oil density x unit conversion factor

Where $S1_c$ = S1 corrected for 'evaporative loss'

Jarvie (2012b) & D. Jarvie (pers. comm. 2013) commented that using S1 [for shale oil resource estimation] may be possible, but with some big assumptions. In his experience, the minimum 'evaporative loss' for S1 in the oil window is 35%, but it may underestimate retained oil by upwards of 500%. This is dependent on a number of factors: oil type, organic richness, lithofacies, sample age, sample handling and preparation, etc. Jarvie (2012b) says that evaporative loss is higher in more organic-lean reservoirs. Jarvie (2012c) compares 20-year old cuttings (S1 = 0 to 3 mg oil/g rock) to fresh sidewall cores (S1 = 0.5 to 11); evidence for a correction factor of c.3.7.

<u>Discussion</u>

Michael *et al*. (2013) give a reasonable and brief description of the calculation of oil present in oil-mature shales and shale-associated reservoirs. Their Figure 2 indicates that TOC exerts a strong but not overwhelming control on oil-in-place, suggesting a reasonable physical association of oil and solid phase organic matter. They unpick this relationship further in the rest of the paper. Their Figure 4 shows the effect of solvent extraction on both S1 and S2 Rock-Eval peaks. As expected, S1 goes close to zero. S2 also decreases substantially, since the heavier components of petroleum (asphaltenes, resins, high molecular material generally) are poorly volatile and appear at the same pyrolysis temperature as the oil evolved from kerogen. Interestingly, they point out that the amount of solvent-extractable S2 is around 100 mg/gC, suggesting that this might be the majority of the sorbed oil. They therefore suggest that S1 might be mainly un-associated with kerogen.

If the S1 is mainly not associated with kerogen, it might be potentially producible, although this depends on a wide range of other reservoir quality and oil quality factors such as permeability, oil viscosity, hydraulic fracture creation and closure rates etc. It would then be necessary to understand the amount of S1-volatile oil which has been lost as a result of bringing the core to the surface and leaving it in the core store. As Dan Jarvie points out, this can be substantial. Michael *et al*.'s Figure 1 helps us to estimate potentially lost oil as a function of API gravity (i.e. oil density). By assuming that the entire minus C15 fraction is lost (probably a top-end loss factor), Figure 1 can be used to

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estimate lost oil, if the API of the unexpelled oil in the source rock can be estimated. Even if this is not known with certainty, in a general sense API reduces with maturity.

With Michael *et al*.'s (2013) correlation between API and C15 minus (below), an approximate correction can be made and the lighter (S1-volatile) oil actually in the rock can be estimated. A correction of around 30% can be estimated for R_o of 0.6-0.7. This would be much higher at higher maturities (note that instantaneous API should be used as this is what is being generated at a given maturity).

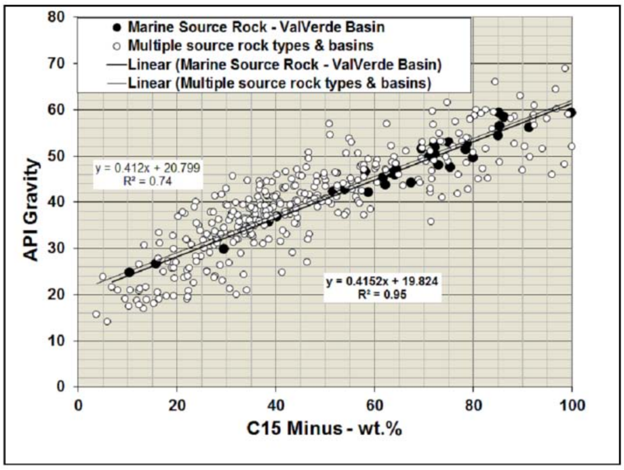

Figure 1 of Michael *et al*. (2013).

8.3. Oil-filled pore space method

USEIA (2013) use an established reservoir engineering equation as employed for calculating conventional oil field volumetrics, but use it for a shale oil reservoir rather than one composed of porous sandstone or carbonate. However, in an unexplored basin, reliable information on the key input criteria are lacking, i.e. porosity, oil saturation or oil formation gas volume factor.

$$\text{OIIP (bbl)} = 7758\ (A * h) * \emptyset * S_o / B_o$$

A is the area, in acres ; h is net organically-rich shale thickness, in feet; Ø is the porosity; S_o is the fraction of the porosity filled by oil; B_o is the oil formation volume factor that is used to adjust the oil volume in the reservoirs to the oil volume at the surface.

USEIA (2013) then quote a 'risked' OIIP. Their 'risk factor' is an indicator of how much is known or unknown about the shale formation and factors (e.g. geological complexity and lack of access) that could limit portions of the prospective area from development. In the case of the Lias Weald Basin, the risk factor is 32%.

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	Shale gas	**Shale oil**
Prospective area (mi^2)	1735	1735
Net organic-rich shale thickness (ft)	149	149
Phase	Associated gas	Oil
Reservoir pressure	Normal	Normal
Average TOC (%)	3.0	3.0
Gas concentration (bcf/mi^2)	14.5	
OIIP concentration (million bbl/mi^2)		30.9
OIIP concentration (bbl/acre-ft)		324
Risk factor applied	0.32	0.32
Risked GIP (tcf)	8.0	
Risked OIP (billion bbl)		17.1
Recovery factor (%)	8	4
Risked recoverable gas (tcf)	0.6	
Risked recoverable oil (billion bbl)		0.69

Table 1. Figures for the Liassic Weald Basin play as used by USEIA (2013). Note: these are for the Lias only.

10. References

See main report.

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Appendix B: Rock-Eval geochemical analysis of 103 shale samples from wells in the Weald area: results and their interpretation

N.J.P. Smith, C. Vane, V. Moss-Hayes & I.J. Andrews

1 Introduction

One hundred and three samples were taken from cores and cuttings in 12 wells in the Weald Basin to contribute modern Rock-Eval data to the analysis of the unconventional hydrocarbon prospectivity in the basin.

The samples were run on the BGS Rock-Eval machine in late August 2013.

Although a number of oil, and smaller gas, discoveries (Figure 1) have been made in the Weald Basin since the 1980s, the source rock(s) responsible has not been positively identified. The gas fields and discoveries are located near the Jurassic-early Cretaceous depocentre, whereas the oil fields occur in two bands farther out of the basin on its northern and southern margins. A study by BGS for the Department of Energy in 1983 conducted a thorough analysis of the source rocks by spore colour, vitrinite reflectance and pyrolysis. It concluded that "the present sparse data indicate that oil has probably been generated from the Lias and/or the Lower Oxford Clay of the Weald. Reliable evidence does not yet exist that higher horizons have done so" (Lamb 1983).

Five Jurassic intervals contain thick shales in the Weald Basin, which are often organic-rich: Lias, Fuller's Earth, Oxford Clay, Kimmeridge Clay and Purbeck shales. Other intervals contain some shales which have been cored whilst targeting the conventional reservoirs (e.g. within the Corallian). Early Cretaceous gas-prone strata, containing lignites, and the younger Gault Clay have not been sampled.

2 Methods

Of the 103 samples five were from the Purbeck Beds (PB), three from the Portland Beds (PL), 37 from the Kimmeridge Clay (KC), two from the Corallian (CR), 13 from the Oxford Clay (OXC), 18 from the Fuller's Earth (FE), 14 from the Lias (LI), one from the Penarth Group (PNG), three from the Devonian (DEV) and five from the Silurian (SIL).

A map of the wells sampled (Figure 1) shows their geographical coverage. The wells include Portsdown 1 lying south of the Weald Basin *sensu stricto* in a small sub-basin on the Hampshire-Dieppe High. The spreadsheet of data derived from the Rock-Eval analysis (Appendix 1A) records depths, formations and the main parameters measured - S1 (free hydrocarbons), S2 (bound hydrocarbons), T_{max} (the temperature at which S2 peaked), S3 (carbon dioxide) and the total organic carbon (TOC).

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The conventional petroleum generative potential is calculated by summing the S1 and S2 values obtained during pyrolysis. Values over 5 mgHC/gRock represent good source rocks and those over 50 mgHC/gRock represent world class potential.

In addition, the principal useful parameters derived from the data include Production Index (PI), Hydrogen Index (HI) and Oxygen Index (OI). PI is derived by dividing the sum of the S1 and S2 hydrocarbons into S1. HI is derived by the ratio of S2 mg HC per gram of organic carbon and values above 350 are generally rated to be good source rocks (for conventional hydrocarbons, Tissot & Welte 1978, fig. V.1.11). OI is the ratio of mg carbon dioxide per g organic carbon. HI and OI are plotted (Figure 3) to be comparable with a van Krevelen diagram (atomic H/C versus atomic O/C), showing the branching of the different kerogen types I (lacustrine, algal, oil prone), II (marine, oil prone), III (terrestrial, gas prone) and IV (oxidised or inertinite). Well known international source rocks (e.g. Toarcian Shale of the Paris Basin) are also shown for comparison.

Note. Matching known cored intervals from composite and end-of-well reports and the defined formation level to actual core held is not a straightforward process.

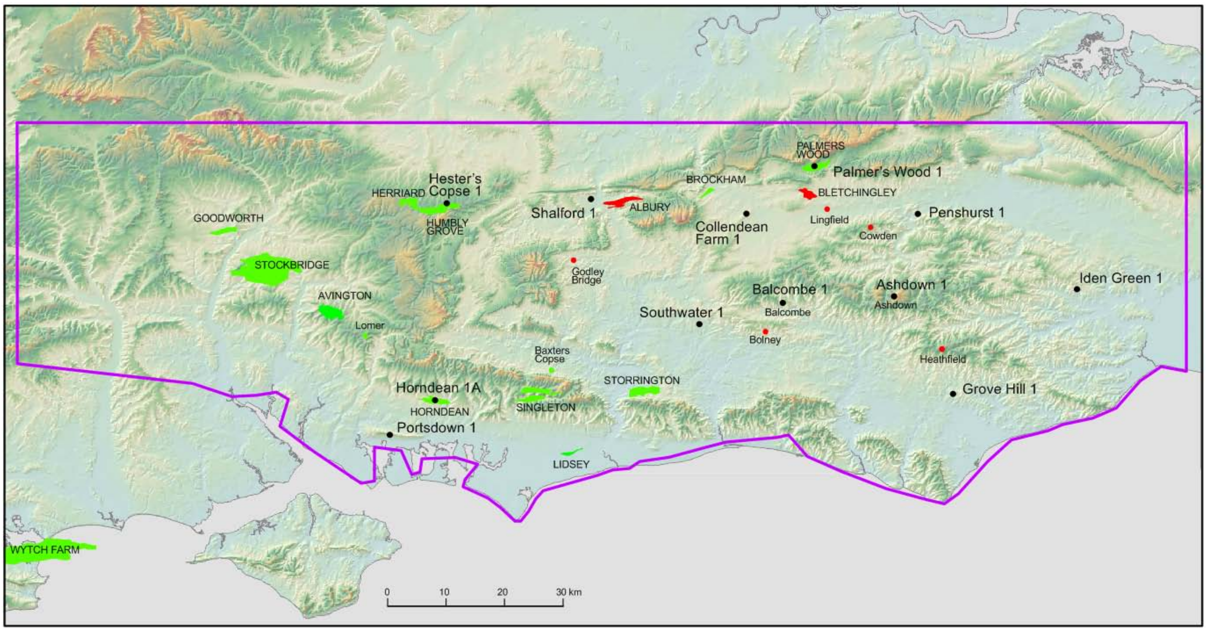

Figure 1. Location of the 12 wells in the Weald Basin sampled for geochemical analysis in this study. Oil fields (green), gas fields (red) and discoveries are also shown.

3 Results

3.1 Silurian

Five samples were analysed from the Silurian in Shalford 1. These are graptolite-bearing purple, green and grey mudstones.

Some of the previous measurements on these strata seem anomalous, especially their apparent immaturity suggested by Lamb (1983). This study shows that based on T_{max} figures alone these strata

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are probably in the dry gas window. Four of the samples give very high T_{max} values (494-495°C) and one is very low, indicating an unreliable T_{max} because S2 is too low, due to overmaturity.

All five samples from the Silurian shales have very low S1/S2 values, perhaps making all these T_{max} values unreliable. It is unclear as to whether this state is due to attaining overmaturity and consequent destruction of original organic matter (favoured explanation) or whether the shales were very lean as a result of deposition in, or subsequent exposure to, an oxidising environment.

3.2 Devonian

The Devonian occurs in black shale facies in south-west England, but is often found in a red bed or carbonate facies in the Weald. In the Palmers Wood 1 well, the cored carbonate facies lacks thick shales and the three fine-grained lithologies sampled were organically lean. The low T_{max} may reflect the low S2 and therefore should be interpreted as overmature, rather than immature. However, this remains unproven.

3.3 Triassic

The Westbury Shales of the Penarth Group (latest Triassic) contain dark mudstones representing deposits of the first organic-rich transgression from the Tethys Ocean into the UK, but these are not widely present in the Weald. The one sample (from Portsdown 1) yielded a low TOC (0.5%).

3.4 Lias

Sixteen samples were analysed from the Lias (8 Lower, 1 Middle, 5 Upper, 2 undifferentiated).

The highest TOC in a Lias sample was 1.62% (from Grove Hill 1) and the S2 yield reached a maximum of only 2.56 mgHC/gRock.

The T_{max} ranged from 428 to 441 (R_o equivalent 0.5-0.8%) – all but two samples were within the oil window.

On the van Krevelan diagram, all the Lias samples plot in the Type III kerogen field (Figure 4a).

The Upper Lias was previously rated as the best and most likely source rock for the Weald Basin hydrocarbons (Lamb 1983). Upper Lias TOC in the Weald ranged from 0.42-4.84% (Lamb 1983), whereas the highest value in the present study in the Lias is only 1.62%. None of the central Weald wells had TOC values over 2%, and the 4.84% value was recorded from fairly low-gamma shale in the Middleton well near the south coast (Lamb 1983, fig. 5.11) from a putative sub-basin on the Hampshire-Dieppe High. This well also recorded the highest Middle Lias value, suggesting that a local accumulation of organic matter occurred in this sub-basin.

The Weald Basin extends across the English Channel into France, where it terminates a short distance inland in the Boulonnais region, and is separated from the Paris Basin by the Dieppe High. The Paris Basin is famous for its Lower Toarcian shale which is the source rock for its hydrocarbon fields and is one of the classic shales containing Type II kerogen (Tissot & Welte 1978, Fig. 4).

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3.5 Fuller's Earth

A total of 18 samples were analysed from the Fuller's Earth, including 14 from Horndean 1A.

Two samples had TOC contents of slightly greater than 2% (Hester's Copse 1 and Horndean 1A) suggesting that this formation may be a prospective source rock. In the extensively sampled Horndean 1A well, the other samples had between 0.39-1.85% TOC. S2 exceeds 5 mgHC/gRock (green cells of Appendix 1A) in three samples from the Fuller's Earth.

The T_{max} of the Fuller's Earth samples from Horndean 1A were variable, but mostly within the oil window (R_o equivalent = 0.5-0.8%).

One sample plots as Type II kerogen, with the remainder having lower HI and higher OI plotting in the Type III kerogen field.

3.6 Oxford Clay and Corallian

Thirteen samples were taken from the Oxford Clay, and two from the Corallian.

The Oxford Clay is confirmed as a potential source rock, having in excess of 2% TOC in three out of the six wells sampled at this stratigraphic level (in Grove Hill 1, Portsdown 1 and Shalford 1). The maximum was 5.13% TOC. In two samples S2 exceeds 5 mgHC/gRock (green cells of Appendix 1A) and the Oxford Clay is known to be bituminous at some outcrops.

The samples were mostly within the oil window, but again there was a range from R_o (equivalent) of 0.5 to 0.7%.

One Oxford Clay sample from Shalford 1 aligns with the Type I kerogen field (OI=11, HI=551) (Figure 4b).

3.7 Kimmeridge Clay

A total of 37 samples were analysed from the Kimmeridge Clay.

The Kimmeridge Clay TOC samples ranged from 0.47-21.31%, with 60% of the samples over 2%. At the Balcombe 1 well, the TOC in the Kimmeridge Clay ranged from 1.5-4.14%. Several other wells had higher values, with the three highest at Penshurst 1 in a 23 ft-thick sequence, which were amongst the shallowest sampled. S2 exceeds 5 mgHC/gRock (green cells of Appendix 1A) in all the samples where TOC > 2%. Six Kimmeridge samples (in Ashdown 1, Southwater 1 and Penshurst 1) had over 50 mgHC/gRock (S1+S2) which represents a world class source rock.

Most Kimmeridge samples were in the immature field, with Ro (equivalent) of 0.4-0.6%; the maximum of 0.7% was recorded in three wells.

The data shows that a significant amount of the immature and hydrogen-rich samples is of Type I kerogen (Figure 4c). There is a broad range of HI values covering the Type I kerogen field with very high values indicating immaturity (Penshurst's Kimmeridge Clay). Some of the Kimmeridge Clay at Southwater 1, Iden Green 1 and Balcombe 1 also aligns with the Type I kerogen field.

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Scotchman (1991) found Type II kerogens in the basin centre and Type III on the basin margins. His data included only the Warlingham borehole within the Weald Basin, which plotted as Type II in a van Krevelen diagram (Scotchman 1991, fig. 7).

A very similar plot to Figure 4, showed HI from 310-660 in the Type I field (labelled 'Wessex Basin', Williams 1986, fig. 7). The Foudry Bridge (just north of the Weald Basin) and Warlingham boreholes had abundant lamellar alginite in the very rich horizons, but higher sporinite in the horizons with lower pyrolysis yields (Williams 1986).

The Palmers Wood 1 core near 2401.5 ft (732.1 m) (down-hole depth) was sampled previously (Scotchman 1994), showing a 32.1% carbonate content and 1.9% TOC resulting in an HI of 250 and T_{max} of 428, with a vitrinite reflectance (R_o) of 0.46. The new BGS analysis gives 2.3% TOC, HI = 298 and T_{max} = 431, giving a calculated R_o of 0.6%.

Kimmeridge Clay samples from the BGS Warlingham borehole (Scotchman 1991) had relatively low carbonate contents and high TOC, giving high HI (max. 560) and lower T_{max} consistent with its position nearer the basin margin. The average vitrinite reflectance (R_o) was low, but a few higher values perhaps represent reworked material. The oxygen index was not given, but plotted as Type II on a van Krevelen graph (Scotchman 1991, fig. 7), whereas Lamb (1983) listed the dominant kerogen as algal.

3.8 Portland Beds

The three samples from the Portland Beds all have low TOC.

3.9 Purbeck Beds

Five samples were analysed from the Purbeck Beds.

One sample from the Purbeck has a TOC > 2% (7.78% in Penshurst 1). The S1+S2 yield was also greater than 50 mgHC/gRock, indicating this to have world class source potential. The Purbeck Shales are known to be bituminous at some outcrops.

Most Purbeck samples were in the immature field. One sample gave a rather high, perhaps anomalous R_o equivalent of 0.8%.

There is a broad range of HI values covering the Type I kerogen field with very high values indicating immaturity (Penshurst's Purbeck sample).

4 Conclusions

Of the 105 samples, only 28 have a total organic carbon content of more than 2%. Most of these are within the Kimmeridge Clay, with one in the Purbeck Beds, three in the Oxford Clay and two in the Fuller's Earth. All the Lias samples were lean.

None of the samples reach values where S1 exceeds the TOC - the 'oil crossover' (Jarvie 2012b) - indicating that no shales with 'potential producibility' were sampled. Most of the ratios were less than 0.33.

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All the Jurassic samples, across a wide range of burial depths, were within the early part of the oil window (green cell background on spreadsheet) or immature (yellow). The Silurian was in the dry gas window.

When uplift at each well is taken into account, the relationship between R_o (and T_{max}) and burial depth is strengthened (Figure 2).

It is important to note the wide spread of data points at each depth. Most these points show R_o enhancement, but a few also show R_o suppression. The most likely reason for the high R_o points is a large amount of reworked vitrinite within the samples.

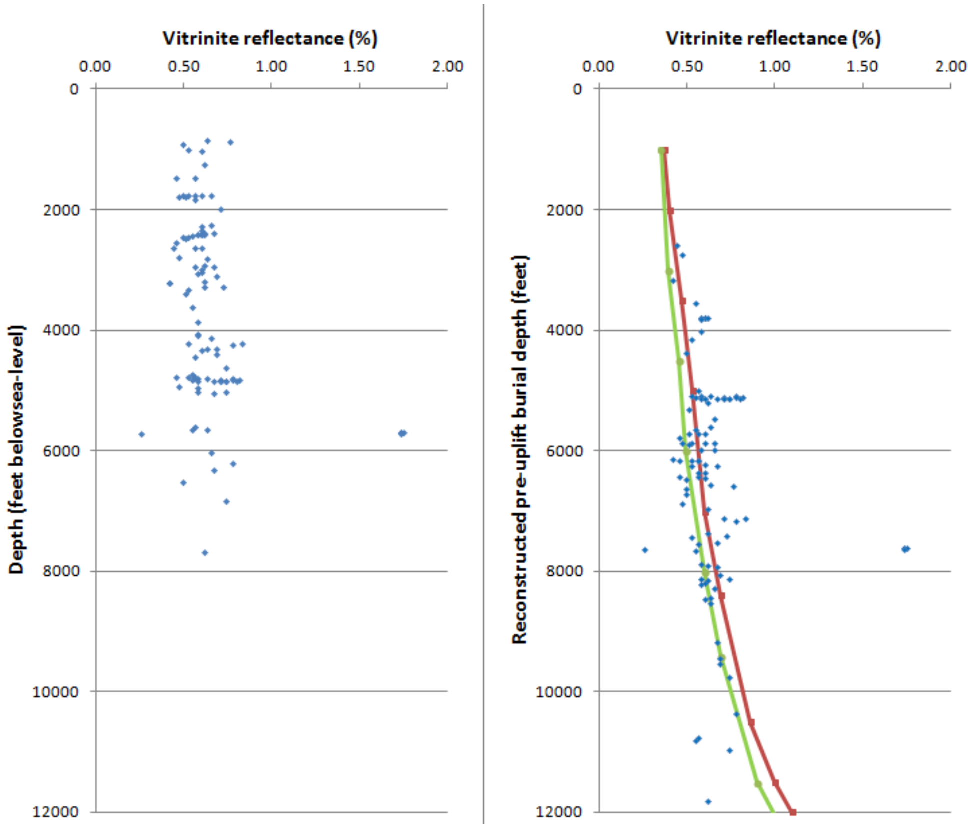

Figure 2. Plot of calculated vitrinite reflectance (from T_{max}) against (a) present-day depth (below sea-level) and (b) reconstructed pre-uplift burial depth based on well-by-well uplift estimates. Two alternative generalised burial curves are shown in red and green.

Lower HI values reflect lower TOC, because the Horndean 1 Fuller's Earth samples with high TOCs plot in the Type II field, whereas those with low TOC and low S2 plot with significantly lower HI. This could be viewed, instead, as a modification due to increased maturity, but is obviously not the case in this well.

Over half of the samples plot in the primarily gas prone field. Below 5,000 ft the HI of the samples is less than 150 and Penshurst 1, with the shallowest samples having some of the highest values, indicates that the HI is declining with depth of burial (Figure 3).

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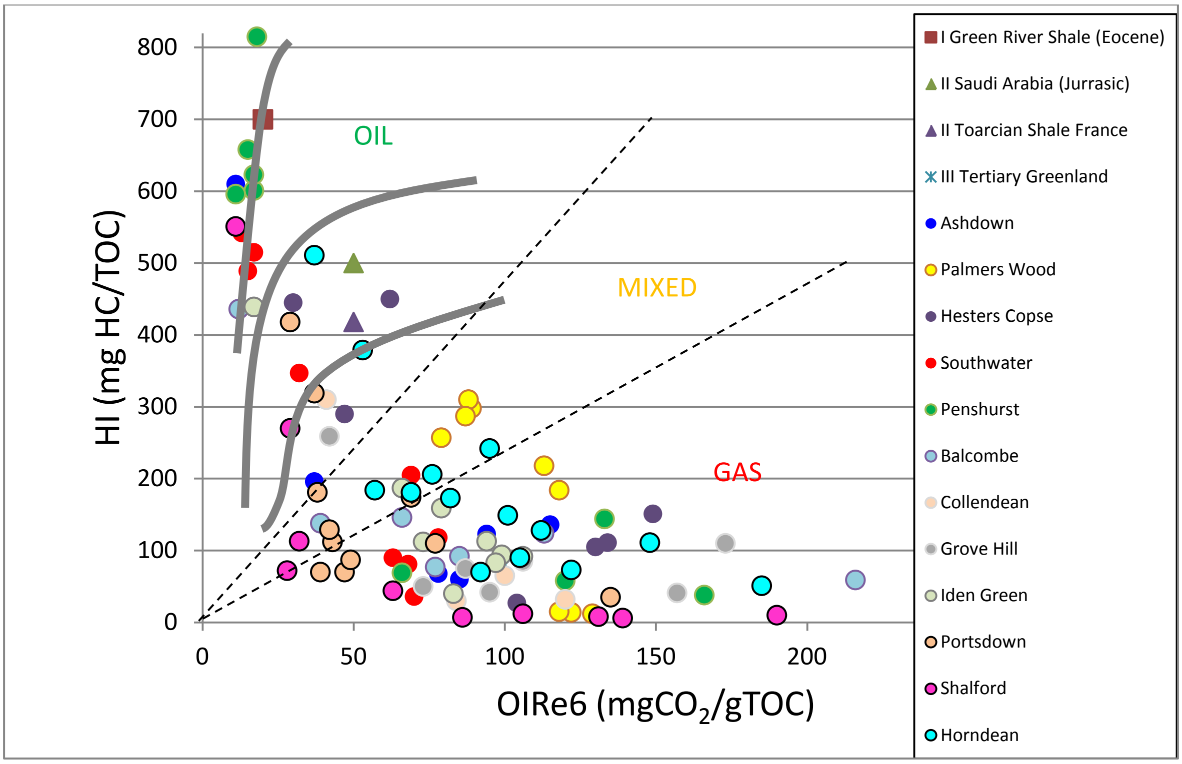

Figure 3. Hydrogen index versus oxygen index (modified van Krevelen diagram) showing the idealized maturation paths of type I (near vertical grey line through Green River Shale), and type II (French Toarcian and Saudi Arabian examples between curved grey lines). The bulk of the Weald samples plot below the grey lines and represent Type III kerogens. The likely maturation path in this graph is towards the bottom left so the Type III samples probably indicate gas-prone characteristics rather than increased maturity. See Figure 1 for the locations of the wells.

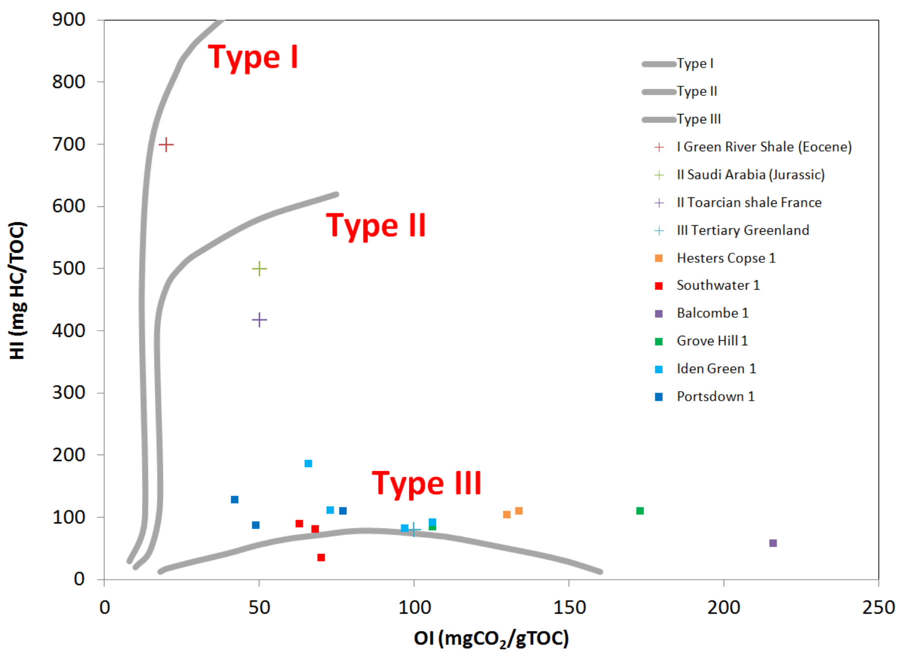

Figure 4a. Hydrogen index versus oxygen index (modified van Krevelen diagram) for the Lias samples. See Figure 1 for the locations of the wells.

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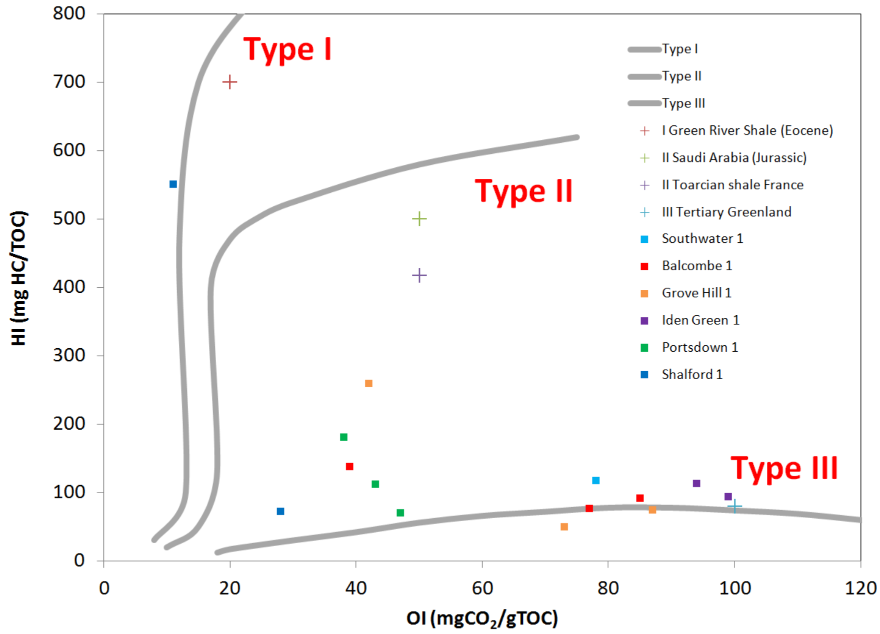

Figure 4b. Hydrogen index versus oxygen index (modified van Krevelen diagram) for the Oxford and Corallian Clay samples. See Figure 1 for the locations of the wells.

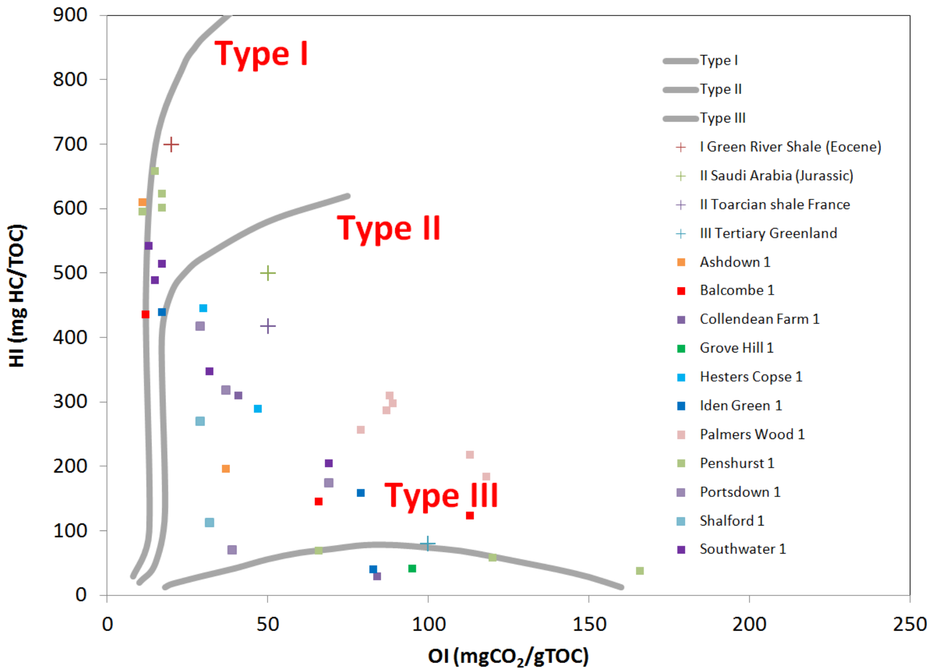

Figure 4c. Hydrogen index versus oxygen index (modified van Krevelen diagram) for the Kimmeridge Clay samples. See Figure 1 for the locations of the wells.

Having combined this new data with the analyses of Lamb (1983) a revised conclusion might be that the isotopically lighter Kimmeridge Clay (Burwood et al. 1991) and some other intervals in the Purbeck and Oxford Clay make a contribution to *in-situ* or almost *in-situ* oil in the central part of the basin. Lias source rocks are the source rocks for the oil in the Weald Basin's conventional fields

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(Great Oolite, Corallian and Portland reservoirs) although the Lias is relatively lean in the samples taken here. This is despite the fact that younger formations than the Lias are only marginally mature or not yet mature, whereas the Lias is mature. Additional oil may be present in other untested carbonates interbedded within the shales as part of a hybrid Bakken-type system as well as within the shales themselves. This is supported by oil-to-source correlation using biomarkers and isotopic composition (Burwood *et al*. 1991). Large amounts of oil-prone macerals or bitumen retard the normal progression of R_o with maturity and this might be comparable with the relationship between elevated HI and low T_{max} in the Kimmeridge Clay noted by Scotchman (1991, fig. 16).

Deeper hydrocarbon shows do exist, but they may not all be sourced from the Lias, and need careful analysis as pre-Triassic source rocks are likely to be present beneath the Weald Basin.

Small gas fields in the Weald Basin may be derived from the gas-prone sediments indicated by the modified van Krevelen plot.

The Weald Basin could be defined as lying north of the Hampshire-Dieppe High. The Hampshire-Dieppe High had a thinner Jurassic sequence than the basin and was also eroded by the late Cimmerian unconformity. South of the Hampshire-Dieppe High the Lias has a higher TOC content (see Middleton 1 data in Lamb 1983) and may therefore be more comparable, in terms of TOC content with the Paris Basin Toarcian, with which this southern area is contiguous. The Middleton 1 Lias is probably associated with the nearby Lidsey discovery and a small half graben subsequently inverted into the Portsdown Anticline.

5 Review of published geochemical data

5.1 Lias Claystones

Organic-rich lithologies have long been known from the classic Lias outcrops of the Dorset coast and also in the nearby Paris Basin. These have been well studied, and while some authors optimistically extrapolate this data from Dorset to the subsurface of the Weald Basin, many others refer to a lowering of TOC values eastwards from Dorset into and across the Weald Basin (e.g. Scott & Colter 1975, Butler & Pullan 1990, Hawkes *et al*. 1998, Ainsworth *et al*. 1998, Magellan Petroleum 2011, USEIA 2013).

There are insufficient data to map this deterioration in organic carbon content in detail or to link it to facies variations, but it may result from differences in palaeogeography and organic input/preservation between the basins. A major west-east facies change is apparent in the overlying Middle Jurassic (basinal muds/Frome Clay – Great Oolite shoals – back shoal bioclastics; Sellwood *et al*. 1989) and it could be postulated that a comparable precursor existed during the Early Jurassic.

Lamb (1983) supplied the following data for the Weald Basin:

	Source rock potential (TOC)	**Source rock maturity for oil**
Fuller's Earth	The hydrocarbon potential of the Fuller's Earth is generally **poor to moderate**, except where lenses of organically rich mudstones occur; there it is **good to excellent**. TOC = 0.45-3.48%.	**Maturity** has been reached **in a belt** extending between Cowden and Godley Bridge, with peak oil generation having been measured in the vicinity of Cowden 1, and probably also present around Godley Bridge 1. Limited hydrocarbon generation has occurred as evidenced by the light hydrocarbon analyses. Max R_o contour = 0.85%

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		(Fig. 5.13).
Upper Lias	The Upper Lias Clays have **poor to moderate** source potential. TOC = 0.42-4.84%.	Most of the area is **mature**, with peak oil generation for herbaceous kerogen being reached **in a belt** between Cowden and Godley Bridge. Light hydrocarbon analysis confirms hydrocarbon generation in the areas that have reached maturity. Max R_o contour = 0.85% (Fig. 5.10).
Middle Lias	The Middle Lias has generally fair TOC contents with low P1 contents and poor to moderate P2 yields suggesting a **poor to moderate** hydrocarbon source potential. TOC = 0.25-2.10%.	Most of the area is **marginally mature**, **with a belt** between Cowden and Godley Bridge being **mature**. Within this belt the end of oil generation for herbaceous kerogen has been approached. Light hydrocarbon analysis confirms the marginal maturity to maturity of the sediments in the area. Max R_o contour = 1.1% (Fig. 5.8). Cowden 1 R_o = 1.05%.
Lower Lias	The Lower Lias sediments are potentially **poor to moderate** hydrocarbon source rocks. TOC of Blue Lias = 0.45-2.25% and Green Ammonite Beds etc = 0.34-1.90%.	**Maturity** has been reached **over most of the area**, but especially **in a belt** extending between Cowden in the east and Godley Bridge in the west. Max R_o contour = 1.1% (Fig. 5.5). Cowden 1 R_o = 1.15%.

Oil to source rock correlation studies by Lamb (1983) concluded that, based on the then-available sparse data, oil had probably been generated from the Lias and/or the lower Oxford Clay of the Weald.

Ebukanson & Kinghorn (1985) published TOC values for the Lower Lias reaching 7.36% at Charmouth (Shale-with-Beef) and 5.98% at Lyme Regis (Blue Lias). In Henfield 1 and Warlingham the maximum was only 2.5%. Maximum R_o = 0.62% in Henfield 1.

Ebukanson & Kinghorn (1986a) published R_o values for the Lower Lias ranging from 0.32% at outcrop to 0.9% in Arreton 2 and 0.85% in Penshurst 1 (4518-4550 ft md).

Ebukanson & Kinghorn (1986b) modelled maturities for a pseudo-well in the deepest part of the Mesozoic Weald Basin (NW Sussex – southern Surrey) where base Jurassic is at 5,400 ft (1650 m). R_o is close to 1.2%, sufficiently mature for significant generation of gas. They thought it likely that the gas in Godley Bridge had been sourced from the Lias. Ebukanson & Kinghorn (1986b) "offer a suggestion" that oils in the Weald (and adjacent Hampshire area) were sourced from varying contributions from the Lias, Oxford Clay and Kimmeridge Clay. Towards the basin margins the Lower Lias may have been the main source; the Oxford Clay and Kimmeridge Clay having an increased contribution towards the central area.

Penn *et al*. (1987) quoted from Ebukanson & Kinghorn (1985), saying that some Lower Lias shales contain up to 7% TOC [Note: these high figures are from the Dorset outcrops]. These are in the oil window over much of the Weald Basin and are over-mature for oil generation in the deepest, axial parts. The Lower Lias is marginally mature in the Pewsey Basin, but is immature on the Hampshire-Dieppe High.

McLimans & Videtich (1987, 1989) showed a map of R_o values for the Lias at the end of the Cretaceous. Their maximum R_o is 0.9%. Large areas were predicted/modelled to have reached R_o = 0.7-0.9% prior to inversion.

Fleet *et al*. (1987) illustrated variations through a typical Blue Lias cycle from Lyme Regis, Dorset, with average source potentials of 23 kg/t in laminated shales, 9 kg/t in mudstones and 4 kg/t in limestones.

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McLimans & Videtich (1987, 1989) concluded that "the Lias is the primary source of Wealden oils". The oils are of "high maturity" and it was considered that only the Lias had a sufficient volume of source rock at sufficient maturity to have yielded this oil.

Ebukanson & Kinghorn (1990) gave TOC values for various lithologies across southern England: Lower Lias (max 7.36%), Oxford Clay (max 12.36%) and Kimmeridge Clay (max 20.48%). The geographical spread of these data was not discussed, but six wells in our study area are included.

Weedon & Jenkyns (1990) sampled the Belemnite Marls at Charmouth. They reported a maximum TOC of 5.9%.

Butler & Pullan (1990) reported that in the Weald Basin the Lias clays, particularly those of the Lower Lias, have TOCs of 0.5-2.1% and are considered to be a fair to good oil and gas source, although the interval shows considerable vertical and lateral variation in richness, deteriorating in quality in the eastern part of the [Weald] basin. These authors suggested that hydrocarbon generation from the Lias began in the deepest parts of the Weald Basin in early Cretaceous times, with peak generation in the Mid to Upper Cretaceous. The areal extent of [oil-] mature Lias shale covers much of the central Weald. Burial depth studies indicate that the Lower Lias "could have entered the gas window" in the deepest part of the Weald Basin towards the end of the Cretaceous.

Burwood *et al*. (1991) proposed a mixed Lower and Upper Lias source for the oil fields of the Weald Basin, with the Lower Lias dominant in the west (e.g. Great Oolite fields of Humbly Grove, Stockbridge, Horndean and Storrington) and the Upper Lias dominant in the central Weald (e.g. Corallian fields at Palmer's Wood and Balcombe).

Unit	**[Average] source potential (S2 kg/t)**	**Maximum source potential (S2 kg/t)**	**HI**	**HI (max)**
Upper Lias	3.2	5.0	305	400
Lower Lias	6.0	38.0	325	630

Summary of source rock data for southern England from Burwood *et al.* (1991)

Hawkes *et al*. (1998) concurred that "the Lias J1 sequence forms an important oil-prone source rock interval in the Wessex Basin. In the Weald Basin the interval is generally characterised by a higher terrestrial input due to its proximity to the emergent London-Brabant Massif. As a consequence of this, Lias source rock potential is poorer and more gas prone [in the Weald]. Oil-prone source potential improves to the south-west …" but they proposed that the Lias was only locally developed in the Weald Basin adjacent to active faults e.g. Ashdown Fault."

Cornford (1998) reported that the interbeds of laminated shales in the Blue Lias of Dorset contain an average of 2% TOC (up to a maximum of 18%) and that the shales of the Black Venn Marls are also rich in organic matter.

Kiriakoulakis *et al.* (2000) published TOC values of 5.68% and 6.68% from the Shales-with-Beef surrounding a zoned concretion in Dorset.

Scotchman (2001) reported TOC values of 1.1-1.5% from the Blue Lias in the Kimmeridge 5 well and 4.6-7.2% TOC from Shales-with-Beef and 2.3-5.9% from Black Ven Marl (both from Charmouth, Dorset). The Blue Lias in Kimmeridge 5 is 'oil-window mature'. TOC values of up to 7.2% occur in

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organic-rich 'paper shales' in the Shale-with-Beef and lower Black Ven Marls, with average values of 5-6%.

During 2002-04, four MSc students at the University of Newcastle on Tyne produced Rock-Eval reports on the Lias in wells in the Wessex Basin:

> Ferguson (2002) studied the Lias in Chickerell 1. The average TOC was 1.9%, with a maximum of 5.73% in the Belemnite Marls. R_o calculated from T_{max} reached a maximum of 0.8%.
>
> El-Mahdi (2004) studied the Lias in Down Barn Farm 1. The average TOC was 2.7%, with a maximum of 5.2% in the Shales-with-Beef. R_o calculated from T_{max} reached a maximum of 0.8%.
>
> Salem (2003) and Eltera (2004) studied the Lias in Kimmeridge 5, where a maximum TOC of 4.05% was found in the Blue Lias (the average TOC for the Lias = 1.73%). R_o calculated from T_{max} reached a maximum in the Lias of 1.1%.

Deconnick *et al.* (2003) sampled the Blue Lias at Lyme Regis, Dorset. They report a maximum TOC of 12.1%.

England (2010) studied the Lower Lias of the Wessex Basin. The maximum TOC recorded by him was 7.4%, with two horizons being particularly organic-rich: one in the upper Blue Lias Formation, the other being more diachronous (Black Ven Marl/Belemnite Marl in the Portland-Wight Basin and Belemnite Marl/Green Ammonite Beds in the Dorset, Weymouth and Central Wessex areas) (Table 1). The kerogen types consist of mixtures of Types II and III organic matter, with samples having a TOC of below 2% generally consisting of gas-prone Type III kerogen, while those with higher TOC values contain oil-prone Type II kerogen.

	TOC (%)
Eype Clay	0.23-2.51
Green Ammonite Beds	0.33-4.92
Belemnite Marl	0.45-5.73
Black Ven Marls	0.96-4.41
Shales-with-Beef	0.98-7.43
Blue Lias	0.61-5.77

Table 1. Summary of TOC data from the Lias of Dorset (from England 2010).

Magellan Petroleum (2011) described a 500 ft (150 m) thick lower unit (of Lower Lias limestones) with 1.0-1.3% TOC and 600 ft thick upper unit with 0.5-2.5% TOC. In the basin centre, individual shale units have TOCs up to 3.2%. They also noted deterioration in quality to the east. The major source kitchen lies near Godley Bridge, where the Lias has TOCs of up to 2.4%. There, the top of the oil window is at 6,000 ft and peak generation is at 8,000 ft. The Lias is not fully into the gas window.

Akande (2012) found 8.14% TOC in a Blue Lias shale from Dorset.

P. Farrimond (pers. comm.) reports up to 6.6% TOC in the Blue Lias in Dorset.

USEIA (2013) summarise that "The Lias, Kimmeridge, and Oxford clays contain Types II (algal sapropelic), III (terrestrial plant), and II/III (mixed or degraded) kerogen sources. Thermal maturity is highly variable, dependent upon the complex structural evolution of the basins. In general, thermal

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maturity increases towards the centres of the Wessex and Weald basins, where it reaches adequate rank for shale oil exploration.

The Lower Lias Clays (L. Jurassic), the most important source rock in the region as well as the main shale target, consist of interbedded shales, mudstones, marls and micritic limestones. Lower Lias shales contain 0.5% to 2.1% TOC, reaching as high as 7%. The isotopic character of conventional oils in the Weald Basin (35-42° API gravity) matches with that of the Lower Lias, indicating close source rock genesis. Organic matter is predominantly sapropelic oil-prone kerogen derived from marine plankton. While vertical TOC variation is considerable, the eastern Weald Basin appears to have lower TOC.

The Arreton 2 well, a key data point located south of the Isle of Wight monocline, recorded oil-prone thermal maturity of 0.8% to 0.9% R_o in the Lias. Similar oil-prone maturity was noted in Penshurst 1 in the central Weald Basin. Thermal maturity modelling indicates that the Lias is within the oil window across much of the Wessex-Channel Basin, perhaps becoming marginally gas-prone in the Pewsey Sub-Basin."

5.2 Oxford Clay

Lamb (1983) supplied the following data:

	Source rock potential (TOC)	**Source rock maturity for oil**
Oxford Clay	The sediments of the Lower and Middle Oxford Clay are potentially **moderate to good** source rocks especially the bituminous member. TOC = 0.47-7.83%. The Upper Oxford Clay is potentially **poor**. TOC = 0.42-1.78%.	**Maturity** has been reached only in the **north-east corner of the area** around Cowden. Peak oil generation for the amorphous kerogen is indicated in the vicinity of Cowden 1 (R_o = 0.89%) and probably continues westwards to Godley Bridge. Light hydrocarbon analyses confirm that hydrocarbon generation has occurred in this belt. Max R_o contour = 0.7% (Fig. 5.15).

Oil-to-source rock correlation studies by Lamb (1983) concluded that, based on the then-available sparse data, oil had probably been generated from the Lias and/or the Lower Oxford Clay of the Weald. There was no reliable evidence that higher horizons had done so.

Ebukanson & Kinghorn (1985) published TOC values for the Oxford Clay reaching 12.36% in Chickerell 1. Max R_o = 0.44%.

Ebukanson & Kinghorn (1986a) published R_o values for the Oxford Clay ranging from 0.42% at Cranborne 1 and Marchwood 1 to 0.74% in Penshurst 1.

Penn *et al*. (1987) reported that the Oxford Clay has Type II kerogen, especially in the lower part. Up to 12% TOC is found in the lower and middle parts [presumably after Ebukanson & Kinghorn (1985)], but only 1% in the upper part [presumably after Lamb (1983)]. The Oxford Clay is in the oil window in the Weald Basin.

McLimans & Videtich (1989) suggested that the Oxford Clay had generated oil in the deep basin locations, but that volumes were low.

Butler & Pullan (1990) reported that the basal parts of the Oxford Clay have TOCs up to 5%, being considered a moderately rich oil-prone source. Oxford Clay (oil) maturity was reached in the deepest parts of the basin in late Upper Cretaceous times.

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Unit	**[Average] source potential (S2 kg/t)**	**Maximum source potential (S2 kg/t)**	**HI**	**HI (max)**
Oxford Clay	20.2	34.6	598	623

Summary of source rock data for southern England from Burwood *et al*. (1991).

Burwood *et al*. (1991) found no evidence that the Oxford Clay had contributed to the Wealden oils.

Hawkes *et al*. (1998) concurred that the Oxford Clay is probably immature over most of the Wessex Basin.

England (2010) confirmed differences between an anoxic lower unit and an oxic upper unit of the Oxford Clay Formation in five wells in the Wessex Basin (as previously described in central England by Kenig *et al*. 1994, Norry *et al*. 1994, Peters *et al*. 2006). The lower unit is characterised by higher TOC (up to 6.8%) and type II kerogen. It is generally immature in the onshore Wessex Basin (max R_o = 0.58%).

Akande (2012) found up to 8.11% TOC in Oxford Clay samples from Dorset.

5.3 Kimmeridge Clay

Gallois (1979) published Rock-Eval data from the Kimmeridge Clay in the Foudry Bridge well. The average TOC there is 9.45% with an average R_o of 0.33 (maximum 0.49).

Lamb (1983) supplied the following data:

	Source rock potential (TOC)	**Source rock maturity for oil**
Purbeck Group	At Humbly Grove 1, Hellingly 1 and Ashour 1, the shales within the Purbeck Beds are potentially **good to very good** source rocks. TOC = 0.43-4.03%.	Immature.
Portland Group	The Portland Beds have **poor to good** hydrocarbon potential. TOC = 0.25-0.86%.	Immature. Max R_o = 0.52%.
Kimmeridge Clay	The sediments are potentially **good to excellent** source rocks, the middle subdivision being the most promising with several oil shales having been detected. TOC = 0.55-19.71%. Lower unit = 1.01-2.41%; middle unit = 1.50-10.38%; upper unit = 0.91-4.52%.	**Maturation** indices indicate that only a **small area** in the vicinity of Cowden 1 and Godley Bridge 1 is sufficiently mature for oil generation from the amorphous component. Light hydrocarbon analyses indicate the generation of some hydrocarbons in the marginally mature to mature area and the presence of some migrated hydrocarbons. Max R_o contour = 0.6% (Fig. 5.20).

Oil to source rock correlation studies by Lamb (1983) concluded that, based on the then-available sparse data, there was no reliable evidence that the Kimmeridge Clay (or younger) sediments had generated oil.

Farrimond *et al*. (1984) provided TOC values for various lithologies in the upper Kimmeridge Clay outcrops in Dorset. These range from 0.9-4.2% for cementstone (i.e. diagenetic carbonate), 3.1% for a calcareous mudstone, 2.6-9.3% for laminated, coccolith-rich limestone and 28.2-57.2% for oil shale.

Ebukanson & Kinghorn (1985) published TOC values for the Kimmeridge Clay reaching 20.48% at Kimmeridge Bay, Dorset. Max R_o = 0.48%.

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Ebukanson & Kinghorn (1986a) published R_o values for the Kimmeridge Clay ranging from 0.34% at outcrop to 0.6% in Penshurst 1 (2308-2412 ft md).

Williams (1986) presented a map showing that R_o values could reach 1.0% in the Kimmeridge Clay in the centre of the Weald Basin. However, in the Foundry Bridge and Warlingham wells, bordering the London Platform, the Kimmeridge Clay is immature (R_o = 0.33-0.39%).

Penn *et al*. (1987) reported that the Kimmeridge Clay contains predominantly Type II kerogen, with TOC values up to 20% in upper part. The base of the formation entered the oil window only in the axial part of the Weald Basin.

McLimans & Videtich (1989) suggested that the Kimmeridge Clay has generated oil in the deep basin locations, but that volumes are low.

Butler & Pullan (1990) reported that shales of the Kimmeridge Clay form an extremely rich oil-prone source in the Weald Basin, with TOCs in excess of 10%, and that it is probable that they reached [oil] maturity in the very centre of the basin in late Upper Cretaceous times. They mapped a "speculative area of possible thermally mature Kimmeridge Clay" in the middle of the basin.

Scotchman (1991) published some geochemical data for the Kimmeridge Clay, including the Warlingham borehole, in the study area. At Warlingham, TOC averaged 3.95% with an average R_o of 0.48%. He commented that VR is strongly dependent on organic facies and is a poor measure of maturity. The data show a wide range with up to five populations in each sample and no relationship with estimated burial depth.

Unit	**[Average] source potential (S2 kg/t)**	**Maximum source potential (S2 kg/t)**	**HI**	**HI (max)**
Kimmeridge Clay	11.3	40.5	440	611

Summary of source rock data for southern England from Burwood *et al*. (1991).

Burwood *et al*. (1991) proposd that oil in a Kimmeridge micrite at Balcombe 1 is sourced from adjacent Kimmeridge Clay. The top of the Kimmeridge Clay reaches the oil window in this deepest part of the Weald Basin.

Scotchman (1994) used biomarkers in an attempt to more accurately determine maturity levels. The hopane isomerisation reaction showed greatest sensitivity. He also added R_o data from Palmer's Wood 1 (TOC = 1.9%, T_{max} = 428, R_o = 0.46).

Buchanan (1998) quoted Ebukansen & Kinghorn (1986) in saying that the Kimmeridge Clay is immature in the Wessex Basin.

Hawkes *et al*. (1998) concurred that "the Kimmeridge Clay is … immature over the whole of southern England".

Using 2,456 analyses from the Swanworth Quarry 1 and Metherhills 1 boreholes in Dorset, Tyson (2004) published mean and median organic contents of 4.24% and 3.22% respectively. The middle of the formation has the highest TOC (8-9%) with 1-2% at the base and top. The highest TOC linked to lowest sedimentation rates. The maximum figure in the boreholes is 35%. At outcrop, cm-thick intervals have TOCs of up to 42-60%.

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Gallois (2004) noted that the 60cm-thick Blackstone at Kimmeridge Bay, Dorset, has an organic carbon content of more than 50% and yields 60 gallons of oil per ton of rock when retorted.

Lewan & Hill (2006) analysed a Blackstone bed (Kimmeridge Clay) sample (presumably from Dorset). TOC = 54%, T_{max} = 409, HI = 604, OI = 15, S2 = 325; S3 = 8. Fischer Assay = 284 l/ton; 320 mg/g rock.

Lithology	**Gamma-log (gAPI)**	**TOC (%)**
Medium-dark to dark-grey marl	8-115 (c.100)	1-3
Medium-dark to dark-grey to greenish-black shale		6
Dark grey to greenish-black to olive-black laminated shale	20-30 (25)	8
Greyish-black to brownish to black mudstones		8-15 (>35)
Silty mudstone, siltstone and fine-grained sandstone	65-85	<2
Coccolith limestone	30	
Dolostone		
Limestone	40	

The Blackstone is heterogeneous, containing organic-poor layers (< 10 % TOC) intercalated between more numerous organic-rich beds (40–60% TOC; Huc *et al*. 1992; Herbin *et al*. 1995). Analysis of the Blackstone in Swanworth Quarry 1 gave a value of 35 wt% TOC.

The Swanworth Quarry 1 and Metherhills cores record a broadly organic-rich interval spanning the *eudoxus* to *pectinatus* zones, with an average of 7-8 wt% TOC. Total organic carbon values from the *wheatleyensis* Zone reach 35 wt % (the Blackstone). In the overlying *pallasioides–fittoni* zones, values decline to an average of 1 wt%, reflecting a fall in sea level. Imprinted upon this long-term trend are smaller scale fluctuations in organic-carbon content. These fluctuations comprise intercalated cycles of mudstones that are enriched, and depleted, in TOC. On a broad level, this data show the presence of five main organic-rich intervals (TOC values commonly > 15 wt %) in the Kimmeridge Clay in the type area. These horizons can be traced from Dorset to Yorkshire and into the North Sea (Gallois 1979, Cox & Gallois 1981, Herbin & Geyssant 1993, Herbin *et al*. 1993, 1995). Tyson (1996) linked these organic-rich intervals to maximum marine-flooding surfaces.

Akande (2012) found up to 10.98% TOC in Kimmeridge Clay samples from Dorset.

6 References

See main report.

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Appendix B1. Selected output from the Rock-Eval analysis of 12 wells in southern Britain. The various maturity windows are indicated by the T_{max} cell background colour: yellow = immature, green = oil window, orange = shale wet gas window, red = shale dry gas. High S1 and high TOC values are also highlighted in green.

Sample ID	Borehole	Average depth (ft)	Formation	Qty (mg)	S1 (mg/g)	S2 (mg/g)	PI	T_{max} (°C)	TpkS2 (°C)	S3CO (mg/g)	S3'CO (mg/g)	S3 (mg/g)	S3' (mg/g)	PC (%)	RC (%)	TOC (%)	HI	OICO	OI	Pyro MINC (%)	Oxi MINC (%)	MINC (%)
SSK31044	Ashdown 1	843	PB	68.25	0.03	0.87	0.04	433	475	0.31	0.50	1.22	26.80	0.13	1.31	1.44	60	22	85	0.74	2.10	2.84
SSK31043	Ashdown 1	873	PB	64.53	0.04	1.59	0.03	440	482	0.12	0.80	1.35	34.70	0.19	0.98	1.17	136	10	115	0.96	5.31	6.27
SSK31045	Ashdown 1	899	PB	68.66	0.04	0.66	0.06	425	467	0.07	0.40	0.76	22.20	0.09	0.88	0.97	68	7	78	0.61	3.28	3.89
SSK31046	Ashdown 1	1250	PL	66.13	0.07	1.63	0.04	432	474	0.11	1.00	1.24	20.10	0.20	1.12	1.32	123	8	94	0.57	6.60	7.17
SSK31047	Ashdown 1	1815	KC	62.13	2.32	56.65	0.04	429	471	0.60	1.00	1.00	10.00	4.97	4.32	9.29	610	6	11	0.29	2.83	3.13
SSK31048	Ashdown 1	2810	KC	62.83	0.18	3.67	0.05	433	475	0.17	0.60	0.70	14.20	0.36	1.51	1.87	196	9	37	0.40	2.67	3.07
SSK31054	Palmers Wood 1	2400	KC	66.26	0.23	5.37	0.04	431	473	0.25	0.40	1.66	25.40	0.53	1.56	2.09	257	12	79	0.70	2.66	3.36
SSK31053	Palmers Wood 1	2401.5	KC	68.57	0.19	6.85	0.03	431	473	0.30	0.70	2.05	26.50	0.67	1.63	2.30	298	13	89	0.74	3.16	3.89
SSK31052	Palmers Wood 1	2401.9	KC	66.84	0.19	7.14	0.03	430	472	0.28	0.70	2.03	26.20	0.69	1.61	2.30	310	12	88	0.73	3.17	3.90
SSK31051	Palmers Wood 1	2402	KC	66.47	0.25	6.82	0.04	431	473	0.30	0.60	2.06	23.60	0.67	1.71	2.38	287	13	87	0.66	2.95	3.61
SSK31049	Palmers Wood 1	2404	KC	66.41	0.10	3.02	0.03	432	474	0.45	1.00	1.94	25.50	0.35	1.29	1.64	184	27	118	0.72	4.01	4.72
SSK31050	Palmers Wood 1	2406	KC	61.73	0.22	3.35	0.06	430	472	0.28	0.60	1.74	23.50	0.37	1.17	1.54	218	18	113	0.65	4.45	5.11
SSK31055	Palmers Wood 1	4769.6	DEV	67.25	0.00	0.05	0.07	429	471	0.03	0.10	0.45	11.20	0.02	0.35	0.37	14	8	122	0.31	2.08	2.39
SSK31081	Palmers Wood 1	4770	DEV	67.46	0.00	0.05	0.06	423	465	0.12	0.10	0.53	12.00	0.03	0.38	0.41	12	29	129	0.33	1.14	1.47
SSK31056	Palmers Wood 1	4771	DEV	66.16	0.00	0.05	0.06	427	469	0.10	0.00	0.39	8.00	0.02	0.31	0.33	15	30	118	0.22	1.85	2.07
SSK31075	Hesters Copse 1	3050	PL	67.77	0.04	0.26	0.12	430	472	0.24	0.20	0.99	13.20	0.07	0.88	0.95	27	25	104	0.36	1.44	1.81
SSK31076	Hesters Copse 1	3210	KC	69.31	1.09	26.13	0.04	421	463	0.77	0.90	1.74	11.80	2.36	3.51	5.87	445	13	30	0.34	1.86	2.20
SSK31077	Hesters Copse 1	3320	KC	59.28	0.51	9.34	0.05	427	469	0.40	0.90	1.52	12.20	0.90	2.32	3.22	290	12	47	0.35	2.96	3.31
SSK31073	Hesters Copse 1	4206	FE	61.89	0.23	9.22	0.02	444	486	0.18	0.50	1.28	20.80	0.84	1.21	2.05	450	9	62	0.58	2.47	3.05
SSK31074	Hesters Copse 1	4231	FE	60.38	0.07	1.10	0.06	441	483	0.09	0.40	1.09	23.40	0.14	0.59	0.73	151	12	149	0.65	5.17	5.81
SSK31078	Hesters Copse 1	4720	LLI	61.29	0.19	1.19	0.14	428	470	0.32	0.40	1.47	29.30	0.18	0.95	1.13	105	28	130	0.81	2.92	3.73
SSK31079	Hesters Copse 1	4950	LLI	61.61	0.14	1.04	0.12	430	472	0.17	0.50	1.26	17.80	0.15	0.79	0.94	111	18	134	0.50	7.20	7.70
SSK31082	Southwater 1	3270	KC	68.98	0.26	4.98	0.05	438	480	0.33	0.50	1.68	20.60	0.51	1.92	2.43	205	14	69	0.57	3.56	4.13
SSK31083	Southwater 1	4075	KC	62.02	0.75	10.90	0.06	430	472	0.14	0.50	1.01	16.50	1.01	2.13	3.14	347	4	32	0.46	1.90	2.36
SSK31084	Southwater 1	4133	KC	66.61	3.08	56.63	0.05	434	476	0.51	1.20	1.33	14.10	5.04	5.40	10.44	542	5	13	0.41	2.17	2.58
SSK31085	Southwater 1	4306	KC	61.10	2.18	38.99	0.05	433	475	0.36	0.70	1.32	16.70	3.48	4.09	7.57	515	5	17	0.47	1.15	1.62
SSK31086	Southwater 1	4332	KC	58.35	1.80	30.87	0.05	431	473	0.29	0.80	0.93	9.70	2.77	3.54	6.31	489	5	15	0.28	0.58	0.86
SSK31087	Southwater 1	5040	OXC	63.59	0.23	1.47	0.13	435	477	0.32	0.40	0.98	18.70	0.19	1.06	1.25	118	26	78	0.52	2.25	2.77
SSK31088	Southwater 1	6210	ULI	66.32	0.25	1.12	0.19	441	483	0.13	0.50	0.78	15.50	0.15	1.09	1.24	90	10	63	0.43	1.55	1.98
SSK31105	Southwater 1	6830	MLI	66.26	0.31	1.00	0.23	439	481	0.22	0.20	0.84	19.00	0.15	1.09	1.24	81	18	68	0.52	0.37	0.89
SSK31106	Southwater 1	7670	LLI	65.64	0.15	0.24	0.39	432	474	0.18	0.10	0.46	11.90	0.05	0.61	0.66	36	27	70	0.33	2.14	2.47

Sample ID	Borehole	Average depth (ft)	Formation	Qty (mg)	S1 (mg/g)	S2 (mg/g)	PI	T_{max} (°C)	TpkS2 (°C)	S3CO (mg/g)	S3'CO (mg/g)	S3 (mg/g)	S3' (mg/g)	PC (%)	RC (%)	TOC (%)	HI	OICO	OI	Pyro MINC (%)	Oxi MINC (%)	MINC (%)
SSK31107	Penshurst 1	993	PB	67.76	1.62	63.38	0.02	427	469	0.37	0.90	1.37	17.60	5.47	2.31	7.78	815	5	18	0.50	7.81	8.31
SSK31108	Penshurst 1	1025	PL	68.46	0.01	0.26	0.03	431	473	0.07	0.10	0.24	5.20	0.03	0.15	0.18	144	39	133	0.14	5.45	5.59
SSK31109	Penshurst 1	1764	KC	64.19	0.05	0.79	0.05	431	473	0.06	0.50	0.75	18.60	0.10	1.04	1.14	69	5	66	0.52	7.20	7.72
SSK31112	Penshurst 1	1768	KC	62.59	2.43	71.15	0.03	427	469	1.02	0.70	2.02	15.20	6.22	5.62	11.84	601	9	17	0.43	1.33	1.76
SSK31111	Penshurst 1	1781	KC	63.33	7.40	140.22	0.05	424	466	1.78	1.80	3.24	14.70	12.46	8.85	21.31	658	8	15	0.44	4.68	5.12
SSK31114	Penshurst 1	1791	KC	62.14	2.67	72.98	0.04	426	468	1.04	1.80	1.37	8.70	6.40	5.85	12.25	596	8	11	0.28	0.25	0.53
SSK31113	Penshurst 1	2262	KC	63.54	0.04	0.53	0.08	431	473	0.28	0.20	1.09	19.50	0.09	0.82	0.91	58	31	120	0.54	1.83	2.37
SSK31115	Penshurst 1	2342	KC	61.28	0.01	0.18	0.05	431	473	0.23	0.10	0.78	15.00	0.05	0.42	0.47	38	49	166	0.41	1.40	1.81
SSK31110	Penshurst 1	1767	KC	69.20	2.40	76.21	0.03	434	476	1.07	0.90	2.02	12.80	6.64	5.60	12.24	623	9	17	0.37	1.08	1.45
SSK31089	Balcombe 1	1975	KC	63.60	0.22	1.86	0.11	437	479	0.26	0.70	1.69	22.90	0.24	1.26	1.50	124	17	113	0.64	2.03	2.67
SSK31090	Balcombe 1	2380	KC	65.79	0.22	2.25	0.09	435	477	0.10	0.80	1.02	17.40	0.25	1.29	1.54	146	6	66	0.49	7.83	8.32
SSK31091	Balcombe 1	3040	KC	67.67	1.49	18.05	0.08	431	473	0.20	0.50	0.51	11.10	1.66	2.48	4.14	436	5	12	0.31	1.70	2.01
SSK31092	Balcombe 1	4300	OXC	61.06	0.18	0.86	0.18	436	478	0.07	0.40	0.86	18.30	0.12	0.99	1.11	77	6	77	0.51	3.17	3.68
SSK31093	Balcombe 1	4390	OXC	66.93	0.23	1.08	0.17	436	478	0.12	0.50	0.99	19.30	0.15	1.02	1.17	92	10	85	0.54	2.41	2.94
SSK31094	Balcombe 1	4610	OXC	67.52	0.20	1.93	0.10	439	481	0.06	0.40	0.54	12.00	0.20	1.20	1.40	138	4	39	0.34	1.87	2.20
SSK31095	Balcombe 1	5610	ULI	64.41	0.05	0.09	0.34	429	471	0.18	0.60	1.96	28.30	0.09	0.32	0.41	22	44	478	0.78	5.39	6.17
SSK31096	Balcombe 1	5655	ULI	68.74	0.16	0.41	0.28	428	470	0.08	0.50	1.49	25.10	0.10	0.59	0.69	59	12	216	0.70	3.20	3.89
SSK31080	Collendean Farm 1	2621.5	KC	60.27	0.20	7.68	0.02	429	471	0.22	0.50	1.01	15.90	0.70	1.78	2.48	310	9	41	0.44	4.47	4.92
SSK31097	Collendean Farm 1	2624.5	KC	62.75	0.00	0.26	0.00	431	473	0.10	0.40	0.73	18.30	0.05	0.82	0.87	30	11	84	0.51	8.83	9.34
SSK31098	Collendean Farm 1	5017.5	FE	66.57	0.02	0.31	0.05	439	481	0.02	0.30	0.48	17.20	0.05	0.43	0.48	65	4	100	0.48	7.87	8.34
SSK31099	Collendean Farm 1	5022.5	FE	67.07	0.00	0.08	0.05	430	472	0.04	0.10	0.30	12.00	0.02	0.23	0.25	32	16	120	0.33	9.37	9.70
SSK31122	Grove Hill 1	1765	KC	64.33	0.04	0.28	0.12	429	471	0.21	0.10	0.63	16.40	0.05	0.61	0.66	42	32	95	0.45	2.60	3.05
SSK31121	Grove Hill 1	2241	CR	62.52	0.08	0.68	0.11	434	476	0.36	1.80	2.63	57.00	0.19	1.48	1.67	41	22	157	1.59	3.10	4.70
SSK31100	Grove Hill 1	2420	OXC	64.03	0.03	0.50	0.05	428	470	0.12	0.50	0.73	15.60	0.08	0.92	1.00	50	12	73	0.44	2.37	2.80
SSK31101	Grove Hill 1	2480	OXC	62.95	0.02	0.88	0.02	426	468	0.38	0.10	1.02	23.50	0.12	1.05	1.17	75	32	87	0.64	2.46	3.11
SSK31102	Grove Hill 1	2549	OXC	66.38	0.11	7.25	0.02	423	465	0.38	0.60	1.19	13.50	0.67	2.13	2.80	259	14	42	0.38	1.80	2.18
SSK31103	Grove Hill 1	2945	LI	66.75	0.04	1.22	0.03	429	471	0.19	1.00	1.92	27.10	0.19	0.92	1.11	110	17	173	0.76	4.54	5.30
SSK31104	Grove Hill 1	2997	LI	68.90	0.05	1.37	0.04	431	473	0.28	0.80	1.71	23.10	0.19	1.43	1.62	85	17	106	0.65	3.48	4.13
SSK31236	Iden Green 1	1460	KC	67.16	0.07	2.15	0.03	429	471	0.23	0.50	1.06	16.10	0.23	1.12	1.35	159	17	79	0.45	2.25	2.70
SSK31116	Iden Green 1	1466	KC	64.63	0.27	21.28	0.01	423	465	0.57	0.70	0.82	6.90	1.85	3.00	4.85	439	12	17	0.20	0.44	0.64
SSK31117	Iden Green 1	1750	KC	60.29	0.02	0.35	0.04	425	467	0.12	0.20	0.73	14.80	0.06	0.82	0.88	40	14	83	0.41	1.90	2.31
SSK31120	Iden Green 1	2391	OXC	61.45	0.04	0.73	0.05	432	474	0.12	0.30	0.77	16.10	0.10	0.68	0.78	94	15	99	0.45	2.44	2.88
SSK31235	Iden Green 1	2460	OXC	65.81	0.12	1.56	0.07	427	469	0.22	0.70	1.30	20.60	0.20	1.18	1.38	113	16	94	0.58	3.15	3.72

Sample ID	Borehole	Average depth (ft)	Formation	Qty (mg)	S1 (mg/g)	S2 (mg/g)	PI	T_{max} (°C)	TpkS2 (°C)	S3CO (mg/g)	S3'CO (mg/g)	S3 (mg/g)	S3' (mg/g)	PC (%)	RC (%)	TOC (%)	HI	OICO	OI	Pyro MINC (%)	Oxi MINC (%)	MINC (%)
SSK31233	Iden Green 1	2930	ULI	68.64	0.07	0.90	0.07	432	474	0.29	0.40	1.06	18.70	0.13	0.96	1.09	83	27	97	0.52	1.65	2.17
SSK31119	Iden Green 1	2950	ULI	67.33	0.04	1.53	0.02	435	477	0.15	0.40	0.99	17.00	0.17	1.19	1.36	112	11	73	0.47	0.07	0.55
SSK31118	Iden Green 1	3100	LLI	68.02	0.10	2.56	0.04	436	478	0.23	0.30	0.91	6.00	0.26	1.11	1.37	187	17	66	0.17	0.03	0.20
SSK31234	Iden Green 1	3180	LLI	59.29	0.10	1.15	0.08	432	474	0.48	0.50	1.32	19.80	0.17	1.08	1.25	92	38	106	0.55	0.51	1.06
SSK31123	Portsdown 1	2635	KC	62.93	0.05	2.94	0.02	422	464	0.18	0.50	1.16	19.90	0.30	1.39	1.69	174	11	69	0.55	2.12	2.67
SSK31124	Portsdown 1	2785	KC	66.42	0.10	12.45	0.01	424	466	0.57	0.70	1.45	13.60	1.12	2.78	3.90	319	15	37	0.39	2.92	3.31
SSK31125	Portsdown 1	3215	KC	65.21	0.19	21.71	0.01	421	463	0.72	0.70	1.52	10.90	1.91	3.29	5.20	418	14	29	0.31	1.48	1.79
SSK31126	Portsdown 1	3605	KC	68.84	0.00	0.95	0.00	428	470	0.18	0.40	0.53	8.90	0.11	1.25	1.36	70	13	39	0.25	0.79	1.04
SSK31127	Portsdown 1	3855	OXC	67.60	0.00	0.83	0.00	430	472	0.15	0.40	0.55	13.10	0.10	1.08	1.18	70	13	47	0.37	2.07	2.43
SSK31128	Portsdown 1	4055	OXC	67.62	0.01	1.44	0.00	430	472	0.15	0.40	0.55	12.30	0.15	1.14	1.29	112	12	43	0.34	2.57	2.91
SSK31129	Portsdown 1	4205	OXC	69.86	0.01	3.62	0.00	427	469	0.31	0.50	0.76	10.30	0.35	1.65	2.00	181	16	38	0.29	2.07	2.37
SSK31130	Portsdown 1	5655	LLI	68.61	0.02	1.46	0.01	433	475	0.10	0.40	0.47	14.50	0.15	0.98	1.13	129	9	42	0.40	2.22	2.62
SSK31131	Portsdown 1	6025	LLI	59.22	0.01	0.86	0.01	434	476	0.07	0.30	0.60	13.60	0.10	0.68	0.78	110	9	77	0.38	4.77	5.15
SSK31132	Portsdown 1	6305	LLI	61.16	0.01	0.72	0.01	435	477	0.06	0.30	0.41	12.60	0.08	0.75	0.83	87	7	49	0.35	5.05	5.40
SSK31133	Portsdown 1	6515	PNG	69.88	0.00	0.18	0.03	425	467	0.15	0.10	0.69	17.70	0.04	0.47	0.51	35	29	135	0.48	4.86	5.35
SSK31228	Shalford 1	2441	PB	67.81	0.08	0.43	0.15	425	467	0.38	0.00	0.62	3.70	0.08	0.90	0.98	44	39	63	0.10	0.02	0.12
SSK31237	Shalford 1	3276	KC	58.12	0.01	1.94	0.01	432	474	0.20	0.50	0.55	9.60	0.20	1.51	1.71	113	12	32	0.27	0.57	0.84
SSK31238	Shalford 1	3381	KC	61.72	0.05	6.48	0.01	426	468	0.26	0.50	0.70	9.50	0.58	1.82	2.40	270	11	29	0.27	3.34	3.61
SSK31239	Shalford 1	4438	CR	59.06	0.01	0.89	0.01	429	471	0.09	0.30	0.34	8.90	0.09	1.14	1.23	72	7	28	0.25	1.21	1.46
SSK31240	Shalford 1	4942	OXC	63.51	0.71	28.25	0.02	424	466	0.38	0.80	0.58	7.50	2.45	2.68	5.13	551	7	11	0.22	1.51	1.74
SSK31230	Shalford 1	5682	SIL	65.26	0.02	0.02	0.48	494	536	0.09	0.00	0.17	0.80	0.01	0.15	0.16	12	56	106	0.02	0.01	0.04
SSK31249	Shalford 1	5695	SIL	66.30	0.00	0.01	0.30	494	536	0.10	0.00	0.19	1.20	0.01	0.09	0.10	10	100	190	0.03	0.01	0.05
SSK31229	Shalford 1	5697	SIL	65.58	0.01	0.01	0.48	495	537	0.12	0.00	0.12	0.60	0.01	0.13	0.14	7	86	86	0.02	0.01	0.03
SSK31232	Shalford 1	5706	SIL	66.35	0.00	0.01	0.25	412	454	0.14	0.00	0.17	1.20	0.01	0.12	0.13	8	108	131	0.03	0.01	0.04
SSK31231	Shalford 1	5714	SIL	61.90	0.01	0.01	0.47	494	536	0.12	0.00	0.25	0.90	0.01	0.17	0.18	6	67	139	0.02	0.01	0.04
SSK31241	Horndean 1A	4794	FE	68.52	0.02	1.75	0.01	441	483	0.08	0.40	0.54	16.10	0.17	0.78	0.95	184	8	57	0.45	4.15	4.60
SSK31242	Horndean 1A	4798	FE	67.14	0.02	0.51	0.03	430	472	0.05	0.20	0.67	18.40	0.07	0.66	0.73	70	7	92	0.51	4.29	4.79
SSK31243	Horndean 1A	4801	FE	64.80	0.01	0.43	0.02	433	475	0.03	0.30	0.72	19.90	0.06	0.53	0.59	73	5	122	0.55	5.26	5.81
SSK31244	Horndean 1A	4810	FE	64.49	0.01	2.40	0.01	441	483	0.08	0.50	0.94	22.50	0.24	0.75	0.99	242	8	95	0.62	4.37	5.00
SSK31245	Horndean 1A	4812	FE	68.60	0.04	10.52	0.00	443	485	0.14	0.20	0.76	15.00	0.91	1.15	2.06	511	7	37	0.41	1.94	2.35
SSK31246	Horndean 1A	4821	FE	64.34	0.00	0.20	0.02	428	470	0.08	0.10	0.72	20.00	0.04	0.35	0.39	51	21	185	0.55	3.86	4.40
SSK31248	Horndean 1A	4827	FE	69.23	0.02	1.28	0.01	437	480	0.08	0.30	1.12	22.40	0.15	0.85	1.00	128	8	112	0.62	3.02	3.64
SSK31134	Horndean 1A	4835	FE	69.59	0.01	1.24	0.01	437	480	0.06	0.20	0.84	16.50	0.13	0.70	0.83	149	7	101	0.45	3.83	4.28

Sample ID	Borehole	Average depth (ft)	Formation	Qty (mg)	S1 (mg/g)	S2 (mg/g)	PI	T_{max} (°C)	TpkS2 (°C)	S3CO (mg/g)	S3'CO (mg/g)	S3 (mg/g)	S3' (mg/g)	PC (%)	RC (%)	TOC (%)	HI	OICO	OI	Pyro MINC (%)	Oxi MINC (%)	MINC (%)
SSK31135	Horndean 1A	4836	FE	67.88	0.01	2.01	0.01	439	482	0.09	0.40	0.95	20.50	0.21	0.95	1.16	173	8	82	0.57	3.09	3.65
SSK31136	Horndean 1A	4837	FE	63.60	0.02	2.56	0.01	437	480	0.10	0.40	0.94	17.80	0.25	0.99	1.24	206	8	76	0.49	3.15	3.64
SSK31225	Horndean 1A	4838	FE	62.04	0.02	0.69	0.02	435	478	0.04	0.30	0.92	16.20	0.09	0.53	0.62	111	6	148	0.45	5.71	6.16
SSK31226	Horndean 1A	4840	FE	65.81	0.01	1.36	0.00	439	482	0.05	0.30	0.52	14.10	0.14	0.61	0.75	181	7	69	0.39	5.93	6.32
SSK31227	Horndean 1A	4843	FE	64.72	0.01	0.69	0.01	430	473	0.06	0.20	0.81	20.10	0.09	0.68	0.77	90	8	105	0.55	4.36	4.92
SSK31227	Horndean 1A	4845	FE	67.83	0.03	7.01	0.00	442	485	0.15	0.40	0.98	18.60	0.63	1.22	1.85	379	8	53	0.52	3.31	3.82

Key to formations: CR = Corallian; DEV = Devonian; FE = Fuller’s Earth; KC = Kimmeridge Clay; LI = Lias (undifferentiated); LLI = Lower Lias; MLI = Mi Lias; OXC = Oxford Clay; PB = Purbeck Beds; PL = Portland Beds; PNG = Penarth Group; SIL = Silurian; ULI = Upper Lias.

Appendix C: Mineralogical analysis of fine-grained sedimentary rock samples from Weald Basin boreholes

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1. Introduction

This appendix presents the results of mineralogical analyses carried out on a suite of 49 fine-grained sedimentary rock samples collected from boreholes located in the Weald Basin of southern England. The samples are representative of fine-grained lithologies from various chrono- and lithostratigraphic intervals including the Purbeck Group, Portland Group, Kimmeridge Clay Formation, Corallian Group, Oxford Clay Formation, Lias Group, Penarth Group and the Silurian system. The study was commissioned by the Department of Energy & Climate Change (DECC) as part of an assessment of potential for unconventional oil and gas exploration in the area.

Mineralogical analysis was carried out using a combination of whole-rock powder and <2 µm clay mineral X-ray diffraction (XRD) techniques. The samples form a subset of those previously analysed using organic geochemical techniques (Rock-Eval, TOC – see Appendix B). Full sample details are shown in Table 1.

2. Laboratory methods

2.1 Initial sample preparation

As indicated in Table 1, the submitted sample batch was variously composed of initially sampled milled powders together with re-sampled drill cuttings and fragments of core. Similarly the masses submitted for each sample varied between ~5 and ~20 g, depending on the borehole and material availability.

Ideally, the two methods of XRD analysis require slightly different initial sample preparation. For powder whole-rock analysis, the milled powders previously prepared for RockEval and TOC analyses are suitable and were employed.

However, samples of cuttings or crushed core rock chips are required for clay mineral XRD analysis. Clay minerals are most frequently fine-grained, while other minerals in sedimentary rocks are typically coarser-grained. In order to concentrate the proportion of clay minerals present, and to reduce the quantity of other minerals (e.g. quartz, feldspar etc) present, fine size fractions (typically <2 µm) are isolated from cuttings or crushed core samples prior to analysis. Milling the samples increases the proportion of quartz and feldspar present in the <2 µm size fraction, and reduces the proportion of clay minerals present, thereby producing inferior analyses.

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Borehole	Depth (ft)	Milled powder sample no.	Stratigraphy	Original sample type	Re-sampled cuttings/core sample no.
Balcombe 1	1970-80	SSK31089	Kimmeridge Clay (KC)	cuttings	SSK40198
	2380	SSK31090	Kimmeridge Clay (KC)	cuttings	SSK40199
	3040	SSK31091	Kimmeridge Clay (KC)	cuttings	SSK40214
	4300	SSK31092	Oxford Clay (OXC)	cuttings	SSK40174
	4390	SSK31093	Oxford Clay (OXC)	cuttings	SSK40175
	4610	SSK31094	Oxford Clay (OXC)	cuttings	na
	5610	SSK31095	Upper Lias (ULI)	cuttings	SSK40177
	5660-65	SSK31096	Upper Lias (ULI)	cuttings	SSK40215
Grove Hill 1	1765	SSK31122	Kimmeridge Clay (KC)	cuttings	na
	2241	SSK31121	Corallian (CR)	cuttings	na
	2420	SSK31100	Oxford Clay (OXC)	cuttings	SSK40390
	2480	SSK31101	Oxford Clay (OXC)	cuttings	SSK40391
	2549	SSK31102	Oxford Clay (OXC)	cuttings	SSK40389
	2945	SSK31103	Lias (LI)	cuttings	SSK40387
	2997	SSK31104	Lias (LI)	cuttings	SSK40388
Iden Green 1	1460	SSK31236	Kimmeridge Clay (KC)	sidewall core	na
	1466	SSK31116	Kimmeridge Clay (KC)	sidewall core	na
	1750	SSK31117	Kimmeridge Clay (KC)	sidewall core	na
	2391	SSK31120	Oxford Clay (OXC)	sidewall core	na
	2460	SSK31235	Oxford Clay (OXC)	sidewall core	SSK40403
	2930	SSK31233	Upper Lias (ULI)	sidewall core	na
	2950	SSK31119	Upper Lias (ULI)	sidewall core	SSK40404
	3100	SSK31118	Lower Lias (LLI)	sidewall core	na
	3180	SSK31234	Lower Lias (LLI)	sidewall core	na
Penshurst 1	993	SSK31107	Purbeck (PB)	Reg sp	SSK40395
	1025	SSK31108	Portland (PL)	Reg sp	SSK40396
	1764	SSK31109	Kimmeridge Clay (KC)	Reg sp	na
	1767	SSK31110	Kimmeridge Clay (KC)	Reg sp	na
Portsdown 1	2640-30	SSK31123	Kimmeridge Clay (KC)	cuttings	SSK40386
	2780-90	SSK31124	Kimmeridge Clay (KC)	cuttings	SSK40385
	3210-20	SSK31125	Kimmeridge Clay (KC)	cuttings	SSK40382
	3600-10	SSK31126	Kimmeridge Clay (KC)	cuttings	SSK40383
	3850-60	SSK31127	Oxford Clay (OXC)	cuttings	SSK40384
	4050-60	SSK31128	Oxford Clay (OXC)	cuttings	SSK40380
	4200-10	SSK31129	Oxford Clay (OXC)	cuttings	SSK40381
	5650-60	SSK31130	Lower Lias (LLI)	cuttings	SSK40377
	6020-30	SSK31131	Lower Lias (LLI)	cuttings	SSK40378
	6300-10	SSK31132	Lower Lias (LLI)	cuttings	SSK40379
	6510-20	SSK31133	Penarth Group (PNG)	cuttings	SSK40376
Shalford 1	2441	SSK31228	Purbeck (PB)	Reg sp	SSK40394
	3274-7	SSK31237	Kimmeridge Clay (KC)	Reg sp	na
	3379-82	SSK31238	Kimmeridge Clay (KC)	Reg sp	na
	4436-9	SSK31239	Corallian (CR)	Reg sp	na
	4940-3	SSK31240	Oxford Clay (OXC)	Reg sp	na
	5682	SSK31230	Silurian (SIL)	Reg sp	na
	5695	SSK31249	Silurian (SIL)	Reg sp	SSK40184
	5697	SSK31229	Silurian (SIL)	Reg sp	SSK40392
	5706	SSK31232	Silurian (SIL)	Reg sp	SSK40393
	5714	SSK31231	Silurian (SIL)	Reg sp	na

Table 1. Sample list

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In this case, as all original sample had been milled (as initially only Rock-Eval and TOC analyses were required), re-sampling of the same intervals was required. Unfortunately re-sampling revealed that some sample material had been exhausted and therefore milled material, by necessity, had to be used in some cases (see Table 1). As all the milled material for sample Grove Hill 2241 ft was consumed for whole-rock analysis, no clay mineral XRD analysis was possible for this sample.

Where core rock chips were used, these were hand-crushed in a pestle and mortar.

2.1.1 Whole-rock analysis

In order to provide a finer and uniform particle-size for powder XRD analysis, a 4.5 g portion of the milled sample was micronised under acetone for 10 minutes with 10 % (0.5 g) corundum (American Elements - PN:AL-OY-03-P). The addition of an internal standard allows the validation of quantification results and also the detection of any amorphous species present in the sample. Corundum was selected as its principle XRD peaks are suitably remote from those produced by most of the phases present in the sample. The dried material was then disaggregated in a pestle and mortar and back-loaded into a standard stainless steel sample holder for analysis.

2.1.2 Carbonate removal

Initial inspection of the whole-rock XRD traces suggested that most of the samples contained significant proportions of various carbonate minerals (calcite, dolomite, siderite etc). Since such carbonate species may 'lock-up' clay minerals and prevent their release during size-separation prior to clay mineral XRD analysis, a buffered acid pre-treatment was employed to remove the carbonate species from all the samples.

For this, crushed core/cuttings/milled material was placed in a 500 ml beaker with ~250 ml of buffered sodium acetate/acetic acid (pH 5.3) and the suspension was treated with ultrasound for 3 minutes. The beakers were then placed in a water bath maintained at 60°C for 6 hours and stirred every hour. The suspensions were then treated to further ultrasound for 3 minutes and left to stand overnight. Next morning the supernatant liquid was discarded. The leaching procedure was then repeated a second time before the material was transferred to a centrifuge bottle and washed three times with distilled water.

2.1.3 <2 µm fraction clay mineral analysis

To separate a fine fraction for clay mineral XRD analysis, the carbonate-free residues prepared in section 2.1.2 were dispersed in distilled water using a reciprocal shaker combined with ultrasound treatment. The suspension was then sieved on 63 µm and the <63 µm material placed in a measuring cylinder and allowed to stand. In order to prevent flocculation of the clay crystals, 1 ml of 0.1M 'Calgon' (sodium hexametaphosphate) was added to each suspension. After a time period determined from Stokes' Law, a nominal <2 µm fraction was removed and dried at 55°C. 100 mg of the <2 µm material was then re-suspended in a minimum of distilled water and pipetted onto a ceramic tile in a vacuum apparatus to produce an oriented mount. The mounts were Ca-saturated using 0.1M $CaCl_2.6H_2O$ solution and washed twice to remove excess reagent.

Where <100 mg <2 µm material was separated (sample Penshurst 1025 ft), ~15 mg of the dried <2 µm material was re-suspended in a minimum of distilled water, Ca-saturated using a few drops of 0.1M $CaCl_2.6H_2O$ solution, washed and pipetted onto a 'zero background' silicon crystal substrate and allowed to air-dry overnight.

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2.2 X-ray diffraction analysis

XRD analysis was carried out using a PANalytical X'Pert Pro series diffractometer equipped with a cobalt-target tube, X'Celerator detector and operated at 45kV and 40mA.

The micronised powder samples were scanned from 4.5-85°2θ at 2.76°2θ/minute. Diffraction data were initially analysed using PANalytical X'Pert Highscore Plus version 2.2d software coupled to the latest version of the International Centre for Diffraction Data (ICDD) database.

Following identification of the mineral species present in the sample, mineral quantification was achieved using the Rietveld refinement technique (e.g. Snyder & Bish 1989) using PANalytical Highscore Plus software. This method avoids the need to produce synthetic mixtures and involves the least squares fitting of measured to calculated XRD profiles using a crystal structure databank. Errors for the quoted mineral concentrations are typically ±2.5%. Where a phase was detected but its concentration was indicated to be below 0.5%, it is assigned a value of <0.5%, since the error associated with quantification at such low levels becomes too large.

The <2 µm oriented mounts were scanned from 2-40°2θ at 1.02°2θ/minute after air-drying, after glycol-solvation, after heating to 375°C for 2 hours and after heating to 550°C for 2 hours. In order to gain further information about the nature of the clay minerals present in the sample, modelling of the <2 µm glycol-solvated XRD profiles was carried out using Newmod-for-Windows™ (Reynolds & Reynolds 1996) software. Modelling was also used to assess the relative proportions of clay minerals present in the <2 µm fraction by comparison of sample XRD traces with Newmod-for-Windows™ modelled profiles. The modelling process requires the input of diffractometer, scan parameters and a quartz intensity factor (instrumental conditions), and the selection of different sheet compositions and chemistries. In addition, an estimate of the crystallite size distribution of the species may be determined by comparing peak profiles of calculated diffraction profiles with experimental data. By modelling the individual clay mineral species in this way, mineral reference intensities were established and used for quantitative standardization following the method outlined in Moore & Reynolds (1997).

3. Results

The results of quantitative powder and <2 µm clay mineral XRD analyses are summarised in Tables 2 to 5. Example labelled XRD traces are shown in Figures 1-5.

3.1 Whole-rock analysis

Powder whole-rock XRD analysis indicates that the samples are composed of variable mineralogical assemblages comprising quartz, feldspar (plagioclase and K-feldspar), carbonates (calcite, Mg-calcite, dolomite, ankerite/Fe-dolomite, siderite, aragonite), clay minerals/phyllosilicates ('mica', kaolinite and chlorite), pyrite and jarosite (Tables 2 and 3). The term 'mica' indicates the presence of undifferentiated mica species possibly including muscovite, biotite, illite and illite/smectite. Trace quantities (1.1%) of bassanite were tentatively identified in one sample (Iden Green 1460 ft).

An example whole-rock XRD trace compared to its component mineral standard patterns is shown in Figure 1.

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Bore-hole	Depth (ft)	Sample No.	*Strat-igraphy	Mineralogy (%)													
				Silicates			Phyllosilicates/clay minerals			Carbonates						Sulphides etc	
				quartz	plag.	K-feld.	'mica'	kaolinite	chlorite	calcite	Mg-calcite	dolomite	ankerite/ Fe-dol.	arag-onite	siderite	pyrite	jarosite
Balcombe 1	1970-80	SSK31089	KC	48.2	1.8	1.6	21.1	1.7	nd	23.7	nd	nd	<0.5	nd	<0.5	1.8	nd
	2380	SSK31090	KC	14.9	3.0	nd	8.9	1.8	nd	46.3	22.1	nd	2.2	nd	nd	0.7	nd
	3040	SSK31091	KC	46.5	3.8	nd	26.4	4.0	2.4	11.1	1.2	1.7	0.9	nd	<0.5	1.8	nd
	4300	SSK31092	OXC	39.8	5.0	nd	17.9	1.4	1.4	31.9	nd	nd	0.8	nd	nd	1.8	nd
	4390	SSK31093	OXC	39.6	2.8	nd	23.6	2.5	2.3	26.1	nd	nd	0.9	nd	nd	2.2	nd
	4610	SSK31094	OXC	36.6	0.9	1.6	35.1	2.5	2.4	18.6	nd	nd	0.8	nd	nd	1.4	nd
	5610	SSK31095	ULI	32.9	2.7	2.6	5.6	2.8	2.8	48.3	nd	nd	0.7	nd	0.7	1.1	nd
	5660-65	SSK31096	ULI	50.6	3.6	2.9	8.2	1.9	2.0	28.3	nd	nd	0.8	nd	<0.5	1.4	nd
Grove Hill 1	1765	SSK31122	KC	39.6	7.3	5.8	17.7	3.0	nd	20.4	nd	nd	4.7	nd	nd	1.6	nd
	2241	SSK31121	CR	28.6	1.7	nd	21.1	1.8	2.2	42.6	nd	nd	nd	nd	0.9	1.1	nd
	2420	SSK31100	OXC	32.3	2.4	10.4	23.9	2.9	2.2	23.6	nd	nd	0.7	nd	nd	1.6	nd
	2480	SSK31101	OXC	30.2	2.9	6.4	22.2	3.6	2.1	25.8	nd	nd	1.7	nd	<0.5	4.9	nd
	2549	SSK31102	OXC	34.4	1.8	6.1	32.3	3.9	2.0	17.6	nd	nd	<0.5	nd	nd	1.8	nd
	2945	SSK31103	LI	26.8	2.2	3.2	11.5	2.9	3.7	43.8	nd	nd	1.8	nd	<0.5	3.9	nd
	2997	SSK31104	LI	41.3	1.8	3.0	13.3	1.1	1.0	37.0	nd	nd	<0.5	nd	nd	1.2	nd
Iden Green 1	1460	SSK31236	KC	41.6	nd	2.0	34.4	1.6	nd	17.5	nd	nd	0.7	nd	nd	1.2	nd
	1466	SSK31116	KC	44.5	2.6	4.0	25.7	4.7	8.4	7.3	nd	0.7	0.7	nd	nd	1.6	nd
	1750	SSK31117	KC	47.9	5.8	6.3	25.2	2.9	nd	7.0	nd	4.0	nd	nd	nd	0.9	nd
	2391	SSK31120	OXC	44.6	1.3	1.2	23.8	2.1	1.2	25.1	nd	nd	nd	nd	nd	0.6	nd
	2460	SSK31235	OXC	35.9	1.1	7.2	17.3	1.6	1.4	32.0	nd	nd	<0.5	0.3	nd	2.9	nd
	2930	SSK31233	ULI	30.6	nd	0.8	41.9	3.7	2.1	15.4	nd	nd	nd	nd	<0.5	5.5	nd
	2950	SSK31119	ULI	44.4	3.4	5.7	30.7	8.9	3.9	1.3	nd	nd	nd	nd	1.1	0.6	nd
	3100	SSK31118	LLI	46.9	7.6	4.5	25.4	9.9	4.2	<0.5	nd	nd	nd	nd	<0.5	0.8	nd
	3180	SSK31234	LLI	35.4	3.1	0.7	37.4	10.2	1.8	6.1	nd	nd	nd	nd	3.8	1.6	nd

*Table 2. Summary of quantitative whole-rock XRD analysis (Balcombe, Grove Hill and Iden Green boreholes). KEY: 'mica' undifferentiated mica species including muscovite, biotite, illite and illite/smectite etc. nd = not detected. * see Table 1 for full stratigraphical names*

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Bore-hole	Depth (ft)	Sample No.	*Strat-igraphy	Mineralogy (%)													
				Silicates			Phyllosilicates/clay minerals			Carbonates						Sulphides etc	
				quartz	plag.	K-feld.	‘mica’	kaolinite	chlorite	calcite	Mg-calcite	dolomite	ankerite/ Fe-dol.	arag-onite	siderite	pyrite	jarosite
Penshurst 1	993	SSK31107	PB	7.2	nd	nd	8.2	nd	nd	56.0	28.0	nd	nd	nd	nd	0.6	nd
	1025	SSK31108	PL	46.7	1.8	2.6	2.8	<0.5	nd	45.8	nd	nd	nd	nd	nd	<0.5	nd
	1764	SSK31109	KC	27.1	1.1	nd	5.9	nd	nd	64.6	nd	nd	0.7	nd	nd	0.7	nd
	1767	SSK31110	KC	31.0	2.6	6.3	38.1	3.1	nd	15.5	nd	nd	nd	nd	<0.5	3.1	nd
Portsdown 1	2640-30	SSK31123	KC	43.6	0.7	2.6	27.0	1.4	nd	21.2	nd	0.7	nd	nd	nd	2.9	nd
	2780-90	SSK31124	KC	24.0	nd	4.3	39.5	9.3	1.2	17.3	nd	nd	nd	nd	nd	4.4	nd
	3210-20	SSK31125	KC	33.5	<0.5	nd	42.0	3.0	1.2	13.6	nd	nd	0.8	1.1	nd	4.2	nd
	3600-10	SSK31126	KC	30.3	nd	1.3	52.4	4.8	1.8	6.7	nd	nd	<0.5	nd	nd	2.7	nd
	3850-60	SSK31127	OXC	31.1	nd	nd	45.3	2.7	1.1	17.6	nd	<0.5	<0.5	nd	nd	1.7	nd
	4050-60	SSK31128	OXC	31.2	nd	1.2	41.0	3.1	1.2	20.8	nd	nd	nd	nd	nd	1.4	nd
	4200-10	SSK31129	OXC	30.2	nd	<0.5	48.8	2.0	0.6	16.6	nd	nd	<0.5	nd	nd	1.3	nd
	5650-60	SSK31130	LLI	34.6	3.3	1.0	36.7	4.8	0.9	16.7	nd	nd	nd	nd	<0.5	1.7	nd
	6020-30	SSK31131	LLI	29.6	2.6	1.8	19.3	2.9	1.8	38.9	nd	2.0	nd	nd	nd	1.2	nd
	6300-10	SSK31132	LLI	26.6	1.8	1.6	19.5	2.6	1.4	43.6	nd	1.7	nd	nd	nd	1.2	nd
	6510-20	SSK31133	PNG	35.5	7.8	2.5	7.2	0.9	1.3	42.2	nd	1.6	nd	nd	nd	1.0	nd
Shalford 1	2441	SSK31228	PB	31.6	nd	0.7	61.7	1.4	nd	nd	nd	nd	nd	nd	<0.5	1.1	3.3
	3274-7	SSK31237	KC	48.4	0.8	2.3	42.2	1.9	nd	2.9	nd	nd	nd	nd	<0.5	1.3	nd
	3379-82	SSK31238	KC	22.0	nd	1.8	48.3	1.4	0.6	17.0	8.1	nd	<0.5	nd	nd	0.6	nd
	4436-9	SSK31239	CR	26.0	nd	nd	59.4	1.9	0.8	8.5	nd	nd	nd	nd	nd	3.4	nd
	4940-3	SSK31240	OXC	36.5	nd	nd	42.3	4.2	1.0	11.1	nd	<0.5	nd	0.9	nd	3.8	nd
	5682	SSK31230	SIL	60.5	10.3	nd	25.0	2.7	1.1	nd	nd	nd	nd	nd	nd	<0.5	nd
	5695	SSK31249	SIL	46.4	7.7	0.7	40.1	2.5	2.1	nd	nd	nd	nd	nd	nd	0.6	nd
	5697	SSK31229	SIL	30.8	6.8	nd	57.5	2.3	1.8	nd	nd	nd	nd	nd	nd	0.8	nd
	5706	SSK31232	SIL	29.7	7.8	nd	53.8	1.7	6.3	nd	nd	nd	nd	nd	nd	0.7	nd
	5714	SSK31231	SIL	44.7	12.9	nd	39.1	1.4	1.3	nd	nd	nd	nd	nd	nd	0.6	nd

Table 3. Summary of quantitative whole-rock XRD analysis (Penshurst, Portsdown and Shalford boreholes). KEY: ‘mica’ undifferentiated mica species including muscovite, biotite, illite and illite/smectite etc. nd = not detected. * see Table 1 for full stratigraphical names

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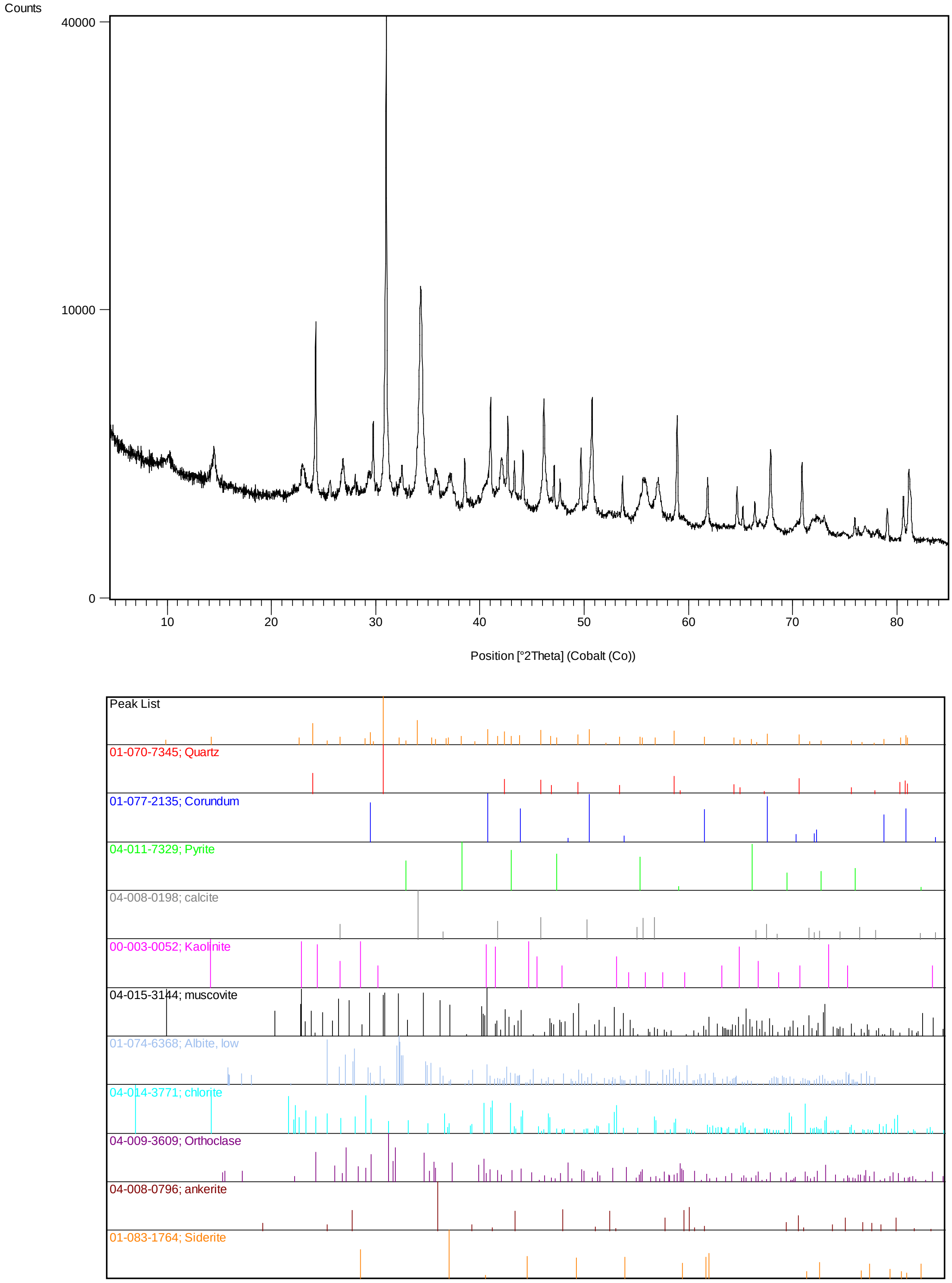

Figure 1. Example whole-rock XRD trace (above) compared to extracted peak data (orange sticks, below) and identified component mineral phases as ICDD standard stick patterns (below), sample Balcombe 5660 ft.

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An average composition for the samples would be composed of ~36% quartz, ~5% feldspar, ~23% carbonate, ~34% clay minerals/phyllosilicates and ~2% pyrite. However, the variability of the assemblages is illustrated by the extremes in the mineral compositions e.g. quartz (~7 to 61%), total carbonate (not detected to 84%) and total clay minerals/phyllosilicate (~3 to 63%).

In general terms, it is noticeable that in comparison to the average composition of the batch, the samples from the Balcombe, Grove Hill and Penshurst boreholes are carbonate-rich while those from the Iden Green borehole are quartz-rich and those from the Portsdown and Shalford boreholes are phyllosilicate/clay mineral-rich.

3.2 <2 µm fraction clay mineral analysis

Less than 2 µm clay mineral XRD analyses indicate that the clay mineral assemblages of the samples are composed of various amounts of illite, illite/smectite, kaolinite and chlorite (Tables 4 and 5).

The generated XRD traces are complex and difficult to interpret, even using state-of-the-art modelling packages. However, modelling individual clay species and then combining these to profile-fit the sample traces produced excellent composite matches of background together with peak positions, heights and widths. To illustrate the efficacy of the modelling approach, an example of a NEWMOD II-modelled profile is shown matched to an experimental ethylene glycol-solvated XRD trace in Figure 2.

3.2.1 Illite

Illite was identified in all the separated <2 µm fractions by its characteristic air-dry spacings of ~9.98, 4.98 and 3.32Å which remain invariant after glycol-solvation and heating. Newmod II™-modelling of the widths of the illite XRD peaks suggests a typical crystallite-size distribution has a mean defect-free distance of 10 layers (10Å units) and a size range between 1 and 30 layers. Generally the illites appear to have low Fe and high K chemistries with average compositions of ~0.1 Fe and ~0.96 K per $(Si, Al)_4O_{10}(OH)2$.

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Bore-hole	Depth (ft)	Sample no. (milled samples shown in red text)	+Strat-igraphy	Clay mineralogy (%)				Illite/ smectite species	Non-clay minerals
				illite	illite/ smectite	kaolinite	chlorite		
Balcombe 1	1970-80	SSK40198	KC	43	38	15	4	*R*1, 78%illite	quartz
	2380	SSK40199	KC	61	26	10	3	*R*1, 78%illite	quartz, calcite
	3040	SSK40214	KC	59	22	15	4	*R*1, 78%illite	quartz, K-feld, plag
	4300	SSK40174	OXC	49	33	10	8	*R*1, 78%illite	quartz, K-feld, plag
	4390	SSK40175	OXC	50	33	10	7	*R*1, 78%illite	quartz, plag
	4610	SSK31094	OXC	48	36	9	7	*R*1, 78%illite	quartz
	5610	SSK40177	ULI	30	10	10	50	*R*3, 88%illite	quartz, K-feld, plag
	5660-65	SSK40215	ULI	52	26	5	17	*R*3, 88%illite	quartz, K-feld, plag
Grove Hill 1	1765	SSK31122	KC	43	43	9	5	*R*1, 78%illite	quartz, K-feld
	2241	na	CR	No material available					
	2420	SSK40390	OXC	51	28	16	6	*R*1, 78%illite	quartz, K-feld, plag
	2480	SSK40391	OXC	46	36*	13	5	*R*1, 78%illite	quartz
	2549	SSK40389	OXC	45	35	14	6	*R*1, 78%illite	quartz
	2945	SSK40387	LI	44	32	17	7	*R*1, 78%illite	quartz, K-feld, plag
	2997	SSK40388	LI	44	34	17	5	*R*1, 78%illite	quartz
Iden Green 1	1460	SSK31236	KC	58	23	13	6	*R*1, 78%illite	quartz, K-feld, plag
	1466	SSK31116	KC	48	35	13	4	*R*1, 78%illite	quartz, plag
	1750	SSK31117	KC	57	27	9	7	*R*1, 78%illite	quartz, plag
	2391	SSK31120	OXC	47	33	14	6	*R*1, 78%illite	quartz, K-feld, plag
	2460	SSK40403	OXC	36	30*	29	5	*R*1, 78%illite	quartz, K-feld, plag
	2930	SSK31233	ULI	52	12	30	6	*R*1, 78%illite	quartz, K-feld, plag
	2950	SSK40404	ULI	42	19	32	7	*R*1, 78%illite	quartz, plag
	3100	SSK31118	LLI	50	8	28	14	*R*1, 78%illite	quartz, K-feld, plag
	3180	SSK31234	LLI	45	13	26	16	*R*1, 78%illite	quartz, K-feld, plag

*Table 4. Summary of the relative proportions of clay minerals in the <2 µm fractions (Balcombe, Grove Hill and Iden Green boreholes). KEY: 'mica' = undifferentiated mica species including muscovite, biotite, illite and illite/smectite etc. *A low intensity peak at 16.9 Å on the ethylene glycol-solvated XRD trace suggests the presence of trace amounts of smectite, possibly drilling mud contamination. + see Table 1 for full stratigraphical names*

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Bore-hole	Depth (ft)	Sample no. (milled samples shown in red text)	+Strat-igraphy	Clay mineralogy (%)				Illite/ smectite species	Non-clay minerals
				illite	illite/ smectite	kaolinite	chlorite		
Penshurst 1	993	SSK40395	PB	56	44	0	0	*R*0, 50%illite	quartz, calcite, plag, K-feld
	1025	SSK40396	PL	68	29*	2	1	*R*1, 78%illite	quartz, K-feld, plag
	1764	SSK31109	KC	54	37	6	3	*R*1, 78%illite	quartz, K-feld, plag
	1767	SSK31110	KC	56	18	22	4	*R*1, 78%illite	quartz, K-feld, plag
Portsdown 1	2640-30	SSK40386	KC	43	44	11	2	*R*0, 50%illite	quartz, K-feld, plag
	2780-90	SSK40385	KC	44	28	25	3	*R*1, 78%illite	quartz
	3210-20	SSK40382	KC	54	25	17	4	*R*1, 78%illite	quartz, plag
	3600-10	SSK40383	KC	51	28	16	5	*R*1, 78%illite	quartz, plag
	3850-60	SSK40384	OXC	51	26	18	5	*R*1, 78%illite	quartz
	4050-60	SSK40380	OXC	51	27	17	5	*R*1, 78%illite	quartz
	4200-10	SSK40381	OXC	52	26	17	5	*R*1, 78%illite	quartz
	5650-60	SSK40377	LLI	45	15	31	9	*R*1, 78%illite	quartz
	6020-30	SSK40378	LLI	48	14	30	9	*R*1, 78%illite	quartz
	6300-10	SSK40379	LLI	52	22	19	7	*R*1, 78%illite	quartz, K-feld, plag
	6510-20	SSK40376	PNG	54	35	6	5	*R*1, 78%illite	quartz, K-feld, plag
Shalford 1	2441	SSK40394	PB	41	49	8	2	*R*0, 50%illite	quartz, K-feld, plag
	3274-7	SSK31237	KC	23	53	21	3	*R*1, 78%illite	quartz, plag
	3379-82	SSK31238	KC	35	44	18	3	*R*1, 78%illite	quartz
	4436-9	SSK31239	CR	35	42	17	6	*R*1, 78%illite	quartz, K-feld, plag
	4940-3	SSK31240	OXC	26	47	22	5	*R*1, 78%illite	quartz
	5697	SSK40392	SIL	36	55	2	7	*R*3, 88%illite	quartz, K-feld, plag, calcite, jarosite
	5682	SSK31230	SIL	37	49	2	12	*R*3, 88%illite	quartz, plag
	5695	SSK40184	SIL	38	50	1	11	*R*3, 88%illite	quartz, K-feld, plag
	5714	SSK31231	SIL	42	46	2	10	*R*3, 88%illite	quartz, K-feld, plag
	5706	SSK40393	SIL	35	57	1	7	*R*3, 88%illite	quartz, plag

*Table 5. Summary of the relative proportions of clay minerals in the <2 µm fractions (Penshurst, Portsdown and Shalford boreholes) KEY: 'mica' = undifferentiated mica species including muscovite, biotite, illite and illite/smectite etc. *A low intensity peak at 16.9 Å on the ethylene glycol-solvated XRD trace suggests the presence of trace amounts of smectite, possibly drilling mud contamination. + see Table 1 for full stratigraphical names*

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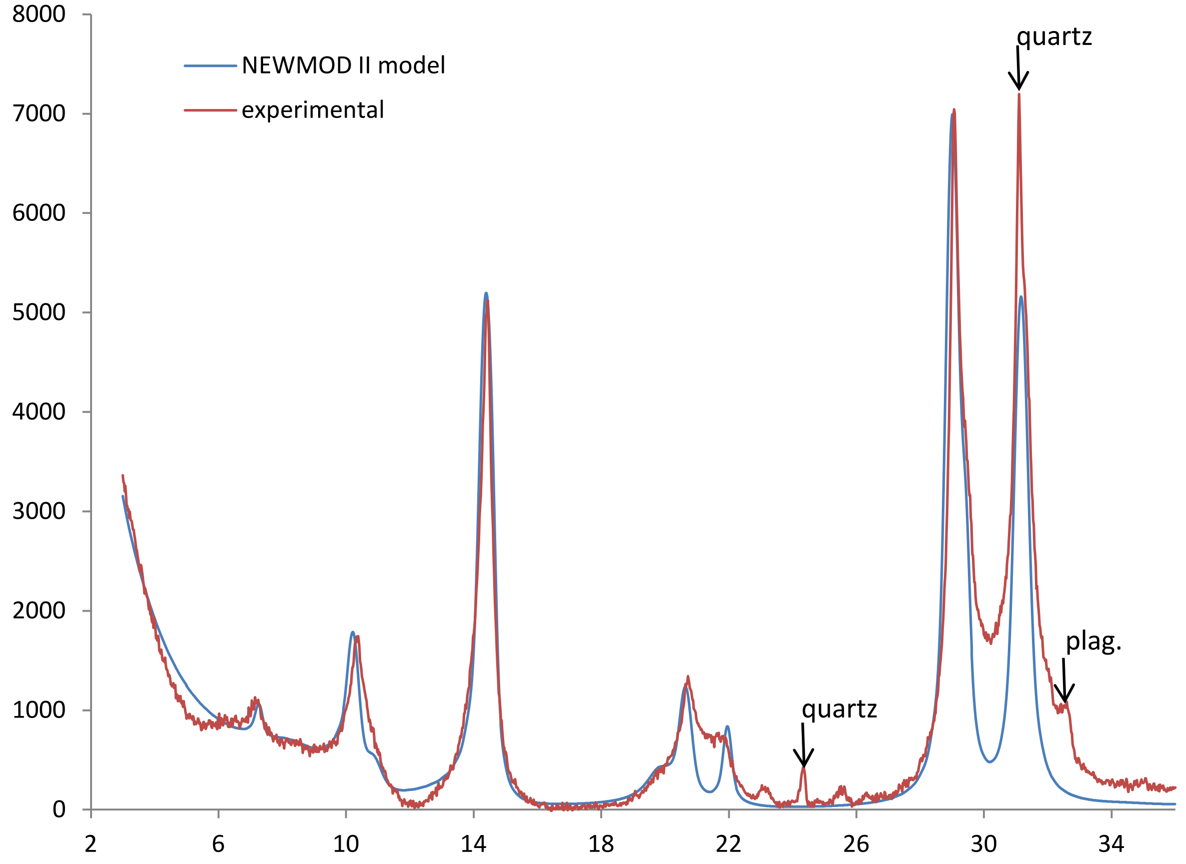

Figure 2. Example comparison of Newmod II™-modelled and experimental ethylene glycol-solvated XRD trace, sample Iden Green 2950 ft. Horizontal axis, °2θCo-Kα; vertical axis, intensity (cps).

3.2.2 Illite/smectite

Illite/smectite (I/S) was also identified as a major component in all the separated <2 µm fractions. Peak positions and Newmod II™-modelling suggest varied compositions for the I/S in terms of composition (% illite, % smectite), structural ordering expressed as Reichweite numbering (*R*) and crystallite size distribution.

In the majority of the samples, the I/S has a 78% illite, 22% smectite composition, is R1-ordered and has a crystallite distribution with a mean defect-free distance of 10 layers (10Å units) and a size range varying from 1 – 30 layers. Ethylene glycol traces show typical broad features at ~12.5, 9.6 and 5.2Å (Figure 3).

However, the I/S present in shallowest samples in the Penshurst, Portsdown and Shalford boreholes (Purbeck Group and Kimmeridge Clay Formation) shows distinctly different characteristics. These samples typically show a strong, broad peak at ~16.8Å together with lower intensity peaks at ~9.05 and 5.44Å on the ethylene glycol-solvated traces (Figure 4). Such peak positions and Newmod II™-modelling suggest that this I/S is an *R*0-ordered species with a 50% illite and 50% smectite composition and a crystallite size distribution with a mean defect-free distance of 10 layers (10Å units) and a size range varying from 1 – 16 layers.

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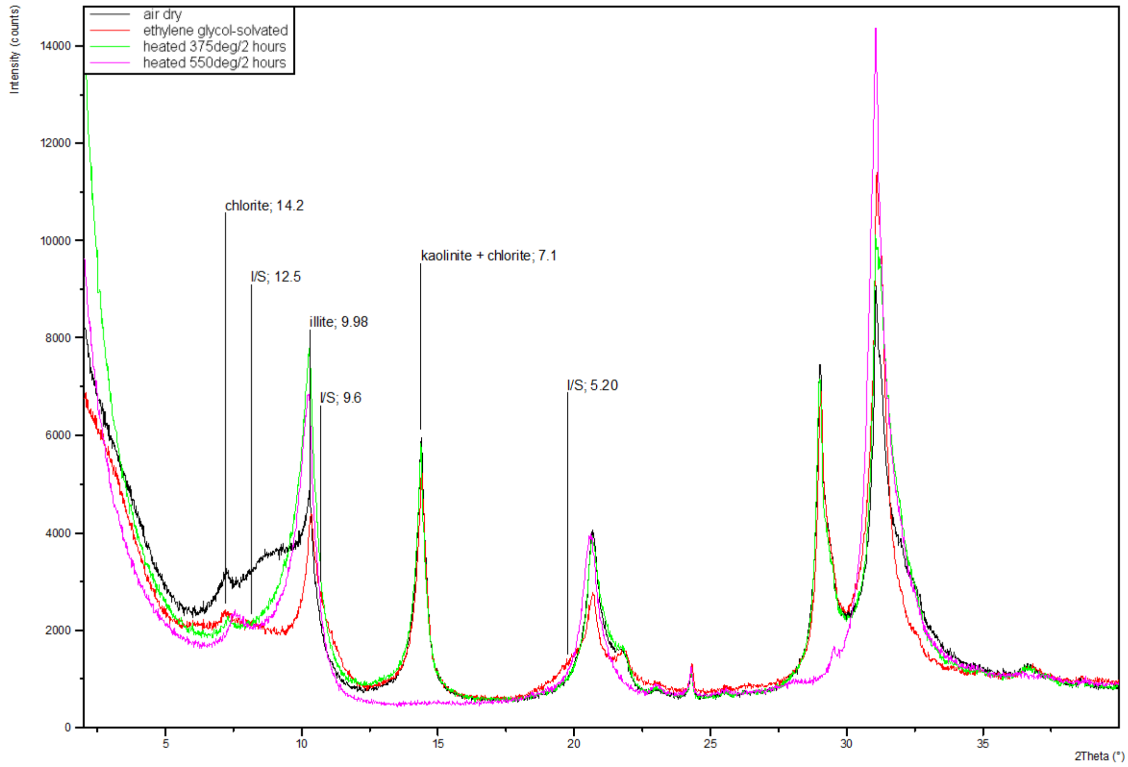

Figure 3. Example <2 µm fraction XRD traces for the most common illite/smectite in the sample batch - an illite-rich (~78%), R*1-ordered species, sample Portsdown 3850-60ft.*

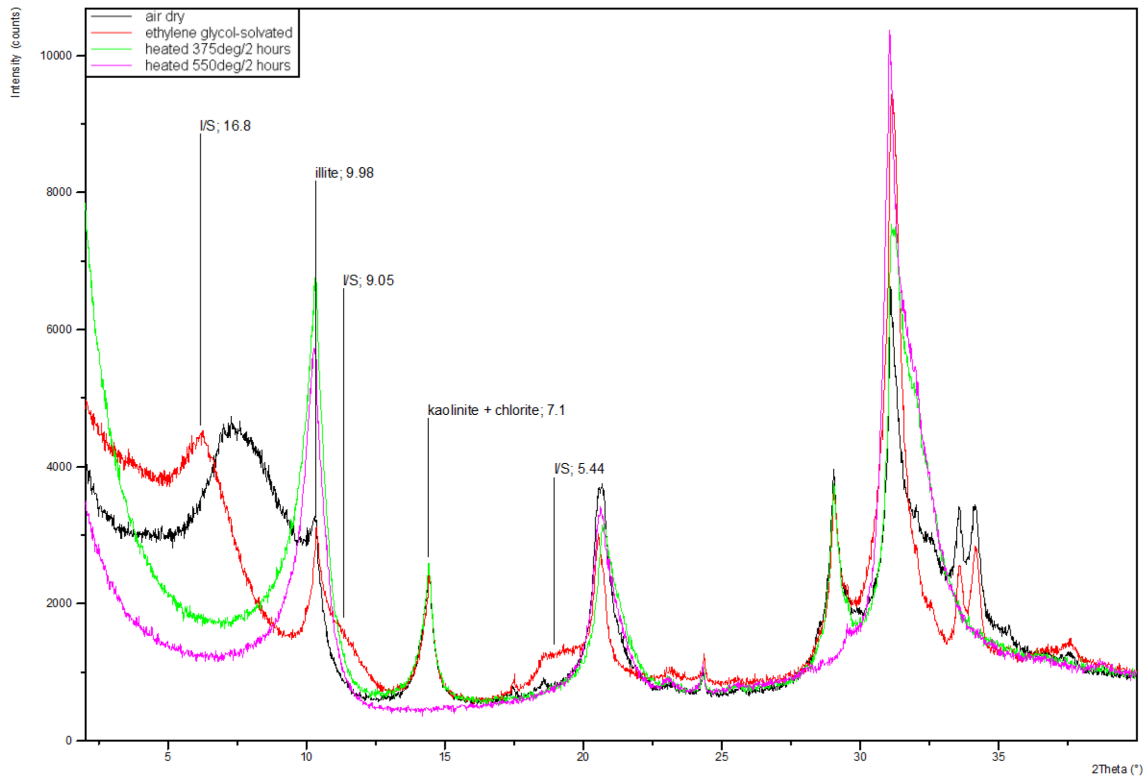

Figure 4. Example <2 µm fraction XRD traces for the illite/smectite identified in the shallow samples from the Penshurst, Portsdown and Shalford boreholes – a 50% illite, 50% smectite, R*0-ordered species, sample Shalford 2441 ft.*

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The I/S in the deeper samples from the Balcombe and Shalford boreholes (Upper Lias Group and Silurian) again shows different XRD characteristics. Ethylene glycol traces clearly resolve a characteristic $d_{001/004}$* peak at ~11.1Å, suggesting long-range *R*3-ordering. Air-dry, glycol and heated peak positions together with Newmod II™-modelling suggest a more illitic (88% illite, 12% smectite) composition and a crystallite distribution with a mean defect-free distance of 10 layers (10Å units) and a size range varying from 1 – 30 layers (e.g. Figure 5).

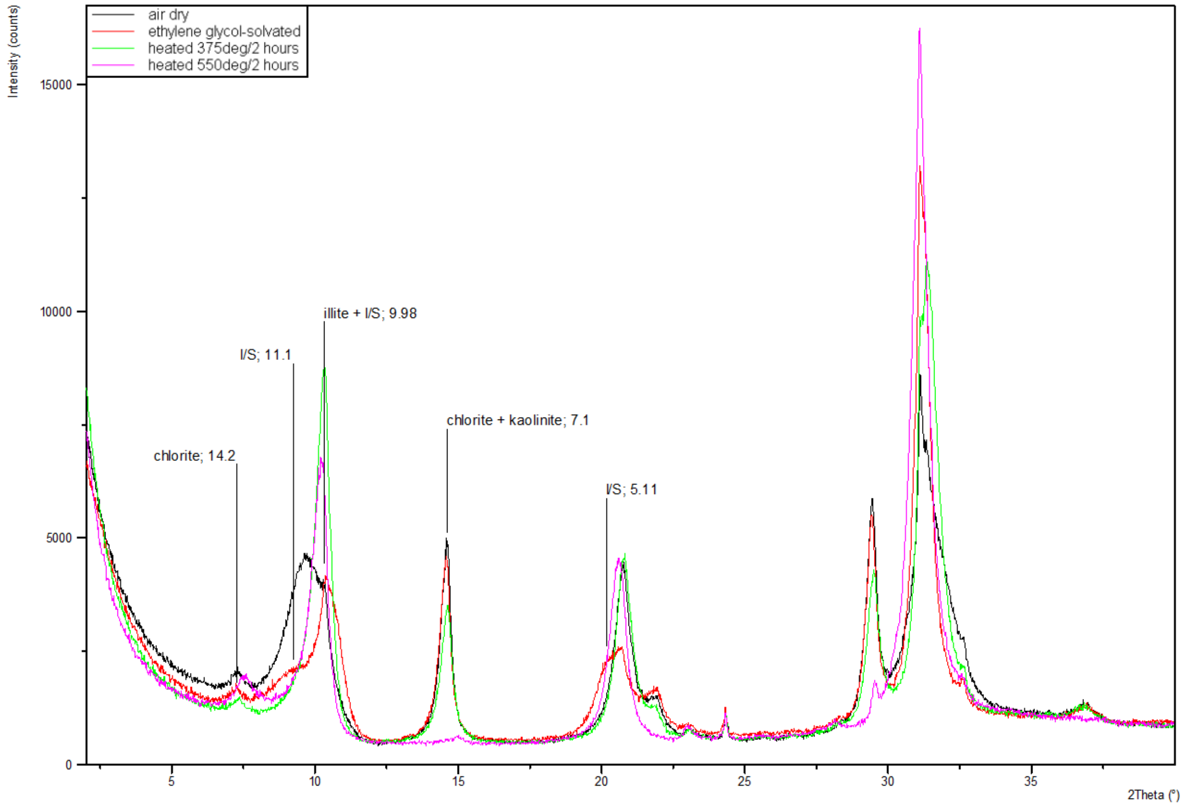

Figure 5. Example <2 µm fraction XRD traces for the illite/smectite identified in the deepest samples from the Balcombe and Shalford boreholes – an 88% illite, 12% smectite, long range R3-ordered species, sample Shalford 5706 ft.

3.2.3 Kaolinite

Kaolinite was also identified by its characteristic air-dry basal spacings of ~7.1 and 3.58Å which remain invariant after glycol-solvation and heating to 375°C but which disappear after heating at 550°C due to the meta-kaolinite's X-ray amorphous state. Kaolinite was identified in all the clay mineral assemblages with the exception of the shallowest sample from the Penshurst borehole (993 ft).

Kaolinite generally forms a minor component (mean 14%) of the clay mineral assemblages of the samples. However kaolinite concentrations are noticeably higher in the samples from the Iden Green and Portsdown boreholes and upper interval of the Shalford borehole.

Newmod II™-modelling suggests crystallite size distributions with a typical mean defect-free distance of 16 layers (7Å units) and a size range of 1 to 40 layers.

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3.2.4 Chlorite

Chlorite was identified by its characteristic air-dry, glycol-solvated basal and heated 375°C spacing peaks at 14.2, 7.1, 4.72 and 3.54Å and particularly the presence of a peak at ~13.9Å after heating for 2 hours at 550°C.

Chlorite forms a minor component (mean 7%) of most of the clay mineral assemblages but increased concentrations were identified in the deepest samples from the Balcombe (Upper Lias Group), Iden Green (Lower Lias Group) and Shalford (Silurian) boreholes. No chlorite was identified in the shallowest sample (Purbeck Group) from the Penshurst borehole (993 ft).

Peak intensity ratios and Newmod II™-modelling suggests that the chlorite species identified in most of the samples are of intermediate Fe/Mg compositions. However the chlorite in the deepest samples from the Balcombe (5610 and 5660 ft) and Shalford (5682, 5695, 5697, 5706 and 5714 ft) boreholes appears to be Fe-rich.

Newmod II™-modelling suggest crystallite size distributions with a typical mean defect-free distance of 10 layers (14Å units) and a size range of 1 to 33 layers.

3.2.5 Non-clay minerals

XRD analysis also indicates the presence of variable amounts of non-clay minerals in the <2 µm fractions. These include quartz, K-feldspar, plagioclase feldspar and jarosite. Despite applying repeated buffered-leaches, calcite was found to form a trace component of a few of the <2 µm fractions obtained from the carbonate-rich samples (Tables 4 and 5).

4. Discussion

The submitted samples from the Balcombe, Grove Hill, Iden Green, Penshurst, Portsdown and Shalford boreholes present a range of mineralogical assemblages including quartz-rich, carbonate-rich and phyllosilicate/clay mineral-rich lithologies. The relatively small number of samples submitted from each borehole and the large stratigraphic range covered precludes a detailed commentary on downhole variation but the extracted clay mineralogies provide an indication of the maturity and burial history of the samples, relevant to their potential as unconventional oil or gas sources and their engineering behaviour.

4.1 Maturity and burial history

Because of their small grain-size and thermodynamic metastability, clay minerals are particularly sensitive to changes in the shallow crustal conditions that control the thermal history of sedimentary basins. Following from the seminal work of Hower *et al*. (1976), clay mineral transformations (reactions) resulting from burial in sedimentary basins have been widely studied and increasingly used to model basin thermal history. During sedimentary burial, a progressive series of clay mineral reactions converts soft mud to hard lithified mudstone and shale. Quantitatively, the most important series of reactions responsible for the lithification of mud is the progressive transformation of smectite to illite via a series of intermediate illite/smectite (I/S) mixed-layer minerals. Progress of this series of dehydration reactions increases the density of the mudstone by mobilising fluids, and also reducing pore-space as a new, bedding-parallel illite invades and fills voids (Merriman & Peacor 1999). The progress of the smectite–to–illite reaction can be measured using X-ray diffraction (XRD)-based techniques such as computer modelling of the percentage illite in I/S, and measuring changes

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in 'illite crystallinity' using the Kübler index (KI). Changes in KI caused by diagenetic burial and very low-grade metamorphism have been correlated with transmission electron microscopy (TEM) measurements of illite crystallite thickness from a variety of mudrocks including mudstone, shale and slate samples (e.g. Warr & Nieto 1998, Merriman & Peacor 1999, fig. 2.19). These show that during burial diagenesis, illite crystallites progressively increase in mean thickness from 2 or 3 (10-Å) layers to 20-25 (10-Å) layers, prior to the onset of very low-grade metamorphism. Progressive increases in illite crystallite thickness are not reversed by basin inversion and uplift and can be used to estimate maximum burial depth, particularly when used with other indicators of thermal maturity such as vitrinite reflectance or apatite fission track analysis.

Reaction-progress in clay minerals in relation to changes observed in organic materials have been used to construct a Basin Maturity Chart summarizing these depth-dependent changes (Merriman & Kemp 1996).

The clay mineral data for the Balcombe, Grove Hill, Iden Green, Penshurst, Portsdown and Shalford borehole samples are plotted on the Basin Maturity Chart in Figure 6. Although a normal geothermal gradient (25°C/km) is shown in Figure 6, Busby *et al*. (2011) suggested a higher than 28°C/km heat flow is likely for southern and eastern England. The following discussion therefore assumes an average geothermal gradient of ~30°C/km.

The majority of the samples analysed contain an *R*1-ordered I/S (~78% illite) which places these samples at the top of the Deep Diagenetic metapelitic zone and suggests maximum burial temperatures of ~125°C, equivalent to burial of perhaps ~4 km at an average geothermal gradient of ~30°C/km. In terms of hydrocarbon zones, the clay data suggest that the samples generally fall within the Light Oil zone or possibly just at the transition to Wet Gas maturity (Figure 6).

The less mature *R*0-ordered, 50%illite I/S identified in the shallowest samples in the Penshurst, Portsdown and Shalford boreholes suggests shallower maximum burial of perhaps 3 km. These samples have only reached the Shallow Diagenetic metapelitic zone and perhaps a maximum burial temperature of 100°C. In terms of hydrocarbon zones, the clay data suggest that these samples fall within the Heavy Oil zone or are perhaps even Immature (Figure 6).

The *R*3-ordered I/S (~88% illite) present in the deepest samples in the Balcombe and Shalford boreholes suggests burial temperatures of ~150°C and places the formation in the mid-part of the Deep Diagenetic metapelitic zone, equivalent to burial of perhaps ~5 km at an average geothermal gradient of ~30°C/km. In terms of hydrocarbon zones, the clay data places these samples in the Wet Gas maturity zone (Figure 6).

4.2 Inferred engineering properties

The words "ductile" and "brittle" have emerged as two key descriptors for characterizing unconventional oil and gas shales. The former are usually relatively organic (TOC)- and clay-mineral rich, while the latter are considered to be more enriched in "silica" (i.e. biogenic and/or detrital quartz)- and/or carbonate (calcite/dolomite) minerals (Slatt 2011).

Under these criteria, the carbonate-rich samples from Balcombe, Grove Hill and Penshurst boreholes and the silica-rich samples from Iden Green borehole could be termed "brittle" while the clay-rich samples from the Portsdown and Shalford boreholes could be termed "ductile". However, detailed

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mineralogical and clay mineralogical analysis enables further predictions of their likely engineering behaviour.

Importantly, the clay mineral maturity of the Weald Basin borehole samples may also be related to the microfabric, pelitic lithology and ultimately therefore to the engineering properties of the sampled lithologies. However, it should be noted that these relationships are complicated by the high carbonate contents, revealed by XRD analysis for the Balcombe, Grove Hill and Penshurst borehole samples.

The Shallow Diagenetic maturity of the shallowest samples in the Penshurst, Portsdown and Shalford boreholes means that these samples are likely to show only a weak bedding-parallel microfabric, developed through compaction and dewatering (e.g. O'Brien & Slatt 1990).

As detailed by Merriman & Peacor (1999), the Deep Diagenetic Zone is characterised by claystone, mudstone and shale pelitic lithologies. Claystones and mudstones lack the fissility of shales that split easily into thin sheets along planes approximately parallel to bedding. At outcrop, claystones and mudstones commonly spall into centimetre-size blocks along polygonal shrinkage cracks, reflecting the presence of illite/smectite. Microfabrics show an overall bedding-parallel orientation. The majority of the samples analysed in this study would be expected to show such characteristics.

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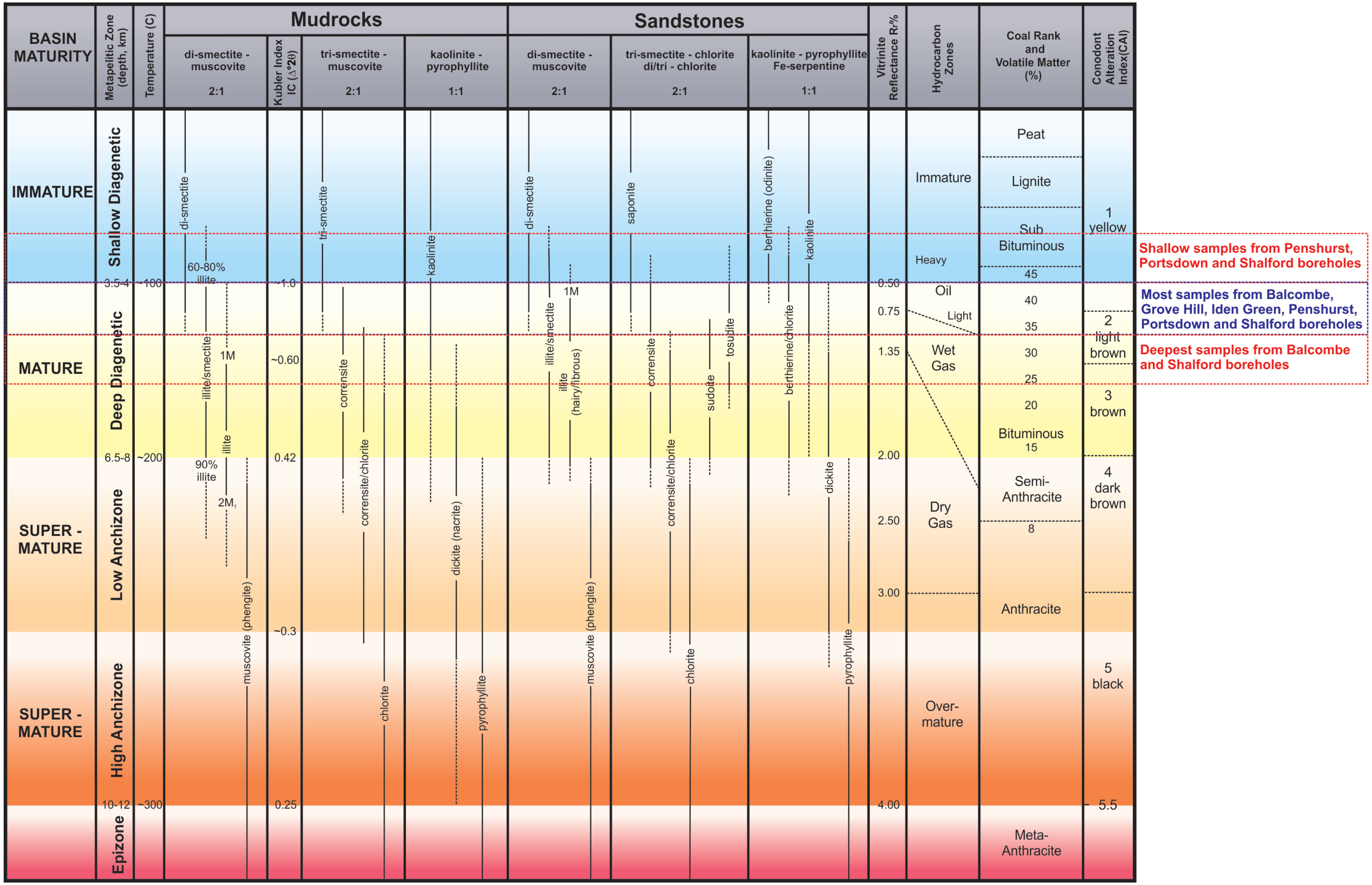

Figure 6. Clay mineral maturity data for the Balcombe, Grove Hill, Iden Green, Penshurst, Portsdown and Shalford borehole samples plotted on the Basin Maturity Chart (Merriman & Kemp, 1996). Note that burial depths are for a 'normal' geothermal gradient of 25°C/km.

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5. Conclusions

This report summarises the results of whole-rock and <2 µm clay mineral X-ray diffraction analyses carried out on a suite of 49 samples of fine-grained sedimentary rock samples collected from six boreholes located in the Weald Basin of southern England.

Several points were noted as a result of these analyses:

- The samples are composed of variable proportions of quartz, feldspar (plagioclase and K-feldspar), carbonates (calcite, Mg-calcite, dolomite, ankerite/Fe-dolomite, siderite, aragonite), clay minerals/phyllosilicates ('mica', kaolinite, chlorite), pyrite and jarosite.
- In very general terms, the samples from the Balcombe, Grove Hill and Penshurst boreholes are relatively carbonate-rich while those from the Iden Green borehole are relatively quartz-rich and those from the Portsdown and Shalford boreholes are relatively phyllosilicate/clay mineral-rich. The carbonate-rich and the silica-rich compositions suggest "brittle" engineering behaviour while the clay-rich compositions suggest "ductile" engineering behaviour.
- <2 µm clay mineral assemblages are generally composed of major amounts of illite, and illite/smectite (I/S) with minor amounts of kaolinite and an intermediate Fe/Mg chlorite. Various I/S compositions were identified. Most samples contain an R1-ordered I/S (~78% illite) but a less mature *R*0-ordered, 50%illite I/S was identified in the shallowest samples in the Penshurst, Portsdown and Shalford boreholes. The deepest samples in the Balcombe and Shalford boreholes contain a more mature, *R*3-ordered I/S (~88% illite).
- Kaolinite shows increased concentrations in the samples from the Iden Green and Portsdown boreholes and the upper interval of the Shalford borehole. Chlorite shows increased concentrations and a change to a more Fe-rich composition in the deepest samples from the Balcombe, Iden Green and Shalford boreholes.
- Despite the complication of high concentrations of carbonate minerals, the sample's clay mineralogies provide an indication of the maturity and burial history of the samples, relevant to their potential as unconventional oil and gas sources and their likely engineering behaviour.
- Clay minerals suggest that the majority of the samples have been buried to ~4 km at above 'normal' geothermal gradients (~30°C/km) and are probably in the Light Oil maturity zone. These samples are likely to show a bedding parallel microfabric.
- The presence of an *R*0 50%illite I/S in the shallow samples from the Penshurst, Portsdown and Shalford boreholes places these samples in the Heavy Oil or even Immature zone, equivalent to burial of perhaps ~3 km at normal geothermal gradients. Such shallow burial means that these samples will probably only show a weak bedding-parallel microfabric.
- The *R*3-ordered I/S (~88% illite) present in the deepest samples from the Balcombe and Shalford boreholes places these samples in the Wet Gas zone, equivalent to burial of perhaps 5 km at normal geothermal gradients. Such burial typically produces a bedding-parallel microfabric.

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6. References

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Appendix D: Estimation of total organic carbon in the Jurassic shales of the Weald area by log analysis

C.M.A. Gent, S.D. Hannis & I.J. Andrews

1 Executive Summary

This appendix documents the calculation of total organic carbon (weight percent (TOCwt%)) from geophysical logs across the Jurassic shale formations of interest in southern England. Geophysical data were available from wells drilled in the 1980s and stored in the British Geological Survey database. These were extracted, verified and analysed using the Passey sonic method to give vertically continuous wt% TOC curves for each well. Estimated clay volume curves were also calculated to apply discriminators to the tabulated outputs. Intervals with clay volume values greater than 0.5 (50%) were considered 'net' for the average wt% TOC and net to gross (N/G) calculations, and intervals with greater than 2wt% TOC were considered organic-rich 'pay' in the pay to gross (P/G) values calculated for each of the Jurassic clay units listed:

- Kimmeridge Clay
- Corallian Clay
- Oxford Clay
- Upper Lias Clay
- Mid Lias Clay
- Lower Lias Limestone-Shale Unit

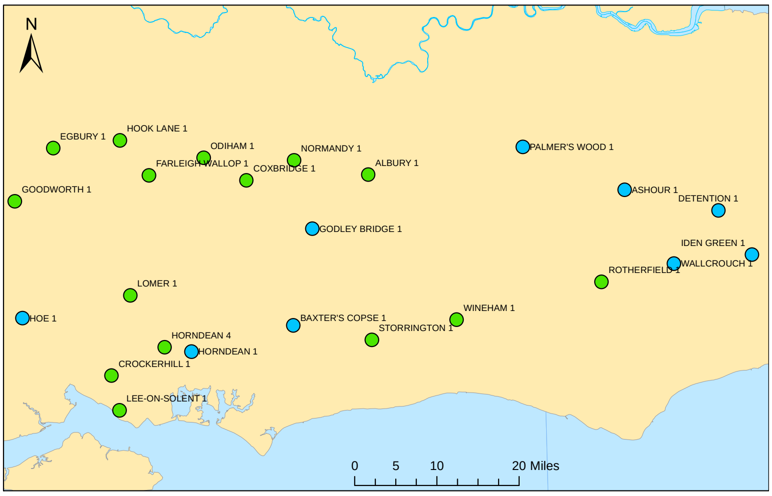

Figure 1. Wells selected for the study across the south of England. Wells with core sample TOC data are shown in blue.

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The formations with the highest calculated wt% TOC and highest proportions of organic-rich shale (P/G) were the Kimmeridge Clay, Corallian Clay and Oxford Clay units. These often had wt% TOC values greater than 4% over intervals of 100's of feet, giving P/G of greater than 0.5 (50%). Of these, the lower section of the Oxford Clay unit showed distinctly high wt% TOC values, with a mature source log signature in central wells. The Lias Group intervals showed lower wt% TOC values and correspondingly lower P/G. Log signatures indicated that this interval was mature and less prospective than the Upper Jurassic formations.

Geographically, the data show two trends:

- The north-west and south-west wells showed higher wt% TOC and P/G, but the formations there are in general thinner and more immature.
- There appears to be a belt from west to east across the central part of the study area which shows lower wt% TOC and P/G but generally thicker sequences with more discrete source intervals. These observations apply to all the formations (and for some formations similar trends were also observed in northern and southern locations).

2 Introduction

Assessing Total Organic Carbon (TOC) values of shales for use in shale gas and shale oil resource estimates has been traditionally done using core samples or less reliable cuttings samples. Core data are very limited both geographically and stratigraphically, and cuttings are affected by a number of drilling-related problems. Recently however, a method for assessing weight percent (wt%) TOC has been developed using analysis of geophysical well logs. This has enabled many wells with no core data to be analysed to give calculated TOC wt% values and complete vertical assessment of TOC wt% per well. Applied across the basin in question, this will improve resource estimates and can be a valuable aid to identifying likely productive intervals.

During the 1980s, numerous boreholes were drilled and logged to assess conventional hydrocarbon prospectivity in the Weald and Wessex Basins of southern England. The geophysical well log data were stored and/or digitised by the British Geological Survey.

The key aim for this study is to calculate TOC estimates in the Weald Basin and produce graphical logs showing these TOC estimates for 20-30 wells. The intervals of interest are all in the Jurassic and include the Lias Group, Oxford Clay, Corallian Clay and the Kimmeridge Clay, which are potential source rocks for conventional hydrocarbons in the basin.

3 Method

The method used for the study is as follows:

1. **Literature Research.** Research of published information relating to methods of deriving TOC weight percent from geophysical logs and Level of Maturity (LOM) from vitrinite reflectance was undertaken. Furthermore, research into good protocol using Senergy's Interactive

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Petrophysics™ (IP) software and RECALL (the British Geological Survey log database) was applied.

2. **Locating and Uploading Data.** Relevant geophysical log curves from RECALL were extracted, and if necessary multiple curves were combined to produce a single log curve per well. Total Organic Carbon (TOC) values were located for specific wells with core data available and uploaded. All data loaded into IP for further analysis.
3. **Verification of Data.** Verification of formation tops and log quality was undertaken using a variety of sources, and if inconsistencies were found the most reliable source of data was used.
4. **Analysis and Calculations using Geophysical Well Logs.** Various calculations were undertaken to determine LOM (for certain formations) for use in IP, TOC (from the Passey method) and the Volume of Clay (VCl).
5. **Presentation of Results.** The TOC was displayed with graphical logs, histograms and tabulated plots per formation. Statistics were produced for TOC for each formation, including averages, max/min and thicknesses of high TOC intervals relative to total reservoir thickness.

3.1 Literature search

***Passey et al.* (*1990*)** developed a method to calculate quantitatively TOC in weight percent from level of maturity (LOM) estimations and log responses in lean versus organic rich shales using a log overlay method known as ΔlogR. The resistivity curves were overlaid against either sonic, density or neutron logs at particular scales and shaded where their overlay indicates organic richness. *The Passey method was chosen for this study as it appears to be an industry-accepted method for calculation of TOC for shale gas, and test results compared favourably with those derived by other calculation methods* (*not described here*).

***Hood et al.* (*1975*)** developed the LOM scale needed in the Passey equation. The scale describes a single numerical scale applicable to the thermal range of interest. It is based on a combination of coal rank, vitrinite reflectance and spore carbonization. They inferred that Vitrinite Reflectance (known as VR or R_o, the latter will be used in this report) is directly related to LOM, therefore with accurate R_o values, LOM can be calculated.

***LeCompte & Hursan* (*2010*)** published a graph relating LOM and R_o with an associated equation of the line of regression. *This equation was used to calculate LOM from the R_o gathered from core data for this study.*

***Lamb* (*1983*)** mentioned that a lower oil maturity cut-off of 0.5% for R_o can be used, as below 0.5% the rock is immature. They also attempted to contour R_o for individual formations in the Jurassic over the Weald, confirming the decreasing maturity in shallower formations. *This was the basis for separating the central Weald as an area of higher maturity* (*and LOM values in this study*).

Williams (1986) used published and outcrop R_o and Time-Temperature Index (TTI) data to calculate burial history and maturity across the Wessex and Weald basins. His model was predominantly based on R_o. The results gave higher maturities than the models by Lamb (1983), but showed the Weald depocentre as a likely area of higher maturity. *This supports the higher maturity* (*and LOM values*) *applied in the central Weald in this study.*

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Ebukanson & Kinghorn (1986) used a chart based on spore data (similar to the coal rank LOM chart) to estimate R_o. Their study was concentrated on the Jurassic throughout England and included all formations of interest to this study. They predicted that the Kimmeridge and Oxford Clays are mainly immature to marginally mature (R_o = 0.3-0.5) and Liassic formations are mature (R_o = 0.5-0.85). *This supported a higher maturity (and LOM value) for the central Weald and gave R_o figures needed to assess the LOM range.*

Scotchman (1991) used limited borehole and outcrop data with TOC, R_o, kerogen type and Hydrogen Index (HI) to model the maturity of the Kimmeridge Clay in southern and eastern England. He plotted the data sets against depth and each other to comment on the reliability of each parameter. He found R_o had a wide spread of data and no relationship with estimated maximum burial depth, suggesting much of the vitrinite had been reworked. This suggests that, R_o alone cannot be used to determine LOM. *Therefore a range was used for the LOM parameter in the calculations in this study, as it is recognised as having high uncertainty.*

3.2 Locating and uploading data

The candidate well list comprised 41 wells which were all contained in the BGS log software RECALL, of these 24 wells were selected as suitable for analysis.

a. The first step was to extract the well data from RECALL as *.las files which can be imported into IP. Many of the wells had digital composite files created, including a suite of logging curves that provide a complete log from top to bottom combining several sections of the well into a continuous data set. If the composite files were unavailable, individual files from each well section were extracted for merging (step b). If neither the composite or individual files were available, the hand-digitalised archive data was used (this data was digitised by hand, often very poorly, and was only used if no other data was available).
b. The data was uploaded into IP. Any individual files were combined manually to create composite curves over the whole well.
c. The TOC and R_o data for the wells with available core and cuttings data were extracted from the geochemical analyses collated for the main report. The TOC were then uploaded into IP. Use of the R_o data is described in Section 3.4.

3.3 Verification of data and quality checking

The data extracted required verification as follows:

a. The uploaded digital curves in IP were compared to those on the composite log plot scans:
    - To verify the curve responses with depth and their scales. Any differences between the digital plot and log plot composite were noted.
    - Any data gaps in the digital curves (often as a result of no data recorded (for example across casing shoes or due to logging problems)) were filled by a straight line) and recorded.
b. The formation tops were loaded into IP and also compared with the composite log plots (if disagreements between the two depths arose, the formation tops provided were chosen preferentially (unless there was a major difference in the two values))

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c. The logging curves were assessed for quality, by checking for unusual responses, checking responses were within tolerance (where suitable curves were available) and noting where poor hole conditions affected the data:
   - the caliper curve (CALI) measures hole size. This identified wash outs (enlargement) in some places, particularly over the clay intervals, which can detrimentally affect other curve responses (in particular those which require pressing against the borehole wall to read correctly, such as the density or neutron data). Where the caliper is open to its maximum extent (curve flat-lining), data from those tools that rely on borehole wall contact were treated as suspect or unreliable.
   - the density correction curve (DRHO) should fall within the -0.1 and 0.1 range for good density (RHOB) data. Outside of this range, the density data were treated as suspect or unreliable.
   - Many of the wells had intervals of poor density data (DRHO out of tolerance), reinforcing the use of sonic data (less affected by poor hole conditions) for the Passey TOC calculations.

3.4 Analysis and calculation of geophysical wellogs

The main objective of the project was to produce logs showing the TOC of wells across the basin, these are accompanied by statistical outputs for each well. To be able to calculate the TOC, the LOM values were established. Also, to discriminate shale source from sand/limestone reservoir a volume of clay cut-off was required.

Volume of Clay (*VCl*). The calculation of the Volume of Clay parameter is based on the gamma ray (GR) response. In general a higher GR value is indicative of a larger percentage of clay. The output curve is scaled between 0-1 (1 being 100% clay and 0 being 100% 'clean'). It was used as a discriminator in subsequent calculations, to remove intervals with less than 50% clay (i.e. those considered unlikely to be prospective for shale gas and oil). Each well was subdivided into two intervals (Kimmeridge/Oxfordian and Lias Group) which were processed individually to define the minimum and maximum GR parameters required. Neutron-density data, where good quality was available, was used to cross-verify the GR-derived VCl curves.

Level of Maturity (LOM). A key parameter in the Passey equation for calculating TOC is the Level of Maturity. This can be calculated from R_o values measured on core samples (Hood *et al.* 1975). The R_o values from several boreholes were plotted against depth and by formation, but in general they showed only very poor correlations (as suggested by Scotchman 1991). Therefore, as detailed in the main report, published ranges of values were used, by formation, across the basin. This published data suggested that the central Weald has higher maturity than the rest of the basin (Lamb 1983, Williams 1986); therefore the central Weald

	LOM used (min-max (average)) Equivalent R_o range			
Interval	**Wessex and Outer Weald Basin**		**Central Weald Basin**	
Kimmeridge to Oxfordian	6-7 (6.5)	**0.4-0.5**	7-8 (7.5)	**0.5-0.6**
Lias Group	7-9 (8)	**0.5-0.7**	9-11 (10)	**0.7-1.0**

Table 1. The range of Level of Maturity for the study area for each formation. (Average bracketed). Equivalent R_o range used. See map for area.

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was assigned higher LOM values. As the LOM values could not be accurately assessed for each individual well, a range of LOM values was assigned, to incorporate the maximum and minimum potential LOM values for each formation (as per the published data).

Passey Method for Calculating TOC. The TOC was calculated using the Passey-method inbuilt IP TOC calculator. Wells with core data were implemented first, to assist in selecting the parameters and calibrating the output TOC curve to the core data where appropriate. In the Passey method, (specifically scaled sonic and resistivity) curves were made to overlay in a 'lean shale'. The wells were split vertically into 3 zones, representing the Kimmeridge, Corallian/Oxfordian and Lower Jurassic, and the overlay adjusted in each zone to a lean shale point, consistent across all the wells. The density and neutron overlay plots were used to verify those of the sonic. Where the sonic data was poor quality and density or neutron data was better, the TOC curve calculated from density or neutron logs was used in preference and spliced into the final TOC curve.

The output TOC curves were calculated first at the average LOM (Table 1 (bracketed values)), to give a TOC_M curve (the 'most likely' value). The LOM parameters were then adjusted to the maximum and minimum values in Table 1 and the TOCs recalculated (TOC_L and TOC_H, respectively), to represent the sensitivity of TOC outputs to the LOM parameter. This is displayed as the blue shading on the TOC curve in the graphical log plots (higher LOM values give **lower** TOC values for a given set of logs).

Log Quality Flags. In areas where data was poor or absent, for example, as a result of casing shoe gaps, sonic spikes, or other anomalous data, this was noted. If appropriate the logs were edited (e.g. alternate log spliced in) and the zones were flagged to warn of the different data handling and potentially suspect data over that zone.

3.5 Presentation and explanation of results

The main findings and geographical trends are documented in the Results Section by formation summary tables, and maps are also included.

Results by well are also included at the end of this appendix in the form of graphical log plots and tables of summary statistics. The tables contain TOC statistics, Net/Gross and Pay/Gross values from the formations of interest, with cut-offs applied to discriminate clean intervals, reservoirs and poor TOC values as listed below:

- TOC statistics. Minimum, maximum and mean values are included.
- Net/Gross. This indicates the amount of each formation that is considered to be shale. Intervals where VCl is greater than 0.5 (50% clay) are included as 'net'. Gross is the total formation thickness.
- Pay/Gross. This indicates the amount of each formation that is considered to be potentially prospective for shale gas and oil. Net intervals where TOC is greater than 2wt% are included as organic-rich 'pay'. Gross is the total formation thickness.

Results were displayed graphically for each well in a seven track log plot. These include in track order:

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1. Formations intervals. Intervals of interest are coloured.
2. Measured Depth (MD) below Kelly Bushing (KB) in feet
3. Data quality track, flagged to warn of the different data handling and potentially suspect data over that zone.
4. Gamma Ray (GR) and Caliper. The GR is the natural formation gamma ray response, which tends to be higher in shales. Caliper indicates hole size and can give an indication of enlarged or rugose hole which may affect data quality (see Section 3d).
5. Volume of Clay (VCl) with the 50% clay cut-off represented by 'clean' and 'shaly' shading.
6. The Passey Sonic-Resistivity curves, with yellow shading representing TOC-rich intervals.
7. Final TOC values with grey shading to indicate >2 wt% TOC, blue shading to indicate TOC range (between TOC_L and TOC_H) and, where possible, TOC values from cores/cuttings.

4 Assumptions and limitations

The following assumptions and limitations should be considered when analysing the results and graphical TOC log plots:

- Well thickness is measured thickness, not true vertical thickness. Wells known to have significant deviation are indicated by an asterisk (*) in the table.
- The Level of Maturity parameter required for the Passey method TOC calculation is assumed to fall within the range chosen (Table 1). Values of LOM outside this range could change the final TOC value significantly. Sensitivity on this parameter is represented by the blue shading on the log plots and the TOC_L and TOC_H values in the tables are based on the values in Table 1.
- The Passey method also requires the selection of a 'Lean Shale' point where a shale is assumed to have no organic content. Where possible similar lean shale stratigraphic intervals have been chosen for each well for consistency. In general, a different 'lean shale' point has been chosen for each group of formations (Kimmeridge/Oxford (incl. Corallian)/Lias). No sensitivity on this parameter has been done for this study, so this should be taken into consideration when examining the absolute TOC values reported here.
- The VCl parameters selected have been chosen as consistently as possible between wells, backed up by neutron-density data where possible to enable the distinction between clean and shaly intervals. A cut-off of 0.5 has been arbitrarily applied to remove non-clayey intervals.
- Stratigraphic formation tops for each well were provided from the main part of this study.
- The numbers and locations of wells used in this study were limited by the availability of suitable, good quality geophysical log data.

5 Results

Each interval of interest has been assessed and the results on this interval reported separately. Comments have been made on the geographical distribution of wells in relation to their TOC values calculated and where possible, intervals of likely mature source shale have been highlighted. According to Passey *et al.* (1990), a mature source rock interval can be distinguished from one which is immature by increased resistivity (Figure 2). The results for each individual well are reported at the

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end of this appendix. These include graphical log plots, histograms of TOC calculated for each formation and tabulated curve statistics. When assessing the absolute values and quality of the results reported here, the assumptions and limitations (above) should be taken into consideration.

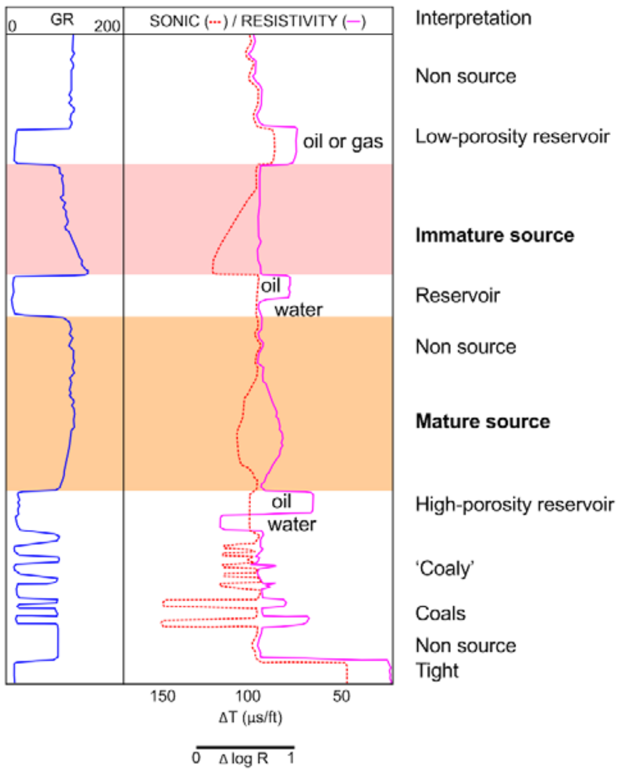

Figure 2. A schematic guide for the interpretation of a variety of features seen on the ΔlogR overlays. The part relating to distinguishing the maturity of source shale for this study is highlighted (modified from Passey et al. 1990).

5.1 Kimmeridge Clay (Table 2)

The Kimmeridge Clay is on average the richest TOC interval with mean values between 2.4wt% (*Ashour 1*) and 7.9wt% (*Hoe 1*). It also contains the thickest shales of the formations studied, with net (shale) thicknesses varying from 395 ft (*Normandy 1*) to 1270 ft (*Godley Bridge 1*), and high N/G values ranging from 0.75 (*Ashour 1*) to 0.96 (*Hoe 1*).

With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 237 ft (*Iden Green 1*) to 884 ft (*Wallcrouch 1*) and pay/gross (P/G) varies from 0.36 (*Iden Green 1*) to 0.96 (*Hoe 1*); the majority of the data showed a P/G between 0.5 and 0.8.

However, the Kimmeridge Clay is often subdivided based on the presence of two micrite beds. These can be used to define three subdivisions: the upper Kimmeridge, the middle Kimmeridge (bound by the two micrites) and the lower Kimmeridge.

Observations from the graphical logs plots show poorer TOC in the upper and lower part of the Kimmeridge Clay. The major TOC-bearing intervals within the Kimmeridge can be mostly attributed

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to the middle Kimmeridge and the top of the lower Kimmeridge. These two zones show higher TOC in most wells studied and form a distinctive, geographically persistent response across the study area.

Geographical Variation and Maturity (*Figure 3*)

In general, wells in the east of the study area show poorer TOC values, although the net thicknesses are larger. This poor TOC and lower P/G zone stretches in a belt across the central Weald incorporating *Godley Bridge 1* to *Iden Green 1*. The wells in the west and across the northern margin of the study area show higher TOC % as well as higher P/G**.**

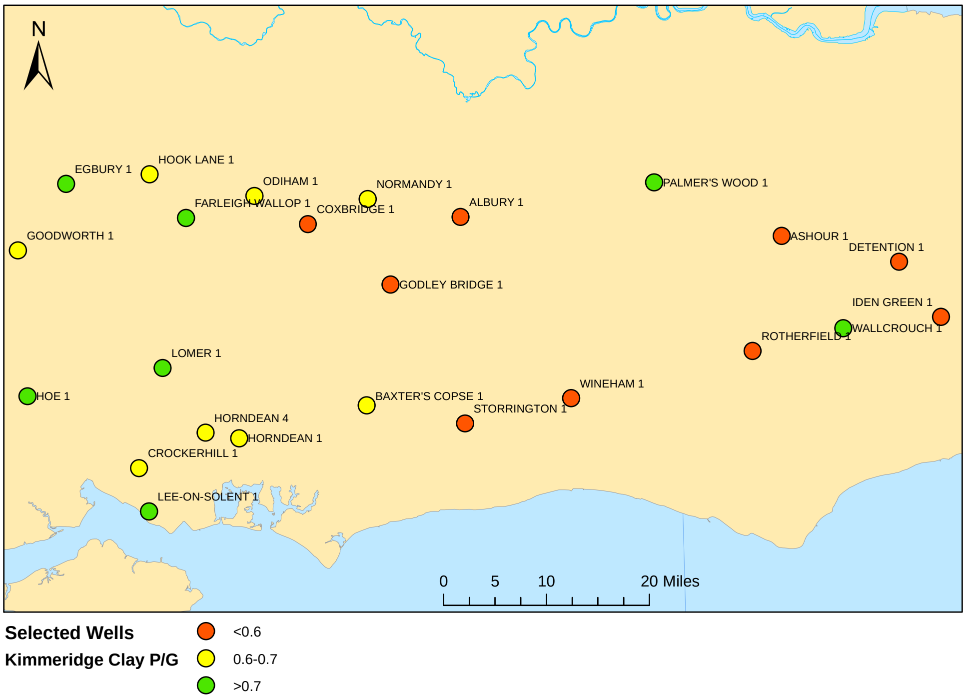

Figure 3. Geographical distribution of pay/gross (P/G) values for the Kimmeridge Clay.

The Kimmeridge Clay in the west is generally immature. Although they have higher average TOC wt% values and P/G, they do not show the same discrete mature source rock intervals that can be observed in the eastern wells. Using the Passey schematic for identifying source rock intervals, the Kimmeridge as a whole is suggested to be immature, although more mature shales are likely to be found in the low TOC central belt.

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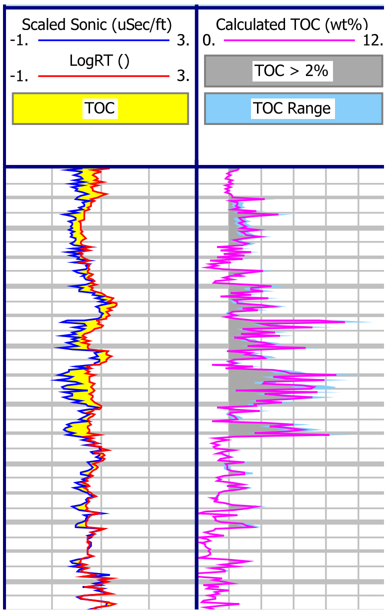
Rotherfield 1



Lomer 1

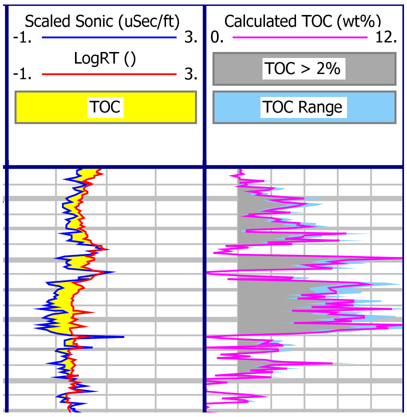


Figure 4. A comparison of two similar signals in wells to show the effect of a different assumed maturity (LOM). The two wells show similar LogRT separation across the Kimmeridge. However, *Rotherfield* 1 has a higher LOM parameter in comparison with *Lomer 1*. Note how the TOC is reduced by at least 2wt% by applying the higher LOM parameter.

Some of the wells in the central belt which have low calculated TOC values also have higher LOM parameters applied than wells outside the central belt (Table 1). Using the Passey method, which is dependent on the Level of Maturity (LOM) (Table 1); larger LOM values give correspondingly smaller TOC values. Thus it may be that these lower TOC wt% values in the central belt are a direct result of the higher LOM parameters applied (Figure 4). The absolute TOC values should therefore be treated with caution according to the limitations and assumptions listed on page 7.

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Name	**Avg TOC over net shale thickness (calculated wt%)**	**G, gross formation thickness (ft)**	**N, net (shale) thickness (ft)**	**N/G**	**P, pay thickness (ft)**	**P/G**
Albury 1	3.6	617.8	441.0	0.71	325.8	**0.53**
Ashour 1	2.4	1182.0	885.3	0.75	402.3	**0.34**
Baxters Copse 1	3.6	902.5	755.3	0.84	571.0	**0.63**
Coxbridge 1	3.5	1025.0	858.8	0.84	617.8	**0.60**
Crockerhill 1	4.0	746.6	704.3	0.94	511.0	**0.68**
Detention 1	3.1	742.0	513.0	0.69	368.3	**0.50**
Egbury 1	4.8	583.5	513.8	0.88	454.8	**0.78**
Farleigh Wallop 1	3.9	695.5	652.5	0.94	494.0	**0.71**
Godley Bridge 1	3.6	1656.0	1270.8	0.77	830.0	**0.50**
Goodworth 1	3.0	635.3	629.8	0.99	418.7	**0.66**
Hoe 1	7.9	482.9	465.7	0.96	461.8	**0.96**
Hook Lane 1	3.4	577.5	553.7	0.96	391.4	**0.68**
Horndean 1	4.0	582.1	530.5	0.91	384.5	**0.66**
Horndean 4	3.5	482.5	471.7	0.98	293.7	**0.61**
Iden Green 1	3.0	664.1	477.9	0.72	236.9	**0.36**
Lee-on-Solent 1	4.6	634.6	592.1	0.93	480.0	**0.76**
Lomer 1	4.6	777.0	717.3	0.92	559.3	**0.72**
Normandy 1	3.9	442.0	395.1	0.89	280.2	**0.63**
Odiham 1	3.7	573.0	536.3	0.94	389.8	**0.68**
Palmers Wood 1	4.3	761.2	677.4	0.89	546.9	**0.72**
Rotherfield 1	2.8	1273.0	1061.4	0.83	658.5	**0.52**
Storrington 1	3.1	1289.8	1106.1	0.86	697.4	**0.54**
Wallcrouch 1	3.9	1179.9	932.5	0.79	884.9	**0.75**
Wineham 1	3.5	1263.5	1096.0	0.87	677.0	**0.54**
Formation average	3.8		701.6	0.87	497.3	**0.63**

Table 2. Summary of the average wt% TOC over net shale thickness, gross thickness, net (shale) thickness and pay thickness (for organic-rich shale) for the Kimmeridge Clay across the analysed wells.

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5.2 Corallian Clay (Table 3)

The Corallian Clay is a good source rock interval with mean TOC values between 1.0wt% (*Godley Bridge 1*) and 6.9wt% (*Egbury 1*). The net shale thicknesses (compared to the Kimmeridge) are thin, varying from 50 ft (*Hook Lane 1*) to 265 ft (*Storrington 1*), with high N/G values ranging from 0.88 (*Horndean 1*) to 1.0 (12 wells).

With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 29.5 ft (*Godley Bridge 1*) to 166 ft (*Storrington 1*) and P/G varies from 0.19 (*Godley Bridge*) to 1.0 (*Odiham 1*), with the majority of wells ranging from 0.4 to 0.98. A positive correlation between average wt% TOC values and P/G is also observed.

The Corallian Clay shows a distinctive log trace, lying between the cleaner Corallian Sandstone Unit and the Corallian Limestone Unit below. The interval is distinguished by a small but consistent deflection of the scaled sonic curve, with minimal spikes. This gives a smooth, high-TOC log signature, without the high frequency, high amplitude 'spikey' peaks and troughs, seen in the Kimmeridge sections.

Geographical Variation and Maturity (*Figure 5*)

In general, wells in central and southern areas show poor wt% TOC values and P/G from *Baxters Copse* 1 to *Detention 1*. Wells across the northern margin of the study and in the west show higher TOC values and P/G. The shales in the lower TOC value wells are leaner, with the graphical log plot of *Godley Bridge 1* showing complete overlap of the scaled sonic and resistivity indicating a non-source shale.

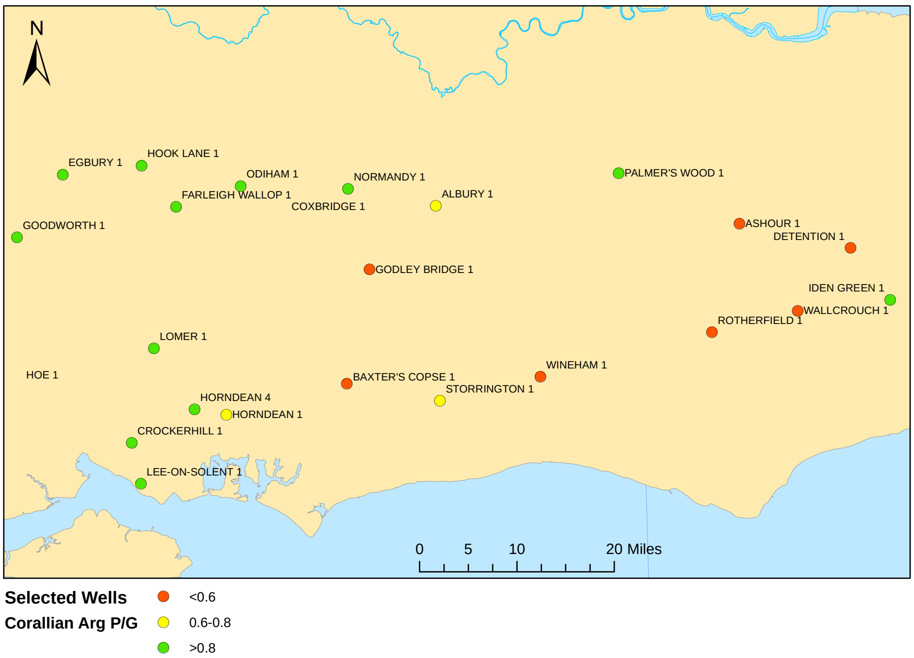

Figure 5. Geographical distribution of pay/gross (P/G) values for the Corallian Clay.

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From a maturity perspective, the Corallian Clay shows a typical immature log signature in which, as for most of the Kimmeridge Clay, the Log RT stays constant as the scaled sonic increases (Figures 1 & 6).

At the *Hoe 1* and *Coxbridge 1* wells, there is no Corallian Clay present as it has been removed by faulting.

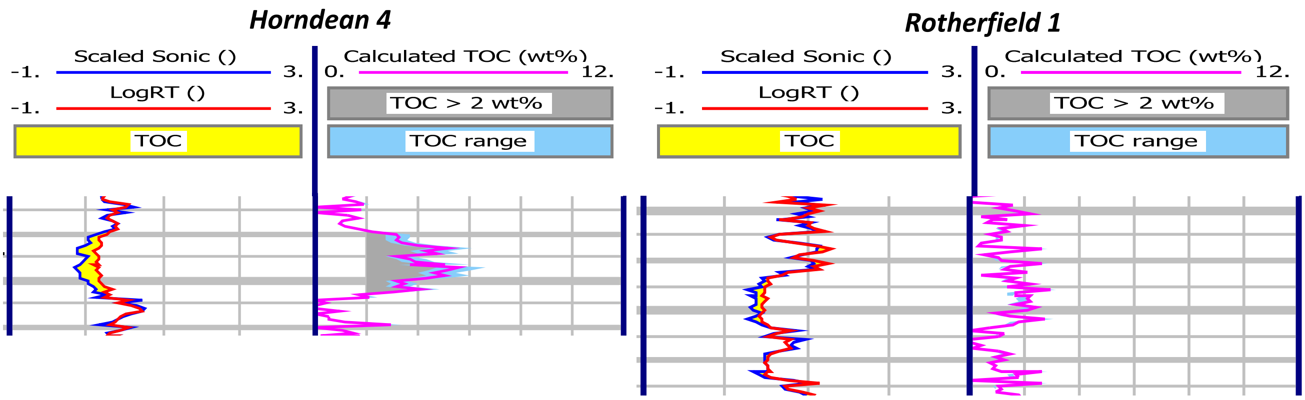

Figure 6. An example of the Corallian Clay in the TOC (purple track) richer marginal southern well (Horndean 4) and the TOC-poorer central well (Rotherfield 1).

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Name	**Avg TOC over net shale thickness (calculated wt%)**	**G, gross formation thickness (ft)**	**N, net (shale) thickness (ft)**	**N/G**	**P, pay thickness (ft)**	**P/G**
Albury 1	3.6	187.4	187.4	1.00	146.8	**0.78**
Ashour 1	1.7	101.0	99.8	0.99	36.0	**0.36**
Baxters Copse 1	1.8	223.0	220.8	0.99	86.0	**0.39**
Crockerhill 1	4.2	97.6	97.4	1.00	95.5	**0.98**
Detention 1	1.9	82.0	72.8	0.89	35.0	**0.43**
Egbury 1	6.9	75.5	72.3	0.96	68.3	**0.90**
Farleigh Wallop 1	6.5	77.5	77.5	1.00	74.3	**0.96**
Godley Bridge 1	1.0	159.5	158.3	0.99	29.5	**0.19**
Goodworth 1	4.6	81.0	81.0	1.00	75.8	**0.94**
Hook Lane 1	5.3	54.8	50.9	0.93	45.6	**0.83**
Horndean 1	3.9	153.8	135.9	0.88	116.6	**0.76**
Horndean 4	3.7	136.0	134.5	0.99	123.6	**0.91**
Iden Green 1	3.8	64.5	64.3	1.00	60.7	**0.94**
Lee-on-Solent 1	5.8	98.8	96.5	0.98	94.2	**0.95**
Lomer 1	3.8	102.0	102.0	1.00	96.0	**0.94**
Normandy 1	6.1	119.0	118.6	1.00	116.0	**0.98**
Odiham 1	5.3	108.0	108.0	1.00	108.0	**1.00**
Palmers Wood 1	3.6	82.0	80.6	0.98	71.5	**0.87**
Rotherfield 1	1.7	112.5	112.5	1.00	35.9	**0.32**
Storrington 1	2.5	268.3	265.6	0.99	165.8	**0.62**
Wallcrouch 1	2.1	94.1	92.6	0.98	52.0	**0.55**
Wineham 1	2.0	189.0	189.0	1.00	87.5	**0.46**
Formation average	3.3		123.1	1.0	79.3	**0.67**

Table 3. Summary of the average wt% TOC over net shale thickness, gross thickness, net (shale) thickness and pay thickness (for organic-rich shale) for the Corallian Clay across the analysed wells. Note the absence of the Corallian in Coxbridge 1 and Hoe 1.

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5.3 Oxford Clay (Table 4)

The Oxford Clay is a fair to good source rock interval, with mean TOC vales between 1.3wt% (*Palmers Wood 1*) and 4.7wt% (*Crockerhill 1*), and with the majority of the average TOC values falling between 1.6 and 4.3wt%. Net shale thicknesses vary from 162 ft (*Farleigh Wallop 1*) to 481 ft (*Lee-on-Solent 1*), with high N/G values ranging from 0.43 (*Farleigh Wallop 1*) to 1.0 (5 wells), the majority of the data falling between 0.8 and 1.0.

With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 36 ft (*Iden Green 1*) to 382 ft (*Lee-on-Solent 1*) and pay/gross varies from 0.18 (*Iden Green 1*) to 0.77 (*Coxbridge 1*). However, previous studies have concluded that the middle Oxford Clay is a TOC-poor interval and it can sometimes be viewed as a non-source shale. This leanness of the middle to upper Oxford Clay is observed in the results and is the cause of the low P/G values. Conversely, the lower Oxford Clay is an organic-rich interval and shows a distinctive log curve separation as a result of high TOC values from 4 to more than 8wt%.

The average Oxford Clay results from *Rotherfield 1* should be ignored (Table 4), as the log was run through a casing shoe over the lower, TOC-rich part of the formation. Therefore the data only represents the lean upper and middle Oxford Clay.

Geographical Distribution and Maturity (*Figure 7*)

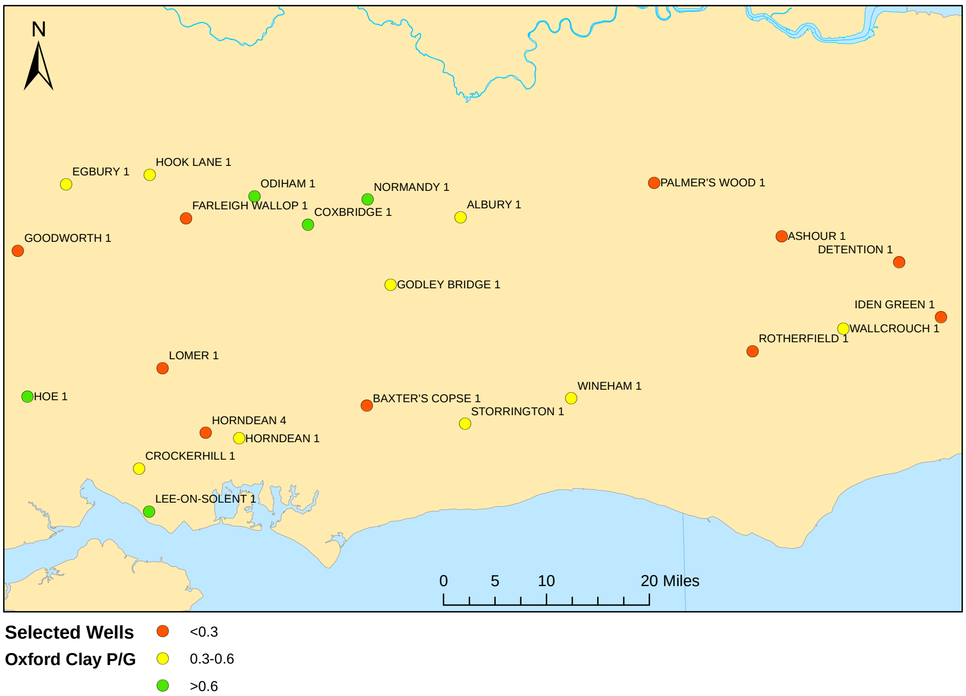

Figure 7. Geographical distribution of pay/gross (P/G) values for the Oxford Clay.

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Overall, the wells in the west and south of the study area have the highest TOC values, with the eastern wells showing lowest TOC values. However, the trends are not as clear as in the Corallian and Kimmeridge intervals. Wells in the east also tend to show lower pay thicknesses, the thinner intervals most notable in *Iden Green 1* and *Wallcrouch 1*.

From the maturity perspective, the lower Oxford Clay is the most mature interval. This is most notable in the wells in the east and in a belt across the central Weald. From *Lomer 1* to *Iden Green 1*, the wells show a clear ΔlogR curve separation with both scaled sonic and resistivity separating relative to each other, denoting a mature source (Figure 2 and Figure 8a). Wells in the west and southwest show a more marginal maturity, as the sonic increases, the ΔlogR also does, but less so from *Egbury 1* to *Horndean 1*. The Oxford Clay in wells across the northern margin of the basin from *Odiham* 1 to *Palmers Wood 1* appears to be immature (Figure 8b).

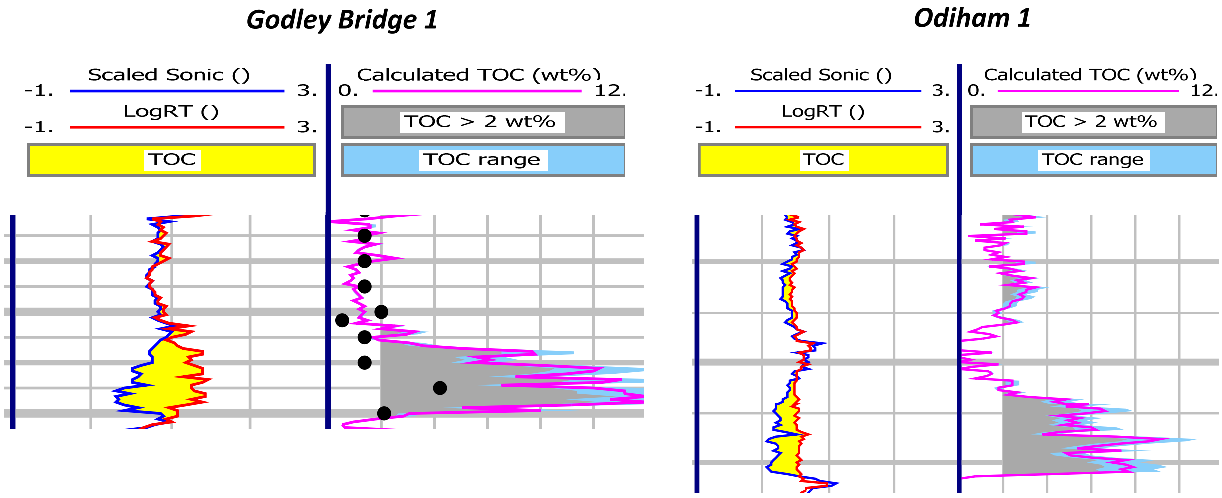

Figure 8. An example of immature vs mature shales in the Oxford Clay. (a) Godley Bridge 1 shows a marked increase in resistivity, suggesting the shales there are mature. (b) Odiham 1 shows a roughly constant resistivity (*red curve*) *indicating immaturity.*

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Name	**Avg TOC over net shale thickness (calculated wt%)**	**G, gross formation thickness (ft)**	**N, net (shale) thickness (ft)**	**N/G**	**P, pay thickness (ft)**	**P/G**	**Maturity comments**
Albury 1	2.4	373.1	365.7	0.98	163.4	**0.44**	Not Mature
Ashour 1	1.8	275.5	261.8	0.95	75.0	**0.27**	Not Mature
Baxters Copse 1	2.1	415.5	415.5	1.00	106.5	**0.26**	Mature
Coxbridge 1	3.2	196.0	196.0	1.00	150.3	**0.77**	Not Mature
Crockerhill 1	2.4	462.0	460.0	1.00	180.3	**0.39**	Mature
Detention 1	1.9	265.5	253.5	0.95	54.8	**0.21**	Spliced Data
Egbury 1	2.3	384.5	367.0	0.95	165.0	**0.43**	Marginally mature
Farleigh Wallop 1	3.5	376.0	162.5	0.43	74.0	**0.20**	Mature
Godley Bridge 1	3.9	381.0	372.8	0.98	165.3	**0.43**	Mature
Goodworth 1	1.8	459.3	458.4	1.00	133.2	**0.29**	Marginally mature
Hoe 1	3.9	424.9	376.7	0.89	315.0	**0.74**	Marginally mature
Hook Lane 1	4.3	404.7	206.7	0.51	160.8	**0.40**	Spliced Data
Horndean 1	3.6	423.3	356.8	0.84	239.7	**0.57**	Marginally mature
Horndean 4	2.1	417.1	404.7	0.97	116.3	**0.28**	Mature
Iden Green 1	1.6	202.0	202.0	1.00	36.1	**0.18**	Marginally mature
Lee-on-Solent 1	4.1	520.4	481.0	0.92	382.6	**0.74**	Marginally mature
Lomer 1	2.7	428.0	335.3	0.78	125.0	**0.29**	Marginally mature
Normandy 1	3.2	284.1	274.9	0.97	172.9	**0.61**	Not Mature
Odiham 1	3.1	259.5	257.5	0.99	162.1	**0.62**	Not Mature
Palmers Wood 1	1.3	311.0	309.2	0.99	80.5	**0.26**	Mature
Rotherfield 1	(1.1)	286.3	284.3	0.99	(12.8)	**(0.05)**	Data fill
Storrington 1	2.6	498.1	466.1	0.94	154.4	**0.31**	Mature
Wallcrouch 1	2.1	277.3	268.9	0.97	87.8	**0.32**	Marginally mature
Wineham 1	2.3	384.0	317.0	0.83	127.3	**0.33**	Mature
Formation average	2.7		327.3	0.91	149.0	**0.41**	

Table 4. Summary of the average wt% over net shale thickness, gross thickness, net (shale) thickness and pay thickness (for organic-rich shale) for the Oxford Clay across the analysed wells. A comment on maturity has been made, based on Figure 1. As a result of splicing, no comment could be made on the maturity for some wells. Note the data fill over the lower Oxford Clay of Rotherfield 1 (excluded from the formation averages).

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5.4 Upper Lias Clay (Table 5)

The Upper Lias Clay represents a relatively poor source rock interval with mean TOC values ranging between 0.53wt% (*Godley Bridge 1*) to 2.9wt% (*Farleigh Wallop 1*), with the majority of values falling between 0.9wt% and 2wt%. Net shale thicknesses vary from 59 ft (*Odiham 1*) to 273 ft (*Storrington 1*), with very high N/G values ranging from 0.53 (*Horndean 1*) to 1.0 (19 wells).

With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 0 ft (four wells) to 190.5 ft (*Wineham 1*) and P/G varies between 0 (five wells) and 1.0 (*Farleigh Wallop 1*), with most of the data falling between 0 and 0.53 (*Hook Lane 1*). As the majority of the wells have TOC wt% on average below the 2wt% cut-off, the pay thicknesses and P/G are affected.

Wineham 1 and *Farleigh Wallop 1* show the highest P/G of 1.0 and 0.83 respectively, because they marginally exceed the 2wt% TOC cut-off.

For *Horndean 4*, *Baxters Copse 1* and *Lee-on-Solent 1*, there was no interpreted Upper Lias Clay, hence their exclusion from Table 5.

Geographical Distribution and Maturity (*Figure 9*)

The only geographical trend observed for the Upper Lias Clay is that wells in the northern margin of the study area have similar P/G values of 0.4-0.5 and similar TOC wt% values of 1.5-2.3%. The rest of the study area has a lower P/G, which is not above 0.16, with the majority less than 0.05.

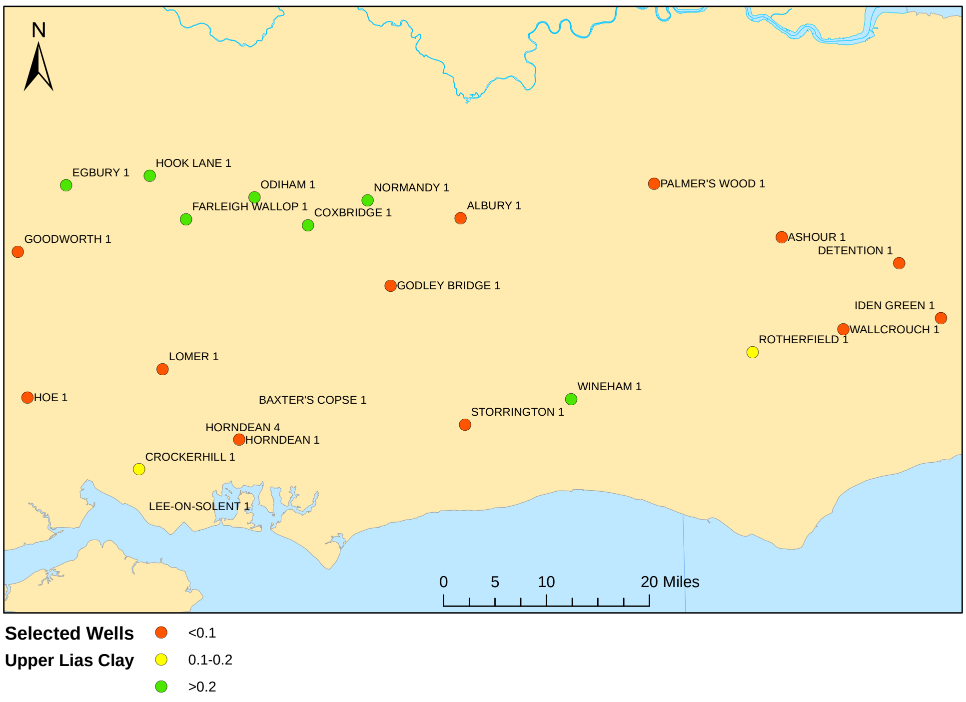

Figure 9. Geographical distribution of pay/gross (P/G) values for the Upper Lias Clay. Wells where the Upper Lias is absent have only labels.

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With regards to maturity, there is an increase in ΔLogR with a corresponding increase in sonic; therefore the Upper Lias Clay can be said to be mainly mature for oil generation (e.g. Wineham 1 and Egbury 1).

Name	Avg TOC over net shale thickness (calculated wt%)	G, gross formation thickness (ft)	N, net (shale) thickness (ft)	N/G	P, pay thickness (ft)	P/G
Albury 1	1.0	110.4	110.4	1.00	0.0	**0.00**
Ashour 1	0.9	123.0	123.0	1.00	0.0	**0.00**
Coxbridge 1	1.8	76.5	76.5	1.00	33.0	**0.43**
Crockerhill 1	1.8	73.2	73.2	1.00	9.8	**0.14**
Detention 1	1.2	151.0	149.5	0.99	1.0	**0.01**
Egbury 1	1.6	143.5	143.5	1.00	73.5	**0.51**
Farleigh Wallop 1	2.9	60.0	60.0	1.00	49.8	**0.83**
Godley Bridge 1	0.5	62.5	61.5	0.98	0.0	**0.00**
Goodworth 1	1.3	85.0	85.0	1.00	1.6	**0.02**
Hoe 1	1.3	106.1	106.1	1.00	1.6	**0.02**
Hook Lane 1	2.4	95.1	95.1	1.00	50.4	**0.53**
Horndean 1	1.4	308.7	164.7	0.53	12.1	**0.04**
Iden Green 1	1.4	104.9	104.9	1.00	5.6	**0.05**
Lomer 1	1.2	144.5	144.5	1.00	0.5	**0.00**
Normandy 1	1.9	74.5	74.5	1.00	33.1	**0.45**
Odiham 1	2.0	59.3	59.3	1.00	27.4	**0.46**
Palmers Wood 1	0.9	164.0	164.0	1.00	0.0	**0.00**
Rotherfield 1	1.9	107.3	107.1	1.00	16.7	**0.16**
Storrington 1	1.3	273.0	273.0	1.00	4.6	**0.02**
Wallcrouch 1	1.0	135.2	135.2	1.00	2.3	**0.02**
Wineham 1	2.5	190.5	190.5	1.00	190.5	**1.00**
Formation average	1.5	126.1	119.1	0.98	24.5	**0.22**

Table 5. Summary of the average wt% TOC over net shale thickness, gross thickness, net (shale) thickness and pay thickness (for organic-rich shale) for the Upper Lias Clay across the analysed wells. Note the absence of Upper Lias Clay in Horndean 4, Baxters Copse 1 and Lee-on-Solent 1.

5.5 Mid Lias Clay (Table 6)

The Mid Lias Clay also represents a relatively fair source rock interval with mean TOC values between 0.7wt% (*Detention 1*) and 4.1wt% (*Farleigh Wallop 1*), with most values falling between 1.1wt% and 2.4wt%. Net shale thickness values are high, varying from 89 ft (*Normandy 1*) to 379 ft (*Goodworth 1*), with high N/G values ranging from 0.84 (*Normandy* 1) to 1.0 (*20 wells*).

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With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 0 ft (three wells) to 178.5 ft (*Crockerhill* 1) and P/G vary considerably from 0.0 (three wells) to 1.0 (*Farleigh Wallop 1*).

This interval shows sensitivity to the LOM parameter and chosen 'lean shale' point. As the TOC wt% data and graphical log plots suggest, much of the data is consistently near 2wt% TOC. Should the data plot at an average of 1.9wt% over 150 ft this would still fall below the 2wt% cut-off (Figure 10).

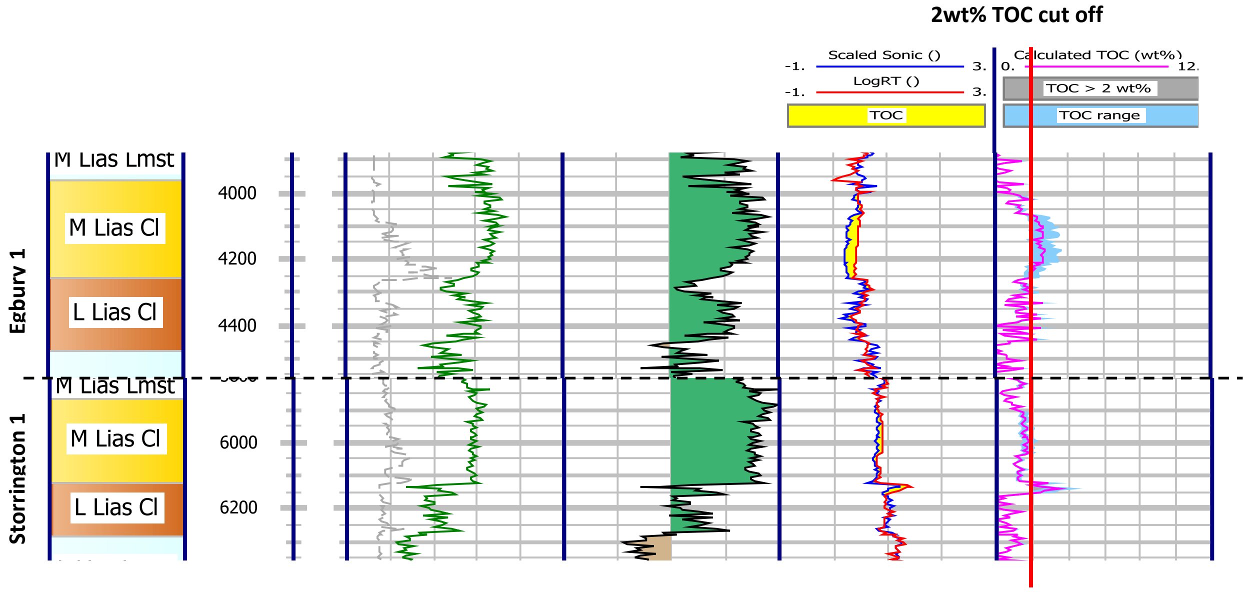

Figure 10. A comparison of two Middle/Lower Lias Clays. In Egbury 1 the Mid Lias Clay has TOC marginally above the 2% cut-off, whereas in Storrington 1 it is marginally below.

Geographical Distribution and Maturity (*Figure 11*)

The only distinguishable geographical distribution trend is that a central belt from Goodworth 1 to Iden Green 1 (including Albury 1 to Palmers Wood 1 on the northern margin) shows lower TOC wt% and hence lower P/G (0.0 at 3 wells to a maximum of 0.28 at Godley Bridge 1). The only exception is Rotherfield 1, which has abnormally high wt% TOC and P/G for its location. For many of these wells, TOC values may just fall below the 2% cut-off (Figure 10).

The other locations in the north-west and south-west show higher TOC values and higher P/G ranging from 0.49 (3 wells) to 1.0 (Farleigh Wallop 1).

The ΔlogR response of the scaled sonic and resistivity logs across all the wells seems to suggest that the Mid Lias Clay is mature.

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Name	Avg TOC over net shale thickness (calculated wt%)	G, gross formation thickness	N, net (shale) thickness (ft)	N/G	P, pay thickness (ft)	P/G
Albury 1	1.4	171.4	169.1	0.99	5.6	**0.03**
Ashour 1	1.3	196.0	196.0	1.00	0.0	**0.00**
Baxters Copse 1	1.1	308.0	308.0	1.00	2.5	**0.01**
Coxbridge 1	2.0	209.0	209.0	1.00	102.5	**0.49**
Crockerhill 1	2.4	193.9	193.9	1.00	178.5	**0.92**
Detention 1	0.7	171.0	143.5	0.84	0.0	**0.00**
Egbury 1	1.9	298.5	298.5	1.00	171.8	**0.58**
Farleigh Wallop 1	4.1	100.0	100.0	1.00	100.0	**1.00**
Godley Bridge 1	1.7	207.0	207.0	1.00	57.0	**0.28**
Goodworth 1	1.1	382.5	379.3	0.99	16.7	**0.04**
Hoe 1	2.0	213.8	213.8	1.00	139.3	**0.65**
Hook Lane 1	2.1	110.3	110.3	1.00	67.8	**0.61**
Horndean 1	2.2	200.0	200.0	1.00	98.1	**0.49**
Horndean 4	2.3	218.0	218.0	1.00	160.1	**0.74**
Iden Green 1	1.6	136.2	136.2	1.00	12.1	**0.09**
Lee-on-Solent 1	2.1	102.0	102.0	1.00	69.9	**0.69**
Lomer 1	1.5	266.5	266.5	1.00	47.5	**0.18**
Normandy 1	2.0	89.0	89.0	1.00	43.8	**0.49**
Odiham 1	2.3	129.6	129.6	1.00	97.5	**0.75**
Palmers Wood 1	1.3	160.0	160.0	1.00	6.2	**0.04**
Rotherfield 1	2.0	203.9	203.9	1.00	130.9	**0.64**
Storrington 1	1.4	254.3	254.3	1.00	5.7	**0.02**
Wallcrouch 1	0.9	209.0	209.0	1.00	0.0	**0.00**
Wineham 1	1.8	263.5	246.0	0.93	44.8	**0.17**
Formation average	1.9	198.5	196.7	0.99	70.7	**0.40**

Table 6. Summary of the average wt% TOC over net shale thickness, gross thickness, net (*shale*) *thickness and pay thickness* (*for organic-rich shale*) *for the Mid Lias Clay across the analysed wells.*

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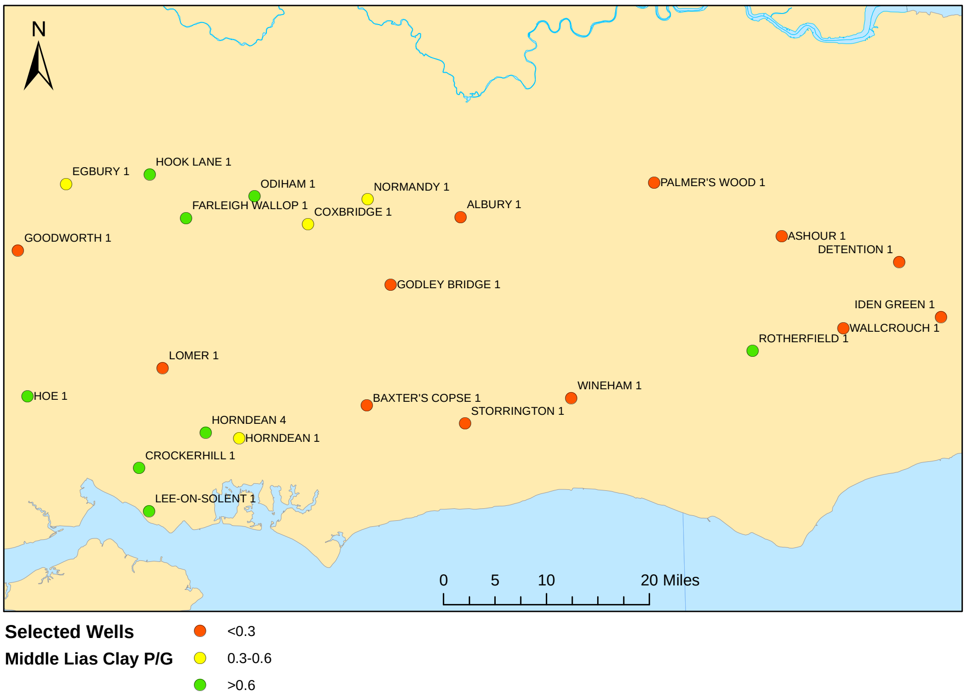

Figure 11. Geographical distribution of pay/gross (P/G) values for the Mid Lias Clay.

5.6 Lower Lias Limestone-Shale Unit (Table 7)

The Lower Lias Limestone-Shale Unit also represents a relatively poor source rock interval with mean TOC values between 0.7wt% (*Iden Green 1*) and 2.0wt% (*Hook Lane 1*), and with most values falling between 0.8wt% and 2.0wt%. Net shale thickness values are high, varying from 33 ft (*Iden Green 1*) to 341 ft (*Godley Bridge 1*), with high N/G values ranging from 0.58 (*Normandy* 1) to 1.0 (*Hoe* 1).

With the cut-offs applied (listed in Section 3.5), the pay thicknesses vary from 2.0 ft (*Palmers Wood 1* and *Iden Green 1*) to 60 ft (*Hook Lane 1*) and P/G varies considerably from 0.02 (*Palmers Wood 1*) to 0.45 (*Hook Lane 1*).

This interval shows similar sensitivity to the LOM parameter as the Mid Lias Clay.

Geographical Distribution and Maturity (*Figure 12*)

The only distinguishable geographical distribution trend is that a central belt from *Goodworth 1* to *Iden Green 1* (including the northern margin *Odiham 1* to *Palmers Wood 1*) shows lower TOC wt% and hence lower P/G (from 0.03 at *Palmers Wood 1* to a maximum of 0.15 at *Godley Bridge 1*). Many of the well intervals are again affected by the 2% cut-off (Figure 10), but the Lower Lias Limestone-Shale Unit does not show as good a source rock potential as the Mid Lias Clay.

The other locations in the north-west and south-west show higher TOC values and higher P/G ranging from 0.14 (*Lee-on-Solent 1*) to 0.45 (*Hook Lane 1*).

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The ΔlogR response of the scaled sonic and resistivity across all the wells seems to suggest that the Lower Lias Limestone-Shale Unit is mature.

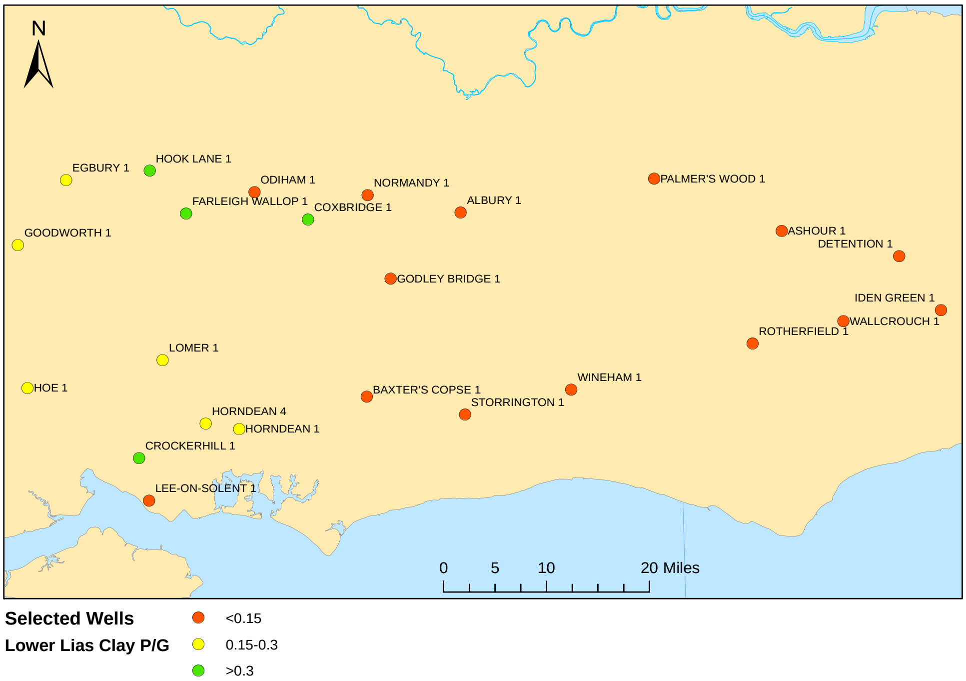

Figure 12. Geographical distribution of pay/gross (P/G) values for the Lower Lias Limestone-Shale Unit.

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Name	Avg TOC over net shale thickness (calculated wt%)	G, gross formation thickness	N, net (shale) thickness (ft)	N/G	P, pay thickness (ft)	P/G
Albury 1	1.3	190.2	131.7	0.69	23.6	**0.12**
Ashour 1	1.0	266.0	227.5	0.86	18.8	**0.07**
Baxters Copse 1	1.0	156.5	118.8	0.76	13.5	**0.09**
Coxbridge 1	1.7	94.0	83.0	0.88	31.3	**0.33**
Crockerhill 1	1.5	149.3	144.7	0.97	44.3	**0.30**
Detention 1	1.5	144.5	135.8	0.94	7.0	**0.05**
Egbury 1	1.4	217.0	202.0	0.93	49.8	**0.23**
Farleigh Wallop 1	1.7	150.0	145.5	0.97	57.8	**0.39**
Godley Bridge 1	1.1	360.5	341.5	0.95	53.5	**0.15**
Goodworth 1	1.4	322.0	311.3	0.97	51.8	**0.16**
Hoe 1	1.4	86.2	85.8	1.00	19.9	**0.23**
Hook Lane 1	2.0	132.7	119.2	0.90	59.6	**0.45**
Horndean 1	1.7	140.0	124.3	0.89	31.8	**0.23**
Horndean 4	1.4	163.4	148.3	0.91	36.4	**0.22**
Iden Green 1	0.7	43.0	33.2	0.77	2.0	**0.05**
Lee-on-Solent 1	1.2	104.0	96.4	0.93	14.8	**0.14**
Lomer 1	1.1	171.5	167.5	0.98	29.0	**0.17**
Normandy 1	1.1	177.0	102.2	0.58	6.2	**0.04**
Odiham 1	1.1	102.6	87.8	0.86	7.9	**0.08**
Palmers Wood 1	0.8	101.1	98.8	0.98	2.0	**0.02**
Rotherfield 1	1.5	159.0	148.5	0.93	17.7	**0.11**
Storrington 1	0.9	163.4	130.1	0.80	19.2	**0.12**
Wallcrouch 1	0.9	155.9	132.7	0.85	3.9	**0.03**
Wineham 1	1.0	164.5	150.5	0.92	22.0	**0.13**
Formation average	1.4	170.4	151.0	0.88	30.6	**0.19**

Table 7. Summary of the average wt% TOC over net shale thickness, gross thickness, net (shale) thickness and pay thickness (for organic-rich shale) for the Lower Lias Limestone-Shale Unit across the analysed wells.

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5.7 Conclusion

Geophysical logs from 24 wells across southern England were analysed using the Passey *et al.* (1990) method for calculating weight percent of Total Organic Content (wt% TOC) from geophysical logs. The calculations were undertaken for the following shale intervals in the Jurassic:

- Kimmeridge Clay
- Corallian Clay
- Oxford Clay
- Upper Lias Clay
- Mid Lias Clay
- Lower Lias Limestone-Shale Unit

Geographic distribution and trends were examined, and source maturity was investigated. The results show that in the Jurassic interval not only are there distinct differences in P/G and TOC wt% per formation, but a geographical variation can also be observed. The geographical distribution generally shows a lower P/G and TOC in a higher-maturity belt stretching west to east across the central Weald, from *Lomer 1* to *Wallcrouch 1*, often including wells across the northern or southern margins of this belt. Wells in the north-west and south-west show a less mature signature, with higher P/G and TOC values.

The Upper Jurassic formations (Kimmeridge Clay, Corallian Clay and Oxford Clay) show the highest TOC wt% values. The high calculated wt% TOC values show a marginally mature source in the Kimmeridge Clay, passing down into a mature source in the base Oxford Clay. The Corallian Clay shows an interval of consistently high wt% TOC, although lacking in maturity. The Kimmeridge Clay is the thickest formation, but within which there is variability: the lower and upper Kimmeridge Clay show the poorest wt% TOC, and the middle Kimmeridge Clay shows the most consistently high wt% TOC values. Where present, it can be seen that the richest intervals are immediately below the mid Kimmeridge micrites (which usually show a clean, low gamma ray and low TOC log response).

The Lower Jurassic Lias Group conversely shows poorer wt% TOC values, and in many wells as a result of the fair to poor wt% TOC values, a good to poor P/G. The Upper Lias Clay is more inconsistent (and is sometimes absent from the wells), and it represents the thinnest formation (shale thickness) with a low P/G. The Mid Lias Clay shows a fair source rock potential, with an average c. 2wt% TOC, whereas the Lower Lias Clay shows a poor source rock potential, with an average c. 1.4wt% TOC.

5.8 References

See main report.

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Appendix D1

The appendix graphical log plots are sorted geographically from east to west.

Appendix Figure	Name	Number	LOM's used (Min-Max (Avg)) Kimm-Oxfrd	LOM's used (Min-Max (Avg)) Lias
1	Hoe 1	SU31NE/357	6-7 (6.5)	7-9 (8)
2	Goodworth 1	SU34SE/14	6-7 (6.5)	7-9 (8)
3	Egbury 1	SU45SW/46	6-7 (6.5)	7-9 (8)
4	Crockerhill 1 *	SU50NE/21	6-7 (6.5)	7-9 (8)
5	Lee-on-Solent 1	SU50SE/51	6-7 (6.5)	7-9 (8)
6	Lomer 1	SU52SE/18	6-7 (6.5)	7-9 (8)
7	Hook Lane 1	SU55SE/20	6-7 (6.5)	7-9 (8)
8	Horndean 4	SU61SE/82	6-7 (6.5)	7-9 (8)
9	Farleigh Wallop 1	SU64NW/50	6-7 (6.5)	7-9 (8)
10	Horndean 1	SU71SW/59B	6-7 (6.5)	7-9 (8)
11	Odiham 1	SU75SW/99	6-7 (6.5)	7-9 (8)
12	Coxbridge 1	SU84NW/60	6-7 (6.5)	7-9 (8)
13	Baxters Copse 1	SU91NW/10	7-8 (7.5)	9-11 (10)
14	Godley Bridge 1	SU93NE/21	7-8 (7.5)	9-11 (10)
15	Normandy 1	SU94NW/25	6-7 (6.5)	7-9 (8)
16	Storrington 1	TQ01SE/27	6-7 (6.5)	7-9 (8)
17	Albury 1	TQ04NE/46	6-7 (6.5)	7-9 (8)
18	Wineham 1 *	TQ21NW/13	6-7 (6.5)	7-9 (8)
19	Palmers Wood 1	TQ35SE/94	6-7 (6.5)	7-9 (8)
20	Rotherfield 1	TQ52NW/16	7-8 (7.5)	9-11 (10)
21	Ashour 1	TQ54SE/67	7-8 (7.5)	9-11 (10)
22	Wallcrouch 1	TQ62NE/3	7-8 (7.5)	9-11 (10)
23	Detention 1	TQ74SW/4	6-7 (6.5)	7-9 (8)
24	Iden Green 1 *	TQ83SW/1	6-7 (6.5)	7-9 (8)
	Other Figures			
25	Weald Basins Wells Map			
26	Final Chosen Wells Map			

The Level of Organic Maturity values are shown here for each well. * Denotes deviated well

Average LOM when calculated give TOC_M value, and is represented on the graphical log plots by the pink Calculated TOC (wt%) curve in Track 7.

Minimum and maximum LOMs give TOC_H and TOC_L values respectively and range indicated by blue shading on the graphical log plots in Track 7.

Each appendix figure for the wells is accompanied by histograms, TOC statistics and a N/G, P/G summary table

The formations of interest have been highlighted below with the corresponding colours shown on the logs.

All other formations should be noted, but do not influence the TOC estimations

For graphical log plots track explanation see associated report section 6.

Abbreviations	Formations
Kimm_Cl	Kimmeridge Clay
Cor_Sst	Corallian Sandstone Unit
Cor_Arg	Corallian Argillaceous Unit
Cor_Lmst	Corallian Limestone Unit
Oxf_Cl	Oxford Clay
KB	Kellaway Beds
Gr_Ool	Great Oolite Group
FE	Fullers Earth
Inf_Ool	Inferior Oolite
U_Lias	Upper Lias
U_Lias_Cl	Upper Lias Clay
M_Lias_Lmst	Middle Lias Limestone
M_Lias_Cl	Middle Lias Clay
L_Lias_Cl	Lower Lias Clay
L_Lias_Lmst	Lower Lias Limestone/Clay
W_Lias	White Lias
B_Juras	Base Jurassic

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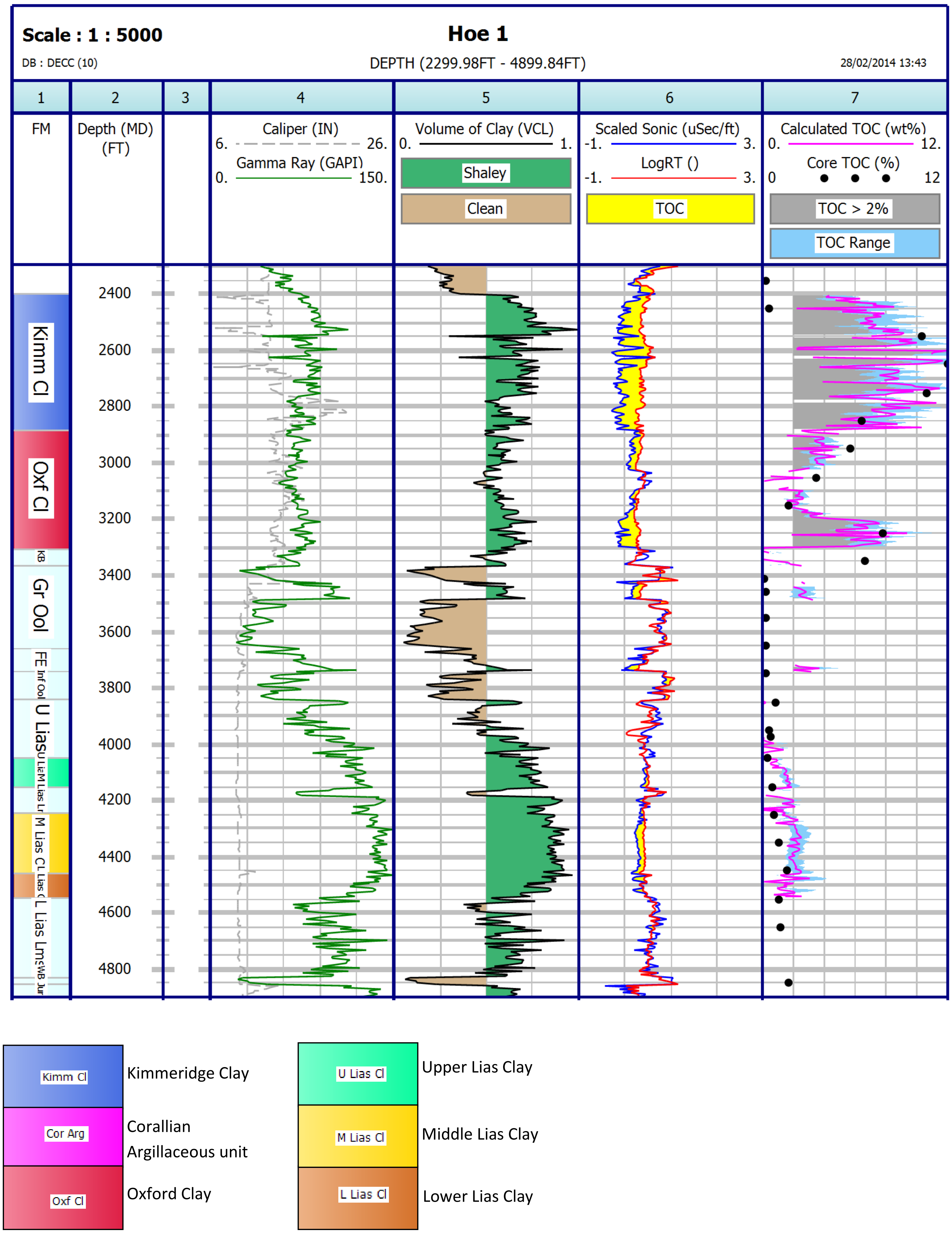
Figure 1: Hoe 1 SU31NE/357



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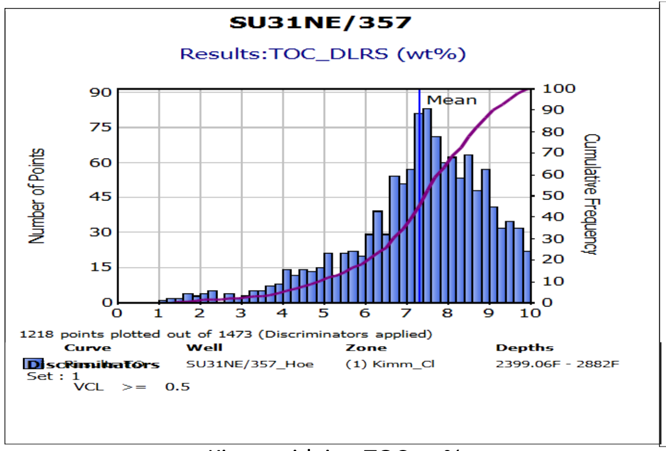
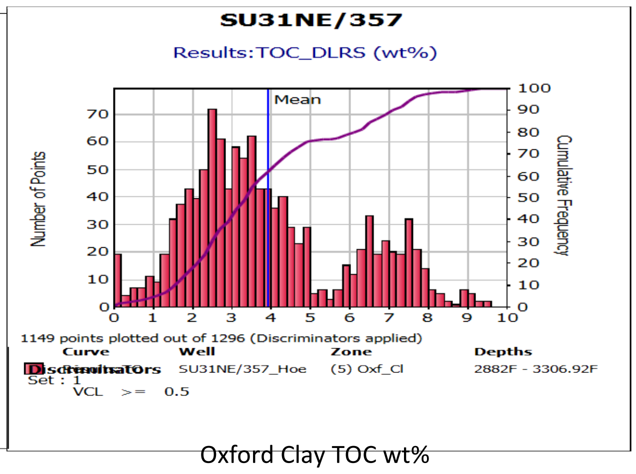
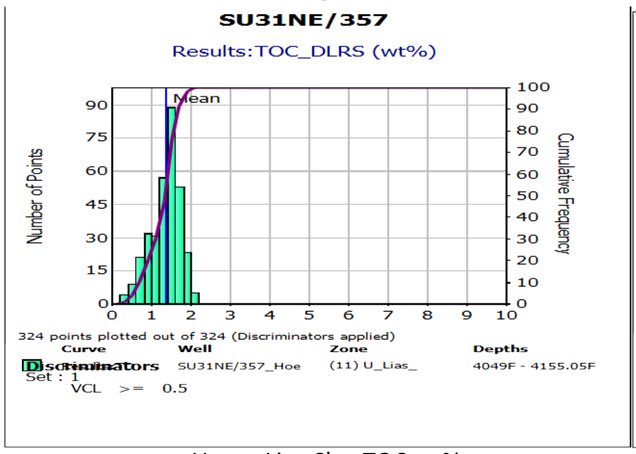


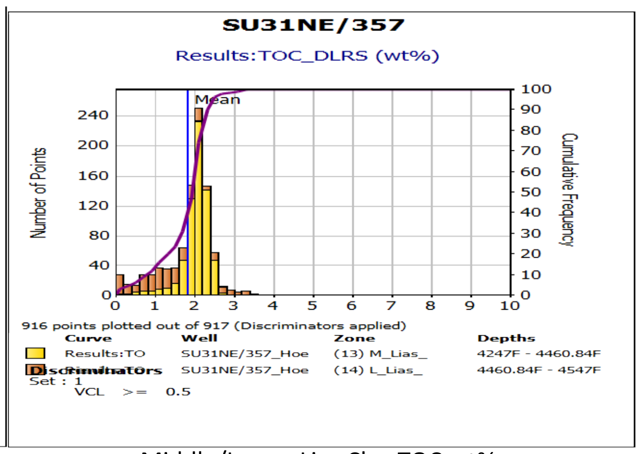
Kimmeridgian TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 1a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Table 1a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (4Pts)	0.44	11.98	7.36
TOC_M	1.03	15.20	7.86
TOC_L	0.99	12.66	6.61
TOC_H	1.08	18.29	9.37
Corallian Argillaceous Unit			
Core TOC (1Pts)	6.44	6.44	6.44
TOC_M	3.02	3.02	3.02
TOC_L	2.62	2.62	2.62
TOC_H	3.49	3.49	3.49
Oxford Clay			
Core TOC (6Pts)	1.72	7.83	5.30
TOC_M	0.00	9.45	3.89
TOC_L	0.00	7.93	3.34
TOC_H	0.00	11.31	4.55
Upper Lias Clay			
Core TOC (2Pts)	0.30	0.59	0.45
TOC_M	0.26	2.14	1.35
TOC_L	0.43	1.71	1.17
TOC_H	0.00	2.78	1.61
Middle/Lower Lias			
Core TOC (4Pts)	0.77	1.57	1.11
TOC_M	0.00	3.50	1.84
TOC_L	0.00	2.63	1.50
TOC_H	0.00	4.78	2.34

Table 1b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	2399.1	2882.0	482.9	465.7	0.96	461.8	**0.96**	462.8	0.96	459.8	0.95
Corallian Argillaceous Unit	2882.0	2882.0	0.2	0.2	1.00	0.2	**1.00**	0.2	1.00	0.2	1.00
Oxford Clay	2882.0	3306.9	424.9	376.7	0.89	315.0	**0.74**	329.1	0.78	296.6	0.70
Upper Lias Clay	4049.0	4155.1	106.1	106.1	1.00	1.6	**0.02**	24.6	0.23	0.0	0.00
Middle Lias Clay	4247.0	4460.8	213.8	213.8	1.00	139.3	**0.65**	197.0	0.92	1.3	0.01
Lower Lias (Upper Clays/Lmst)	4460.8	4547.0	86.2	85.8	1.00	19.9	**0.23**	31.3	0.36	9.5	0.11
All Zones	2399.1	4547.0	1314.1	1248.3	0.95	937.7	**0.71**	1045.0	0.80	767.5	0.58

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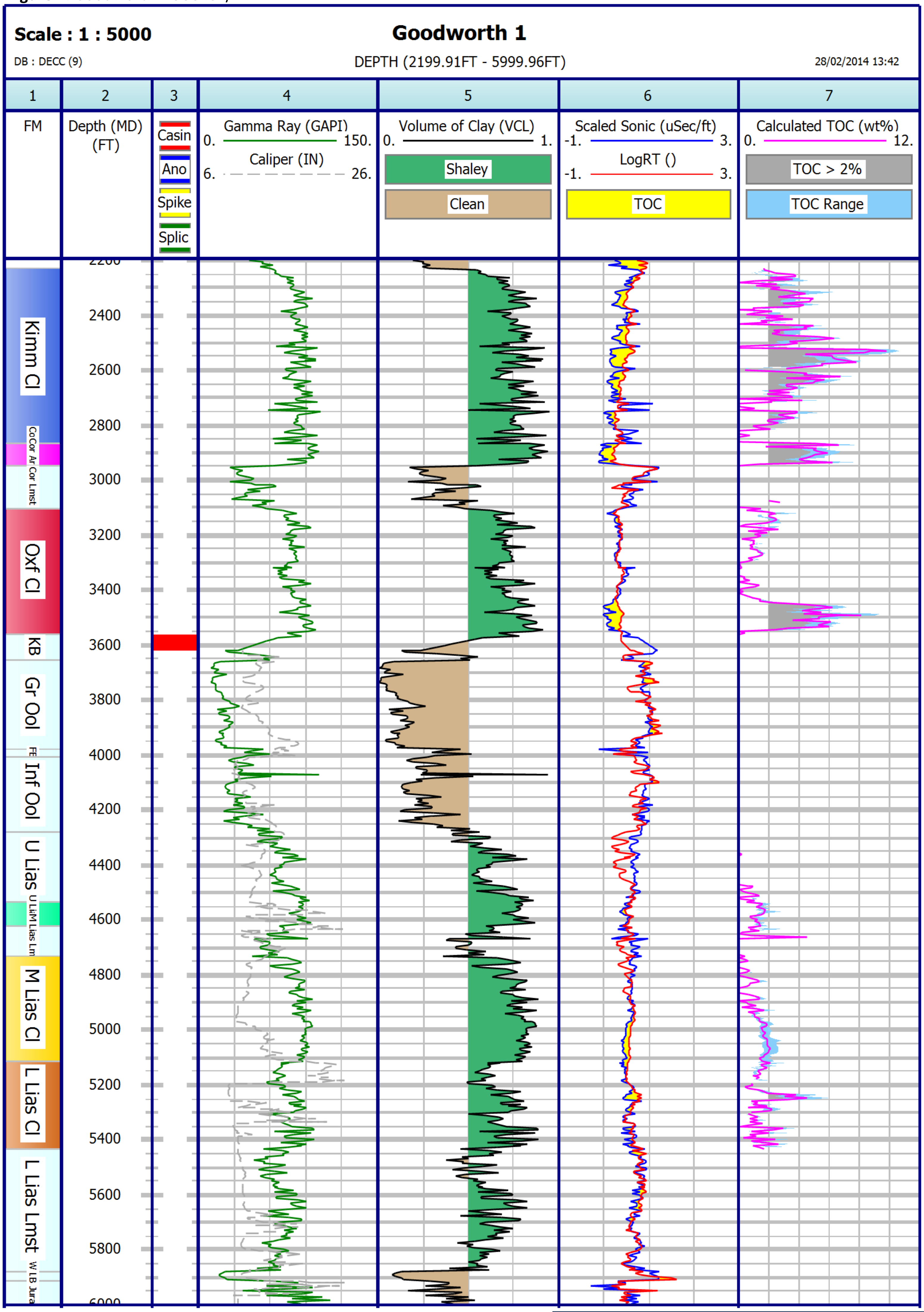
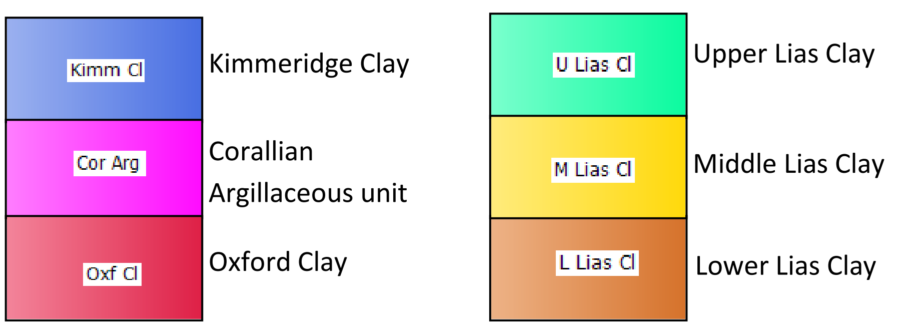
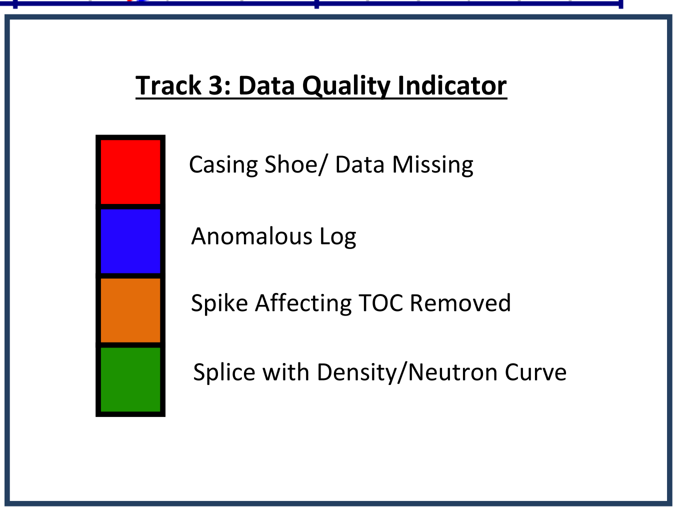
Figure 2: Goodworth 1 SU34SE/14







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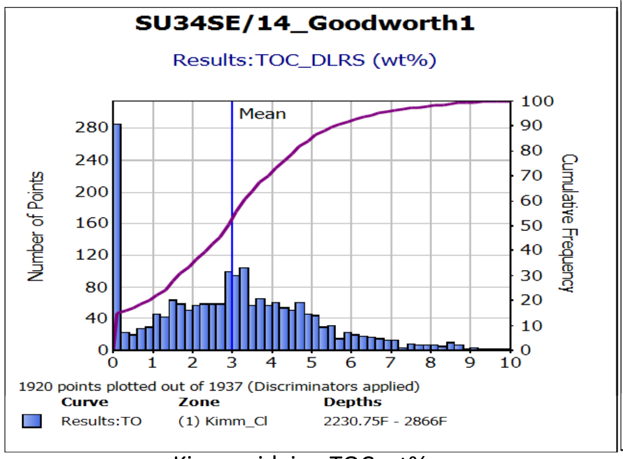
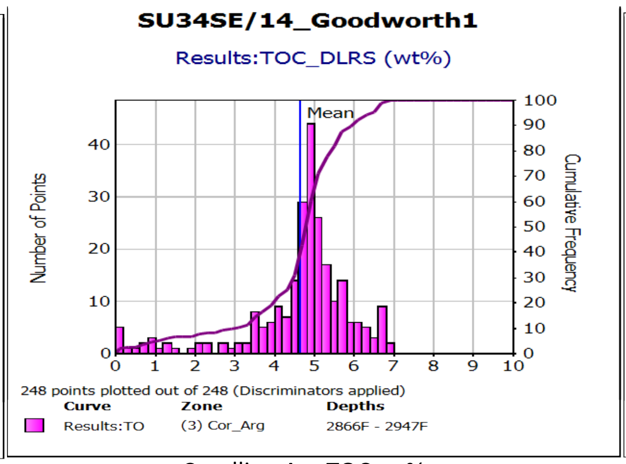
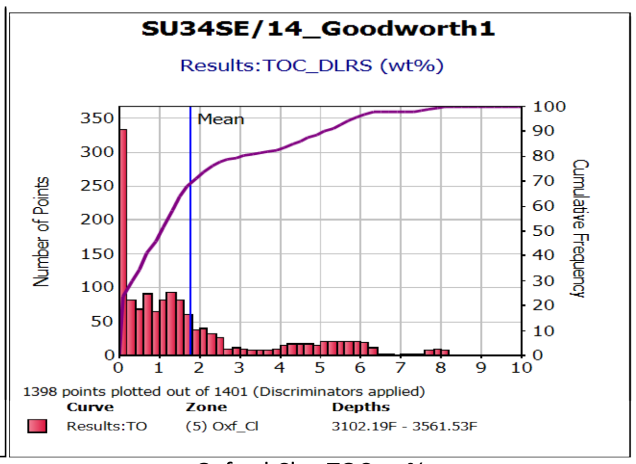


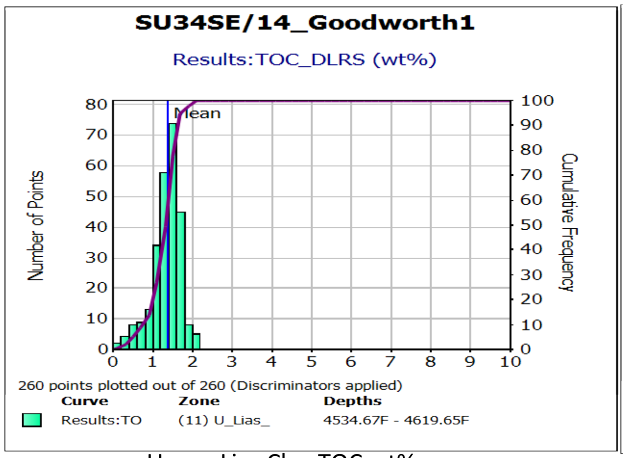
Kimmeridgian TOC wt%



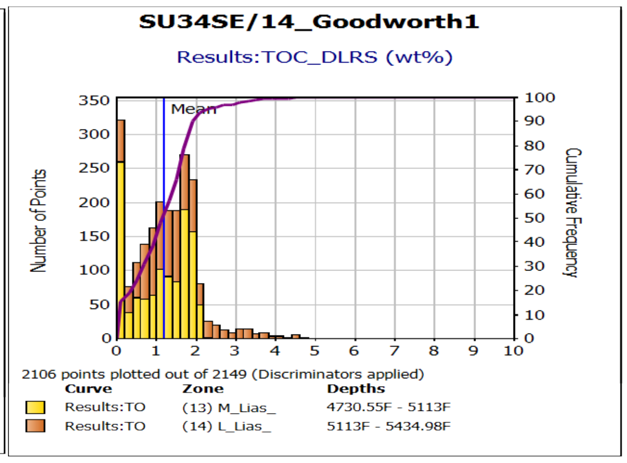
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 2a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**9.80**	**2.98**
TOC_L	0.00	8.21	2.58
TOC_H	0.00	11.73	3.48
Corallian Argillaceous Unit			
TOC_M	**0.00**	**6.98**	**4.63**
TOC_L	0.00	5.89	3.95
TOC_H	0.00	8.31	5.46
Oxford Clay			
TOC_M	0.00	8.18	1.77
TOC_L	0.00	6.88	1.57
TOC_H	0.00	9.76	2.01
Upper Lias Clay			
TOC_M	0.16	2.16	1.34
TOC_L	0.36	1.72	1.17
TOC_H	0.00	2.81	1.60
Middle/Lower Lias			
TOC_M	0.00	4.63	1.20
TOC_L	0.00	3.40	1.05
TOC_H	0.00	6.45	1.45

Table 2a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 2b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	2230.8	2866.0	635.3	629.8	0.99	418.7	**0.66**	436.4	0.69	393.4	0.62
Corallian Argillaceous Unit	2866.0	2947.0	81.0	81.0	1.00	75.8	**0.94**	76.1	0.94	74.8	0.92
Oxford Clay	3102.2	3561.5	459.3	458.4	1.00	133.2	**0.29**	148.0	0.32	116.2	0.25
Upper Lias Clay	4534.7	4619.7	85.0	85.0	1.00	1.6	**0.02**	18.7	0.22	0.0	0.00
Middle Lias Clay	4730.5	5113.0	382.5	379.3	0.99	16.7	**0.04**	127.3	0.33	0.0	0.00
Lower Lias (Upper Clays/Lmst)	5113.0	5435.0	322.0	311.3	0.97	51.8	**0.16**	101.4	0.32	26.9	0.08
All Zones	2230.8	5435.0	1965.0	1944.8	0.99	697.9	**0.36**	907.9	0.46	611.3	0.31

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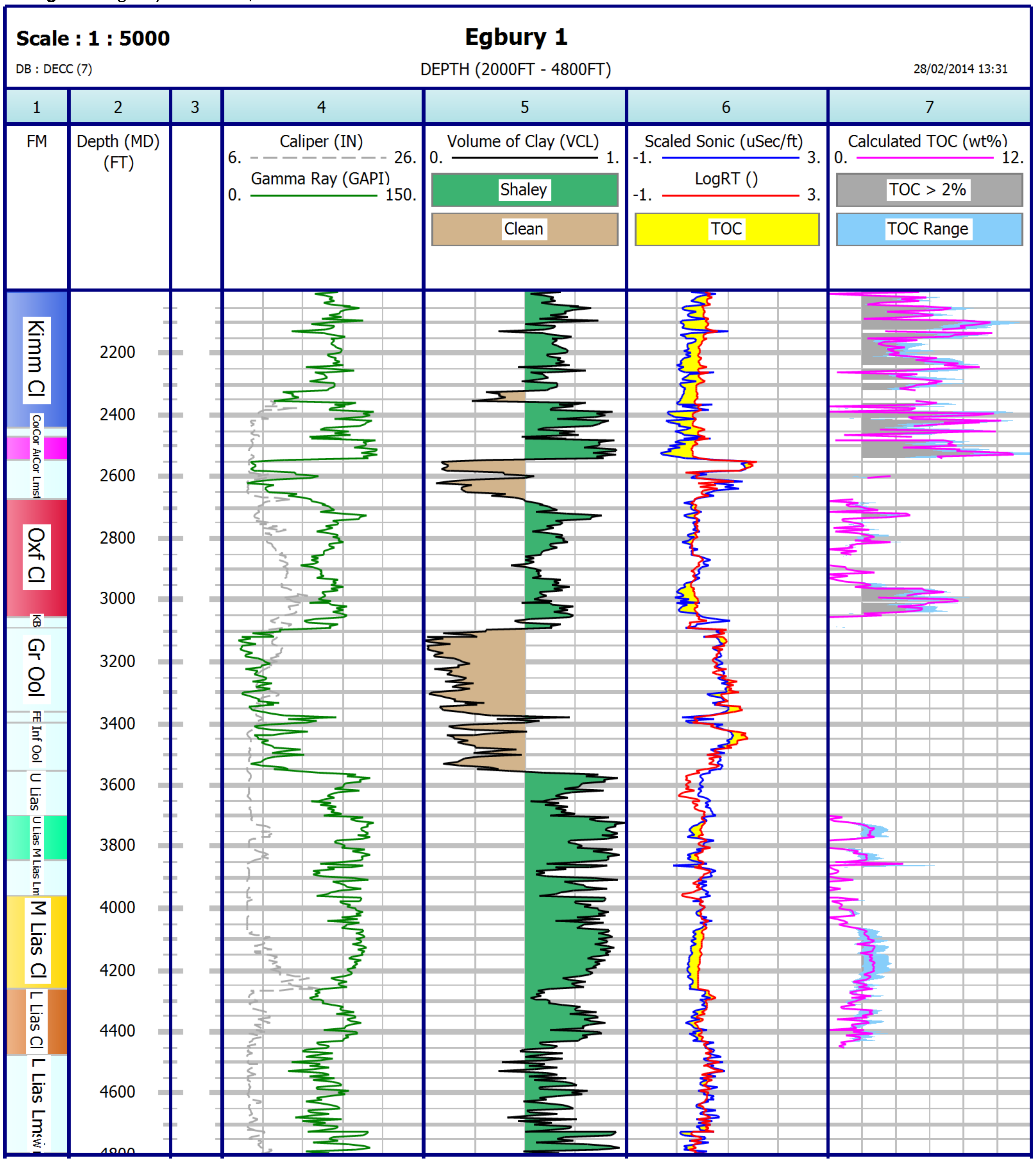
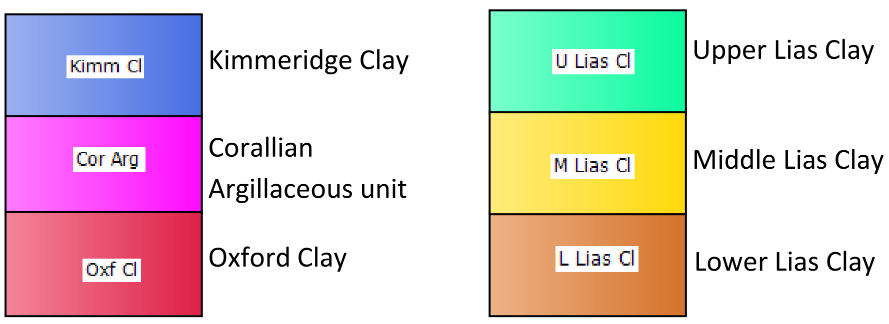
Figure 3: Egbury 1 SU45SW/46





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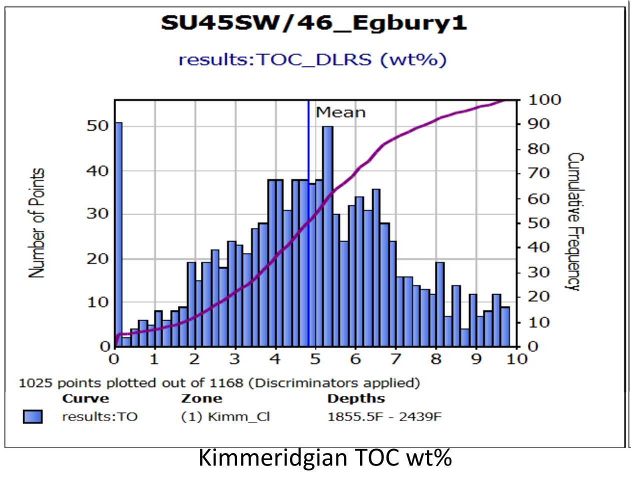
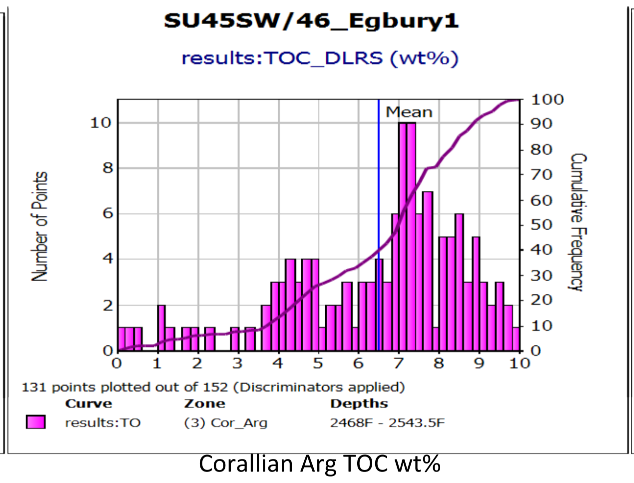
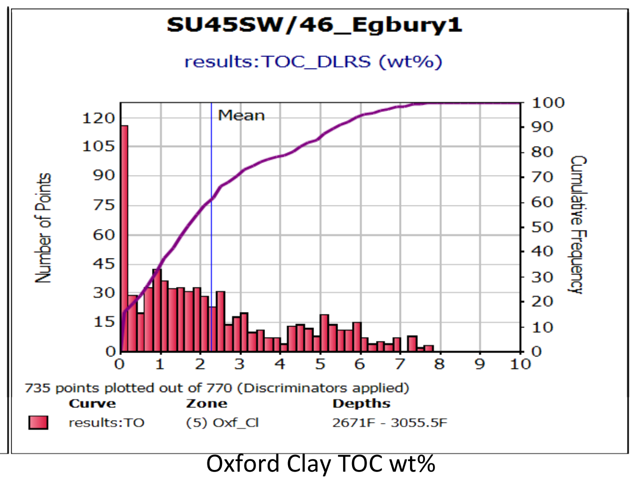


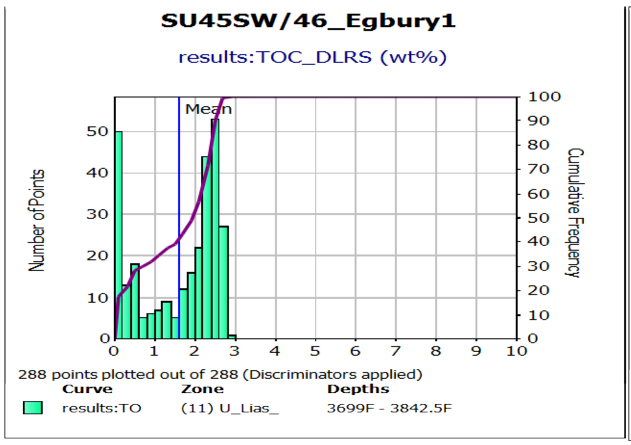
Kimmeridgian TOC wt%



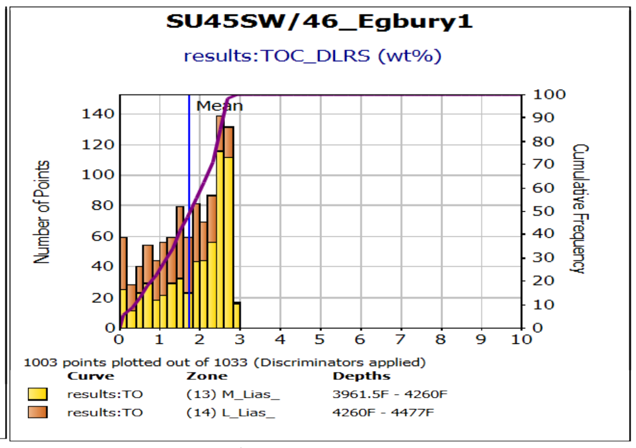
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 3a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**10.75**	**4.83**
TOC_L	0.00	8.99	4.11
TOC_H	0.00	12.88	5.70
Corallian Argillaceous Unit			
TOC_M	**0.00**	**11.16**	**6.88**
TOC_L	0.00	9.33	5.81
TOC_H	0.00	13.38	8.19
Oxford Clay			
TOC_M	0.00	7.72	2.29
TOC_L	0.00	6.50	2.01
TOC_H	0.00	9.21	2.63
Upper Lias Clay			
TOC_M	0.00	2.81	1.59
TOC_L	0.00	2.16	1.31
TOC_H	0.00	3.76	2.02
Middle/Lower Lias			
TOC_M	0.00	2.92	1.71
TOC_L	0.00	2.24	1.41
TOC_H	0.00	3.93	2.16

Table 3a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 3b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	1855.5	2439.0	583.5	513.8	0.88	454.8	**0.78**	464.3	0.80	445.3	0.76
Corallian Argillaceous Unit	2468.0	2543.5	75.5	72.3	0.96	68.3	**0.90**	68.8	0.91	68.3	0.90
Oxford Clay	2671.0	3055.5	384.5	367.0	0.95	165.0	**0.43**	182.5	0.48	149.0	0.39
Upper Lias Clay	3699.0	3842.5	143.5	143.5	1.00	73.5	**0.51**	87.3	0.61	19.0	0.13
Middle Lias Clay	3961.5	4260.0	298.5	298.5	1.00	171.8	**0.58**	203.8	0.68	76.0	0.26
Lower Lias (Upper Clays/Lmst)	4260.0	4477.0	217.0	202.0	0.93	49.8	**0.23**	86.3	0.40	11.0	0.05
All Zones	1855.5	4477.0	1702.5	1597.0	0.94	983.0	**0.58**	1092.8	0.64	768.5	0.45

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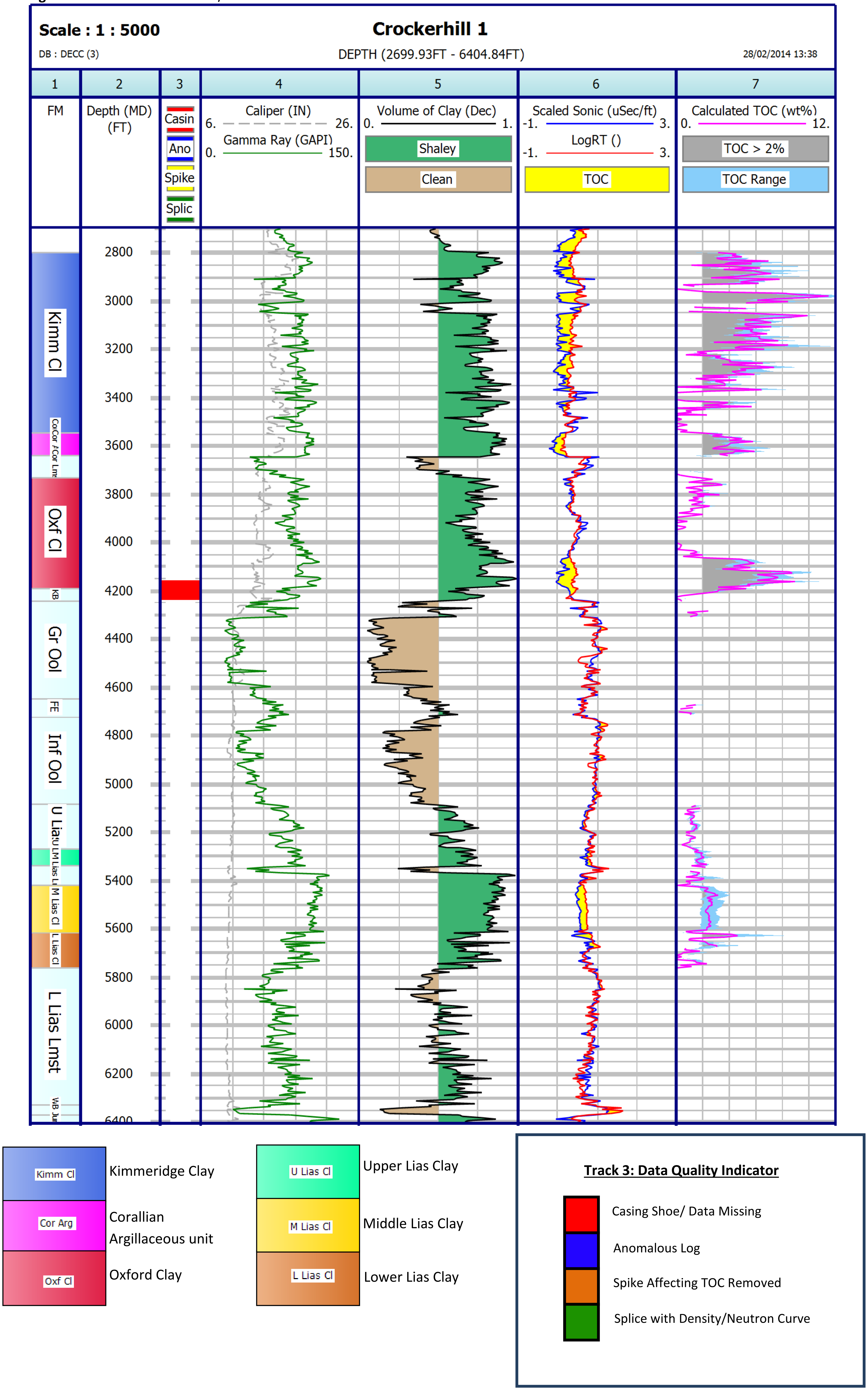
Figure 4: Crockerhill 1 SU50NE/21



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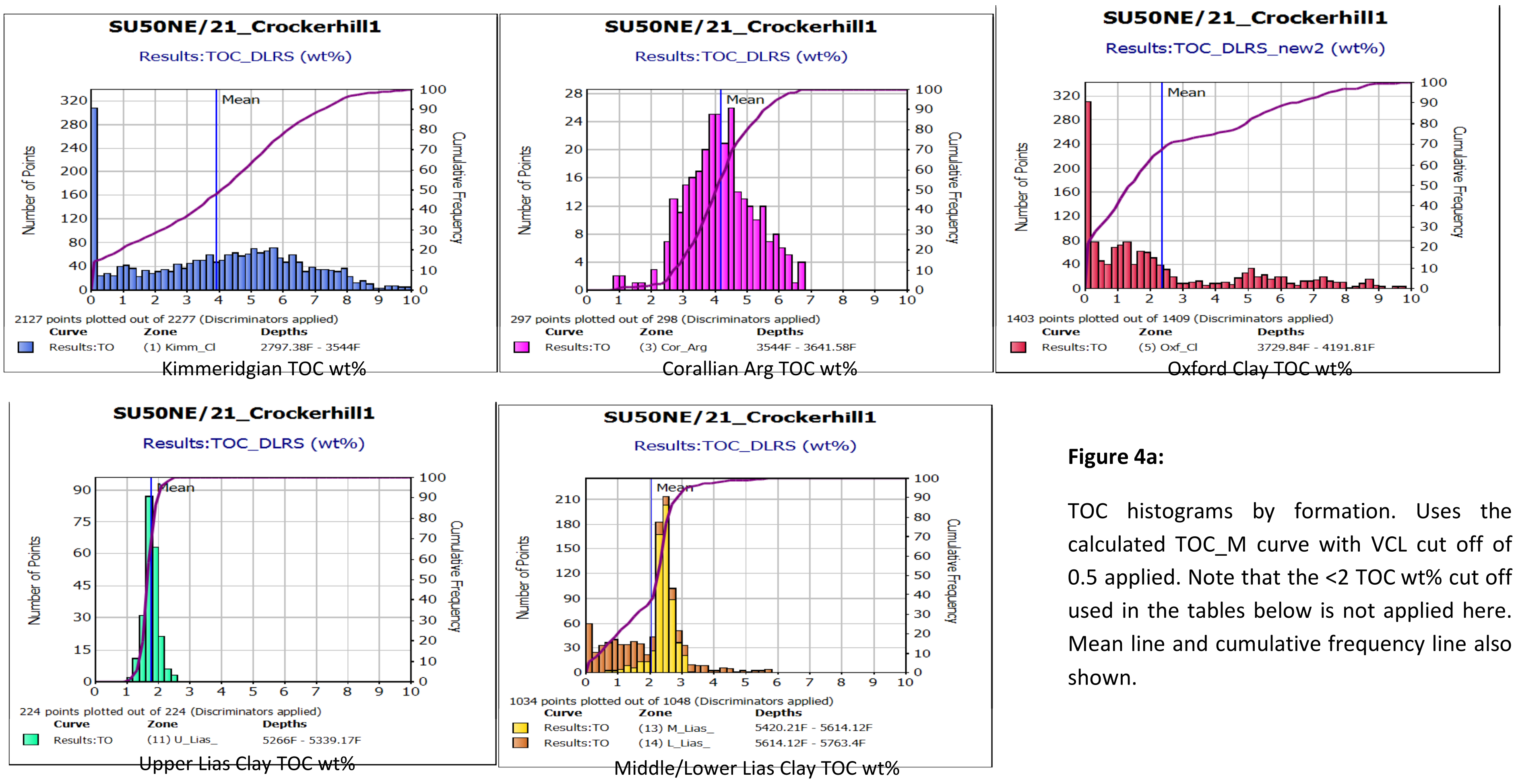

Figure 4a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**11.70**	**3.97**
TOC_L	0.00	9.77	3.40
TOC_H	0.00	14.03	4.68
Corallian Argillaceous Unit			
TOC_M	**0.86**	**6.71**	**4.16**
TOC_L	0.85	5.66	3.57
TOC_H	0.87	7.97	4.88
Oxford Clay			
TOC_M	0.00	9.80	2.37
TOC_L	0.00	8.21	2.07
TOC_H	0.00	11.73	2.74
Upper Lias Clay			
TOC_M	1.09	2.46	1.76
TOC_L	1.00	1.92	1.45
TOC_H	1.23	3.25	2.22
Middle/Lower Lias			
TOC_M	0.00	5.78	2.05
TOC_L	0.00	4.17	1.64
TOC_H	0.00	8.14	2.67

Table 4a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 4b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	2797.4	3544.0	746.6	704.3	0.94	511.0	**0.68**	520.9	0.70	496.9	0.67
Corallian Argillaceous Unit	3544.0	3641.6	97.6	97.4	1.0	95.5	**0.98**	95.5	0.98	94.5	0.97
Oxford Clay	3729.8	4191.8	462.0	460	1.0	180.3	**0.39**	202.0	0.44	161.3	0.35
Upper Lias Clay	5266.0	5339.2	73.2	73.2	1.0	9.8	**0.14**	56.8	0.78	0.0	0.00
Middle Lias Clay	5420.2	5614.1	193.9	193.9	1.0	178.5	**0.92**	187.0	0.96	55.5	0.29
Lower Lias (Upper Clays/Lmst)	5614.1	5763.4	149.3	144.7	1.0	44.3	**0.30**	53.2	0.36	31.5	0.21
All Zones	2797.4	5763.4	1722.5	1673.5	1.0	1019.4	**0.59**	1115.2	0.65	839.6	0.49

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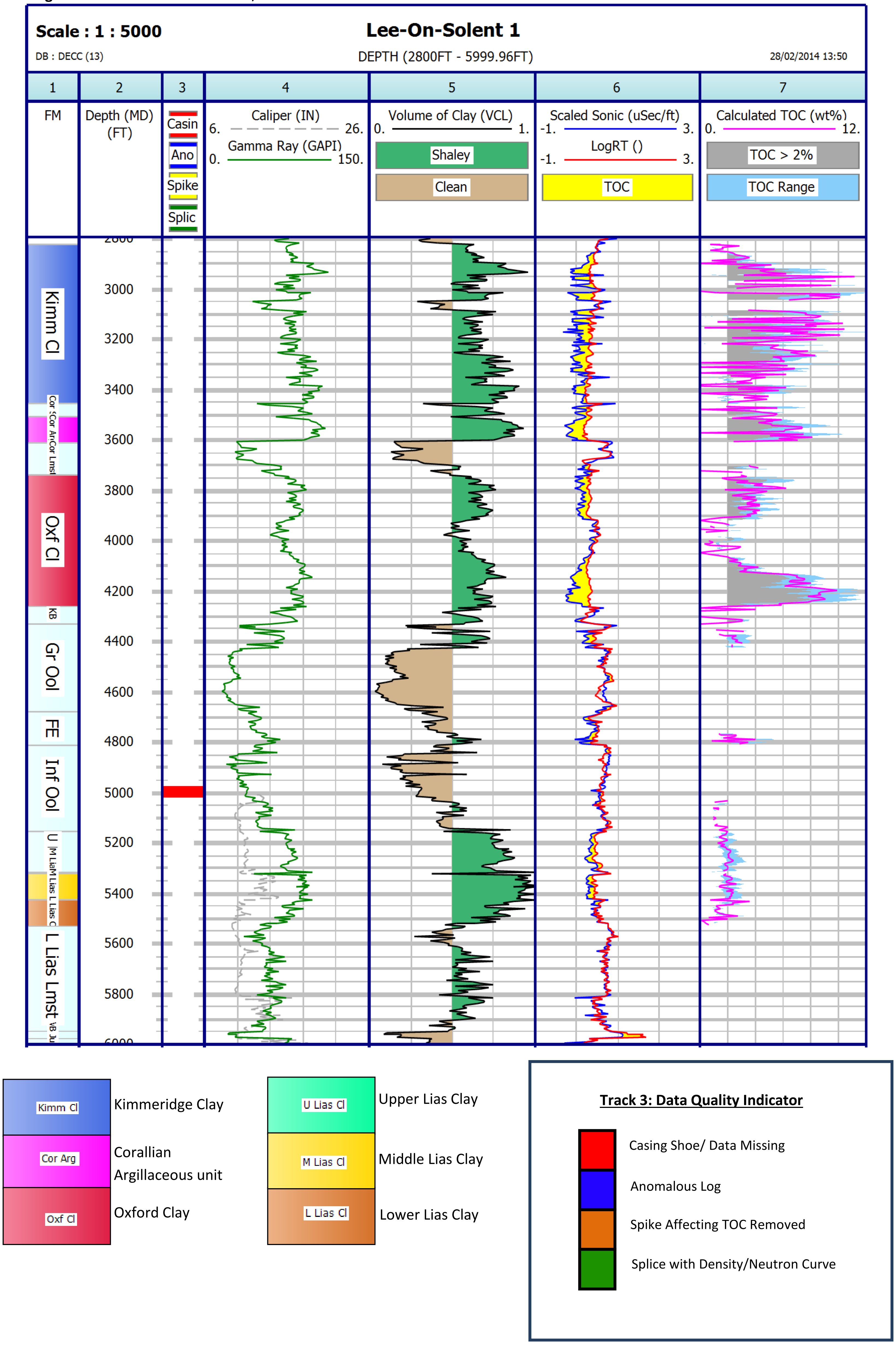
Figure 5: Lee-On-Solent 1 SU50SE/51



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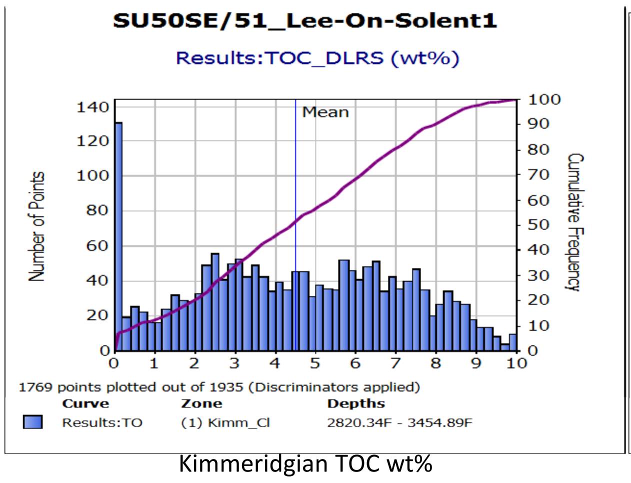
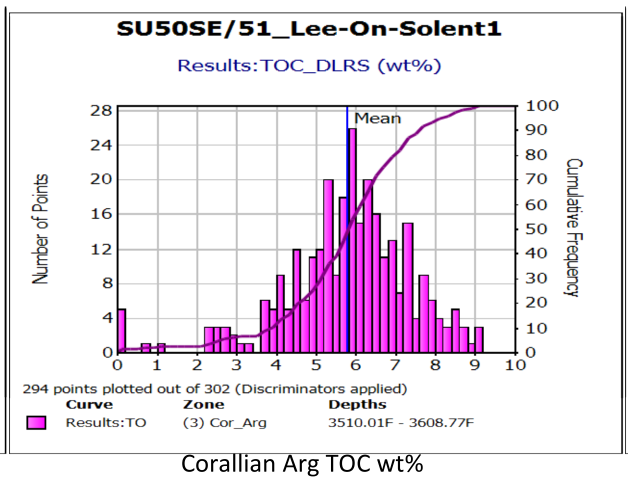
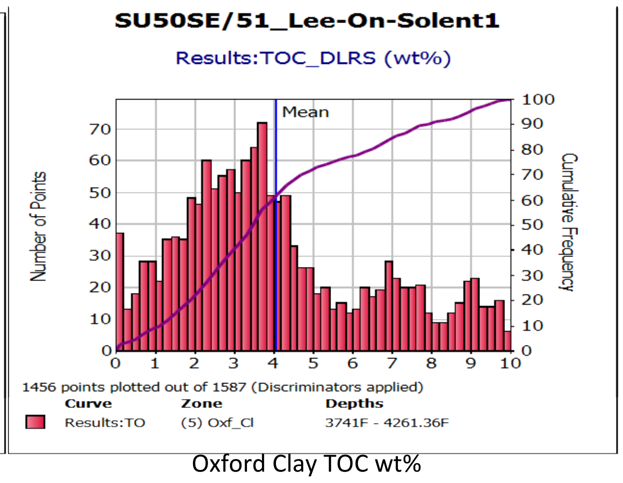


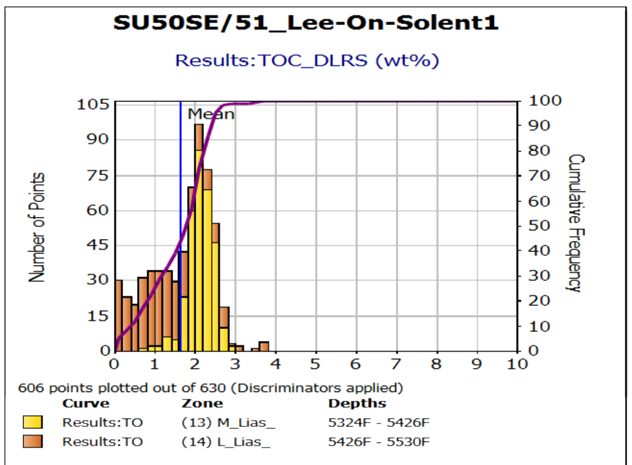
Kimmeridgian TOC wt%



Corallian Arg TOC wt%



Oxford Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 5a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Upper Lias Clay absent

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**11.37**	**4.60**
TOC_L	0.00	9.50	3.92
TOC_H	0.00	13.64	5.43
Corallian Argillaceous Unit			
TOC_M	**0.00**	**9.20**	**5.78**
TOC_L	0.00	7.71	4.90
TOC_H	0.00	11.00	6.85
Oxford Clay			
TOC_M	0.00	10.11	4.09
TOC_L	0.00	8.47	3.50
TOC_H	0.00	12.11	4.79
Middle/Lower Lias			
TOC_M	0.00	3.66	1.66
TOC_L	0.15	2.74	1.38
TOC_H	0.00	5.02	2.08

Table 5a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 5b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	2820.3	3454.9	634.6	592.1	0.93	480.0	**0.76**	489.9	0.77	463.6	0.73
Corallian Argillaceous Unit	3510.0	3608.8	98.8	96.5	1.0	94.2	**0.95**	94.2	0.95	94.2	0.95
Oxford Clay	3741.0	4261.4	520.4	481.0	0.9	382.6	**0.74**	399.0	0.77	361.6	0.70
Middle Lias Clay	5324.0	5426.0	102.0	102.0	1.0	69.9	**0.69**	97.0	0.95	4.6	0.05
Lower Lias (Upper Clays/Lmst)	5426.0	5530.0	104.0	96.4	0.9	14.8	**0.14**	24.0	0.23	5.6	0.05
All Zones	2820.3	5530.0	1459.7	1368.0	0.9	1041.4	**0.71**	1104.0	0.76	929.5	0.64

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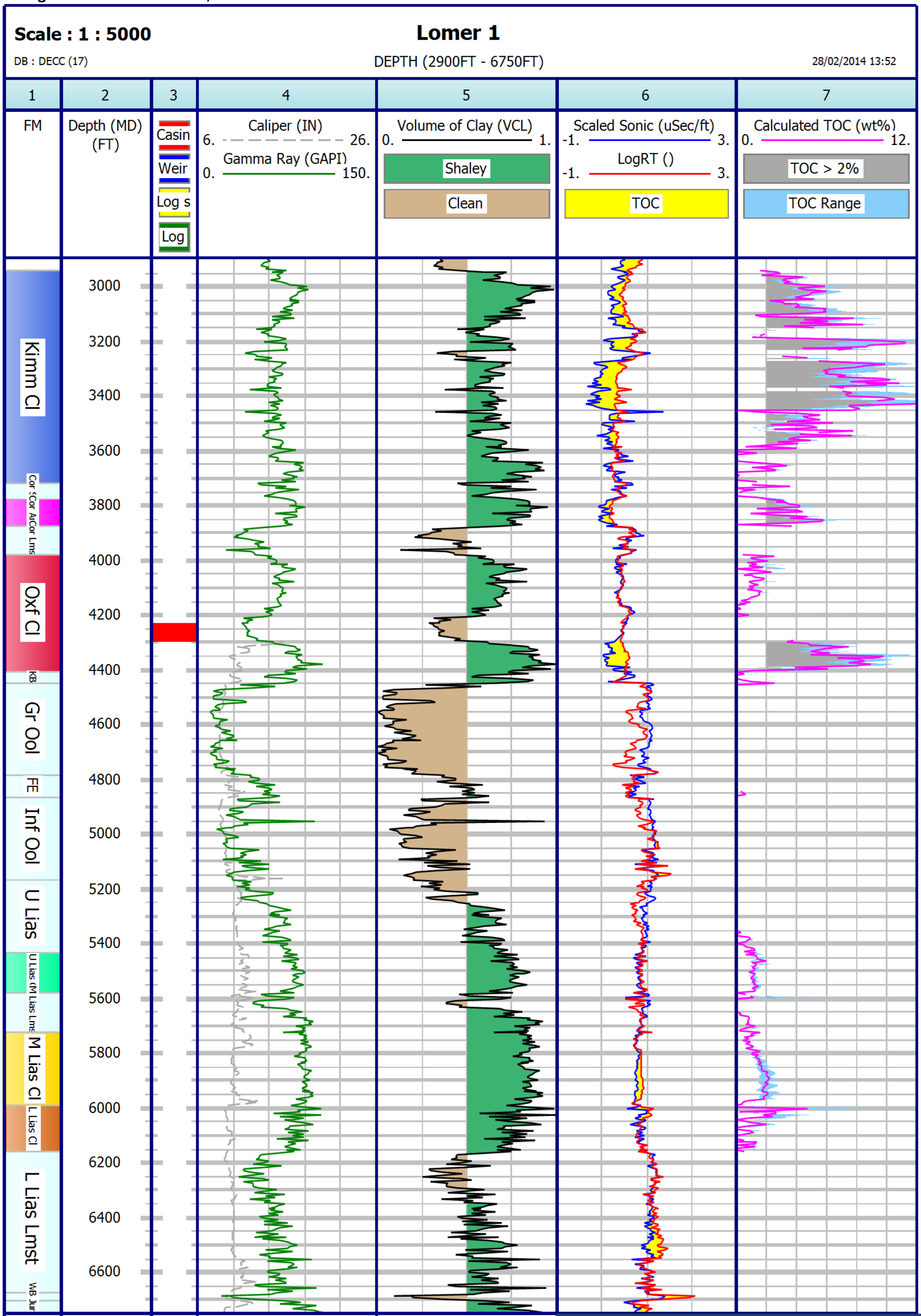
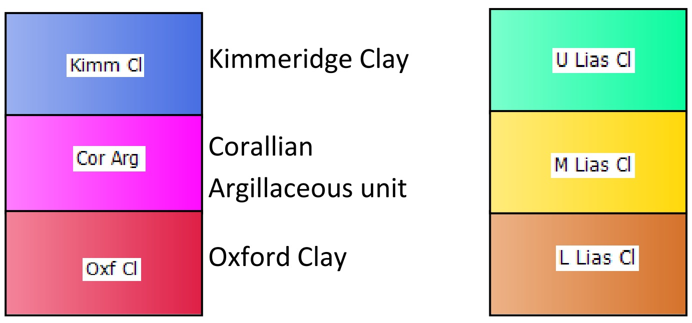
Figure 6: Lomer 1 SU52SE/18





Track 3: Data Quality Indicator

- Casing Shoe/ Data Missing
- Anomalous Log
- Spike Affecting TOC Removed
- Splice with Density/Neutron Curve

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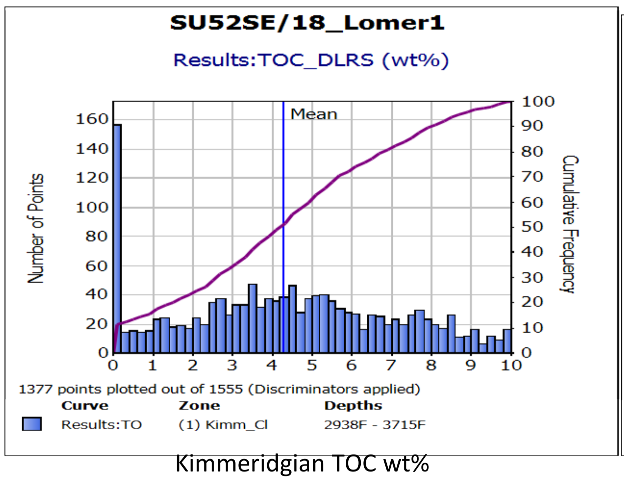
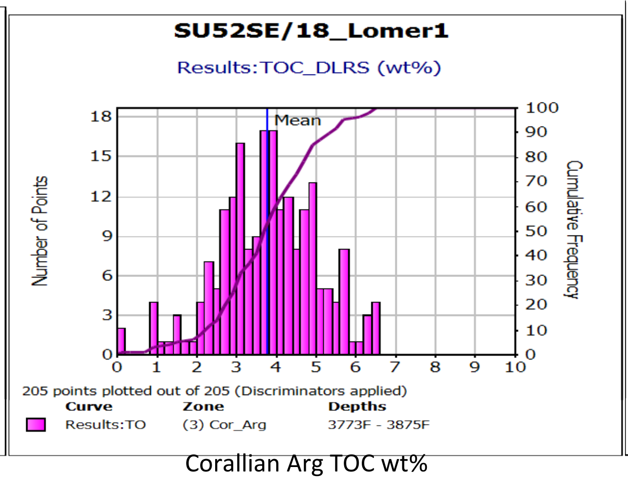
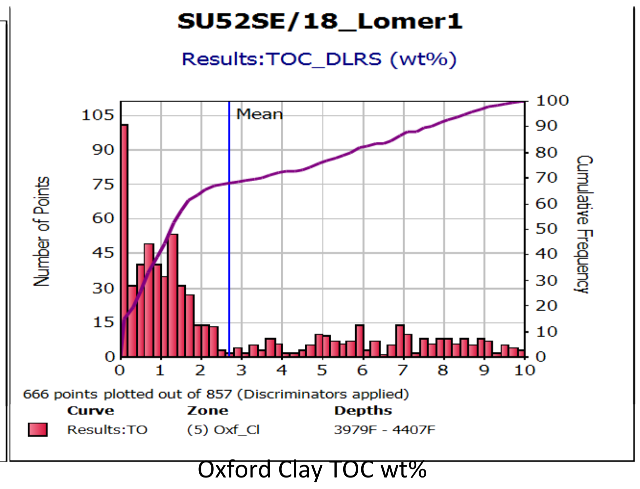


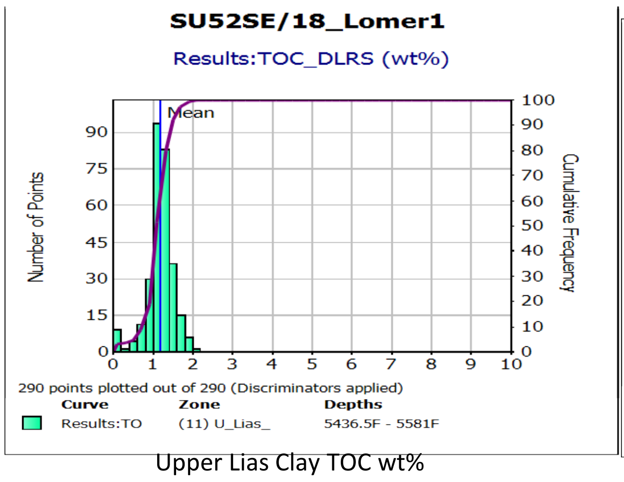
Kimmeridgian TOC wt%



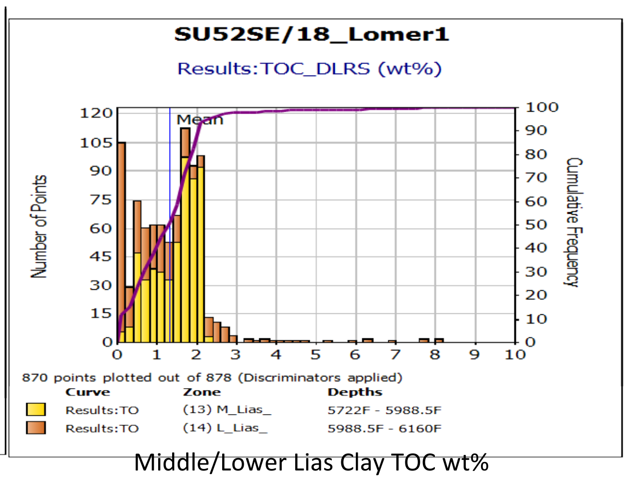
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 6a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**16.46**	**4.56**
TOC_L	0.00	13.70	3.89
TOC_H	0.00	19.83	5.39
Corallian Argillaceous Unit			
TOC_M	**0.00**	**6.57**	**3.79**
TOC_L	0.00	5.55	3.26
TOC_H	0.00	7.81	4.43
Oxford Clay			
TOC_M	0.00	10.55	2.75
TOC_L	0.00	8.83	2.39
TOC_H	0.00	12.64	3.18
Upper Lias Clay			
TOC_M	0.00	2.02	1.17
TOC_L	0.00	1.63	1.05
TOC_H	0.00	2.60	1.36
Middle/Lower Lias			
TOC_M	0.00	8.06	1.32
TOC_L	0.00	5.72	1.14
TOC_H	0.00	11.51	1.61

Table 6a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 6b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	2938.0	3715.0	777.0	717.3	0.92	559.3	**0.72**	567.8	0.73	544.5	0.70
Corallian Argillaceous Unit	3773.0	3875.0	102.0	102.0	1.0	96.0	**0.94**	96.5	0.95	91.5	0.90
Oxford Clay	3979.0	4407.0	428.0	335.3	0.8	125.0	**0.29**	132.5	0.31	116.5	0.27
Upper Lias Clay	5436.5	5581.0	144.5	144.5	1.0	0.5	**0.00**	10.5	0.07	0.0	0.00
Middle Lias Clay	5722.0	5988.5	266.5	266.5	1.0	47.5	**0.18**	136.5	0.51	0.0	0.00
Lower Lias (Upper Clays/Lmst)	5988.5	6160.0	171.5	167.5	1.0	29.0	**0.17**	39.5	0.23	16.5	0.10
All Zones	2938.0	6160.0	1889.5	1733.0	0.9	857.3	**0.45**	983.3	0.52	769.0	0.41

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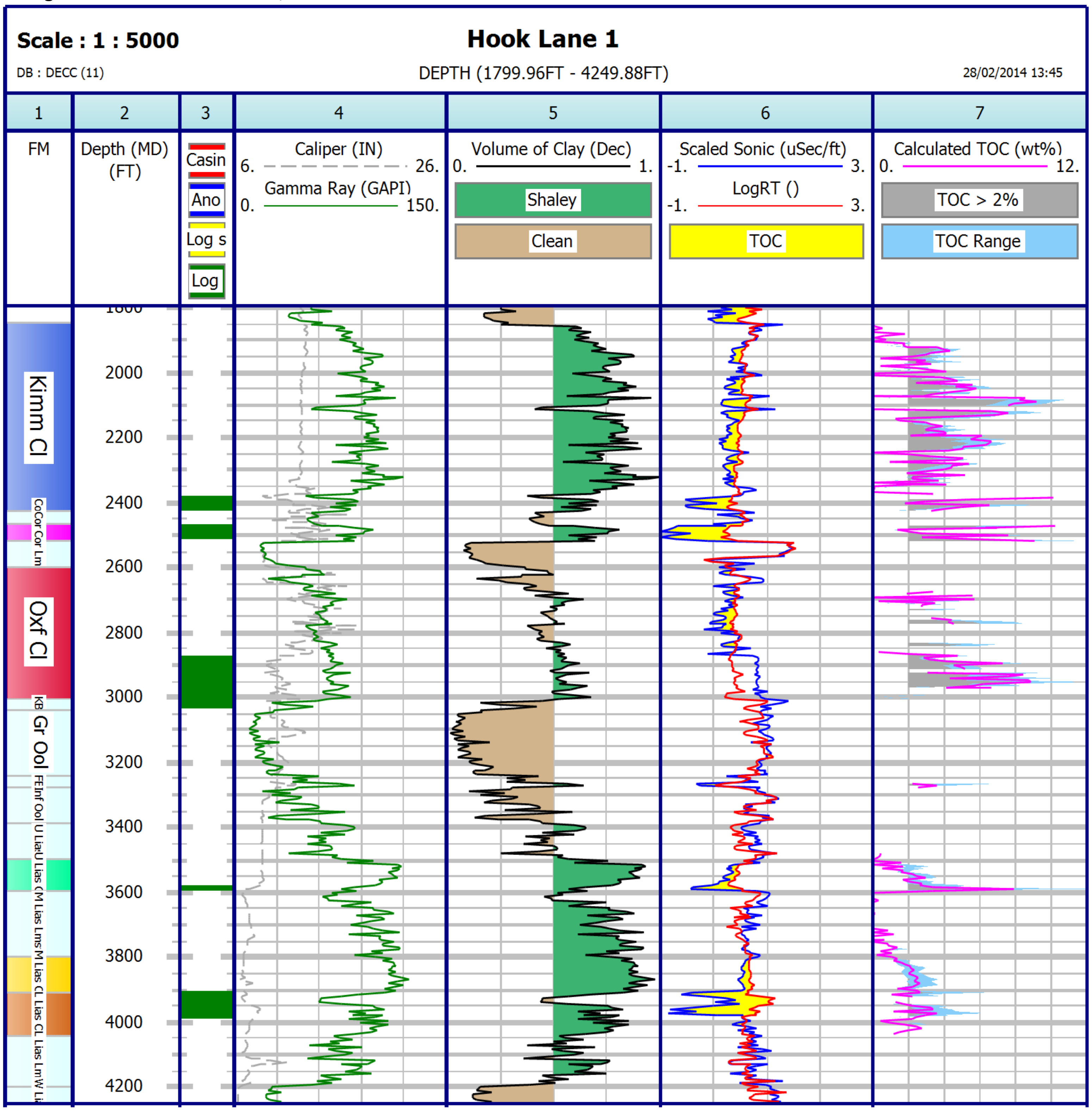
Figure 7: Hook Lane 1 SU55SE/20



Kimm Cl	Kimmeridge Clay
Cor Arg	Corallian Argillaceous unit
Oxf Cl	Oxford Clay
U Lias Cl	Upper Lias Clay
M Lias Cl	Middle Lias Clay
L Lias Cl	Lower Lias Clay

Track 3: Data Quality Indicator

- Casing Shoe/ Data Missing
- Anomalous Log
- Spike Affecting TOC Removed
- Splice with Density/Neutron Curve

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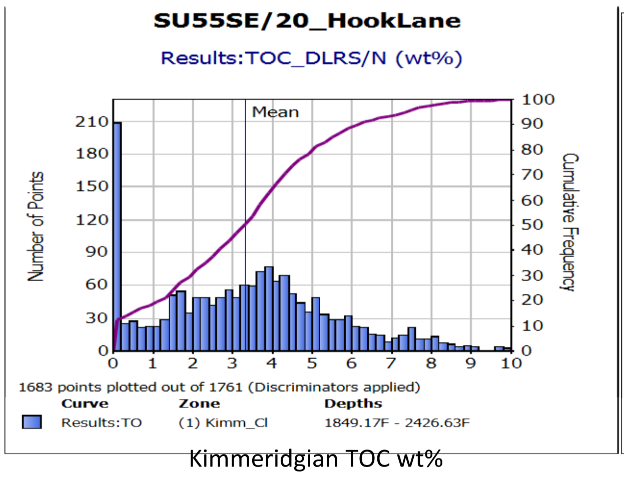
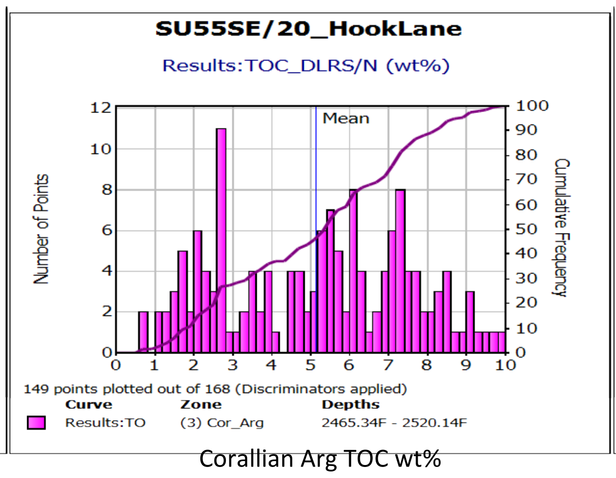
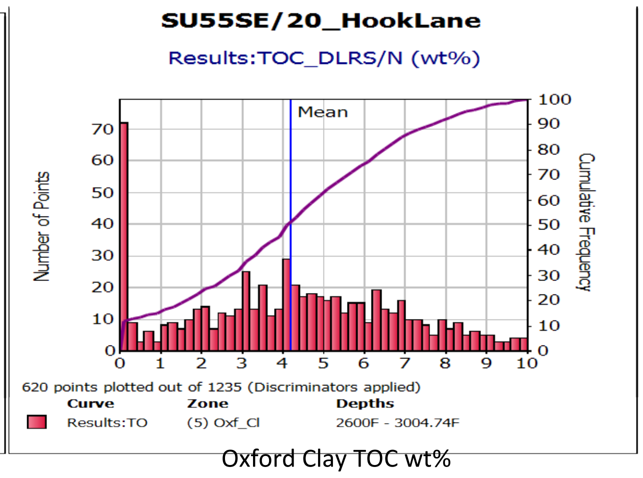


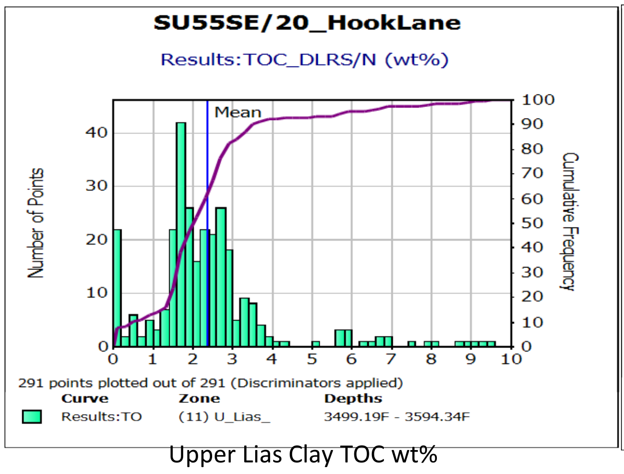
Kimmeridgian TOC wt%



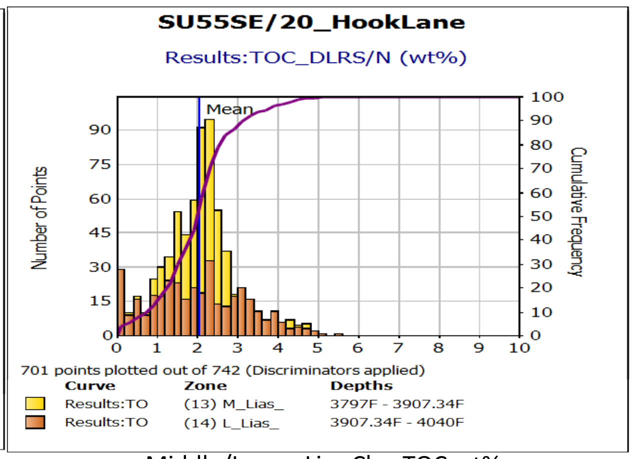
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 7a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**10.75**	**3.35**
TOC_L	0.00	8.99	2.88
TOC_H	0.00	12.88	3.91
Corallian Argillaceous Unit			
TOC_M	**0.60**	**11.38**	**5.35**
TOC_L	0.64	9.51	4.54
TOC_H	0.56	13.65	6.32
Oxford Clay			
TOC_M	0.00	11.91	4.30
TOC_L	0.00	9.95	3.67
TOC_H	0.00	14.29	5.07
Upper Lias Clay			
TOC_M	0.00	9.48	2.37
TOC_L	0.00	6.68	1.86
TOC_H	0.00	13.60	3.15
Middle/Lower Lias			
TOC_M	0.00	5.46	2.04
TOC_L	0.00	4.34	1.84
TOC_H	0.00	7.68	2.65

Table 7a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 7b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
Kimmeridgian	1849.2	2426.6	577.5	553.7	0.96	391.4	**0.68**	403.2	0.70	370.1	0.64
Corallian Argillaceous Unit	2465.3	2520.1	54.8	50.9	0.93	45.6	**0.83**	46.6	0.85	43.6	0.80
Oxford Clay	2600.0	3004.7	404.7	206.7	0.51	160.8	**0.40**	165.7	0.41	155.5	0.38
Upper Lias Clay	3499.2	3594.3	95.1	95.1	1.00	50.4	**0.53**	72.3	0.76	32.3	0.34
Middle Lias Clay	3797.0	3907.3	110.3	110.3	1.00	67.8	**0.61**	88.4	0.80	13.0	0.12
Lower Lias (Upper Clays/Lmst)	3907.3	4040.0	132.7	119.2	0.90	59.6	**0.45**	71.7	0.54	63.8	0.48
All Zones	1849.2	4040.0	1375.1	1135.9	0.83	775.5	**0.56**	848.0	0.62	678.3	0.49

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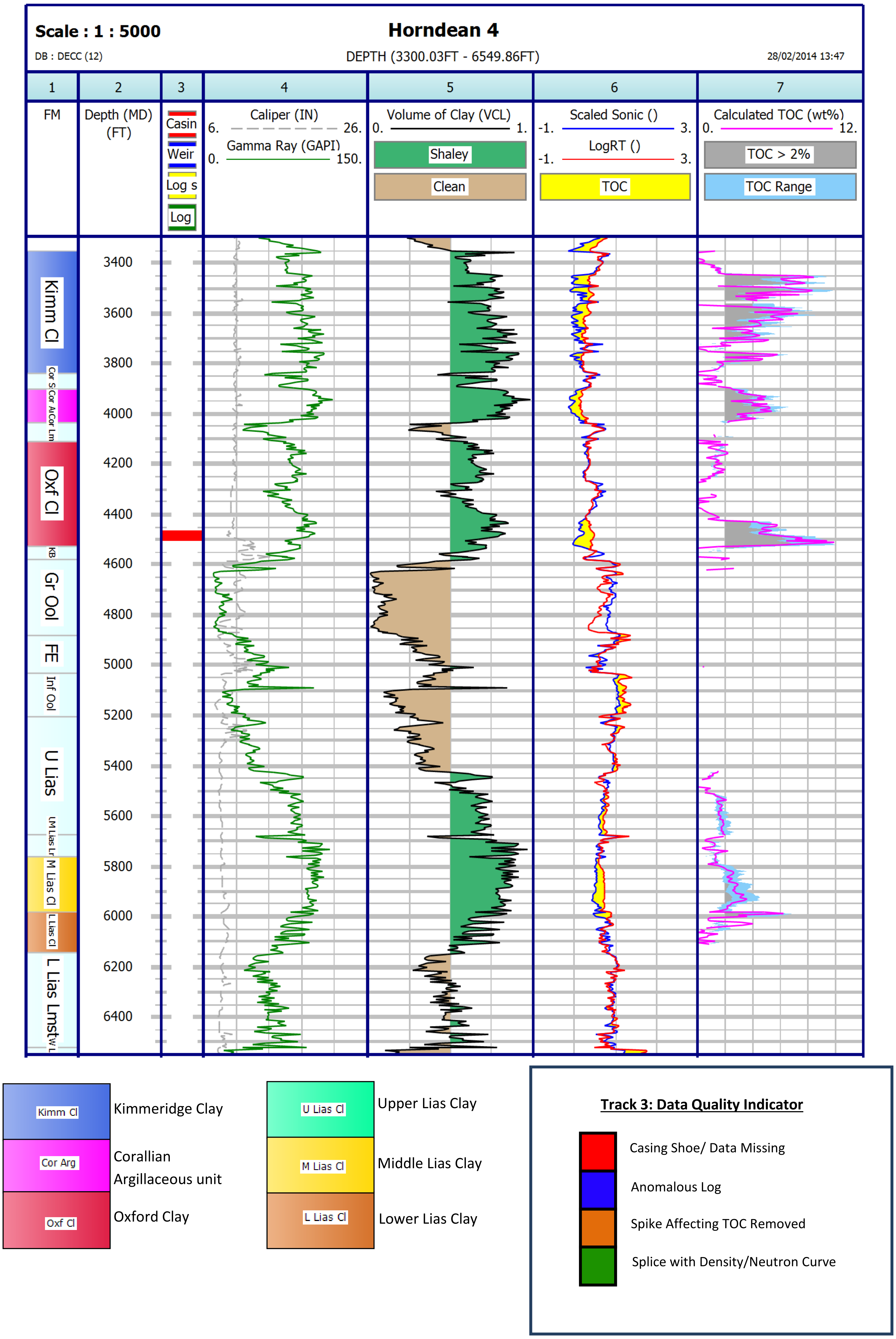
Figure 8: Horndean 4 SU61SE/82



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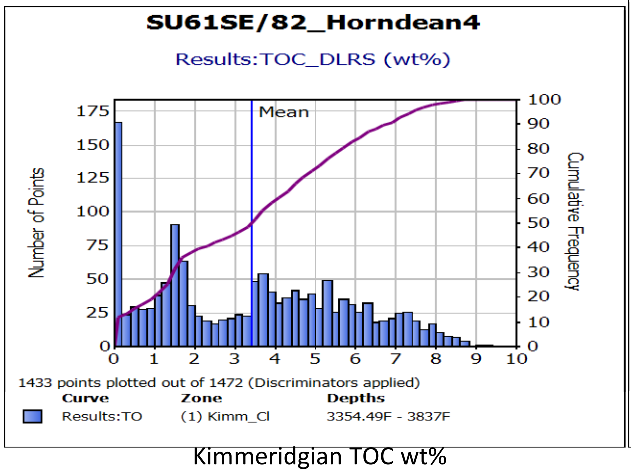
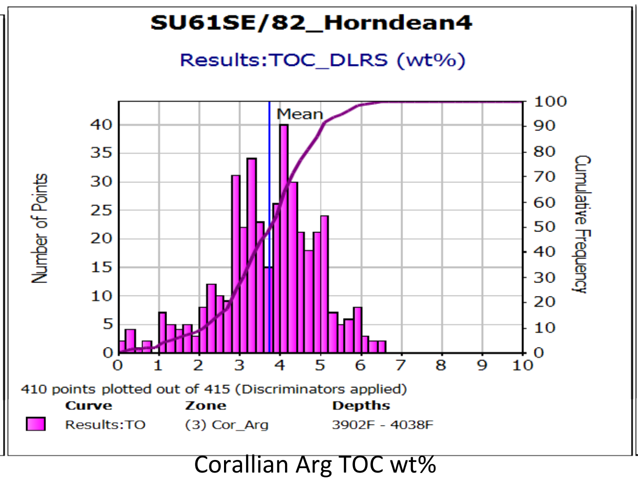
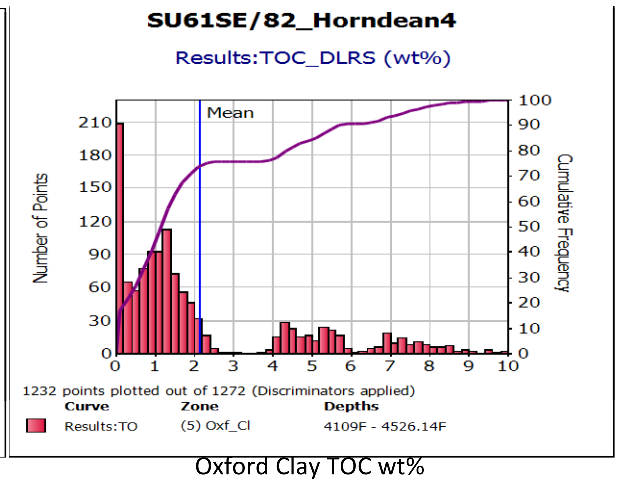


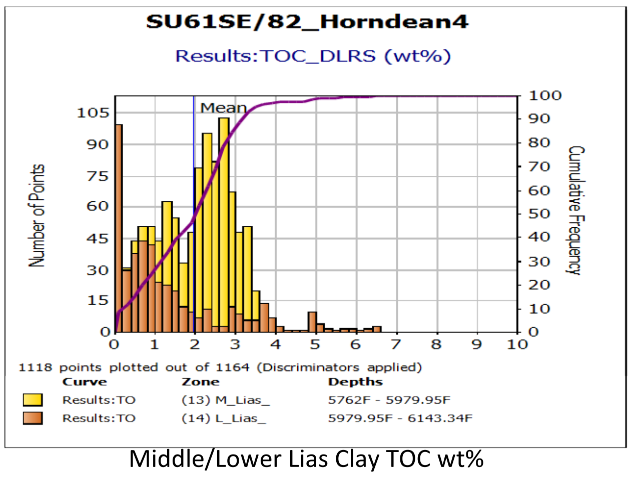
Kimmeridgian TOC wt%



Corallian Arg TOC wt%



Oxford Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 8a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Upper Lias Clay absent

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**14.92**	**3.46**
TOC_L	0.00	12.43	2.98
TOC_H	0.00	17.95	4.05
Corallian Argillaceous Unit			
TOC_M	**0.00**	**6.48**	**3.73**
TOC_L	0.07	5.48	3.21
TOC_H	0.00	7.70	4.35
Oxford Clay			
TOC_M	0.00	10.13	2.14
TOC_L	0.00	8.48	1.89
TOC_H	0.00	12.13	2.45
Middle/Lower Lias			
TOC_M	0.00	6.55	1.95
TOC_L	0.00	4.70	1.57
TOC_H	0.00	9.28	2.52

Table 8a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 8b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	3354.5	3837.0	482.5	471.7	0.98	293.7	**0.61**	304.5	0.63	284.8	0.59
Corallian Argillaceous Unit	3902.0	4038.0	136.0	134.5	0.99	123.6	**0.91**	124.6	0.92	118.7	0.87
Oxford Clay	4109.0	4526.1	417.1	404.7	0.97	116.3	**0.28**	131.7	0.32	103.5	0.25
Middle Lias Clay	5762.0	5980.0	218.0	218.0	1.00	160.1	**0.74**	179.1	0.82	90.6	0.42
Lower Lias (Upper Clays/Lmst)	5980.0	6143.3	163.4	148.3	0.91	36.4	**0.22**	43.0	0.26	29.5	0.18
All Zones	3354.5	6143.3	1417.3	1377.0	0.97	730.1	**0.52**	782.9	0.55	627.1	0.44

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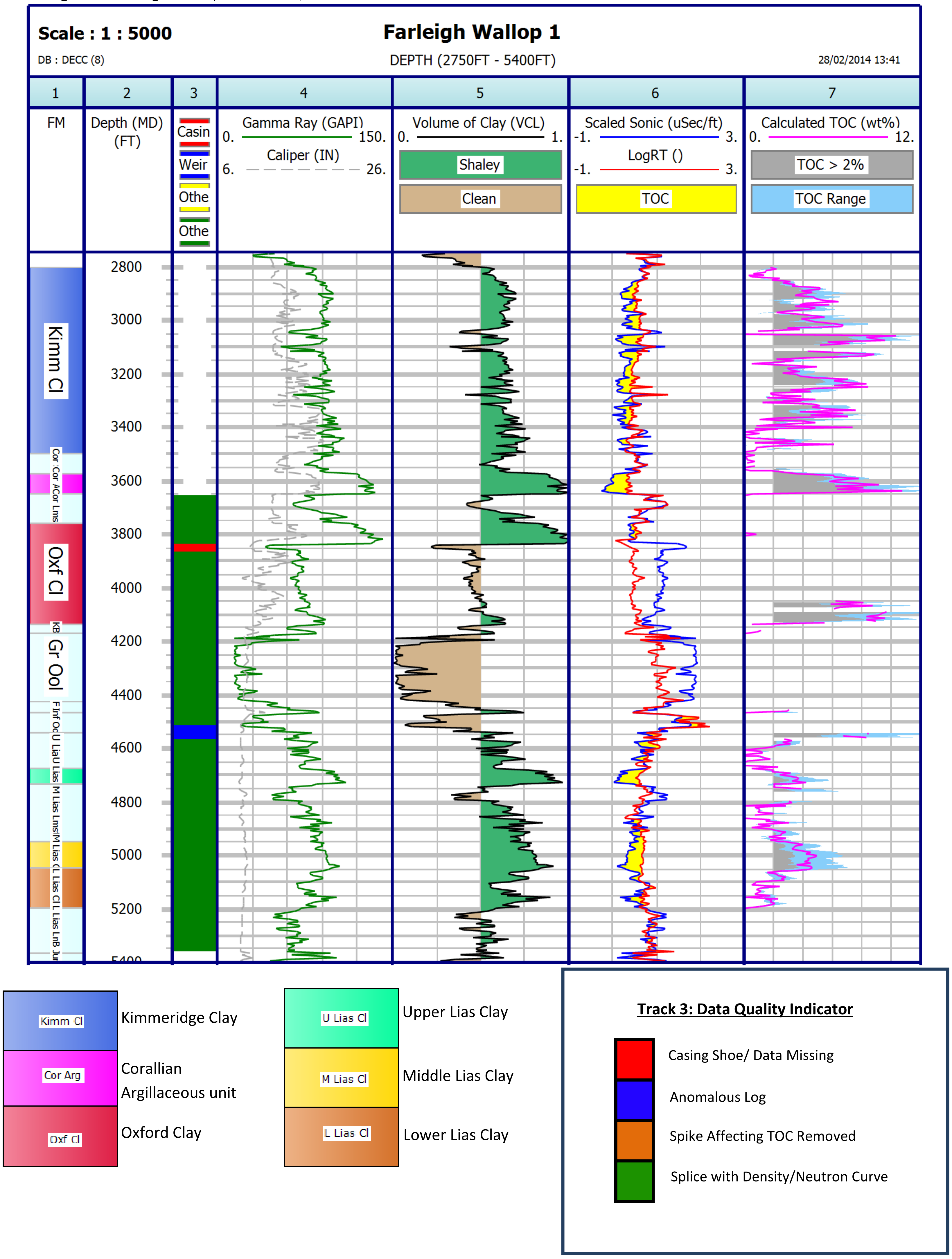
Figure 9: Farleigh Wallop 1 SU64NW/50



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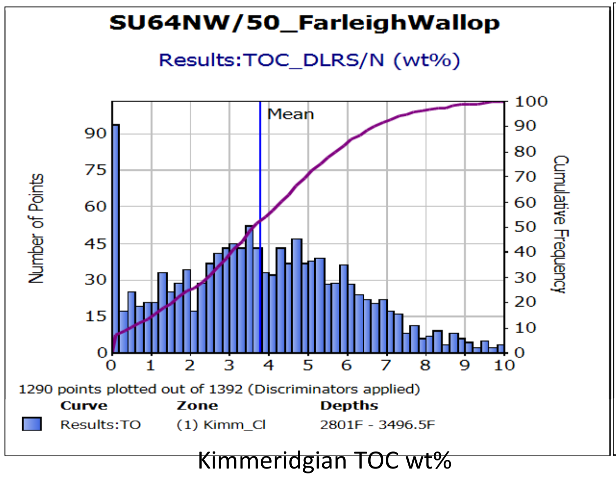
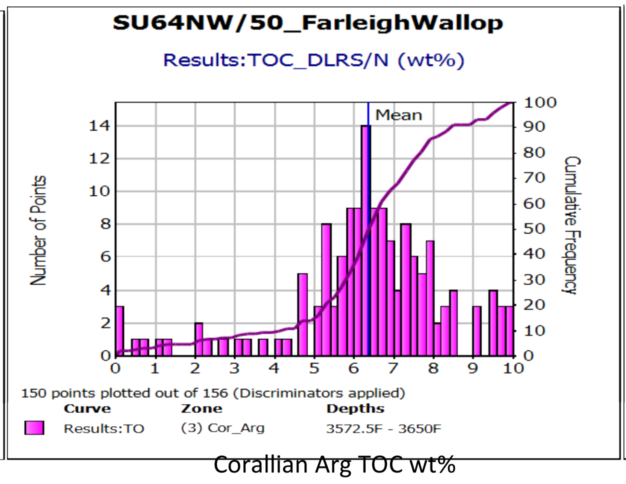
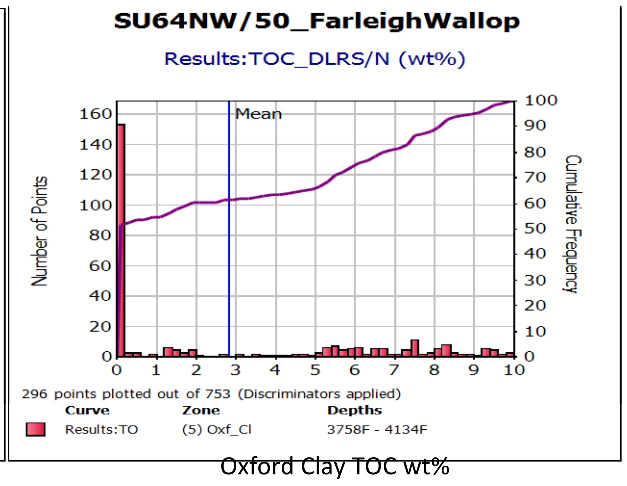


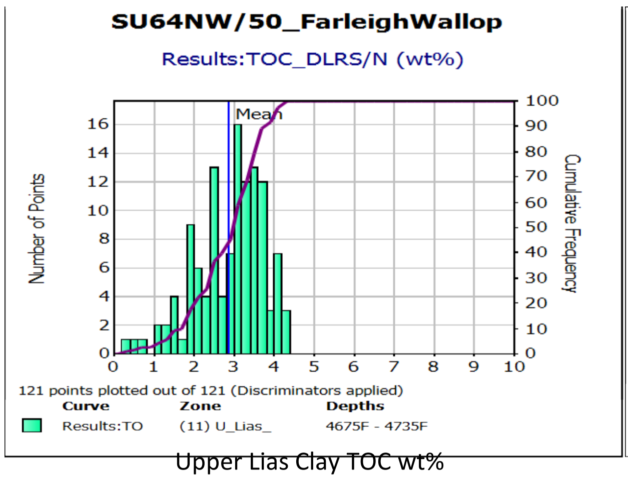
Kimmeridgian TOC wt%



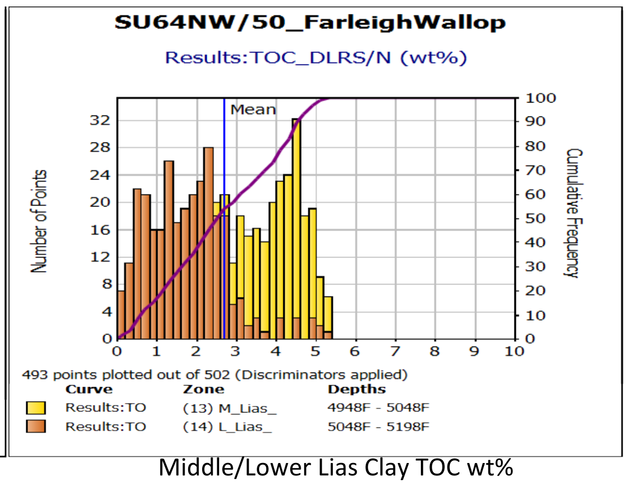
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 9a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**11.84**	**3.87**
TOC_L	0.00	9.89	3.32
TOC_H	0.00	14.21	4.54
Corallian Argillaceous Unit			
TOC_M	**0.00**	**11.91**	**6.53**
TOC_L	0.00	9.94	5.49
TOC_H	0.00	14.29	7.73
Oxford Clay			
TOC_M	0.00	12.53	3.55
TOC_L	0.00	10.46	3.00
TOC_H	0.00	15.04	4.22
Upper Lias Clay			
TOC_M	0.27	4.28	2.88
TOC_L	0.44	3.16	2.21
TOC_H	0.01	5.93	3.87
Middle/Lower Lias			
TOC_M	0.00	5.34	2.70
TOC_L	0.23	3.88	2.09
TOC_H	0.00	7.49	3.60

Table 9a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 9b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	2801.0	3496.5	695.5	652.5	0.94	494.0	**0.71**	510.5	0.73	481.0	0.69
Corallian Argillaceous Unit	3572.5	3650.0	77.5	77.5	1.0	74.3	**0.96**	73.3	0.95	72.8	0.94
Oxford Clay	3758.0	4134.0	376.0	162.5	0.4	74.0	**0.20**	76.0	0.20	73.5	0.20
Upper Lias Clay	4675.0	4735.0	60.0	60.0	1.0	49.8	**0.83**	54.8	0.91	39.5	0.66
Middle Lias Clay	4948.0	5048.0	100.0	100.0	1.0	100.0	**1.00**	100.0	1.00	99.0	0.99
Lower Lias (Upper Clays/Lmst)	5048.0	5198.0	150.0	145.5	1.0	57.8	**0.39**	77.8	0.52	24.3	0.16
All Zones	2801.0	5198.0	1459.0	1198.0	0.8	849.8	**0.58**	892.3	0.61	790.0	0.54

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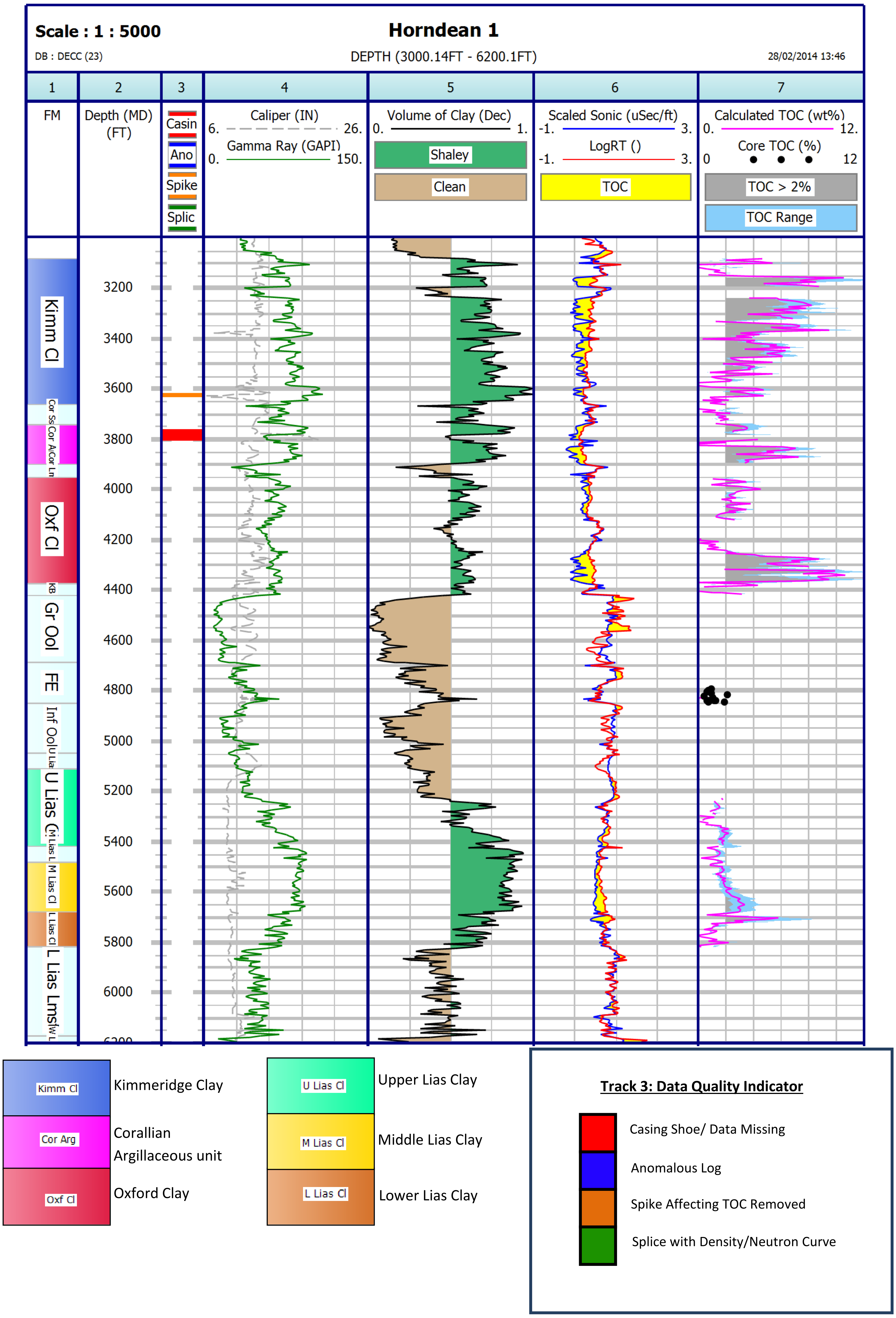
Figure 10: Horndean 1 SU71SW/59B



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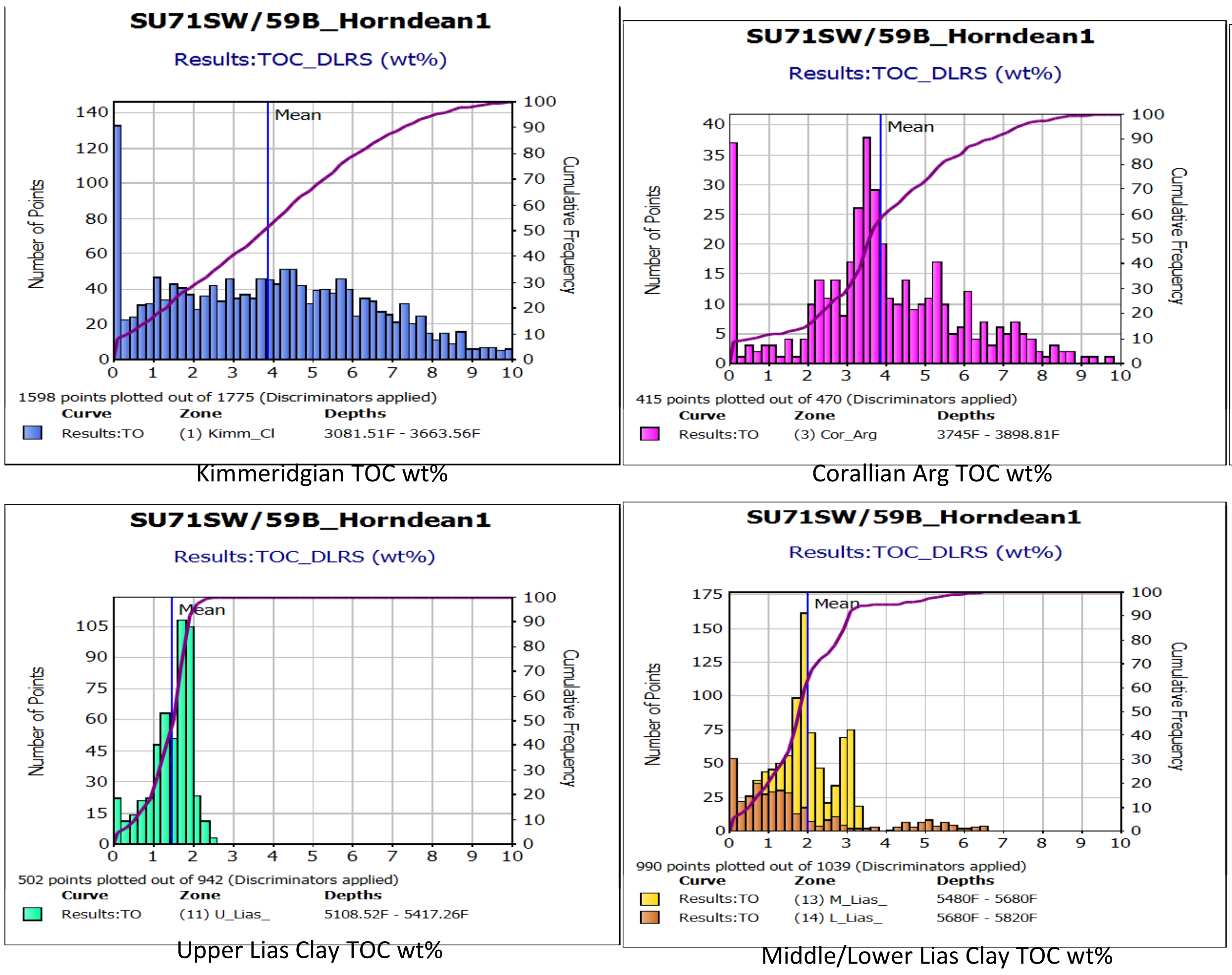

Kimmeridgian TOC wt% | Corallian Arg TOC wt% | Oxford Clay TOC wt% | Upper Lias Clay TOC wt% | Middle/Lower Lias Clay TOC wt%

Figure 10a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	0.00	12.37	3.97
TOC_L	0.00	10.32	3.40
TOC_H	0.00	14.85	4.66
Corallian Argillaceous Unit			
TOC_M	0.00	9.78	3.86
TOC_L	0.00	8.19	3.31
TOC_H	0.00	11.70	4.53
Oxford Clay			
TOC_M	0.00	11.16	3.57
TOC_L	0.00	9.33	3.08
TOC_H	0.00	13.38	4.17
Upper Lias Clay			
TOC_M	0.00	2.53	1.44
TOC_L	0.12	1.98	1.23
TOC_H	0.00	3.36	1.76
Middle/Lower Lias			
TOC_M	0.00	6.57	1.98
TOC_L	0.00	4.71	1.59
TOC_H	0.00	9.31	2.56

Table 10a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 10b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	3081.5	3663.6	582.1	530.5	0.91	384.5	**0.66**	398.0	0.68	372.2	0.64
Corallian Argillaceous Unit	3745.0	3898.8	153.8	135.9	0.88	116.6	**0.76**	117.9	0.77	112.0	0.73
Oxford Clay	3948.7	4371.9	423.3	356.8	0.84	239.7	**0.57**	260.0	0.61	211.1	0.50
Upper Lias Clay	5108.5	5417.3	308.7	164.7	0.53	12.1	**0.04**	81.0	0.26	0.0	0.00
Middle Lias Clay	5480.0	5680.0	200.0	200.0	1.00	98.1	**0.49**	173.0	0.87	59.1	0.30
Lower Lias (Upper Clays/Lmst)	5680.0	5820.0	140.0	124.3	0.89	31.8	**0.23**	41.6	0.30	25.9	0.19
All Zones	3081.5	5820.0	1807.9	1512.2	0.84	882.9	**0.49**	1071.5	0.59	780.3	0.43

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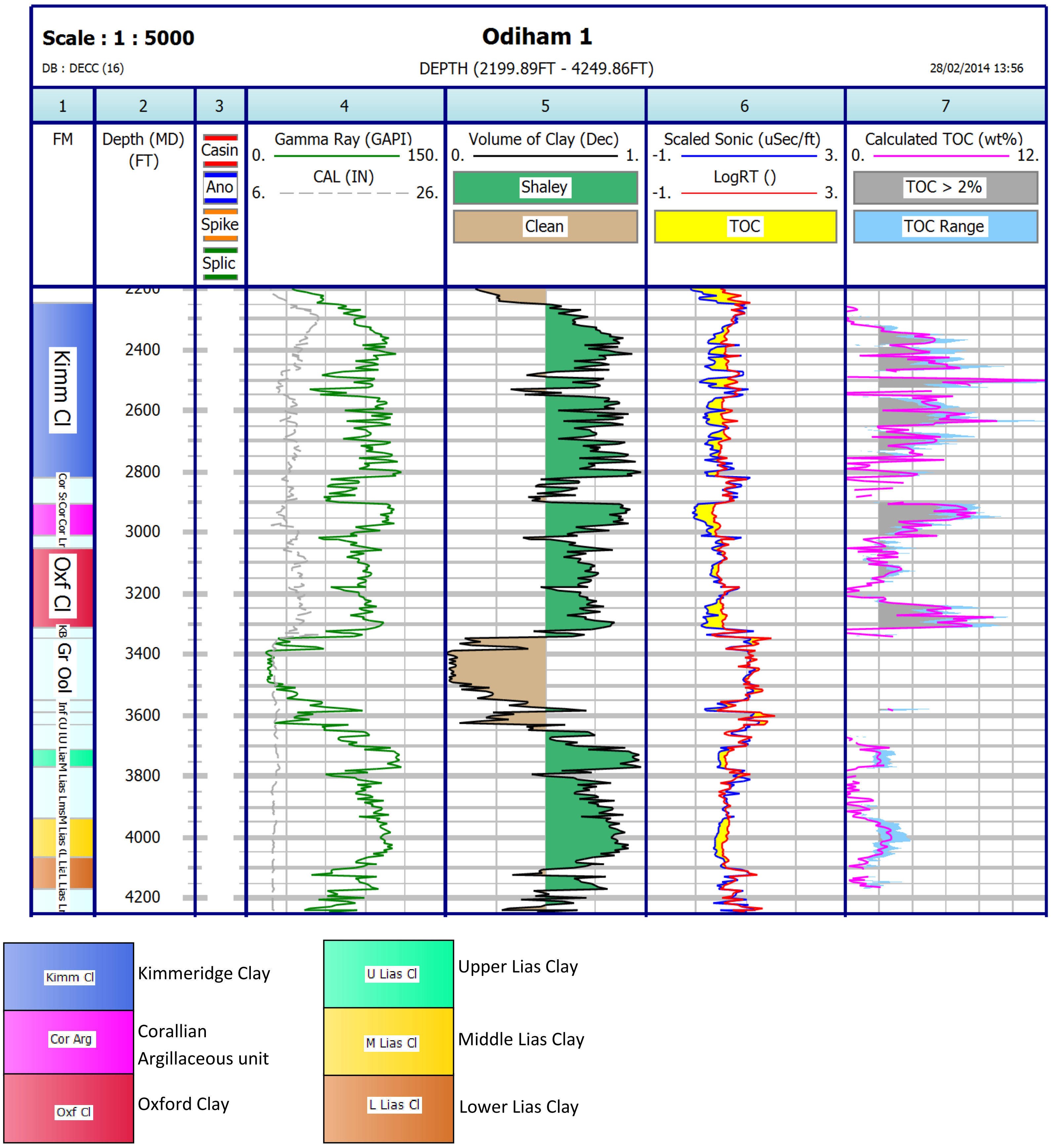
Figure 11: Odiham 1 SU75SW/99



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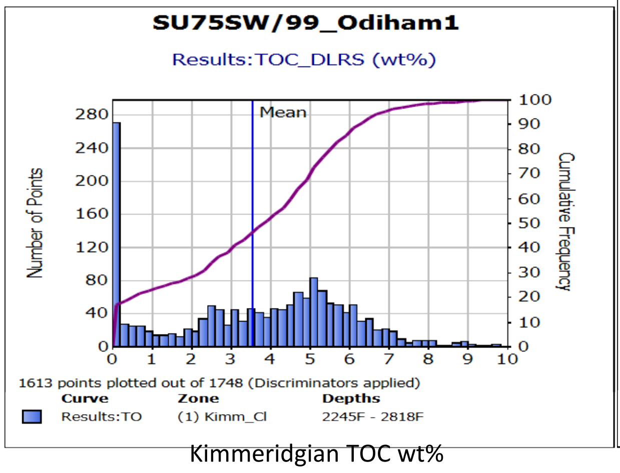
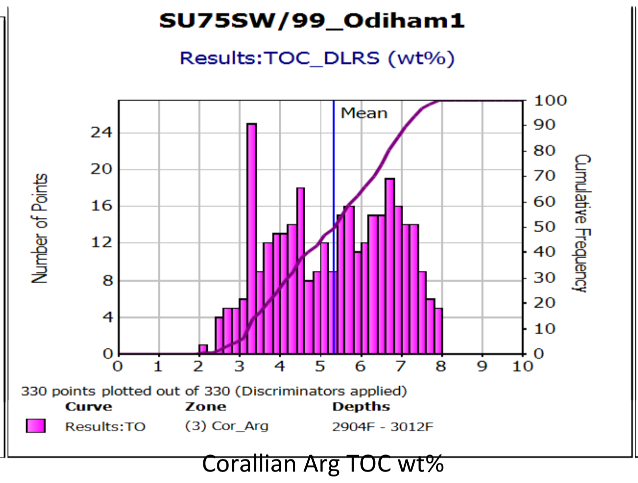
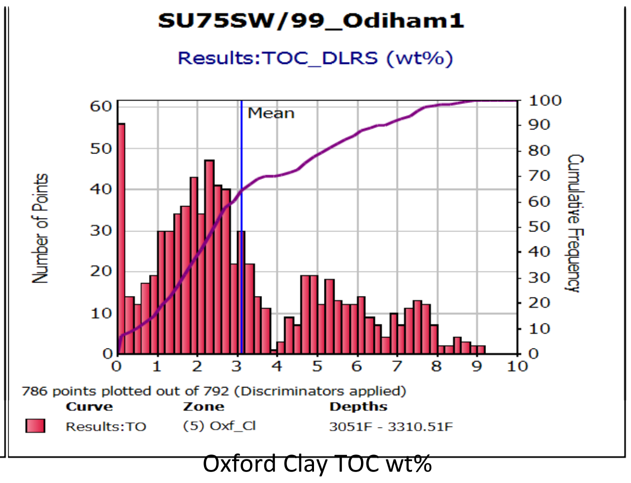


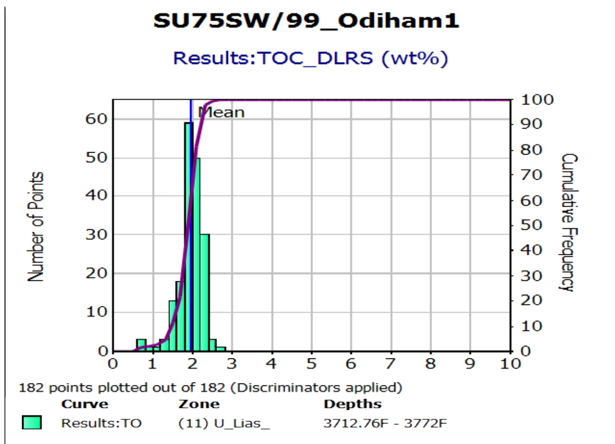
Kimmeridgian TOC wt%



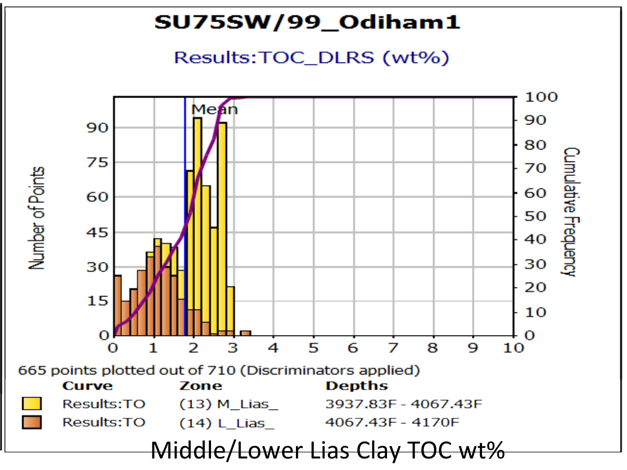
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 11a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**13.26**	**3.66**
TOC_L	0.00	11.06	3.13
TOC_H	0.00	15.93	4.30
Corallian Argillaceous Unit			
TOC_M	**2.16**	**7.99**	**5.30**
TOC_L	1.92	6.72	4.51
TOC_H	2.46	9.53	6.27
Oxford Clay			
TOC_M	0.00	9.11	3.10
TOC_L	0.00	7.64	2.69
TOC_H	0.00	10.89	3.61
Upper Lias Clay			
TOC_M	0.66	2.72	1.95
TOC_L	0.71	2.10	1.58
TOC_H	0.60	3.63	2.50
Middle/Lower Lias			
TOC_M	0.00	3.29	1.78
TOC_L	0.00	2.49	1.47
TOC_H	0.00	4.47	2.26

Table 11a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 11b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	2245.0	2818.0	573.0	536.3	0.94	389.8	**0.68**	398.0	0.69	381.6	0.67
Corallian Argillaceous Unit	2904.0	3012.0	108.0	108.0	1.0	108.0	**1.00**	108.0	1.00	107.8	1.00
Oxford Clay	3051.0	3310.5	259.5	257.5	1.0	162.1	**0.62**	177.5	0.68	147.3	0.57
Upper Lias Clay	3712.8	3772.0	59.3	59.3	1.0	27.4	**0.46**	52.7	0.89	0.2	0.00
Middle Lias Clay	3937.8	4067.4	129.6	129.6	1.0	97.5	**0.75**	121.1	0.93	38.7	0.30
Lower Lias (Upper Clays/Lmst)	4067.4	4170.0	102.6	87.8	0.9	7.9	**0.08**	16.4	0.16	2.0	0.02
All Zones	2245.0	4170.0	1231.9	1178.4	1.0	792.6	**0.64**	873.6	0.71	677.5	0.55

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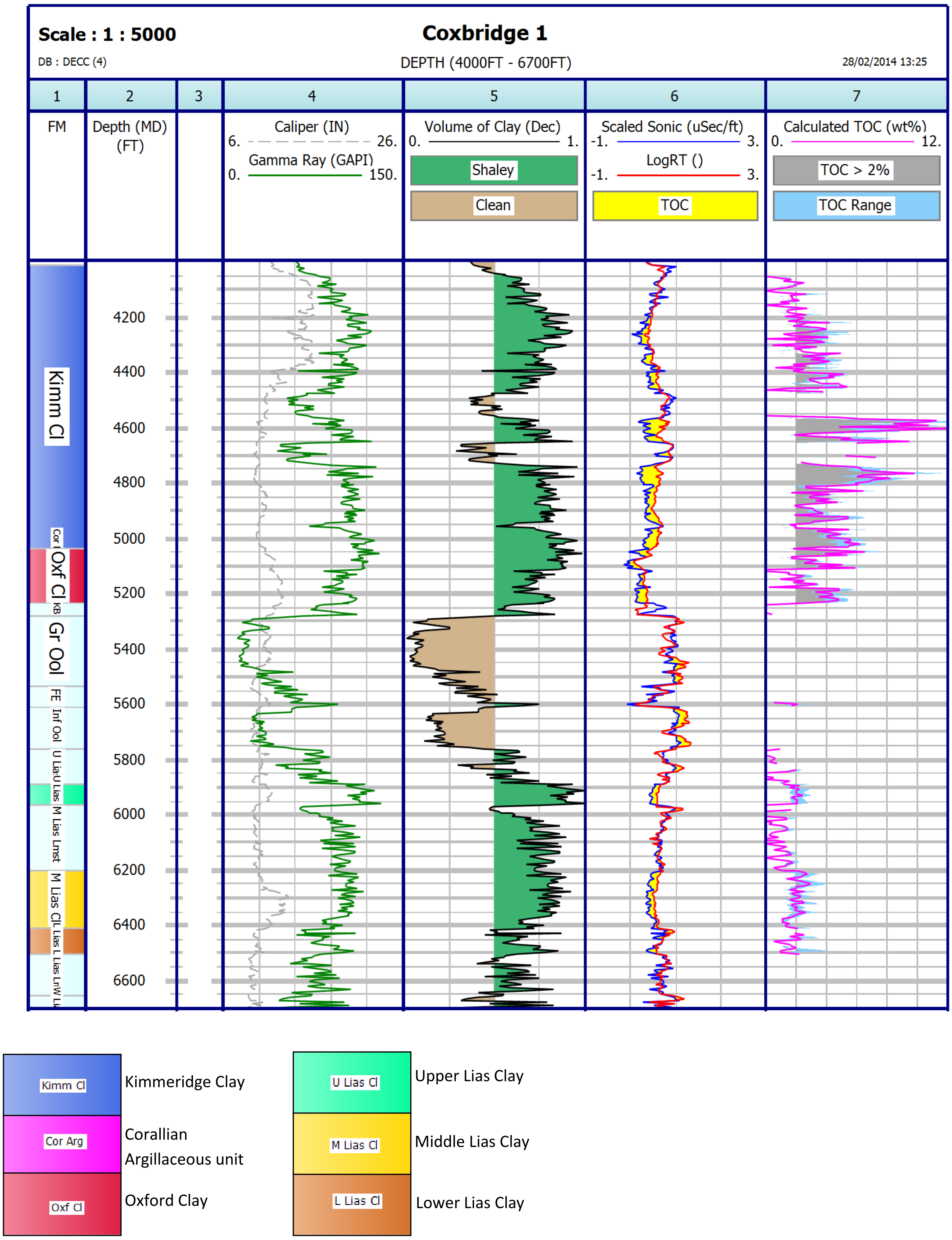
Figure 12: Coxbridge 1 SU84NW/60



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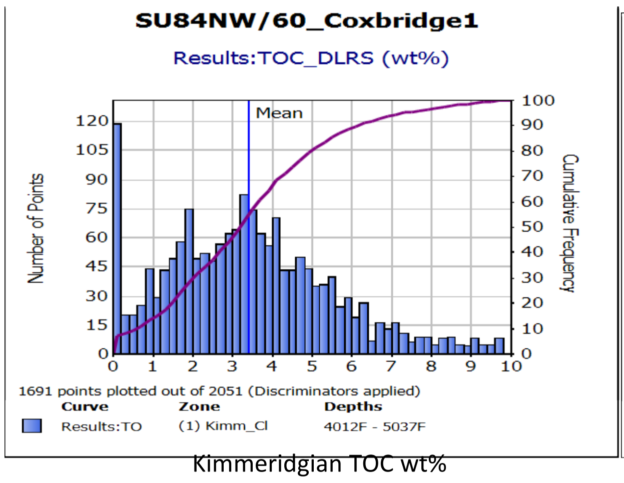
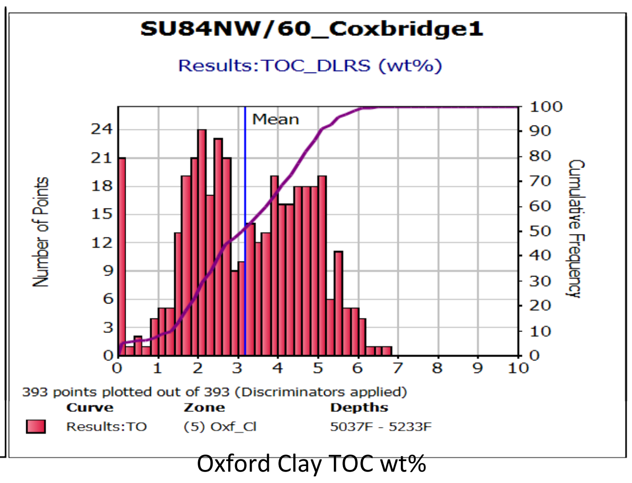
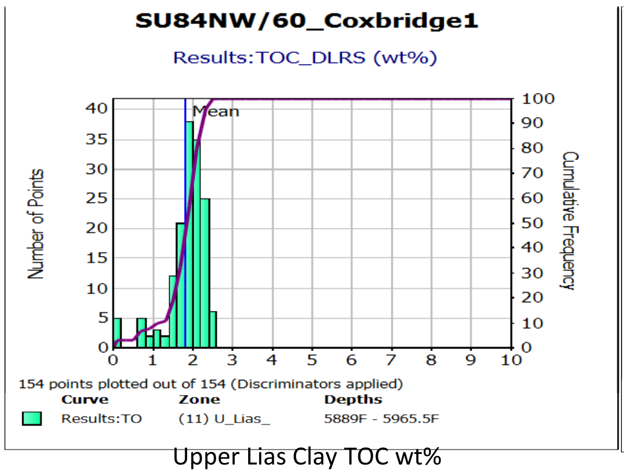


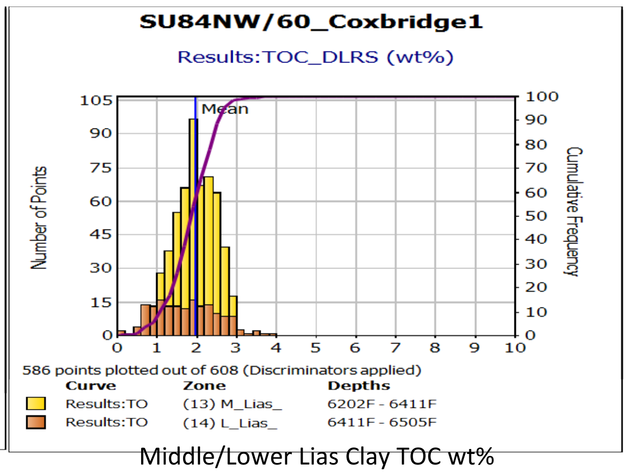
Kimmeridgian TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 12a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Faulting removes Corallian

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**13.31**	**3.53**
TOC_L	0.00	11.10	3.04
TOC_H	0.00	15.99	4.12
Oxford Clay			
TOC_M	0.00	6.64	3.20
TOC_L	0.00	5.61	2.77
TOC_H	0.00	7.90	3.73
Upper Lias Clay			
TOC_M	0.00	2.51	1.84
TOC_L	0.00	1.96	1.50
TOC_H	0.00	3.31	2.35
Middle/Lower Lias			
TOC_M	0.11	3.84	1.94
TOC_L	0.33	2.86	1.57
TOC_H	0.00	5.28	2.48

Table 12a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 12b (Below):

Summarising each formations’ Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	4012.0	5037.0	1025.0	858.8	0.84	617.8	**0.60**	656.3	0.64	585.3	0.57
Oxford Clay	5037.0	5233.0	196.0	196.0	1.0	150.3	**0.77**	161.8	0.83	136.8	0.70
Upper Lias Clay	5889.0	5965.5	76.5	76.5	1.0	33.0	**0.43**	62.0	0.81	0.0	0.00
Middle Lias Clay	6202.0	6411.0	209.0	209.0	1.0	102.5	**0.49**	168.5	0.81	23.0	0.11
Lower Lias (Upper Clays/Lmst)	6411.0	6505.0	94.0	83.0	0.9	31.3	**0.33**	45.3	0.48	13.5	0.14
All Zones	4012.0	6505.0	1600.8	1423.5	0.9	935.0	**0.58**	1094.0	0.68	758.8	0.47

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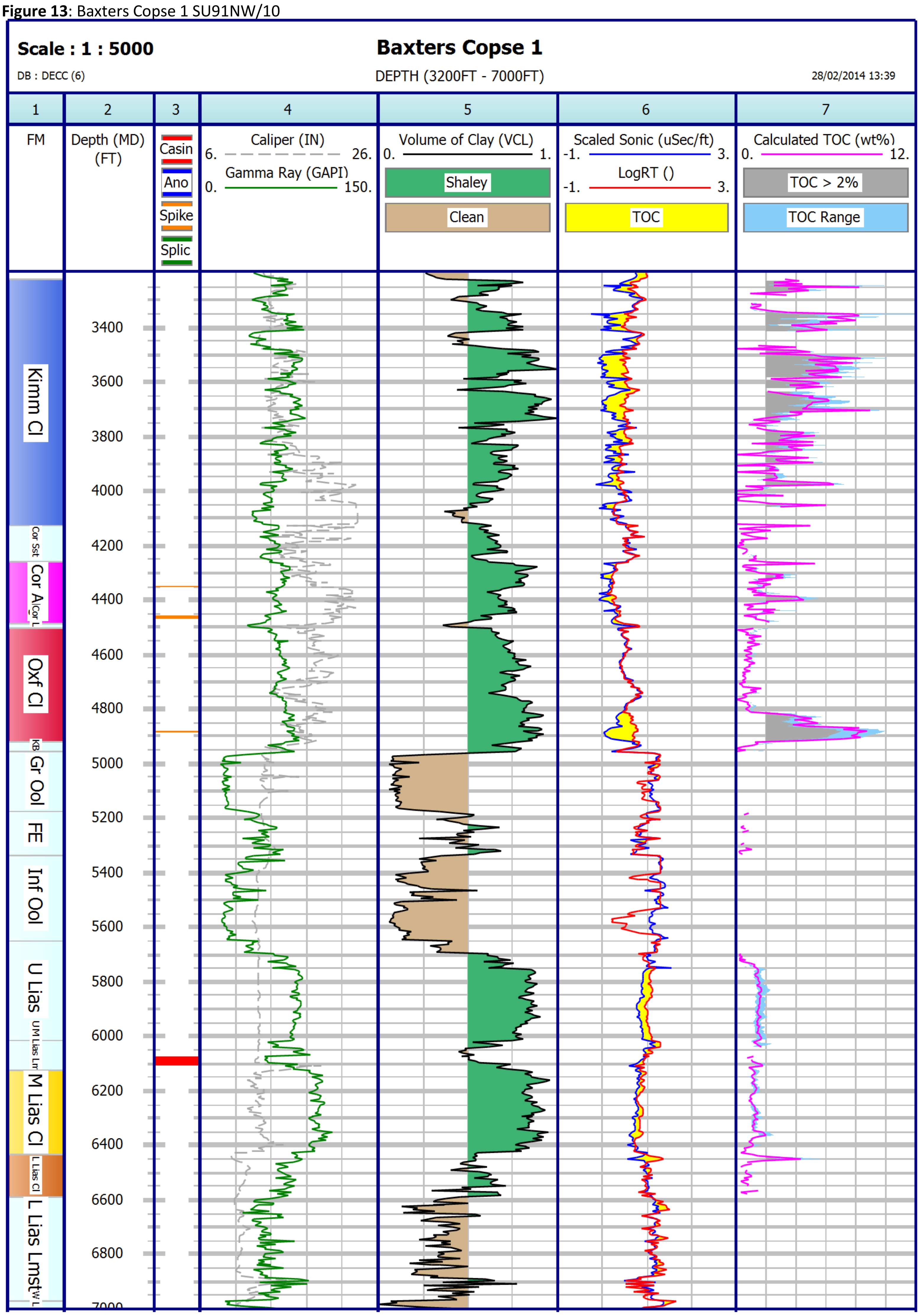
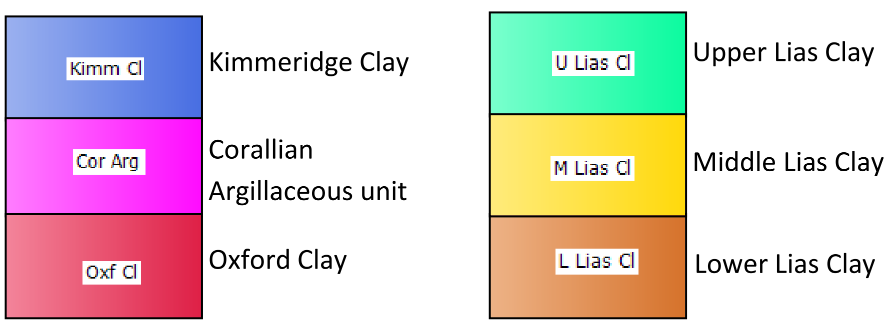
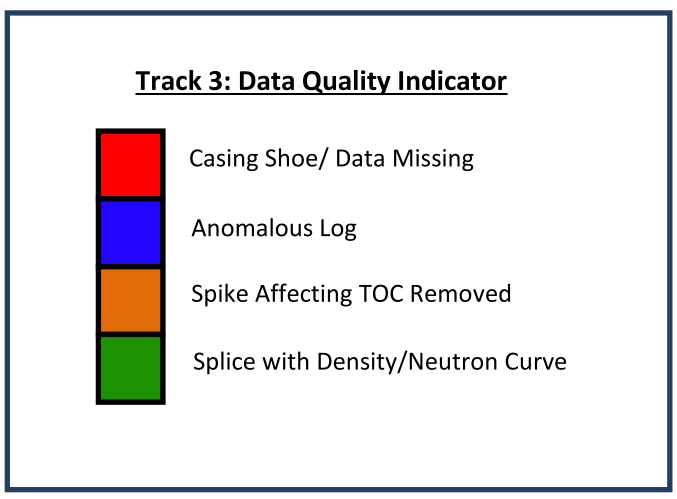
Figure 13: Baxters Copse 1 SU91NW/10







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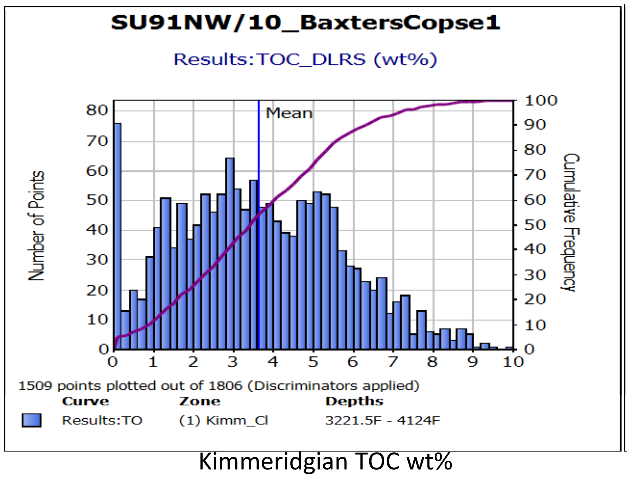
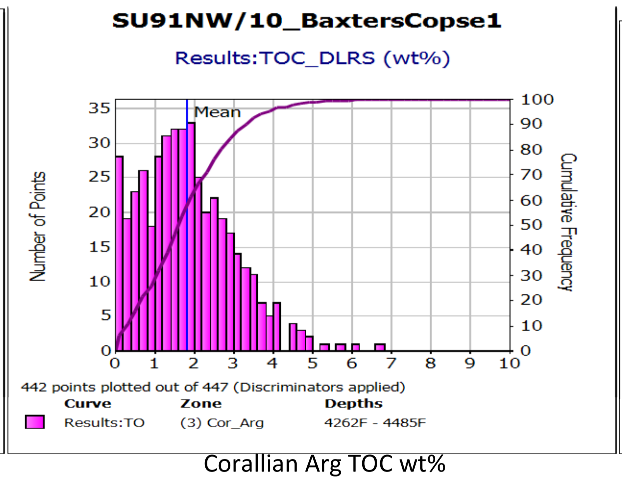
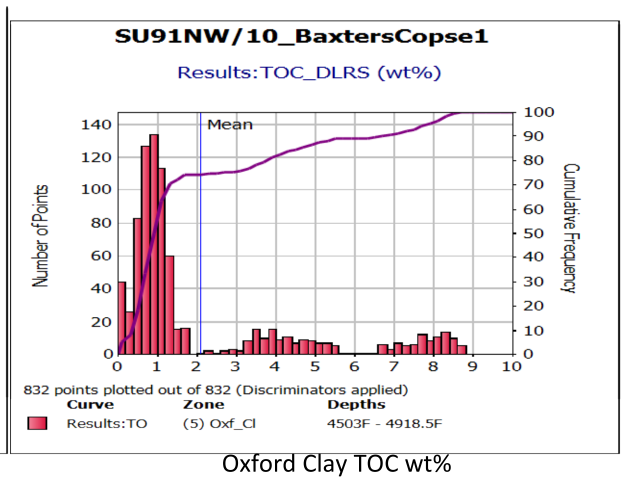


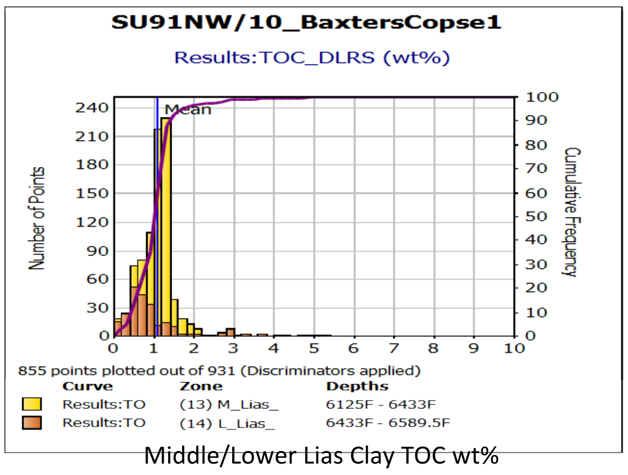
Kimmeridgian TOC wt%



Corallian Arg TOC wt%



Oxford Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 13a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Upper Lias Clay absent

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**10.09**	**3.62**
TOC_L	0.00	8.45	3.12
TOC_H	0.00	12.09	4.24
Corallian Argillaceous Unit			
TOC_M	**0.00**	**6.67**	**1.82**
TOC_L	0.00	5.63	1.63
TOC_H	0.00	7.93	2.04
Oxford Clay			
TOC_M	0.00	8.71	2.07
TOC_L	0.00	7.31	1.84
TOC_H	0.00	10.41	2.35
Middle/Lower Lias			
TOC_M	0.00	5.24	1.11
TOC_L	0.03	3.81	1.01
TOC_H	0.00	7.35	1.26

Table 13a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 13b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	3221.5	4124.0	902.5	755.3	0.84	571.0	**0.63**	590.5	0.65	543.5	0.60
Corallian Argillaceous Unit	4262.0	4485.0	223.0	220.8	0.99	86.0	**0.39**	103.0	0.46	70.5	0.32
Oxford Clay	4503.0	4918.5	415.5	415.5	1.00	106.5	**0.26**	107.0	0.26	106.0	0.26
Middle Lias Clay	6125.0	6433.0	308.0	308.0	1.00	2.5	**0.01**	15.0	0.05	0.0	0.00
Lower Lias (Upper Clays/Lmst)	6433.0	6589.5	156.5	118.8	0.76	13.5	**0.09**	16.0	0.10	11.5	0.07
All Zones	3221.5	6589.5	2005.8	1818.5	0.91	779.5	**0.39**	831.5	0.42	731.5	0.37

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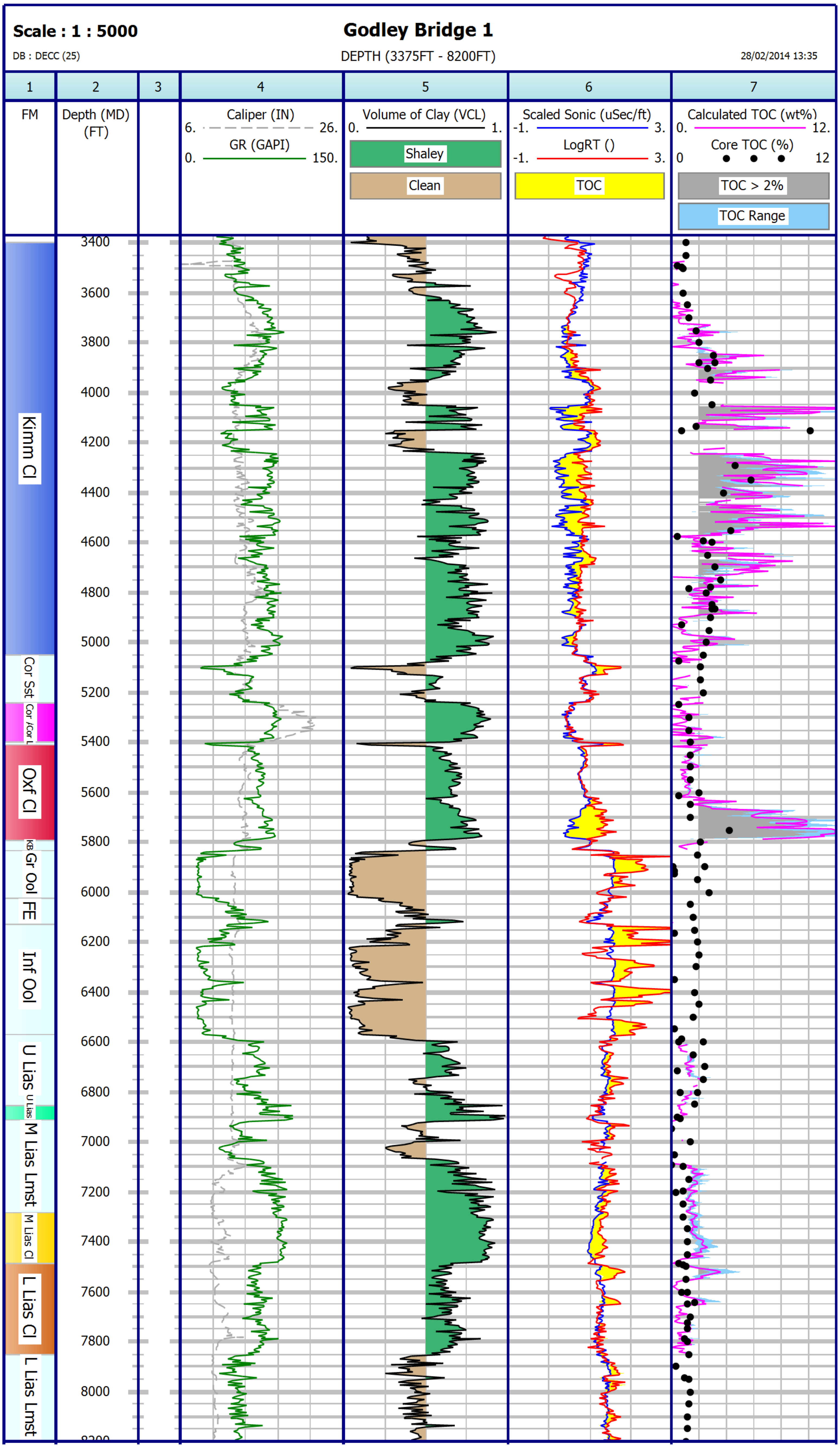
Figure 14: Godley Bridge 1 SU93NE/21



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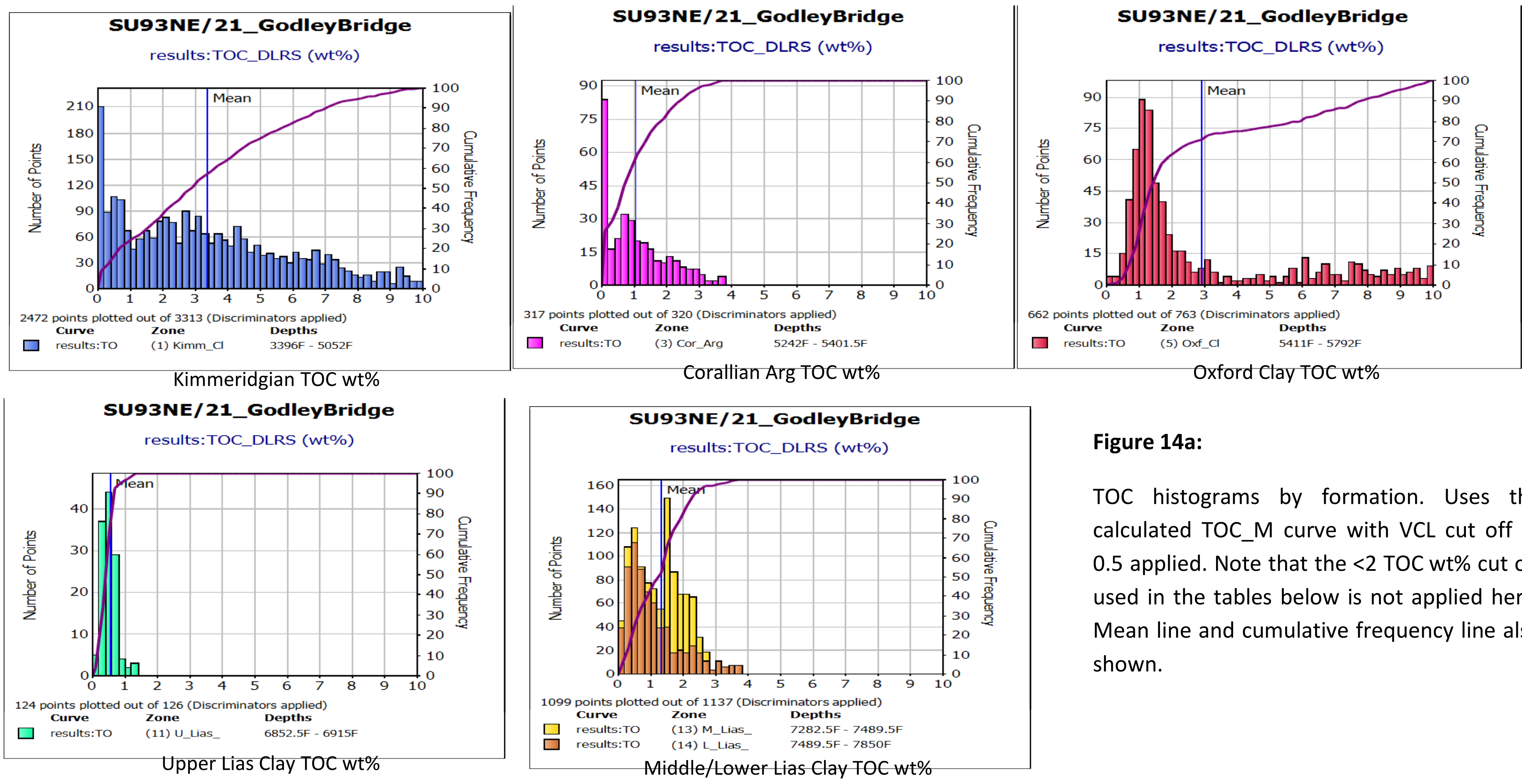

Kimmeridgian TOC wt%

Corallian Arg TOC wt%

Oxford Clay TOC wt%

Upper Lias Clay TOC wt%

Middle/Lower Lias Clay TOC wt%

Figure 14a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (38Pts)	0.45	16.80	4.27
TOC_M	0.00	15.09	3.59
TOC_L	0.00	12.57	3.09
TOC_H	0.00	18.16	4.20
Corallian Argillaceous Unit			
Core TOC (4Pts)	0.48	1.39	1.12
TOC_M	0.00	3.76	1.04
TOC_L	0.00	3.23	0.97
TOC_H	0.00	4.39	1.13
Oxford Clay			
Core TOC (9Pts)	0.56	4.22	1.67
TOC_M	0.00	17.81	3.86
TOC_L	0.08	14.80	3.32
TOC_H	0.00	21.46	4.52
Upper Lias Clay			
Core TOC (8Pts)	0.37	1.67	0.90
TOC_M	0.08	1.32	0.53
TOC_L	0.31	1.15	0.61
TOC_H	0.00	1.57	0.40
Middle/Lower Lias			
Core TOC (12Pts)	0.53	1.66	1.08
TOC_M	0.00	3.76	1.30
TOC_L	0.09	2.80	1.14
TOC_H	0.00	5.16	1.55

Table 14a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 14b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	3396.0	5052.0	1656.0	1270.8	0.77	830.0	**0.50**	871.0	0.53	774.5	0.47
Corallian Argillaceous Unit	5242.0	5401.5	159.5	158.3	0.99	29.5	**0.19**	34.5	0.22	20.5	0.13
Oxford Clay	5411.0	5792.0	381.0	372.8	0.98	165.3	**0.43**	178.3	0.47	154.3	0.41
Upper Lias Clay	6852.5	6915.0	62.5	61.5	0.98	0.0	**0.00**	0.0	0.00	0.0	0.00
Middle Lias Clay	7282.5	7489.5	207.0	207.0	1.00	57.0	**0.28**	112.5	0.54	4.5	0.02
Lower Lias (Upper Clays/Lmst)	7489.5	7850.0	360.5	341.5	0.95	53.5	**0.15**	72.3	0.20	25.5	0.07
All Zones	3396.0	7850.0	2826.5	2411.8	0.85	1135.3	**0.40**	1268.5	0.45	979.3	0.35

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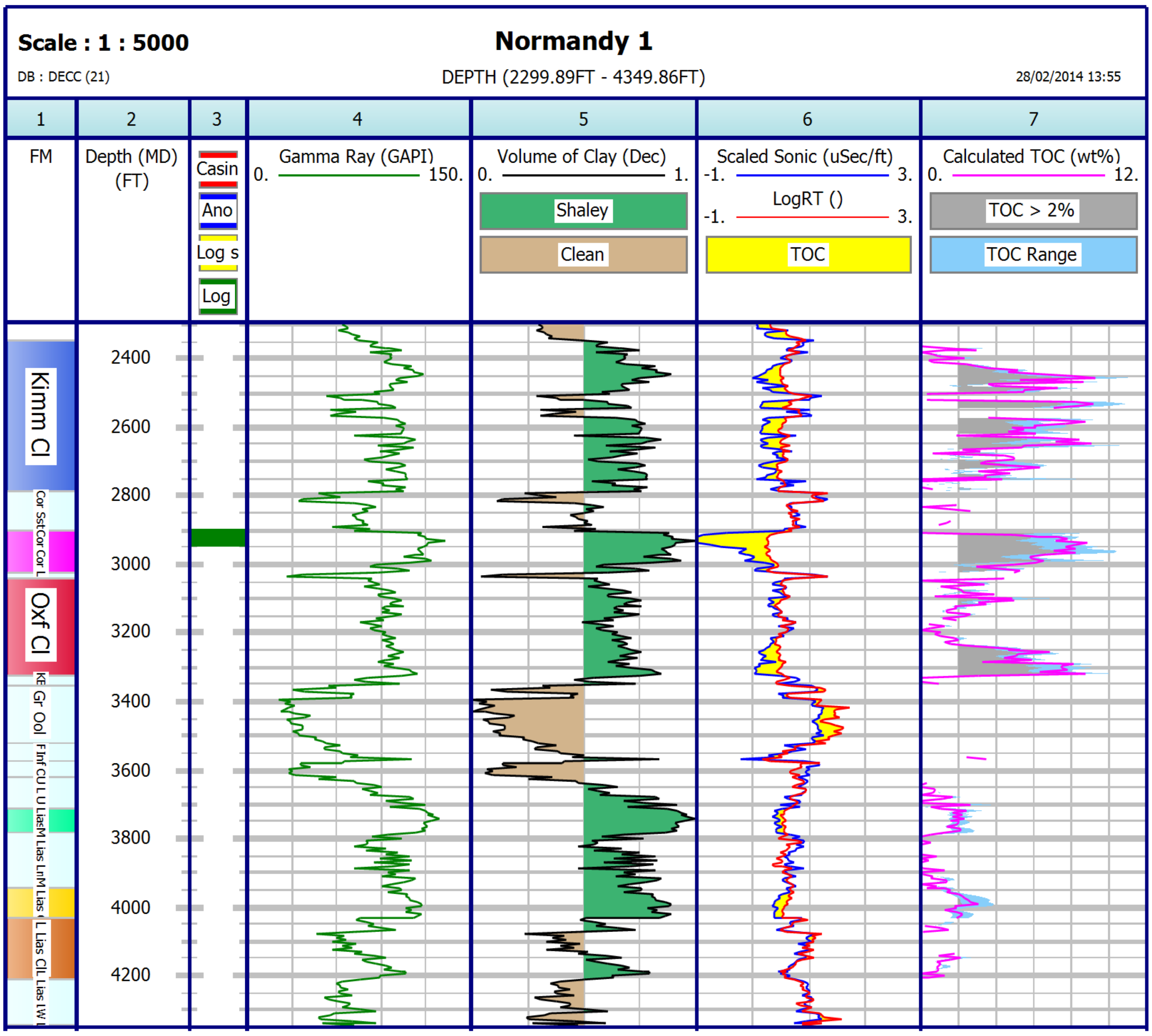
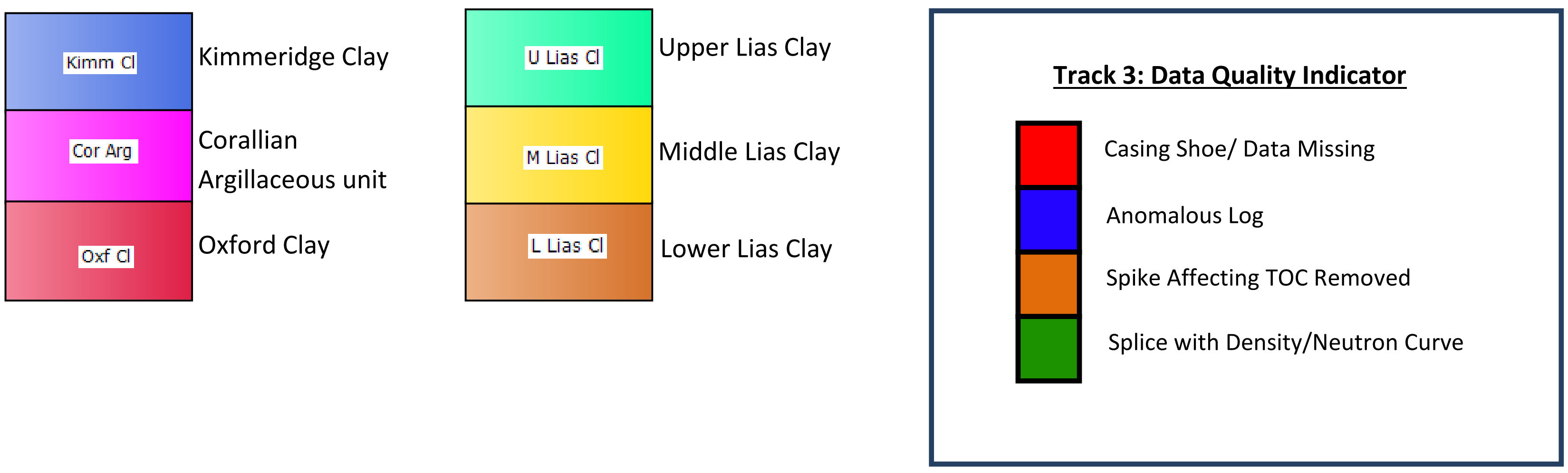
Figure 15: Normandy 1 SU94NW/25





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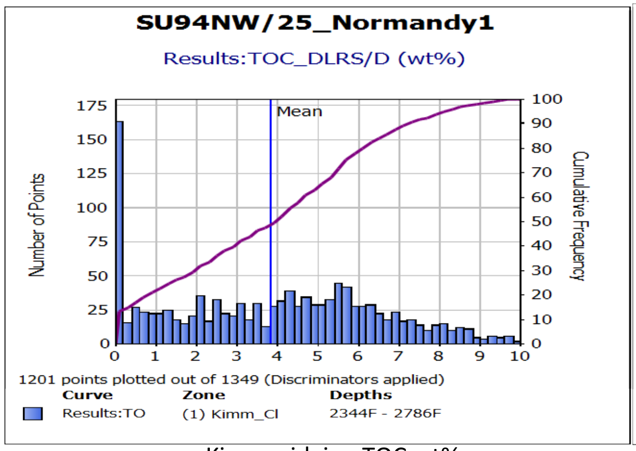
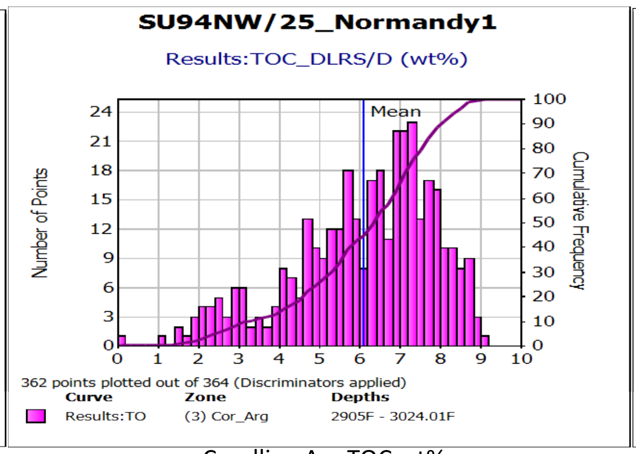
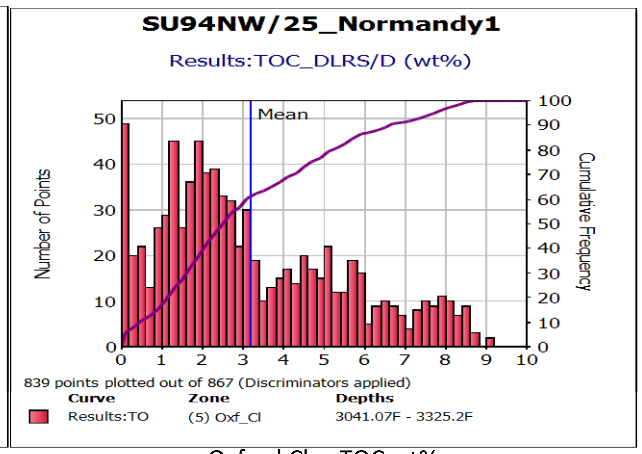


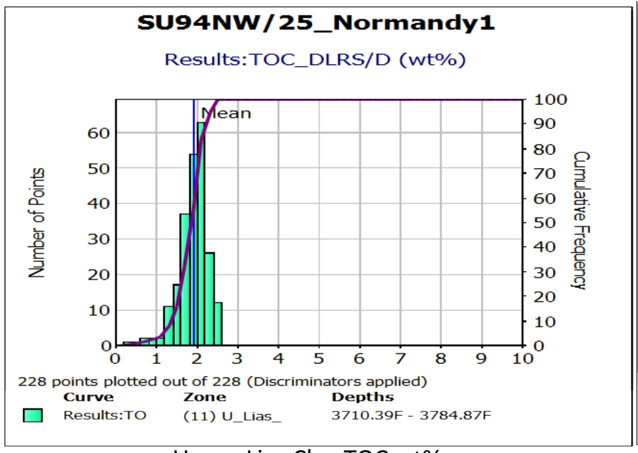
Kimmeridgian TOC wt%



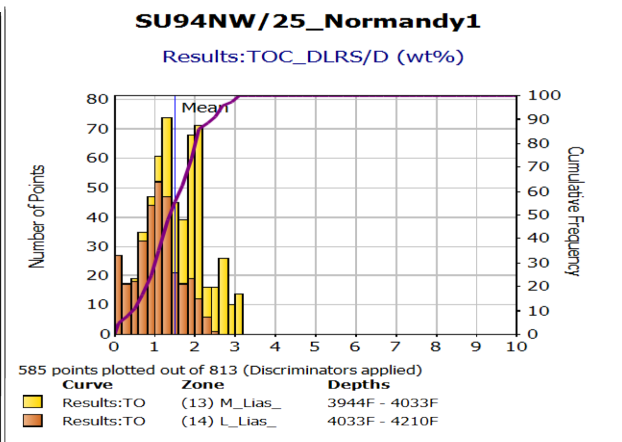
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 15a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**10.40**	**3.85**
TOC_L	0.00	8.71	3.29
TOC_H	0.00	12.46	4.52
Corallian Argillaceous Unit			
TOC_M	**0.00**	**9.03**	**6.08**
TOC_L	0.00	7.57	5.15
TOC_H	0.00	10.79	7.21
Oxford Clay			
TOC_M	0.00	9.12	3.20
TOC_L	0.00	7.65	2.77
TOC_H	0.00	10.91	3.72
Upper Lias Clay			
TOC_M	0.38	2.50	1.90
TOC_L	0.51	1.96	1.55
TOC_H	0.17	3.31	2.42
Middle/Lower Lias			
TOC_M	0.00	3.11	1.51
TOC_L	0.00	2.36	1.27
TOC_H	0.00	4.20	1.85

Table 15a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 15b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	2344.0	2786.0	442.0	395.1	0.89	280.2	**0.63**	287.1	0.65	267.4	0.60
Corallian Argillaceous Unit	2905.0	3024.0	119.0	118.6	1.0	116.0	**0.98**	117.0	0.98	114.3	0.96
Oxford Clay	3041.1	3325.2	284.1	274.9	1.0	172.9	**0.61**	188.3	0.66	155.8	0.55
Upper Lias Clay	3710.4	3784.9	74.5	74.5	1.0	33.1	**0.45**	62.5	0.84	0.0	0.00
Middle Lias Clay	3944.0	4033.0	89.0	89.0	1.0	43.8	**0.49**	66.4	0.75	17.4	0.20
Lower Lias (Upper Clays/Lmst)	4033.0	4210.0	177.0	102.2	0.6	6.2	**0.04**	17.7	0.10	0.0	0.00
All Zones	2344.0	4210.0	1185.6	1054.3	0.9	652.3	**0.55**	739.0	0.62	555.0	0.47

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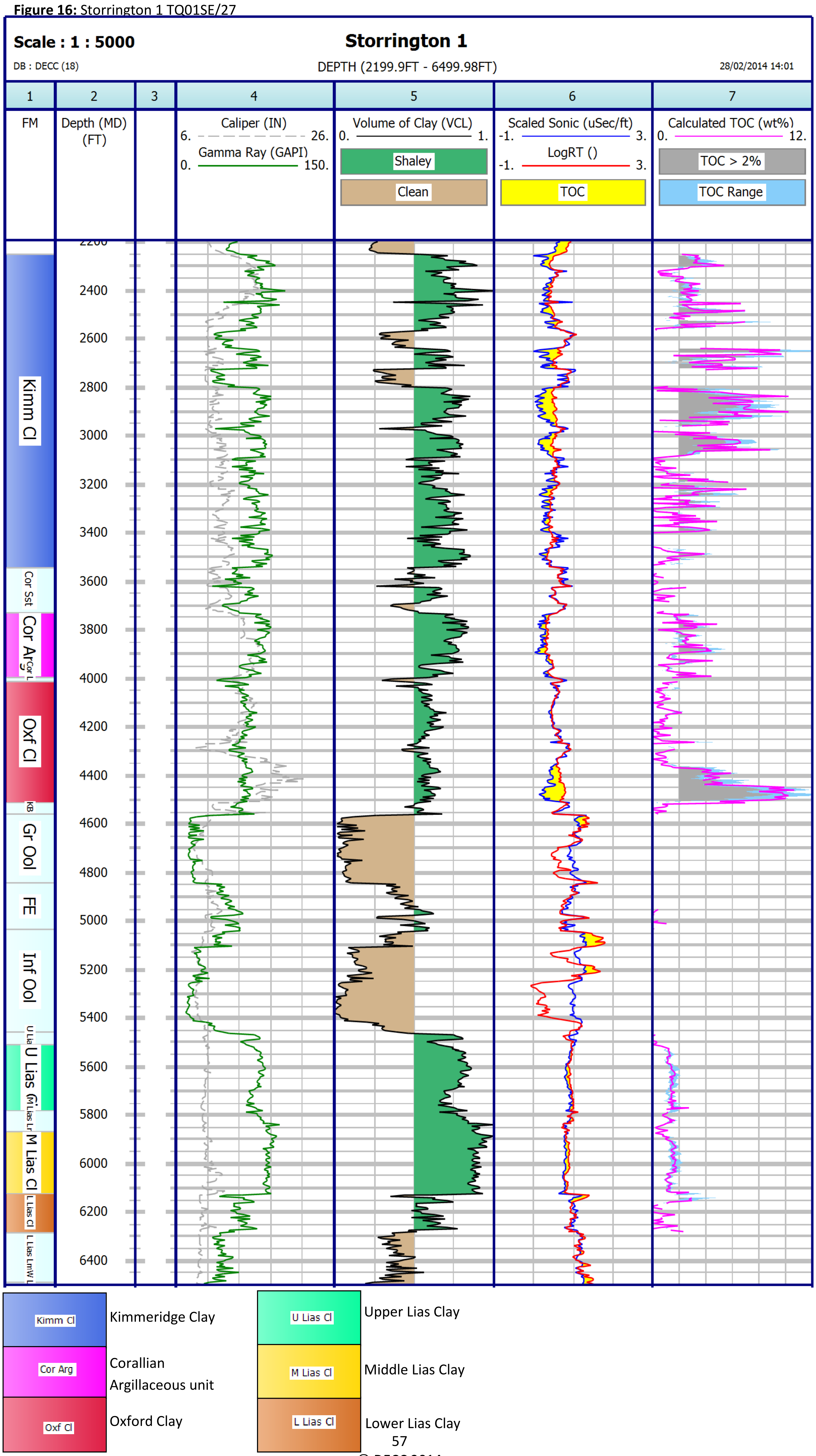
Figure 16: Storrington 1 TQ01SE/27



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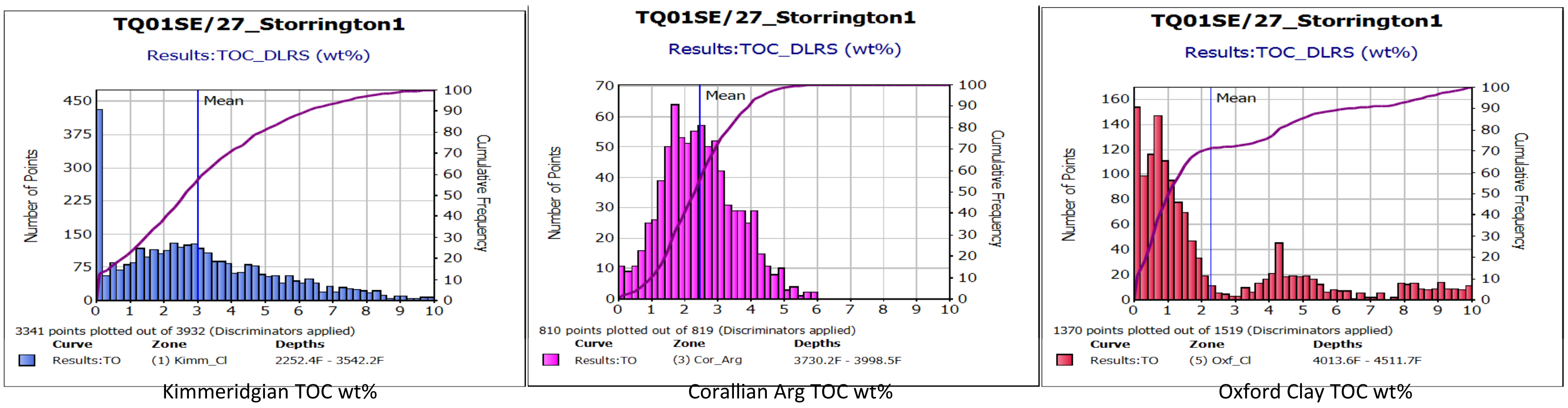

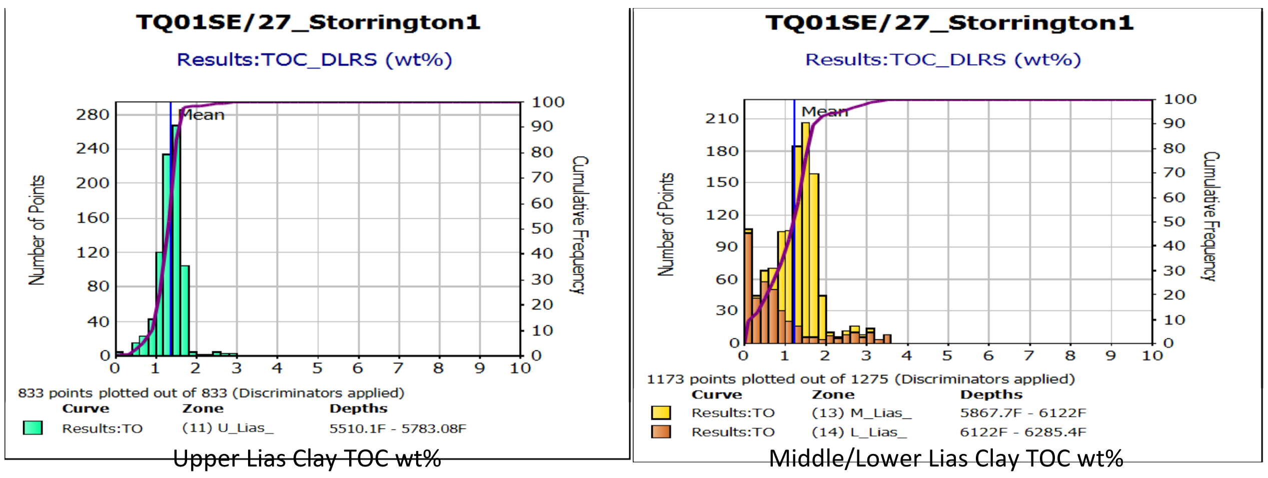

Figure 16a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**12.85**	**3.09**
TOC_L	0.00	10.72	2.67
TOC_H	0.00	15.43	3.60
Corallian Argillaceous Unit			
TOC_M	**0.00**	**5.84**	**2.46**
TOC_L	0.00	4.95	2.17
TOC_H	0.00	6.93	2.82
Oxford Clay			
TOC_M	0.00	11.11	2.57
TOC_L	0.00	9.29	2.25
TOC_H	0.00	13.32	2.97
Upper Lias Clay			
TOC_M	0.00	2.89	1.35
TOC_L	0.06	2.22	1.17
TOC_H	0.00	3.88	1.61
Middle/Lower Lias			
TOC_M	0.00	3.54	1.22
TOC_L	0.00	2.66	1.08
TOC_H	0.00	4.84	1.45

Table 16a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 16b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	2252.4	3542.2	1289.8	1106.1	0.86	697.4	**0.54**	733.2	0.57	648.5	0.50
Corallian Argillaceous Unit	3730.2	3998.5	268.3	265.6	1.0	165.8	**0.62**	186.2	0.69	143.8	0.54
Oxford Clay	4013.6	4511.7	498.1	466.1	0.9	154.4	**0.31**	166.5	0.33	147.5	0.30
Upper Lias Clay	5510.1	5783.1	273.0	273.0	1.0	4.6	**0.02**	38.4	0.14	2.6	0.01
Middle Lias Clay	5867.7	6122.0	254.3	254.3	1.0	5.7	**0.02**	67.1	0.26	4.1	0.02
Lower Lias (Upper Clays/Lmst)	6122.0	6285.4	163.4	130.1	0.8	19.2	**0.12**	22.2	0.14	13.0	0.08
All Zones	2252.4	6285.4	2746.9	2495.1	0.9	1047.1	**0.38**	1213.4	0.44	959.5	0.35

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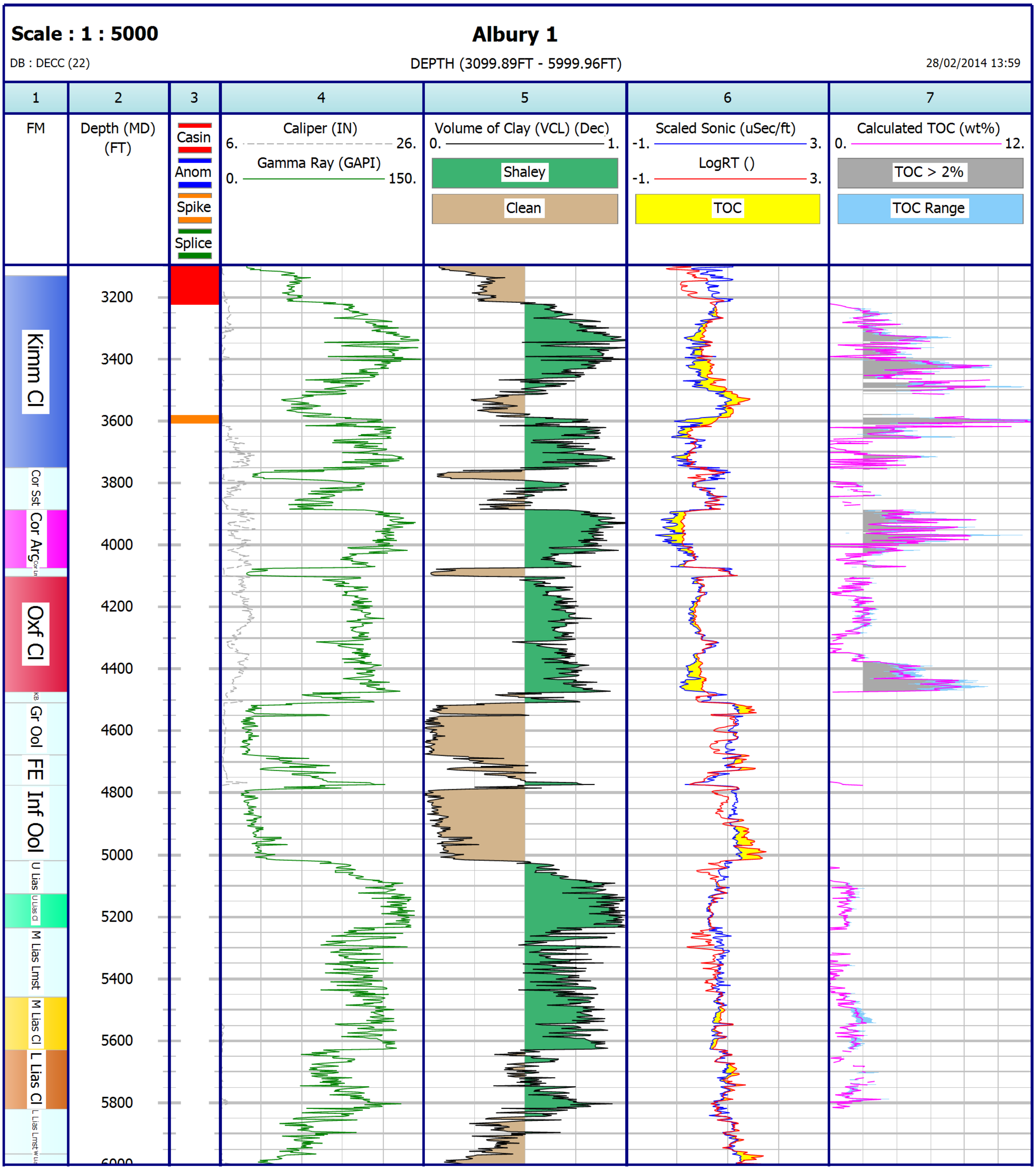
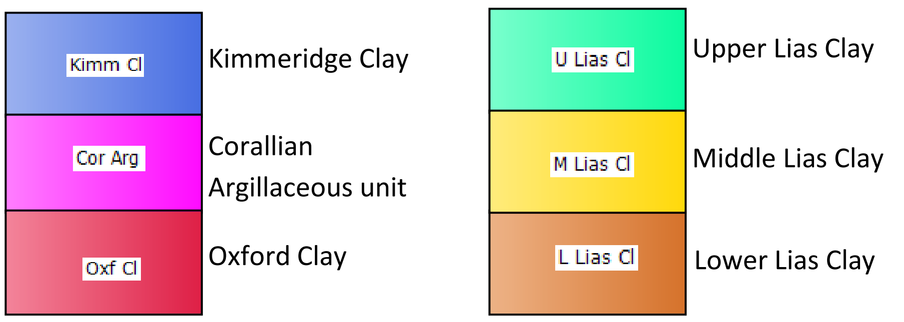
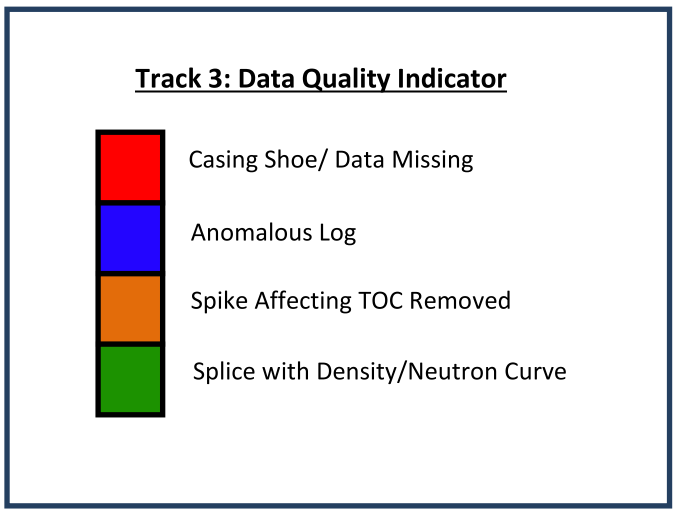
Figure 17: Albury 1 TQ04NE/46







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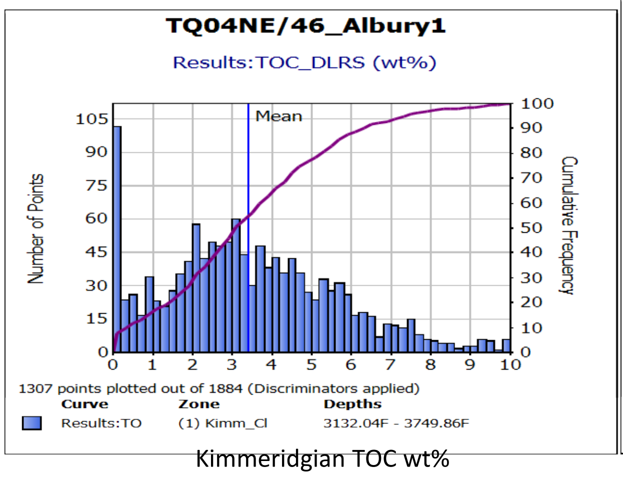
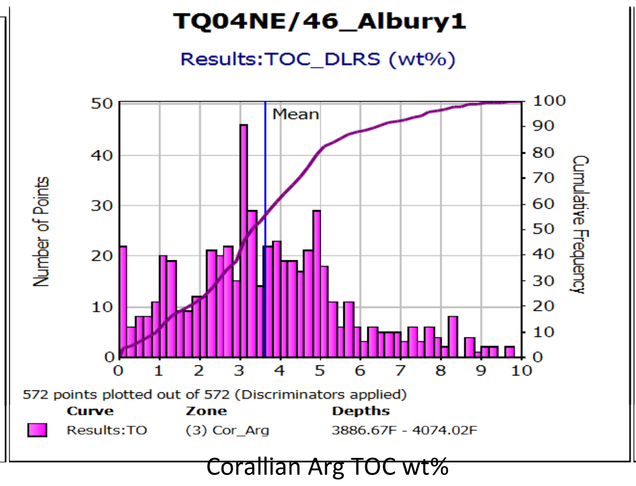
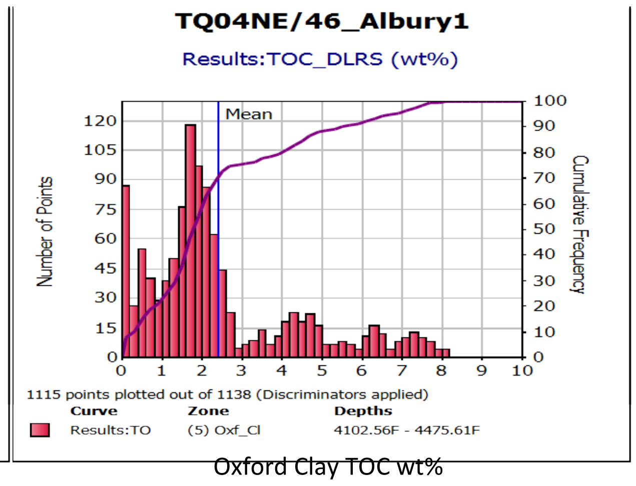


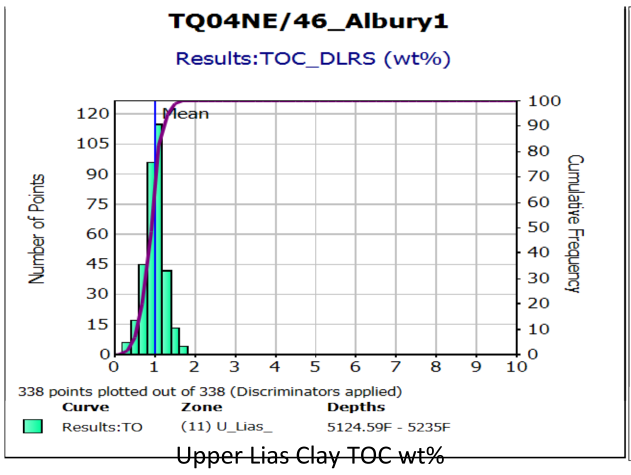
Kimmeridgian TOC wt%



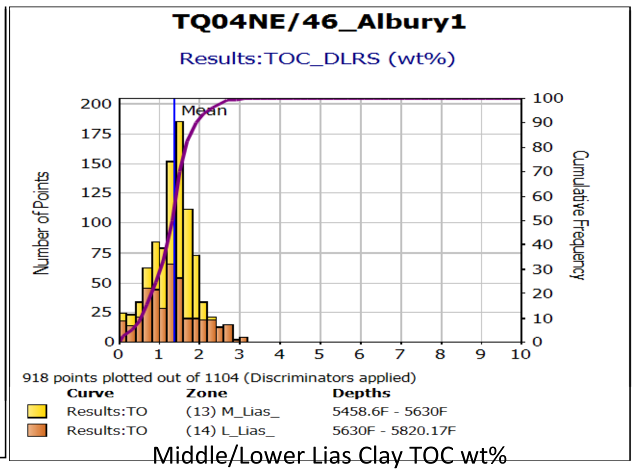
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 17a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**13.63**	**3.64**
TOC_L	0.00	11.37	3.13
TOC_H	0.00	16.39	4.27
Corallian Argillaceous Unit			
TOC_M	**0.00**	**9.64**	**3.62**
TOC_L	0.00	8.08	3.12
TOC_H	0.00	11.54	4.23
Oxford Clay			
TOC_M	0.00	8.16	2.41
TOC_L	0.00	6.86	2.12
TOC_H	0.00	9.74	2.77
Upper Lias Clay			
TOC_M	0.22	1.73	1.00
TOC_L	0.41	1.43	0.93
TOC_H	0.00	2.18	1.09
Middle/Lower Lias			
TOC_M	0.00	3.19	1.36
TOC_L	0.00	2.42	1.18
TOC_H	0.00	4.32	1.63

Table 17a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 17b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	3132.0	3749.9	617.8	441.0	0.71	325.8	**0.53**	339.3	0.55	303.5	**0.49**
Corallian Argillaceous Unit	3886.7	4074.0	187.4	187.4	1.00	146.8	**0.78**	150.8	0.81	141.9	**0.76**
Oxford Clay	4102.6	4475.6	373.1	365.7	0.98	163.4	**0.44**	196.2	0.53	130.3	**0.35**
Upper Lias Clay	5124.6	5235.0	110.4	110.4	1.00	0.0	**0.00**	1.3	0.01	0.0	**0.00**
Middle Lias Clay	5458.6	5630.0	171.4	169.1	0.99	5.6	**0.03**	51.8	0.30	0.0	**0.00**
Lower Lias (Upper Clays/Lmst)	5630.0	5820.2	190.2	131.7	0.69	23.6	**0.12**	36.4	0.19	7.9	**0.04**
All Zones	3132.0	5820.2	1650.2	1405.3	0.85	665.2	**0.40**	775.8	0.47	583.5	**0.35**

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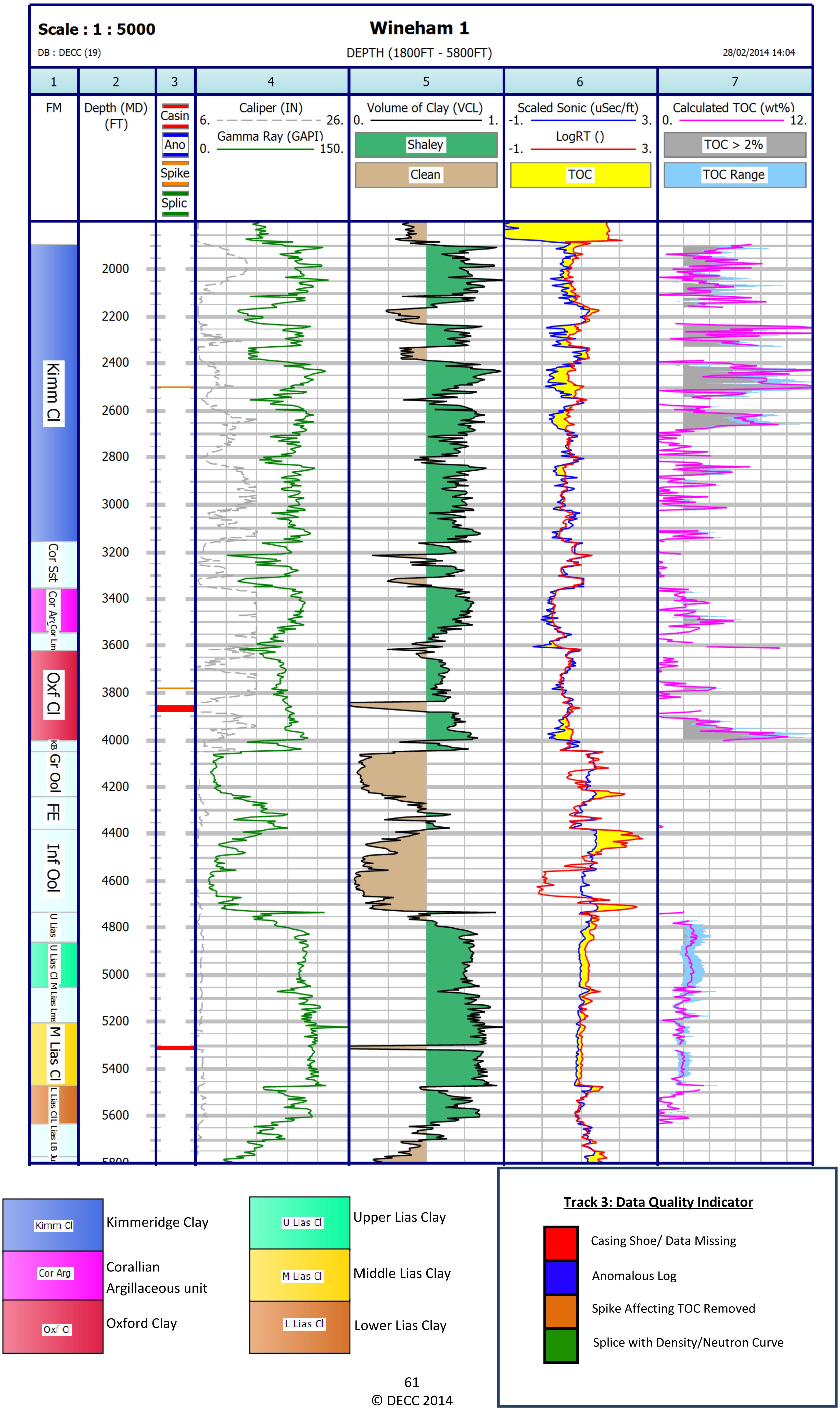
Figure 18: Wineham 1 TQ21NW/13



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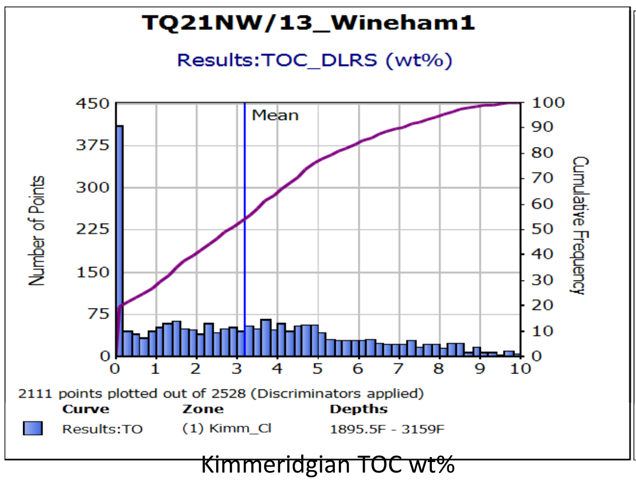
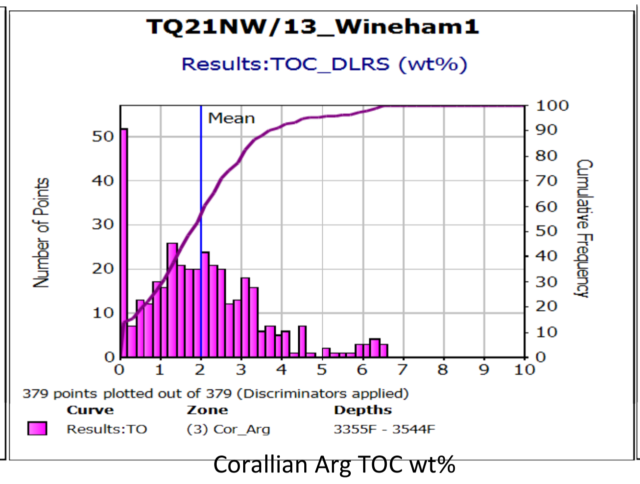
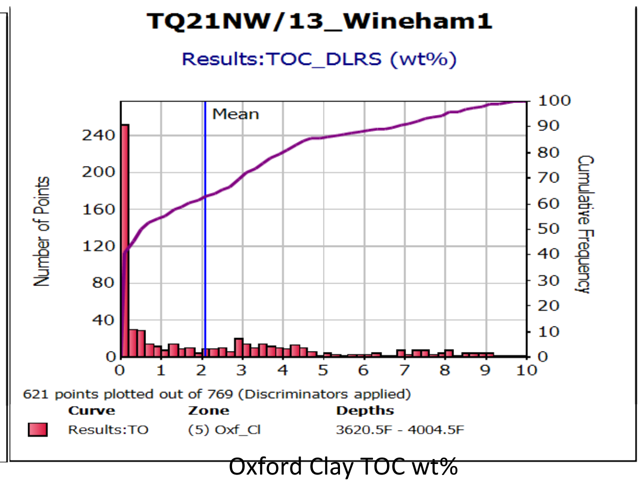


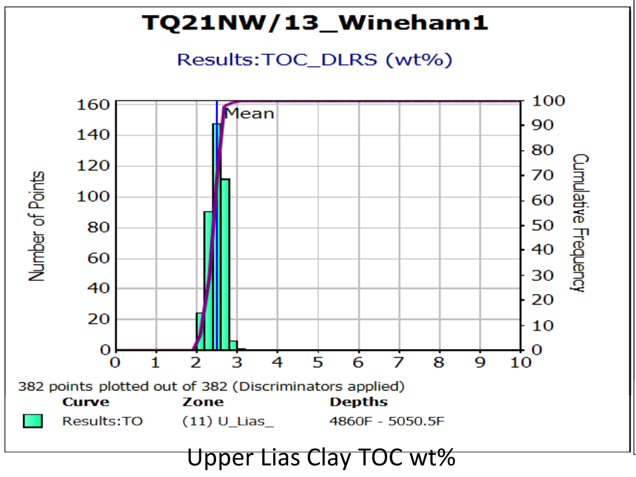
Kimmeridgian TOC wt%



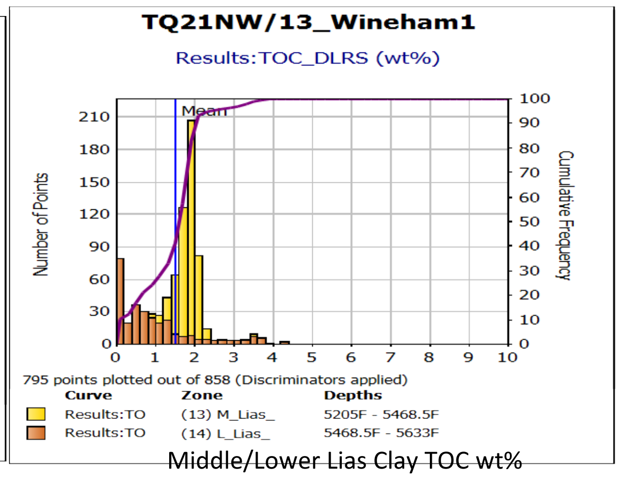
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 18a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**18.55**	**3.52**
TOC_L	0.00	15.42	3.02
TOC_H	0.00	22.36	4.13
Corallian Argillaceous Unit			
TOC_M	**0.00**	**6.59**	**1.99**
TOC_L	0.00	5.57	1.76
TOC_H	0.00	7.83	2.27
Oxford Clay			
TOC_M	0.00	10.93	2.26
TOC_L	0.00	9.14	1.96
TOC_H	0.00	13.10	2.64
Upper Lias Clay			
TOC_M	2.08	3.13	2.50
TOC_L	1.67	2.38	1.95
TOC_H	2.68	4.24	3.30
Middle/Lower Lias			
TOC_M	0.00	4.33	1.50
TOC_L	0.00	3.20	1.26
TOC_H	0.00	6.01	1.87

Table 18a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 18b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	1895.5	3159.0	1263.5	1096.0	0.87	677.0	**0.54**	702.0	0.56	651.5	0.52
Corallian Argillaceous Unit	3355.0	3544.0	189.0	189.0	1.0	87.5	**0.46**	98.0	0.52	71.5	0.38
Oxford Clay	3620.5	4004.5	384.0	317.0	0.8	127.3	**0.33**	130.8	0.34	122.3	0.32
Upper Lias Clay	4860.0	5050.5	190.5	190.5	1.0	190.5	**1.00**	190.5	1.00	72.0	0.38
Middle Lias Clay	5205.0	5468.5	263.5	246.0	0.9	44.8	**0.17**	200.5	0.76	1.8	0.01
Lower Lias (Upper Clays/Lmst)	5468.5	5633.0	164.5	150.5	0.9	22.0	**0.13**	29.5	0.18	16.3	0.10
All Zones	1895.5	5633.0	2455.0	2189.0	0.9	1149.0	**0.47**	1351.3	0.55	935.3	0.38

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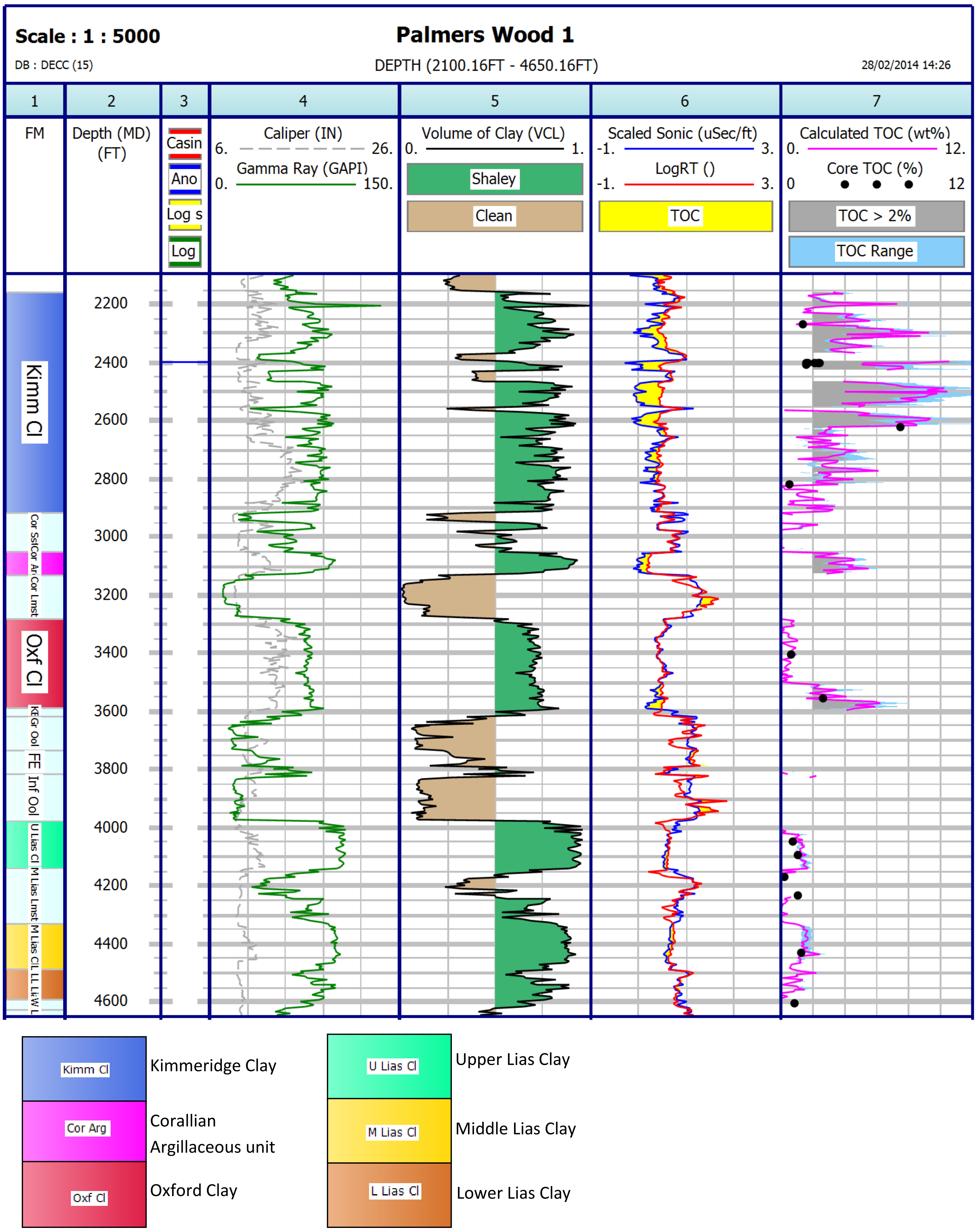
Figure 19: Palmers Wood 1 TQ35SE/94



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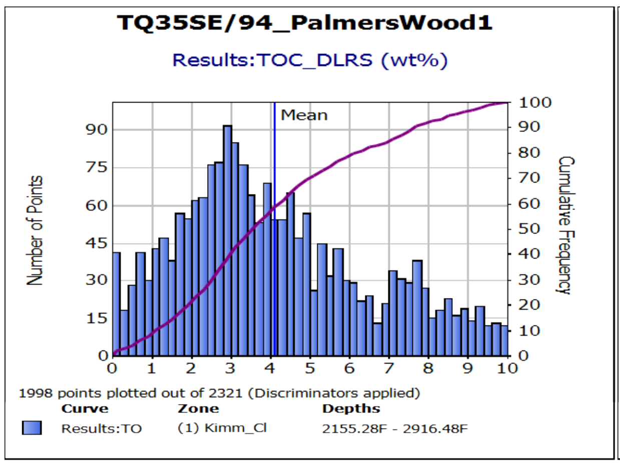
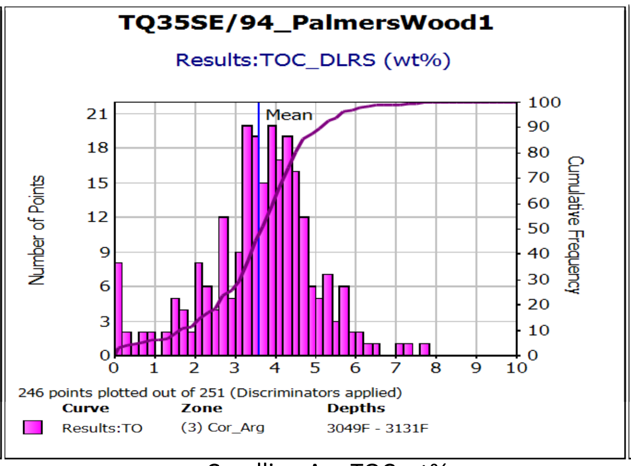
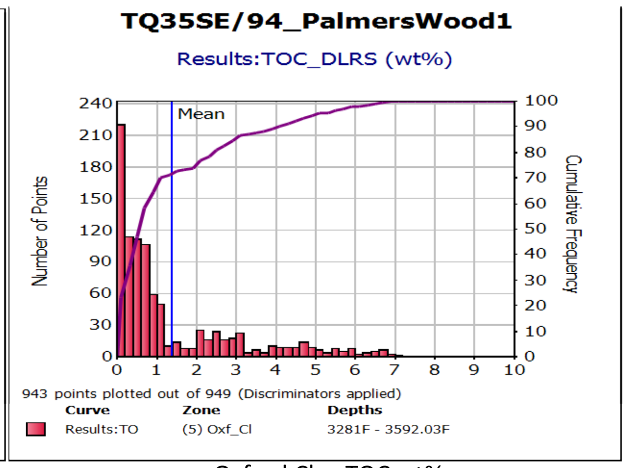


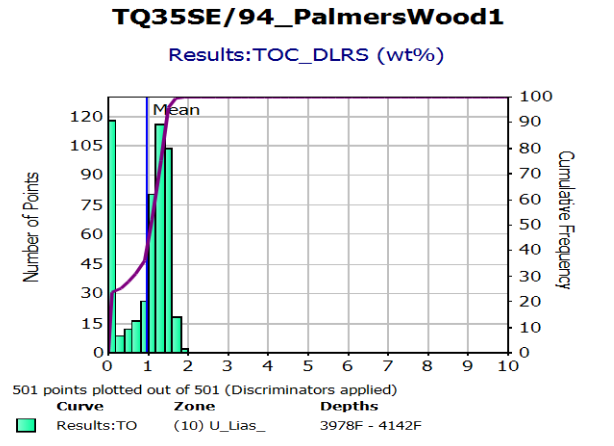
Kimmeridgian TOC wt%



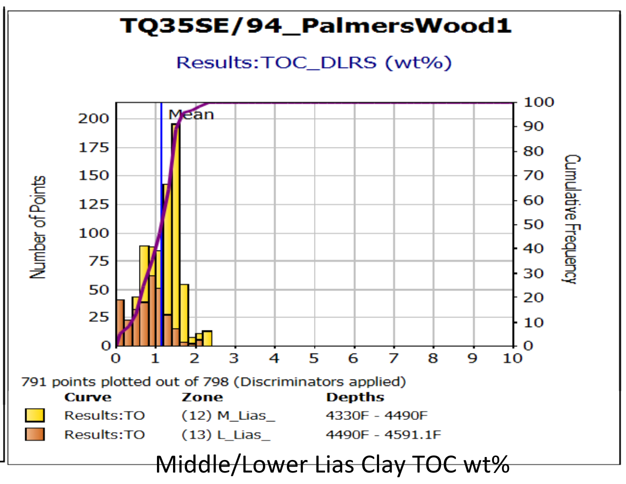
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 19a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (9Pts)	0.52	7.44	2.32
TOC_M	0.00	16.35	4.30
TOC_L	0.00	13.61	3.68
TOC_H	0.00	19.69	5.06
Corallian Argillaceous Unit			
Core TOC (2Pts)	0.52	0.68	0.60
TOC_M	0.00	7.64	3.61
TOC_L	0.00	6.43	3.11
TOC_H	0.00	9.11	4.22
Oxford Clay			
Core TOC (2Pts)	0.68	2.64	1.66
TOC_M	0.00	7.07	1.35
TOC_L	0.00	5.96	1.23
TOC_H	0.00	8.42	1.49
Upper Lias Clay			
Core TOC (3Pts)	0.16	1.10	0.66
TOC_M	0.00	1.84	0.95
TOC_L	0.00	1.50	0.85
TOC_H	0.00	2.33	1.11
Middle/Lower Lias			
Core TOC (3Pts)	0.86	1.25	1.07
TOC_M	0.00	2.37	1.15
TOC_L	0.00	1.87	1.03
TOC_H	0.00	3.12	1.32

Table 19a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 19b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	2155.3	2916.5	761.2	677.4	0.89	546.9	**0.72**	568.3	0.75	518.1	0.68
Corallian Argillaceous Unit	3049.0	3131.0	82.0	80.6	0.98	71.5	**0.87**	72.2	0.88	68.6	0.84
Oxford Clay	3281.0	3592.0	311.0	309.2	0.99	80.5	**0.26**	82.8	0.27	70.7	0.23
Upper Lias Clay	3978.0	4142.0	164.0	164.0	1.00	0.0	**0.00**	6.2	0.04	0.0	0.00
Middle Lias Clay	4330.0	4490.0	160.0	160.0	1.00	6.2	**0.04**	21.7	0.14	0.0	0.00
Lower Lias (Upper Clays/Lmst)	4490.0	4591.1	101.1	98.8	0.98	2.0	**0.02**	3.6	0.04	0.0	0.00
All Zones	2155.3	4591.1	1579.3	1490.0	0.94	707.2	**0.45**	754.8	0.48	657.3	0.42

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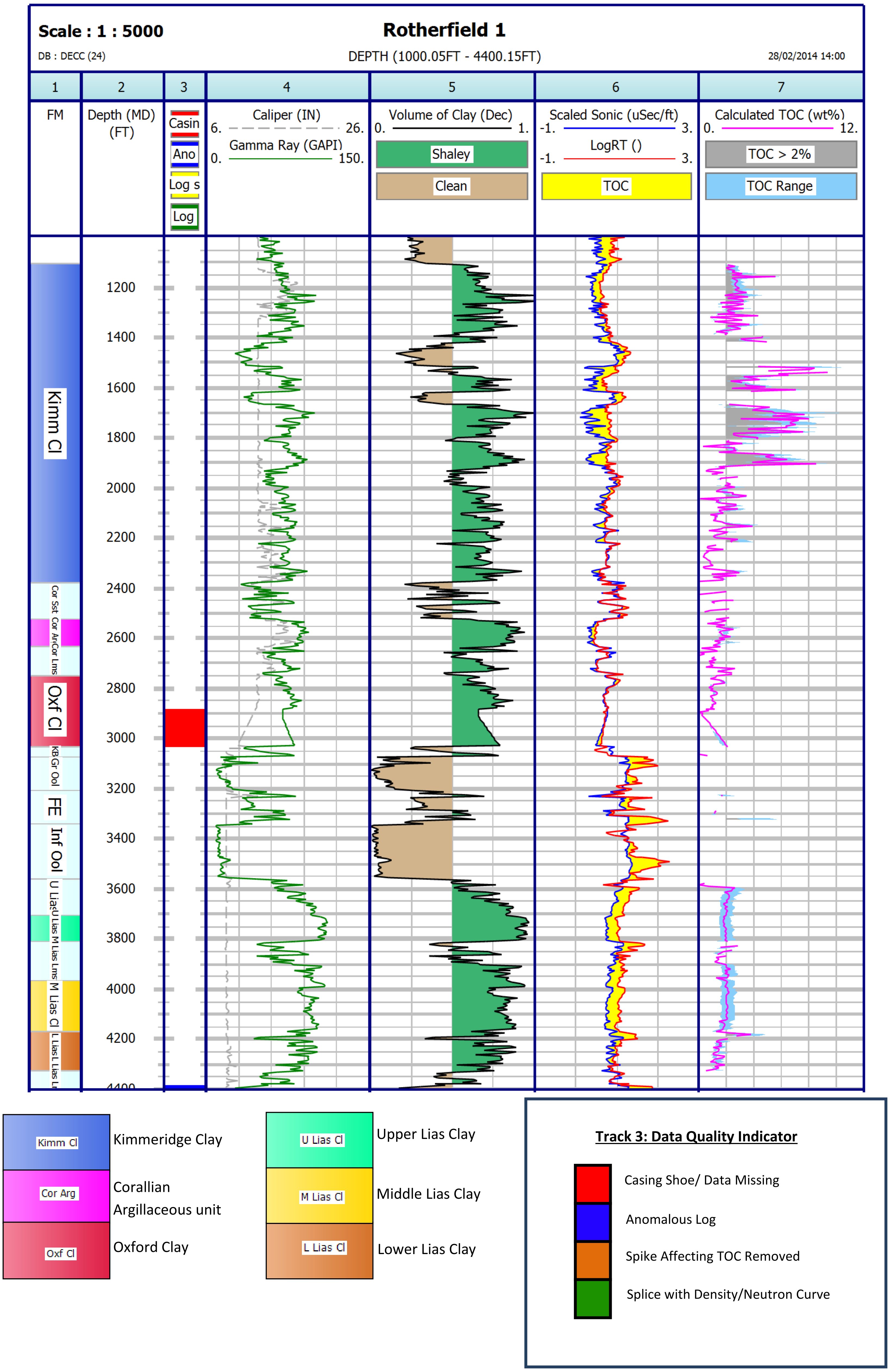
Figure 20: Rotherfield 1 TQ52NW/16



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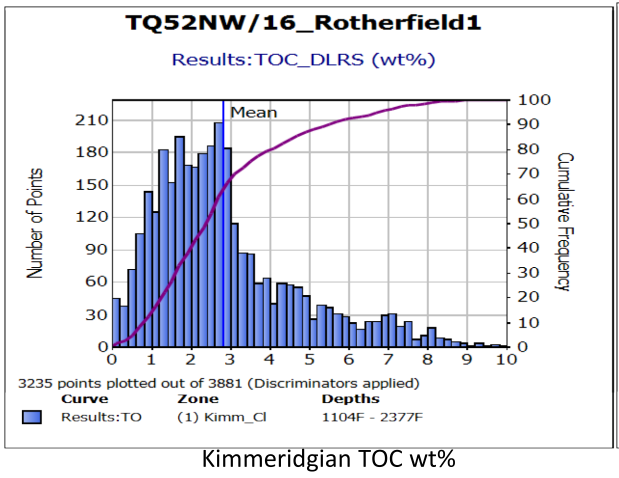
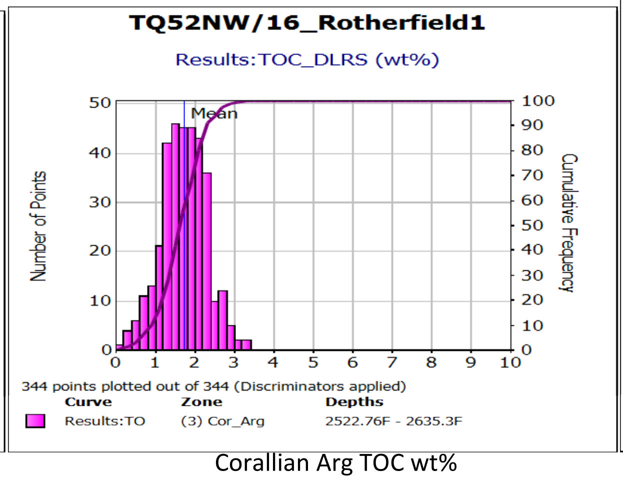
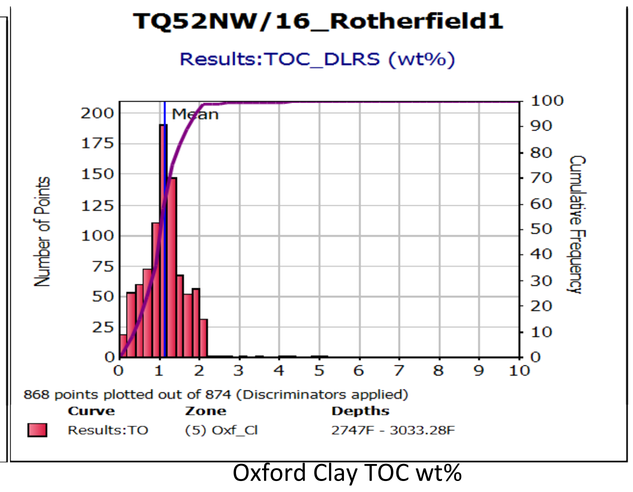


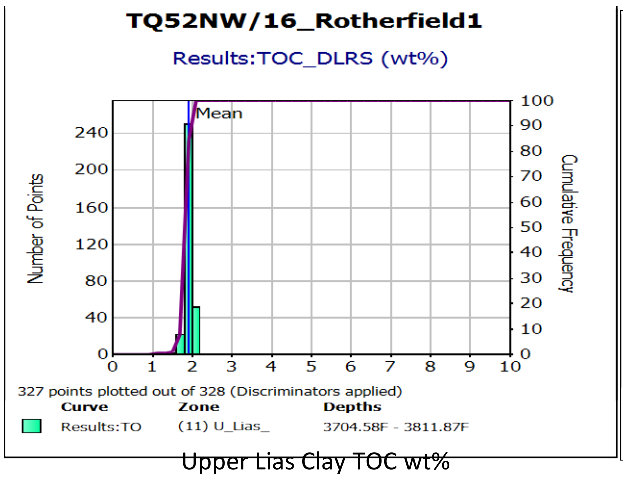
Kimmeridgian TOC wt%



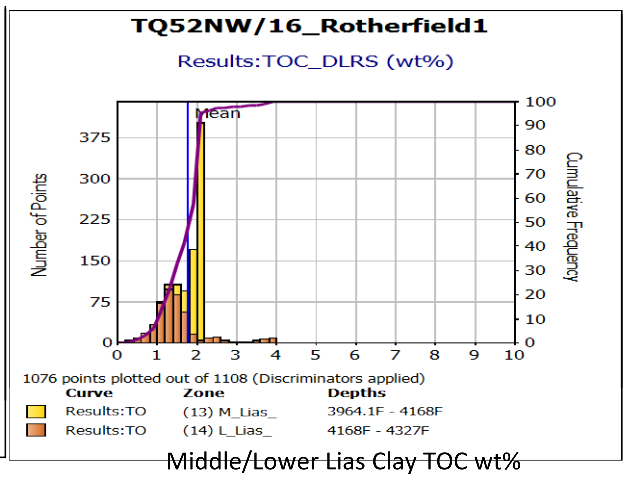
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 20a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Data fill over base Oxford Clay. (Over typically TOC rich interval)

Curve	Min	Max	Mean
Kimmeridge Clay			
TOC_M	**0.00**	**9.86**	**2.82**
TOC_L	0.00	8.26	2.47
TOC_H	0.00	11.80	3.26
Corallian Argillaceous Unit			
TOC_M	**0.01**	**3.25**	**1.72**
TOC_L	0.01	2.67	1.41
TOC_H	0.00	3.56	1.71
Oxford Clay			
TOC_M	0.00	5.14	1.14
TOC_L	0.00	4.23	0.94
TOC_H	0.00	5.86	1.02
Upper Lias Clay			
TOC_M	1.16	2.14	1.91
TOC_L	1.04	1.71	1.56
TOC_H	1.33	2.78	2.44
Middle/Lower Lias			
TOC_M	0.17	4.01	1.77
TOC_L	0.37	2.98	1.46
TOC_H	0.00	5.53	2.24

Table 20a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 20b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Note: Oxford Clay data missing over typically TOC rich interval

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	1104.0	2377.0	1273.0	1061.4	0.83	658.5	**0.52**	718.2	0.56	589.6	0.46
Corallian Argillaceous Unit	2522.8	2635.3	112.5	112.5	1.0	35.9	**0.32**	39.2	0.35	9.5	0.09
Oxford Clay	2747.0	3033.3	286.3	284.3	1.0	12.8	**0.05**	16.4	0.06	2.6	0.01
Upper Lias Clay	3704.6	3811.9	107.3	107.1	1.0	16.7	**0.16**	106.1	0.99	0.0	0.00
Middle Lias Clay	3964.1	4168.0	203.9	203.9	1.0	130.9	**0.64**	194.1	0.95	0.0	0.00
Lower Lias (Upper Clays/Lmst)	4168.0	4327.0	159.0	148.5	0.9	17.7	**0.11**	40.0	0.25	10.2	0.06
All Zones	1104.0	4327.0	2142.0	1917.8	0.9	872.6	**0.41**	1114.1	0.52	611.9	0.29

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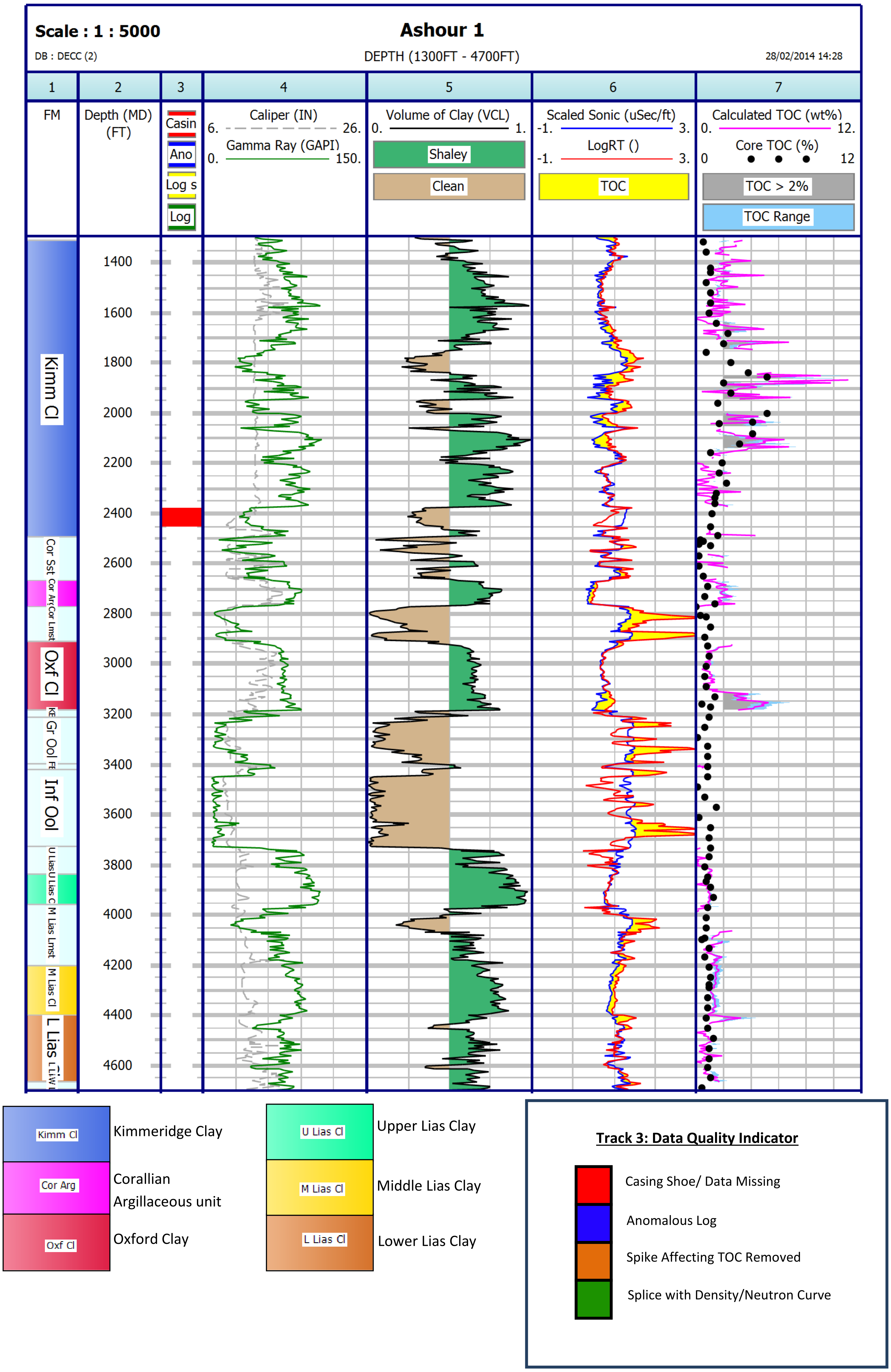
Figure 21: Ashour 1 TQ54SE/67



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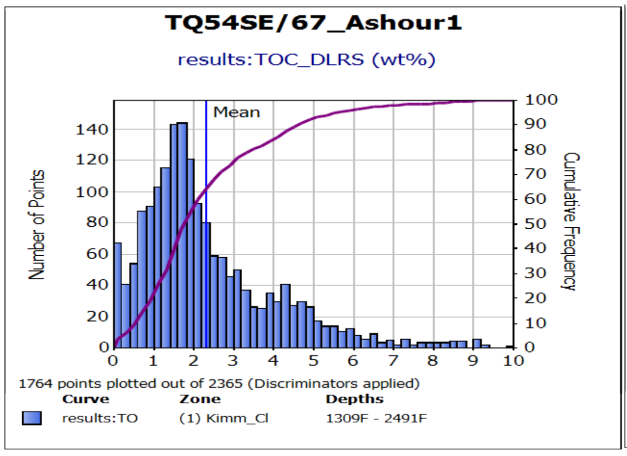
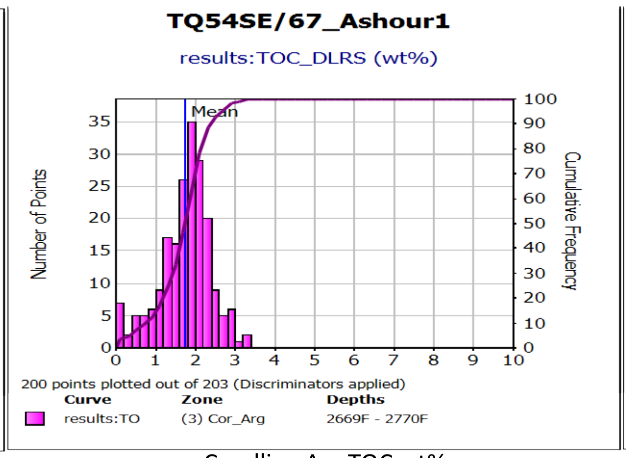
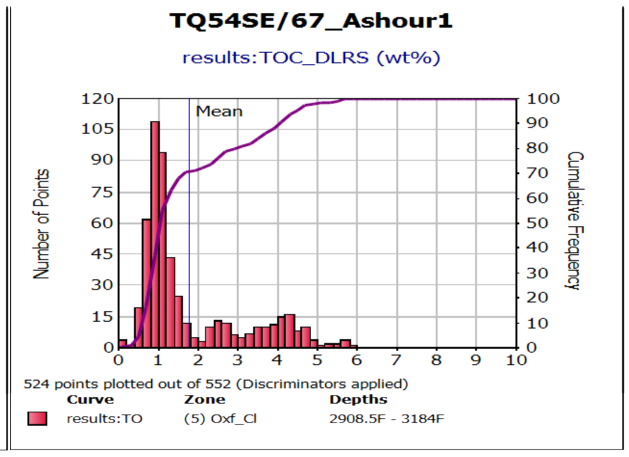


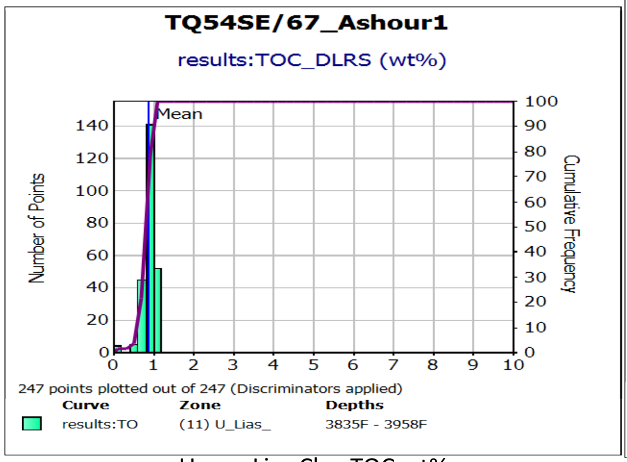
Kimmeridgian TOC wt%



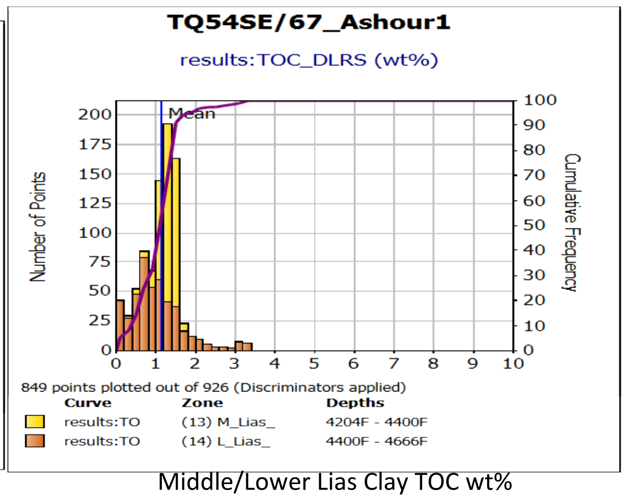
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 21a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Data missing in Kimmeridge, high 0 value

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (26Pts)	0.76	20.86	2.72
TOC_M	0.00	11.33	2.37
TOC_L	0.00	9.47	2.09
TOC_H	0.00	13.41	2.53
Corallian Argillaceous Unit			
Core TOC (3Pts)	0.66	1.33	0.96
TOC_M	0.00	3.33	1.74
TOC_L	0.00	2.89	1.57
TOC_H	0.00	3.88	1.95
Oxford Clay			
Core TOC (8Pts)	0.43	1.38	0.84
TOC_M	0.00	5.85	1.78
TOC_L	0.00	4.96	1.61
TOC_H	0.00	6.93	1.99
Upper Lias Clay			
Core TOC (5Pts)	0.70	1.25	0.95
TOC_M	0.00	1.18	0.88
TOC_L	0.23	1.06	0.86
TOC_H	0.00	1.36	0.93
Middle/Lower Lias			
Core TOC (11Pts)	0.72	1.30	0.96
TOC_M	0.00	3.30	1.15
TOC_L	0.00	2.49	1.03
TOC_H	0.00	4.48	1.33

Table 21a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 21b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	1309.0	2491.0	1182.0	885.3	0.75	402.3	**0.34**	421.3	0.36	341.8	0.29
Corallian Argillaceous Unit	2669.0	2770.0	101.0	99.8	0.99	36.0	**0.36**	53.5	0.53	19.0	0.19
Oxford Clay	2908.5	3184.0	275.5	261.8	0.95	75.0	**0.27**	78.0	0.28	71.0	0.26
Upper Lias Clay	3835.0	3958.0	123.0	123.0	1.00	0.0	**0.00**	0.0	0.00	0.0	0.00
Middle Lias Clay	4204.0	4400.0	196.0	196.0	1.00	0.0	**0.00**	3.5	0.02	0.0	0.00
Lower Lias (Upper Clays/Lmst)	4400.0	4666.0	266.0	227.5	0.86	18.8	**0.07**	32.3	0.12	10.0	0.04
All Zones	1309.0	4666.0	2143.5	1793.3	0.84	532.0	**0.25**	588.5	0.28	441.8	0.21

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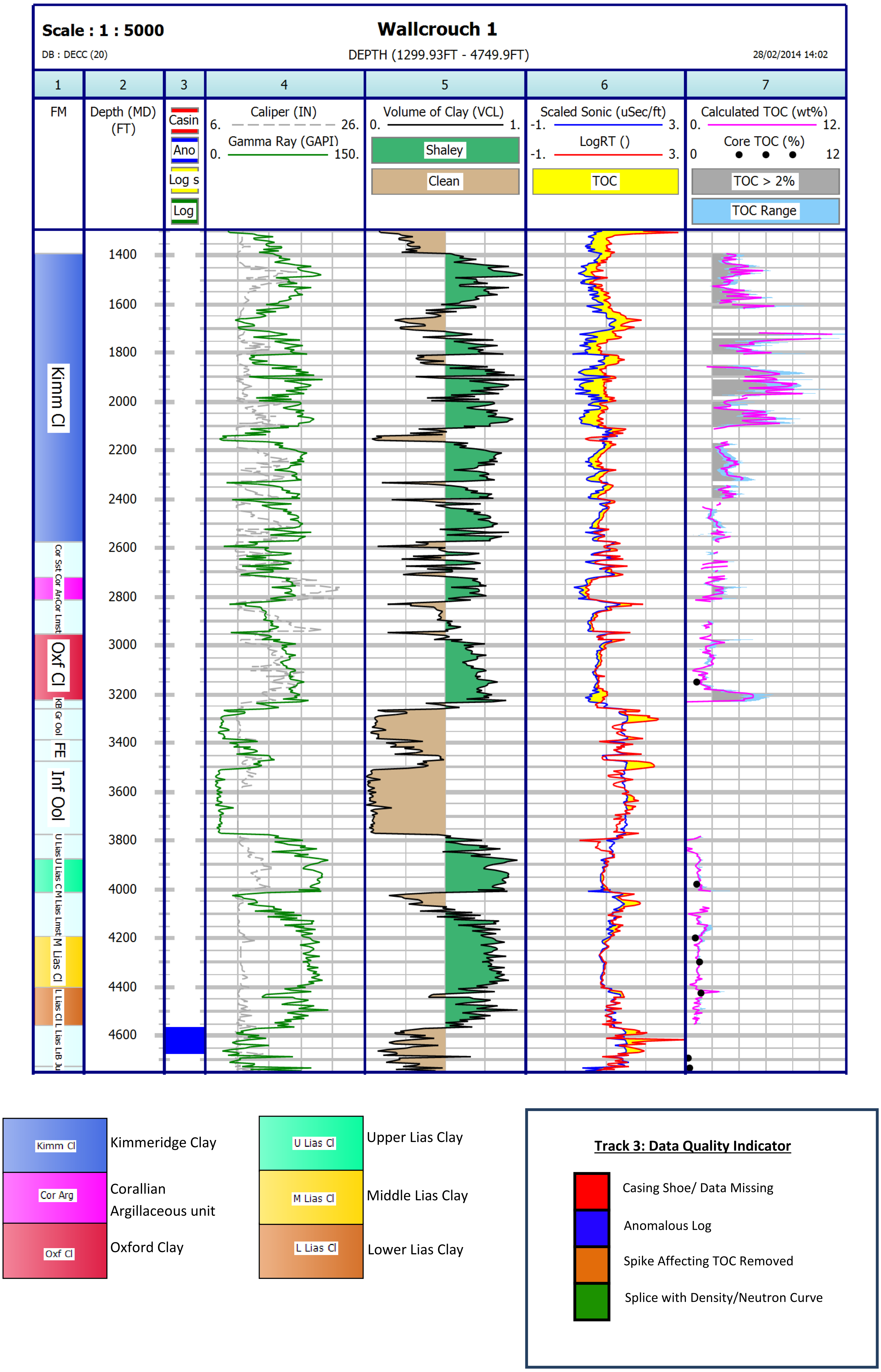
Figure 22: Wallcrouch 1 TQ62NE/3



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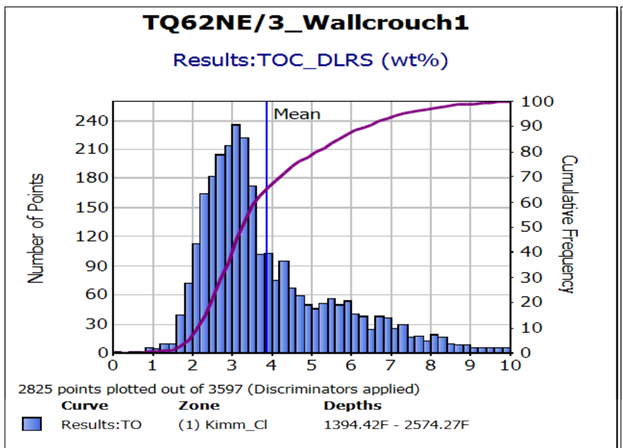
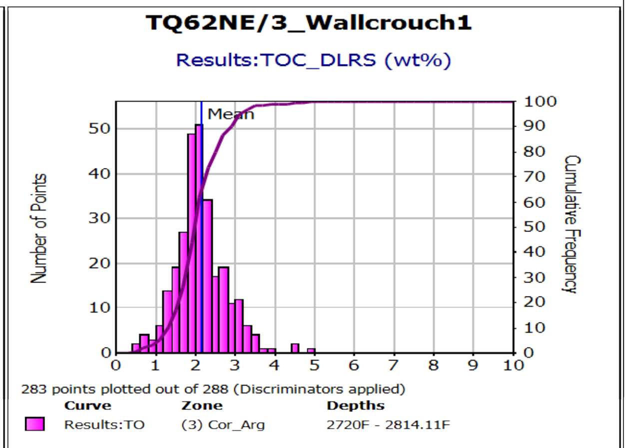
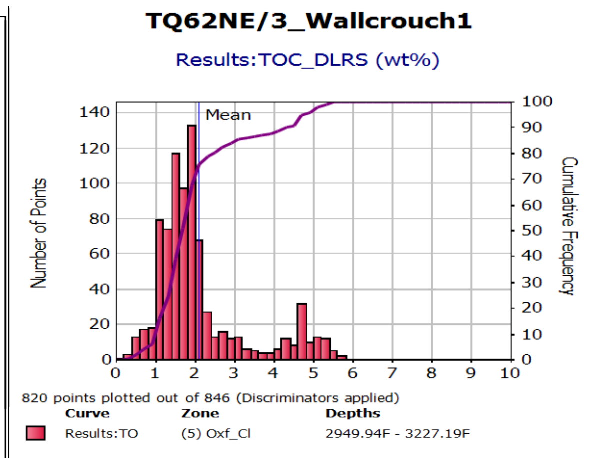


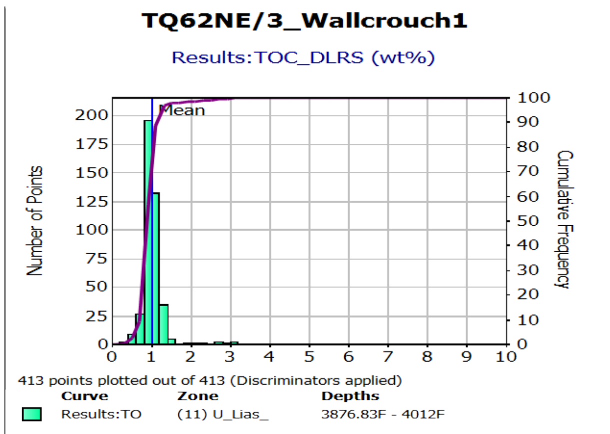
Kimmeridgian TOC wt%



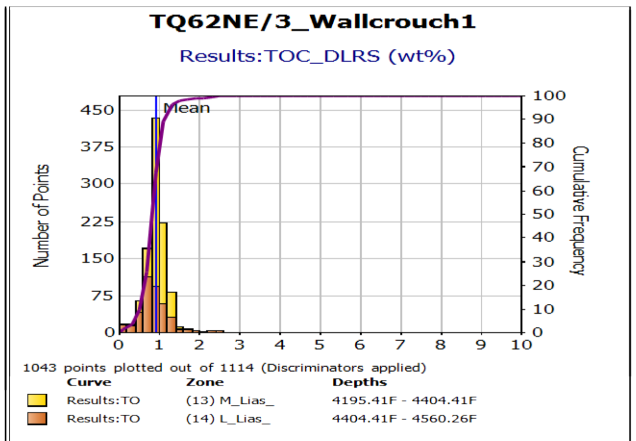
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 22a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (1Pts)	0.82	0.82	0.82
TOC_M	0.00	11.74	3.91
TOC_L	0.06	9.81	3.36
TOC_M	0.00	14.09	4.58
Corallian Argillaceous Unit			
Core TOC (1Pts)	0.82	0.82	0.82
TOC_M	0.44	4.89	2.13
TOC_L	0.50	4.17	1.89
TOC_M	0.36	5.77	2.41
Oxford Clay			
Core TOC (1Pts)	0.82	0.82	0.82
TOC_M	0.14	5.78	2.09
TOC_L	0.26	4.90	1.86
TOC_M	0.00	6.85	2.37
Upper Lias Clay			
Core TOC (1Pts)	0.87	0.87	0.87
TOC_M	0.22	3.20	1.01
TOC_L	0.41	2.43	0.94
TOC_M	0.00	4.34	1.11
Middle/Lower Lias			
Core TOC (3Pts)	0.78	1.14	0.99
TOC_M	0.00	2.59	0.92
TOC_L	0.15	2.01	0.88
TOC_M	0.00	3.43	0.99

Table 22a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 22b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	1394.4	2574.3	1179.9	932.5	0.79	884.9	**0.75**	908.8	0.77	832.9	0.71
Corallian Argillaceous Unit	2720.0	2814.1	94.1	92.6	0.98	52.0	**0.55**	68.4	0.73	32.2	0.34
Oxford Clay	2949.9	3227.2	277.3	268.9	0.97	87.8	**0.32**	133.1	0.48	61.9	0.22
Upper Lias Clay	3876.8	4012.0	135.2	135.2	1.00	2.3	**0.02**	2.6	0.02	1.6	0.01
Middle Lias Clay	4195.4	4404.4	209.0	209.0	1.00	0.0	**0.00**	0.0	0.00	0.0	0.00
Lower Lias (Upper Clays/Lmst)	4404.4	4560.3	155.9	132.7	0.85	3.9	**0.03**	7.6	0.05	0.3	0.00
All Zones	1394.4	4560.3	2051.2	1770.9	0.86	1030.8	**0.50**	1120.4	0.55	928.9	0.45

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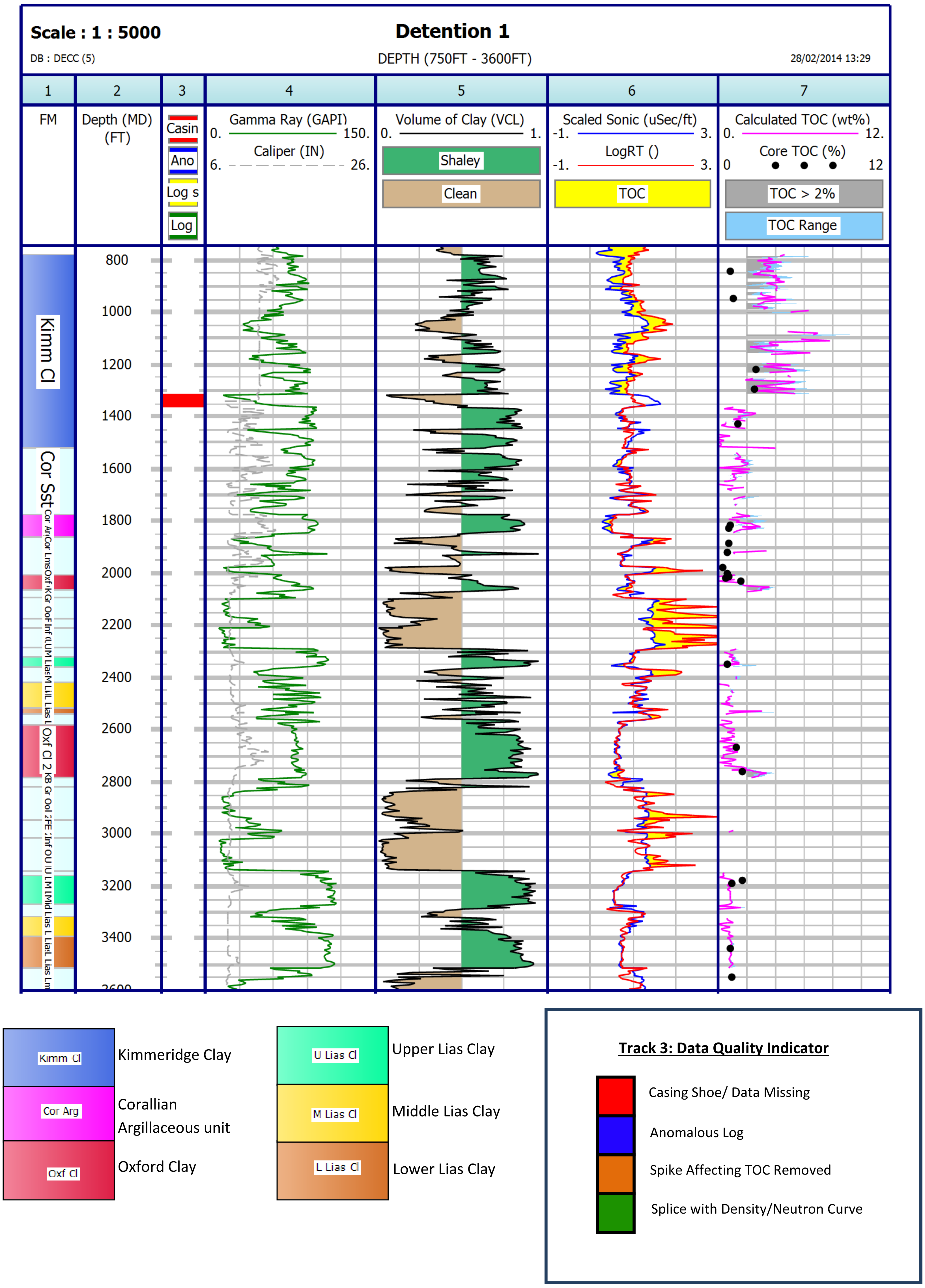
Figure 23: Detention 1 TQ74SW/4



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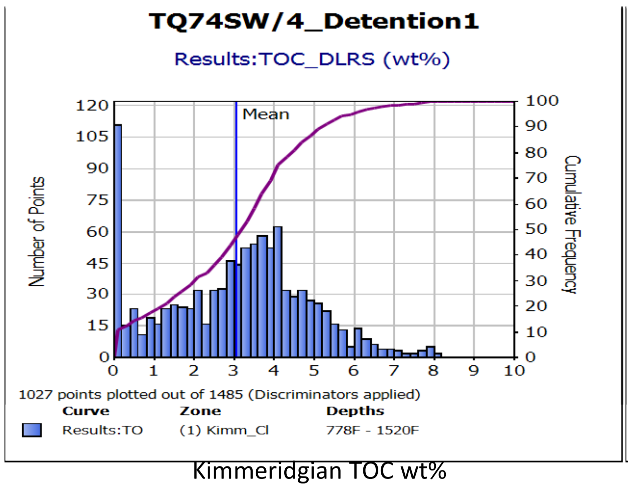
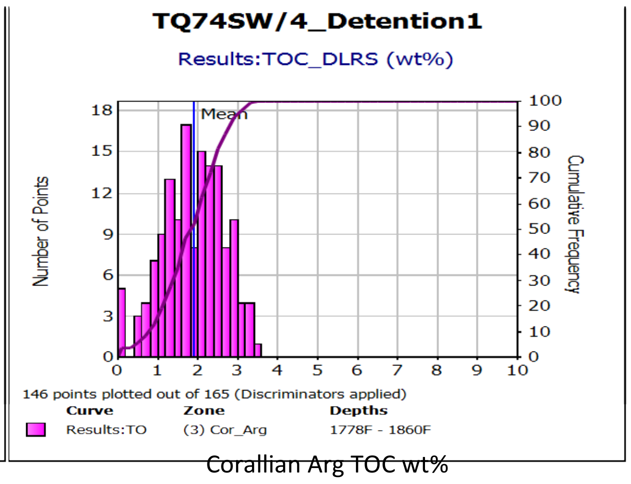
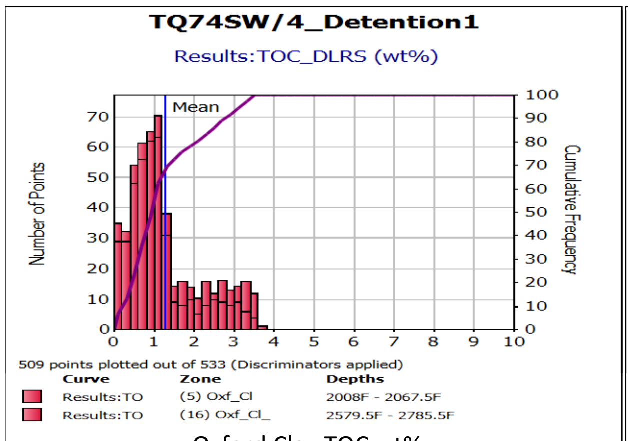
Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (5Pts)	0.82	2.64	1.67
TOC_M	0.00	8.05	3.06
TOC_L	0.00	6.77	2.65
TOC_H	0.00	9.60	3.56
Corallian Argillaceous Unit			
Core TOC (2Pts)	0.76	0.82	0.79
TOC_M	0.00	3.46	1.89
TOC_L	0.00	2.99	1.70
TOC_H	0.00	4.03	2.13
Oxford Clay			
Core TOC (3Pts)	0.48	1.60	0.95
TOC_M	0.00	3.54	1.93
TOC_L	0.00	3.06	1.72
TOC_H	0.00	4.13	2.18
Upper Lias Clay			
Core TOC (1Pts)	0.64	0.64	0.64
TOC_M	0.00	2.21	1.07
TOC_L	0.00	1.75	0.97
TOC_H	0.00	2.88	1.24
Middle/Lower Lias			
Core TOC (2Pts)	0.64	1.24	0.94
TOC_M	0.00	3.35	0.79
TOC_L	0.00	2.53	0.78
TOC_H	0.00	4.56	0.83
Oxford Clay 2			
Core TOC (2Pts)	1.24	1.64	1.44
TOC_M	0.00	3.64	1.12
TOC_L	0.00	3.14	1.06
TOC_H	0.00	4.25	1.19
Upper Lias Clay 2			
Core TOC (2Pts)	0.92	1.68	1.30
TOC_M	0.00	1.10	0.77
TOC_L	0.03	1.01	0.78
TOC_H	0.00	1.25	0.77
Middle/Lower Lias 2			
Core TOC (1Pts)	0.84	0.84	0.84
TOC_M	0.00	1.27	0.76
TOC_L	0.00	1.12	0.77
TOC_H	0.00	1.50	0.77



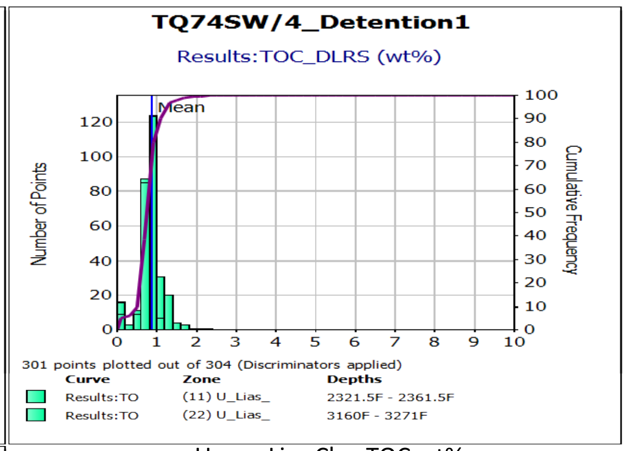
Kimmeridgian TOC wt%



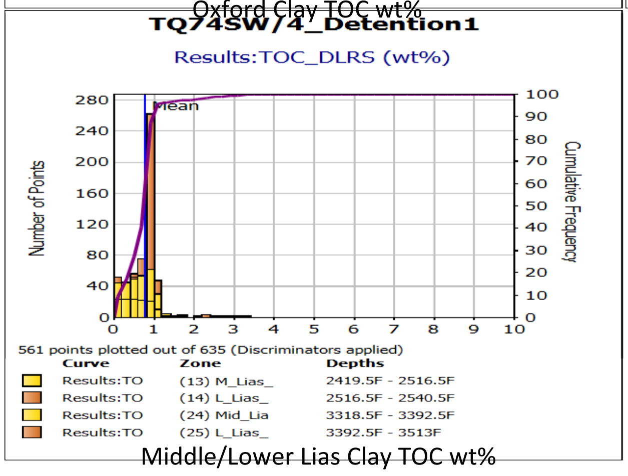
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 23a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Note: Reverse faulting causes repetition of units. Data missing in Kimmeridge, high 0 value

Table 23a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 23b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	778.0	1520.0	742.0	513.0	0.69	368.3	**0.50**	381.0	0.51	352.5	0.48
Corallian Argillaceous Unit	1778.0	1860.0	82.0	72.8	0.89	35.0	**0.43**	39.0	0.48	26.5	0.32
Oxford Clay	2008.0	2067.5	59.5	51.5	0.87	24.8	**0.42**	26.8	0.45	21.8	0.37
Upper Lias Clay	2321.5	2361.5	40.0	38.5	0.96	1.0	**0.03**	2.5	0.06	0.0	0.00
Middle Lias Clay	2419.5	2516.5	97.0	81.3	0.84	0.0	**0.00**	0.0	0.00	0.0	0.00
Lower Lias (Upper Clays/Lmst)	2516.5	2540.5	24.0	15.3	0.64	7.0	**0.29**	8.0	0.33	3.5	0.15
Oxford Clay 2	2579.5	2785.5	206.0	202.0	0.98	30.0	**0.15**	34.8	0.17	26.5	0.13
Upper Lias Clay 2	3160.0	3271.0	111.0	111.0	1.00	0.0	**0.00**	0.0	0.00	0.0	0.00
Middle Lias Clay 2	3318.5	3392.5	74.0	62.3	0.84	0.0	**0.00**	0.0	0.00	0.0	0.00
Lower Lias (Upper Clays/Lmst) 2	3392.5	3513.0	120.5	120.5	1.00	0.0	**0.00**	0.0	0.00	0.0	0.00
All Zones	778.0	3513.0	1556.0	1268.0	0.82	466.0	**0.30**	492.0	0.32	430.8	0.28

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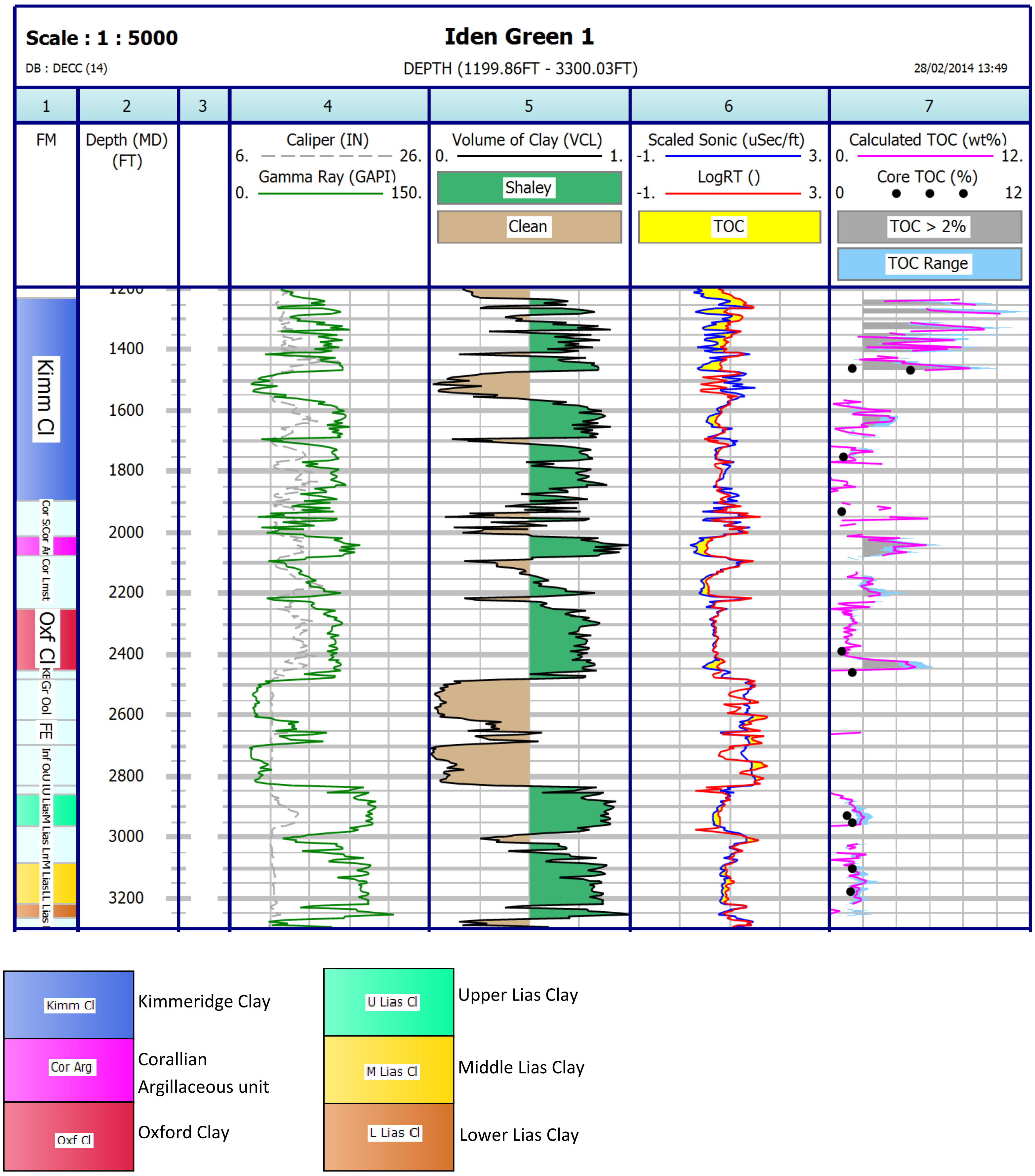
Figure 24: Iden Green 1 TQ83SW/1



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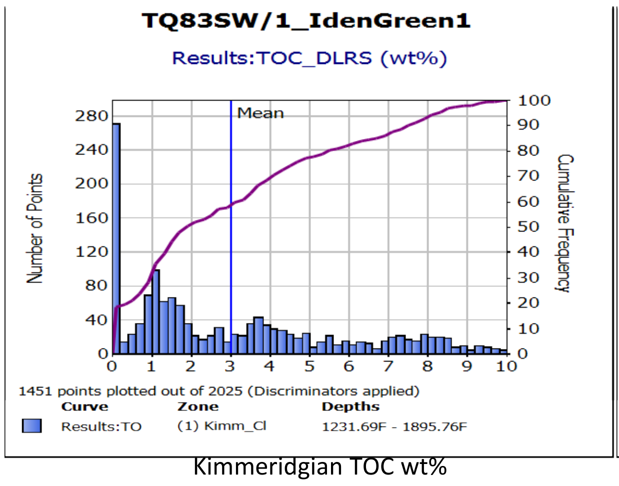
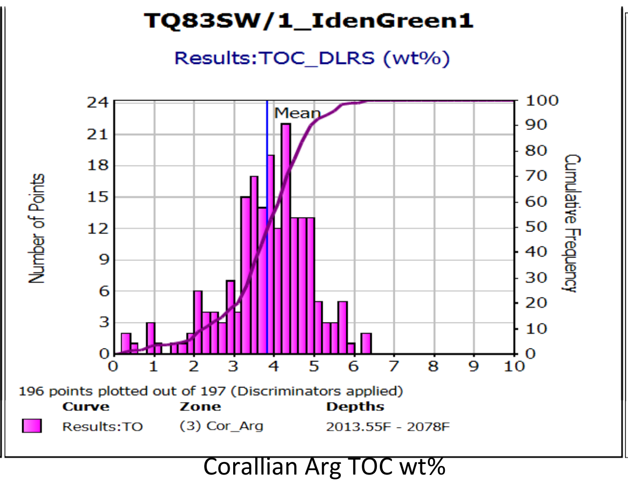
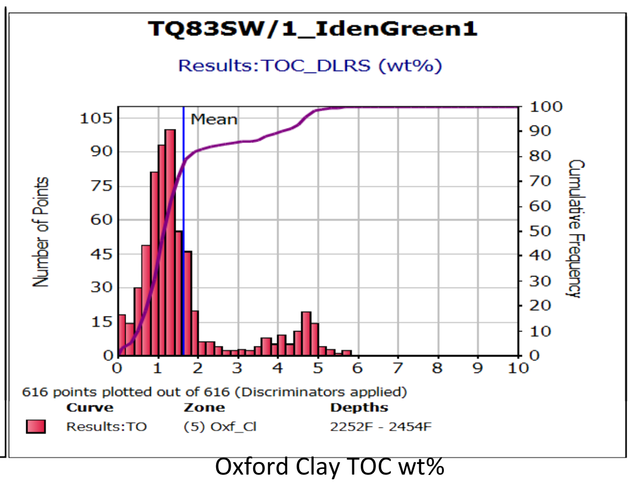


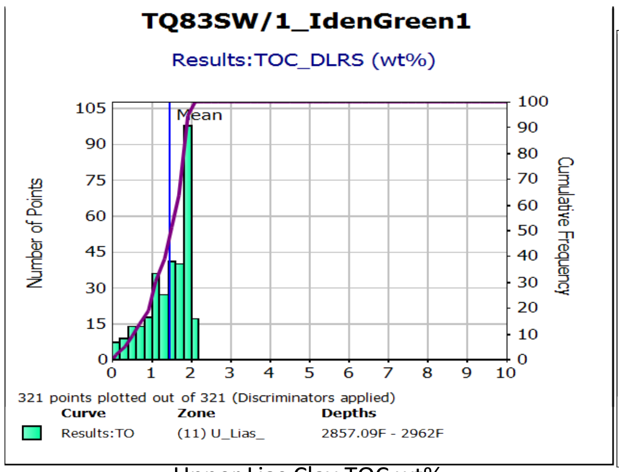
Kimmeridgian TOC wt%



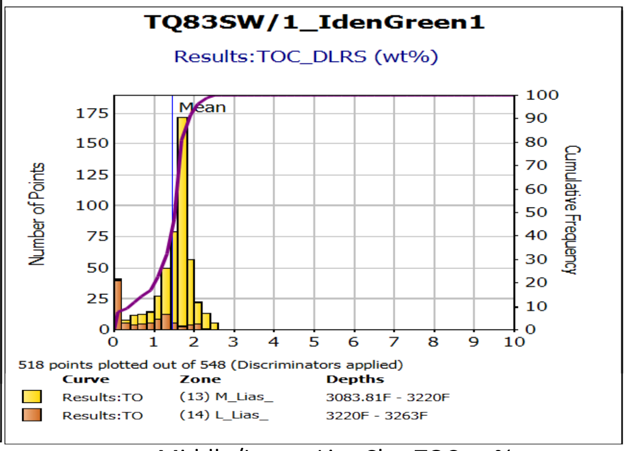
Corallian Arg TOC wt%



Oxford Clay TOC wt%



Upper Lias Clay TOC wt%



Middle/Lower Lias Clay TOC wt%

Figure 24a:

TOC histograms by formation. Uses the calculated TOC_M curve with VCL cut off of 0.5 applied. Note that the <2 TOC wt% cut off used in the tables below is not applied here. Mean line and cumulative frequency line also shown.

Curve	Min	Max	Mean
Kimmeridge Clay			
Core TOC (4Pts)	0.7	4.85	1.945
TOC_M	0.00	10.59	3.02
TOC_L	0.00	8.86	2.61
TOC_H	0.00	12.69	3.53
Corallian Argillaceous Unit			
Core TOC (1Pts)	0.70	0.70	0.70
TOC_M	0.25	6.36	3.84
TOC_L	0.35	5.38	3.30
TOC_H	0.13	7.55	4.49
Oxford Clay			
Core TOC (2Pts)	0.78	1.38	1.08
TOC_M	0.00	5.61	1.63
TOC_L	0.00	4.76	1.48
TOC_H	0.00	6.65	1.81
Upper Lias Clay			
Core TOC (2Pts)	1.09	1.36	1.23
TOC_M	0.00	2.09	1.44
TOC_L	0.00	1.67	1.23
TOC_H	0.00	2.70	1.75
Middle/Lower Lias			
Core TOC (2Pts)	1.25	1.37	1.31
TOC_M	0.00	2.51	1.44
TOC_L	0.00	1.96	1.22
TOC_H	0.00	3.33	1.77

Table 24a (Left):

Summary statistics for TOC wt% by formation. Includes both measured (core) and calculated (log derived) values .

- Core TOC taken from core samples (number of points given)
- TOC_M: Calculated TOC wt% based on the Passey-Sonic method using an average LOM.
- TOC_L and TOC_H: Calculated range of TOC wt% with high and low LOM (graphically represented by the blue shading).

Table 24b (Below):

Summarising each formations' Net to Gross (N/G), Pay to Gross (P/G) and P/G for the TOC wt% range (TOC_L and TOC_H). Summation of all zones of interest is given.

Zone	Top Depth (ft)	Bottom Depth (ft)	Gross Formation Thickness (ft)	Net (shale) Thickness	N/G	Pay Thickness (TOC_M)	P/G (TOC_M)	Pay Thickness (TOC_H)	P/G (TOC_H)	Pay Thickness (TOC_L)	P/G (TOC_L)
All Kimmeridge	1231.7	1895.8	664.1	477.9	0.72	236.9	**0.36**	248.7	0.38	228.0	0.34
Corallian Argillaceous Unit	2013.6	2078.0	64.5	64.3	1.00	60.7	**0.94**	61.7	0.96	58.7	0.91
Oxford Clay	2252.0	2454.0	202.0	202.0	1.00	36.1	**0.18**	43.0	0.21	33.8	0.17
Upper Lias Clay	2857.1	2962.0	104.9	104.9	1.00	5.6	**0.05**	50.2	0.48	0.0	0.00
Middle Lias Clay	3083.8	3220.0	136.2	136.2	1.00	12.1	**0.09**	83.0	0.61	0.0	0.00
Lower Lias (Upper Clays/Lmst)	3220.0	3263.0	43.0	33.2	0.77	2.0	**0.05**	4.3	0.10	0.0	0.00
All Zones	1231.7	3263.0	1214.6	1018.4	0.84	353.4	**0.29**	490.8	0.40	320.6	0.26

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Figure 25: Study Area Wells Map with high maturity belt

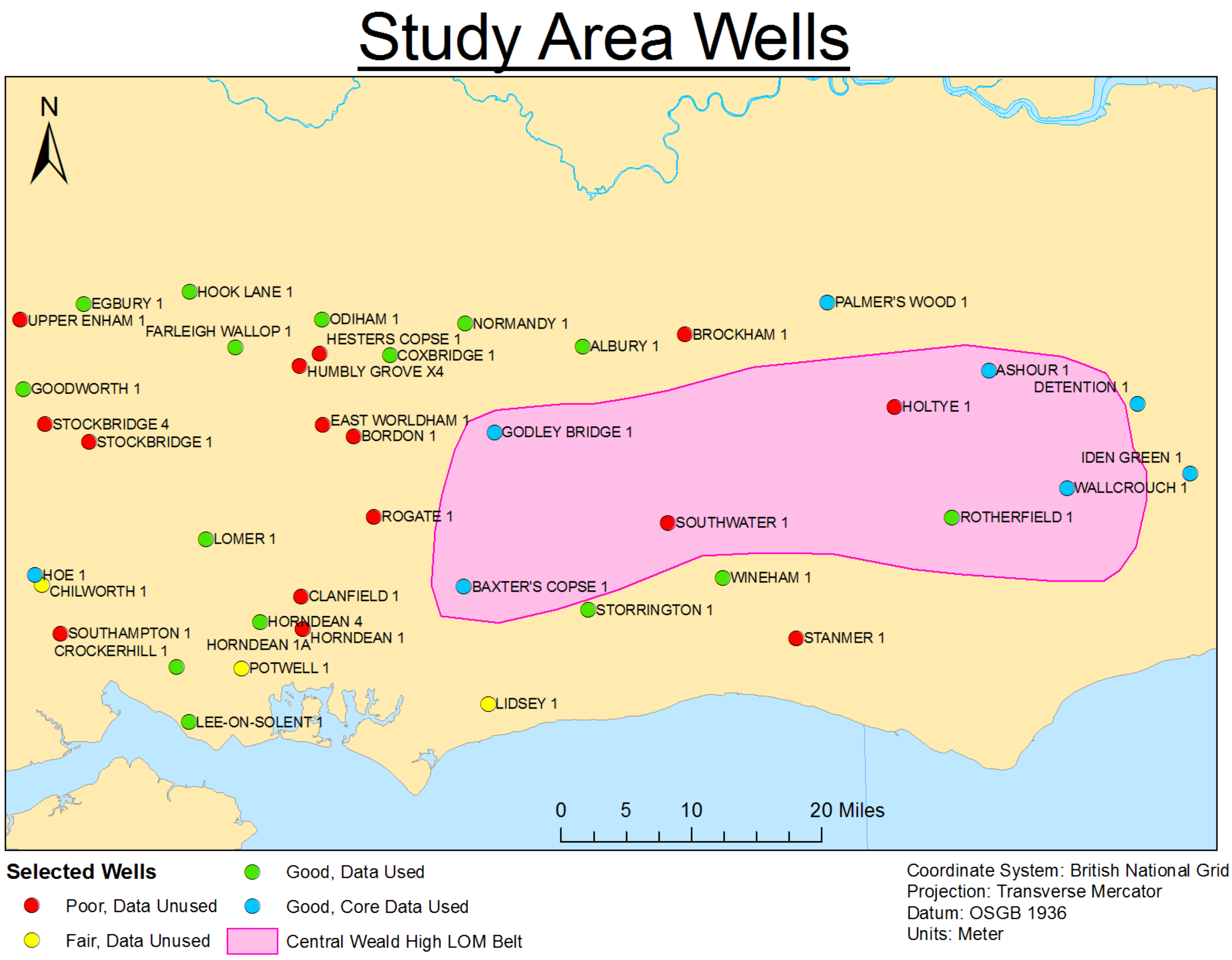
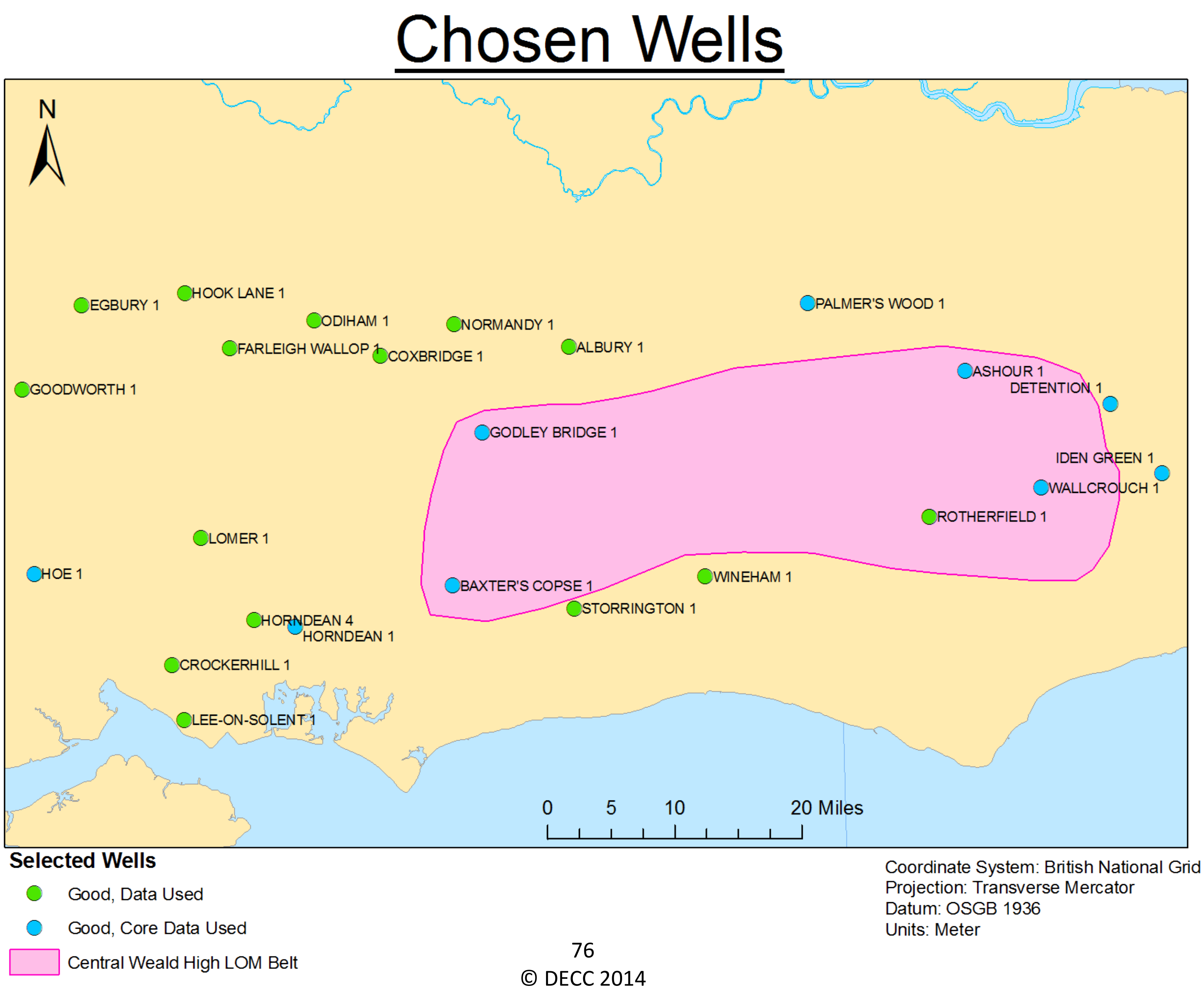


Figure 25: Study Area Wells Map with high maturity belt. Showing final wells chosen for further analysis



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Appendix E: Stratigraphic data from key wells penetrating Jurassic shales in the Weald area

Note that all depths of vertical depths below sea-level, not downhole measured depths relative to KB.

Well abbrev-iation	Well name	KB elevation (ft above MSL)	DEV	Top Kimmer-idge Clay (ft below MSL)	Top Corallian Clay (ft below MSL)	Top Oxford Clay (ft below MSL)	Top Upper Lias Clay (ft below MSL)	Top Mid Lias Clay (ft below MSL)
ALB	Albury 1	376		2755	3512	3727	4779	5114
ASD2	Ashdown 2	585		665	2475	2765	3985	4365
ASH	Ashington 1	91		2096	3599	3860	5364	?
ASR	Ashour 1	281		1129	2389	2627	3554	3924
BAL	Balcombe 1	212		1619	3721	4042	nr	nr
BAX	Baxter's Copse 1	251		2970	4014	4252	5765	5874
BID	Biddenden 1	103		1075	1832	2052	2495	2642
BLE1	Bletchingley 1	215		1735	3235	3528	4675	5170
BOL	Bolney 1	232		1270	3123	3188	4553	4930
BOR	Bordon 1	284	*	3153	4302	4563	5891	6270
BRI	Brightling 1	501		444	1339	1508	2403	2624
BRO	Brockham 1	184		2279	3720	4075	5243	5738
CHI	Chilworth 1	164		1944	2506	2689	3966	4173
CLA	Clanfield 1	426	*	3502	4745	4914	nr	nr
CFM	Collendean Farm 1	277		2098	3798	4123	nr	nr
COX	Coxbridge 1	303	*	2940	F	3629	4286	4571
CRO	Crockerhill 1	194	*	2408	3038	3205	4616	4763
DET	Detention 1	193		585	1585	1816	2947	3188
EW	East Worldham 1	453		2541	4070	4272	5551	5912
EGB	Egbury 1	481		1384	2032	2173	3218	3585
FAI	Fairlight 1	264		636	2036	2298	3101	3501
FARW	Farleigh Wallop 1	679		2122	2893	3082	3996	4269
FARS	Farley South 1	214		1851	2326	2615	4012	4078
FUR	Furzedown 1	397		1963	2631	2853	4183	4773
GB1	Godley Bridge 1	233		3372	5009	5178	6619	7049
GOO	Goodworth 1	249		1982	2617	2854	4286	4715
HEL2	Hellingly 2	128		1122	1622	1792	2567	2627
HES	Hesters Copse 1	500		2517	2990	3132	3940	4123
HOE	Hoe 1	161		2244	F	2721	3888	4086
HOL	Holtye 1	288	*	1025	2829	3134	4300	4846
HOO	Hook Lane 1	482		1373	1986	2118	3023	3315
HOR1	Horndean 1A	242		2823	3503	3707	5128	5238
HOR4	Horndean 4	274		3051	3628	3835	5403	5488
HG	Humbly Grove 1	468		2112	2802	2962	3857	4077
HGX4	Humbly Grove X4	476	*	2704	3384	3537	4480	4656
IDE	Iden Green 1	157	*	1075	1847	2080	2715	2899
INW	Inwood Copse 1	622	*	2384	2904	3098	4019	4350
KIN	Kingsclere 1	537		1172	2213	2281	?	?
KNO	Knockholt 1	671		1202	1884	2102	2689	2889
LEE	Lee-on-Solent 1	39	*	2398	2888	3068	4529	4538
LID	Lidsey 1	35		2535	2794	2890 (F)	?	nr
LOCK	Lockerley 1	118		1954	2566	2732	4097	4382
LOM	Lomer 1	578		2360	3195	3401	4860	5144
MID	Middleton 1	8		1932	2604	2762	3912	3942
MIN	Minsted 1	161	*	3635	4478	4712	nr	nr
NET	Netherhampton 1	250		1112	1690	2010	3345	3490
NOR	Normandy 1	279		2065	2626	2761	3433	3665

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Well abbrev-iation	Well name	KB elevation (ft above MSL)	DEV	Top Kimmer-idge Clay (ft below MSL)	Top Corallian Clay (ft below MSL)	Top Oxford Clay (ft below MSL)	Top Upper Lias Clay (ft below MSL)	Top Mid Lias Clay (ft below MSL)
ODI	Odiham 1	383	*	1769	2405	2550	3205	3428
OAL	Old Alresford 1	607		2661	3517	3711	nr	nr
PAL1	Palmer's Wood 1	459		1696	2590	2822	3519	3871
POT	Potwell 1	157	*	2925	3121	3292	4505	4654
ROG	Rogate 1	355		3267	5037	5326	nr	nr
ROT	Rotherfield 1	281		823	2239	2466	3424	3734
SHAL	Shalford 1	160		2551	4170	4430	5285	5340
SHR	Shrewton 1	468		638	1522	1688	3142	3571
SOU	Southampton 1	11		2294	2734	2869	4235	4244
SWA	Southwater 1	137	*	3255	3848	4141	5476	6001
STA	Stanmer 1	649		1601	2281	2454	3246	3273
STO1	Stockbridge 1	374		1896	2591	2786	4209	4481
STO4	Stockbridge 4	331	*	1850	2683	2916	4339	4802
STR1	Storrington 1	138	*	1885	3290	3383	4798	4887
STA1	Strat A1	138		2102	F	2227	2757	
TAT	Tatsfield 1	666		1475	2334	2546	3095	3389
UPP	Upper Enham 1	430		1521	2187	2376	3728	4127
URC	Urchfont 1	387		-13	566	789	2044	2498
WLC	Wallcrouch 1	381		1018	2339	2569	3539	3819
WES	Westham 1	29		847	1521	1841	?	?
WIN1	Winchester 1	205		1965	3105	3332	4915	5235
WIN	Wineham 1	43	*	1789	3179	3451	4575	4889
YARN	Yarnbury 1	519		658	1345	1485	2861	3316

NB These data present the interpretation used in this study.

F = faulted out; nr = not reached; ? = uncertain

* significantly deviated well

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