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Reservoir evaluation of 8 wells in the Palaeozoic of the Irish Sea area: Petrophysical interpretations of clay volume, porosity and permeability estimations

Energy and Marine Geoscience Programme

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S Hannis

Contributor

E Callaghan

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British Geological Survey offices

BGS Central Enquiries Desk
Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG
Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

The Lyell Centre, Heriot-Watt University, Riccarton, Edinburgh EH14 4AP
Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD
Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE
Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB
Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF
Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU
Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Requests and enquiries should be addressed to Alison Monaghan, 21CXRM Palaeozoic Project Leader, als@bgs.ac.uk.

Foreword

This report is a published product of the 21st Century Exploration Roadmap (21CXRM) Palaeozoic project. This joint industry-Government-BGS project comprised a regional petroleum systems analysis of the offshore Devonian and Carboniferous in the North Sea and Irish Sea.

Carla Riddell and Myles Taylor (Centrica) are thanked for technical review of this report.

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Summary

This report details the reservoir evaluation of 8 wells across the Palaeozoic (Carboniferous and Permian age) rocks of the UK Irish Sea for the 21CXRM Palaeozoic project.

This reservoir evaluation is based on the petrophysical interpretation of available digital wireline log curve data for 8 wells and associated digitised core porosity and permeability data (available for 6 of the 8 wells interpreted, with 7 to 20 measurements per well) across the Palaeozoic interval (according to reinterpreted stratigraphic formations defined and correlated for this project, documented in Wakefield et al., 2016). Outputs of this part of the project include continuous (along borehole) interpretations of porosity, clay volume, and include basic permeability estimations. These interpreted curves were used to calculate Net to Gross (NTG) values and average porosities and permeabilities for each formation in each well analysed.

The highest average porosities were found in the Permian aged Appleby Group (19%; previously termed the Collyhurst Sandstone). This unit also had the highest NTG and second highest average permeabilities of the units examined. Although the highest average permeability is low (0.13 mD) for the Appleby Group, maximum values in the 50-100 mD range are recorded for several wells. The Cumbrian Coast Group (Upper Permian), Pennine Lower Coal Measures (Carboniferous) and Millstone Grit Groups all had reasonable porosities averaging 11-14%, although they have low net to gross values (7-13%).

The Cumbrian Coast Group (Upper Permian) includes some evaporite deposits of no reservoir potential themselves, but these could potentially act as a barrier (trap) to any hydrocarbons beneath them. Most of the other units in the wells examined show heterogeneous properties with low net to gross. Although the Millstone Grit Group generally has a low net to gross because of its high clay volume, cleaner reservoir intervals with reasonable porosity exist and more study on the permeabilities and distribution of these could be worthwhile. The basal limestones appear cleaner, but have very low matrix porosities and so are not considered to be potential reservoirs unless fractures contribute to their porosity and permeability (not examined here).

Note that given the limited number of wells examined and the regional scale of the project, more detailed study of the reservoirs including mapping property trends and identifying prospective intervals was out of scope of this project. A brief examination of the distributions of net to gross and average porosities, both by formation in each well and for the total Palaeozoic interval in each well was not able to highlight any particular property trends or geographic areas with particularly favourable properties.

1 Introduction

The 21CXRM Palaeozoic project aimed to stimulate exploration of the Devonian and Carboniferous plays of the Central North Sea - Mid North Sea High - Moray Firth - East Orkney Basin and in the Irish Sea area. The objectives of the project included regional analysis of the plays and building of consistent digital datasets, working collaboratively with the OGA, Oil and Gas UK and industry.

The project results are delivered as a series of reports and as digital datasets for each area. This report describes the methodology and results of a "quick-look" regional-scale petrophysical study of reservoir quality in the Irish Sea study area. Given this nature of the study, and the time & resources available for it, a full rigorous petrophysical interpretation of each well examined was not within scope. This is explained in the report and should be borne in mind when examining the outputs and results.

1.1 OUTPUTS OVERVIEW

1. **Continuous digital interpreted curves across the Palaeozoic intervals for 8 wells in the Irish Sea (method Section 2.2, 5 describes the selection process). Interpreted from geophysical log responses using Interactive Petrophysics software (IP™, Version 4.2.2015.61, LR-Senergy)**

   Analysis for:

   - Volume of clay*(V_{CL})*
   - Coal intervals *(V_{COAL}) and evaporite intervals (V_{SALT})*
   - Porosity *(PHIE & PHIT)*
   - Permeability estimate *(PermEst)*

2. **Summary petrophysical results (based on interpreted curves (1.)) for the Palaeozoic interval by formation in each well**

   - Gross thickness
   - Net*
   - Net to Gross
   - Average porosity (across the net intervals)

   *"Reservoir" definition *(i.e. Cut offs to derive "Net")*

     - Porosity greater than 5% *(PHIE>0.05)*
     - Clay volume less than 50% *(V_{CL}<0.5)*
     - No coal or salt intervals *(V_{COAL}=0, V_{SALT}=0)*

3. **Digitised core-sample-derived basic porosity-permeability measurement data for the majority of wells in Quadrants 110-113 that have penetrated Palaeozoic intervals and core reports available. Available as an Excel spreadsheet.**

2 Technical details and data preparation

This section outlines the data types, sources of data and preparation required prior to the petrophysical interpretation of selected wells in the Irish Sea.

2.1 DATA TYPES AND SOURCES

A number of data types and sources were required for or contributed to the petrophysical interpretation:

- **Digital geophysical log curve data**, mainly in LAS format (or sometimes LIS or DLIS) were downloaded from CDA for the project (under licence), some BGS legacy data was also used.
- **Scanned company reports** downloaded from CDA, mainly in PDF format:
  - **Composite logs** used to check well location, depths, curves scales, spliced intervals etc
- **Tabulated core porosity and permeability data** (digitised for this project from PDFs of core reports or well completion reports on CDA). Generally the values used and referred to in this report represent helium porosity and horizontal permeability to air. Note that the laboratory and drying methods used were not always stated and associated data e.g. from Special Core Analysis (SCAL) reports was not generally recorded. The digitised dataset of core data (#3 listed in the outputs overview, Section 1.1) does contain some vertical permeability measurements in addition to the horizontal permeabilities.
- **Stratigraphy:**
  - **Well tops**, interpreted by BGS for this project (Wakefield et al., 2016). These were checked with or re-interpreted from the **digital composite log well tops** "DECC composite tops", supplied from DECC/BGS database).
- **Cored intervals** based on BGS digital core-holdings database query. This was used to indicate core locations on log plots to help to distinguish intervals where data was derived from core, or from, for example, side wall cores or cuttings.

2.2 DATA PREPARATION

The software used for the petrophysical interpretation was **Interactive Petrophysics** (IP^{TM}, Version 4.2.2015.61, LR-Senergy software, used under licence). Steps to select the study wells, import and prepare the data are described:

1. Digital geophysical log curve data were copied to IP^{TM} from ODM^{TM} (LR-Senergy well manager software, used for the BGS correlation and re-interpretation of the stratigraphy).
2. The BGS-re-interpreted stratigraphy was loaded into IP for the wells it was available for (reformatted from the ODM-exported .xls file of the formation intervals)[1].
3. BGS-digitised core porosity and permeability data was loaded into IP for the wells it was available for (reformatted from the BGS-digitised tabulation of data for all wells)[1].

[1] *Note that this data was checked and reloaded throughout the process as more data was interpreted or digitised. Given the project time-constraints, these tasks were to a large extent performed simultaneously.*

4. The cored intervals were loaded into IP for the wells it was available for (tops and bases, reformatted from the output of the BGS core database).
5. Wells to interpret were selected based on the length of Palaeozoic interval, stratigraphic intervals and geographic areas covered, and the availability and quality of suitable data over the interval. Figure 1 shows the location of the wells that were selected. The following list indicates the factors taken into consideration in their selection and the number of wells they apply to (listed by well in Table 7, Appendix 3):
    - Thickest Carboniferous section (378 - 1042 m for the wells selected)
    - Updated stratigraphy picked (8 of the 8 selected)
    - Geophysical log curve data for reservoir evaluation, with suitable data quality (variable for each well) (see Table 7, Appendix 3)
    - Core poroperm data available (6 of the 8 selected)
    - Company log composite available for cross checking data (8 of the 8 selected)

    Note that wellbore deviation surveys were not taken into account because the data is presented against measured depth (MD).

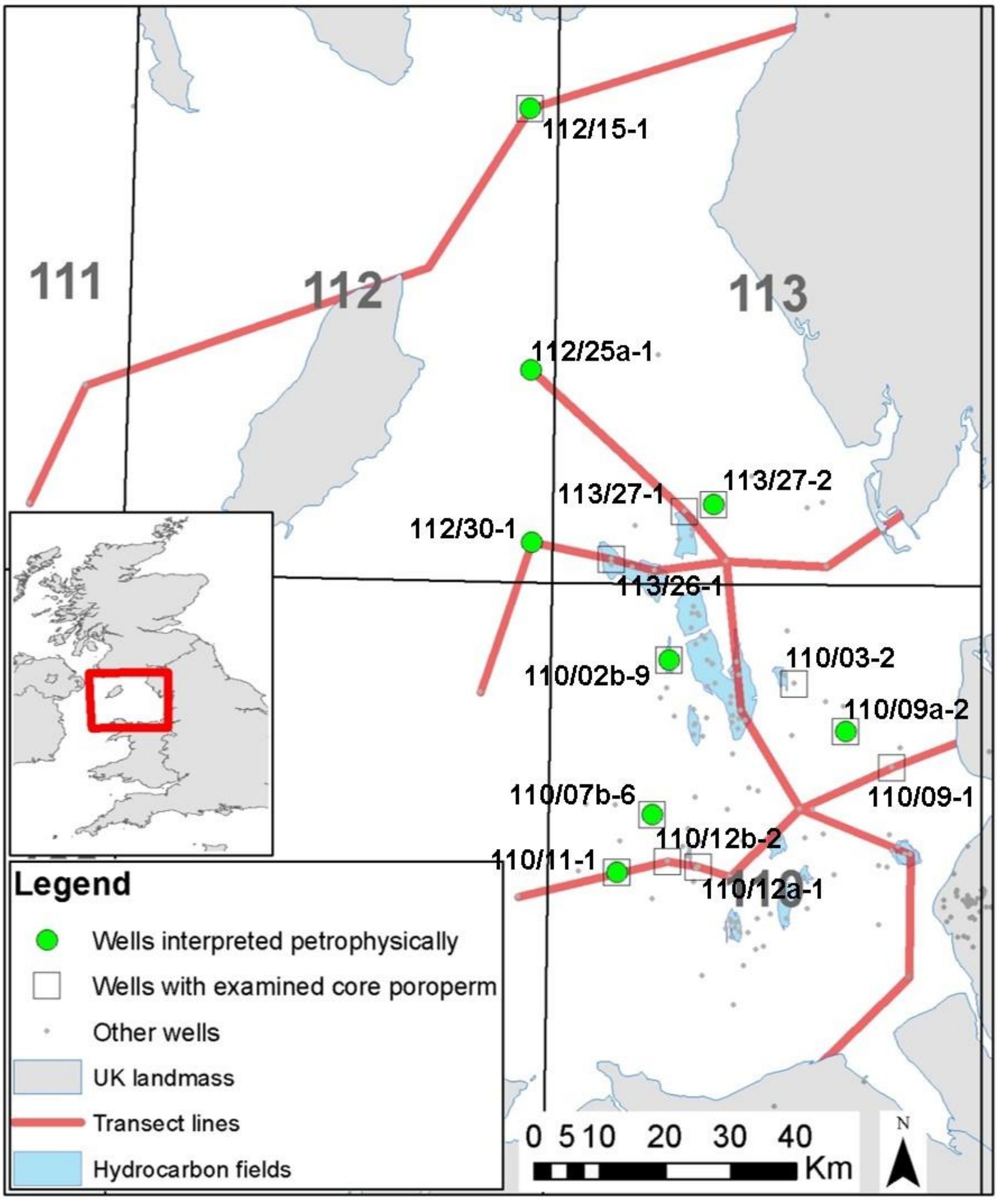


Figure 1 Map of the wells selected for the petrophysical study

3 Curve interpretation method

Continuous interpreted curves were calculated from geophysical log responses over the Palaeozoic interval using Interactive Petrophysics software (IP^{TM}, Version 4.2.2015.61, LR-Senergy). Where available, core data was used to guide parameter selection. Given the "quick-look" and regional nature of this study, some broad assumptions were necessary for the log interpretation. These include the temperature gradient (32.2°C/km with a surface temp of 8°C was used, based on Irish Sea trends), likely mud type (water based mud was assumed, which may affect the output porosities), and that suitable environmental corrections had already been applied to logs. Table 7, Appendix 3 includes some quality control comments and assumptions for individual wells.

3.1 INCORPORATION OF CORE POROSITY AND PERMEABILITY MEASUREMENTS

Core data was not available for all wells (see Table 7, Appendix 3), or all reservoir intervals, but where it was available, core porosity measurements were displayed with the log porosities for comparison and to guide interpretation parameter selection (Section 3.4). Core porosity and permeability measurements were used to derive permeability estimation curves (Section 3.5). Core data is displayed on the log plots in Appendix 1.

The usual procedure for matching core and log porosities on a field - scale would be to first depth shift the core to the logs and then correct the core measurements for downhole in-situ conditions (ideally using SCAL (Special Core Analysis Laboratory) data which includes measurements with different fluid phases and different confining pressures, for example, to understand the degree of overburden stress correction to apply). The log porosities could then be robustly "calibrated" to core porosity measurements, before using them (and potentially other logs) as permeability predictors. Usually a detailed knowledge of depositional environment and reservoir heterogeneity would allow appropriate statistical methods to be selected to define permeability predictors for each identified reservoir unit. However, in the tables of core porosity measurements digitised for this regional-scale project, details about core treatment, depth shifts to apply and the measurement method(s) were not generally captured. Therefore, within this report scope, the "usual" steps to correct the core data described above are not fully implemented (Table 2 summarises the core data available for the wells studied; Table 5, Appendix 2, lists the wells for which a core-depth-shift was possible to determine). These, together with the notes below, explain the limits to the possible match between log and core porosity that could be achieved.

Other points of note for log-core matching include:

- Sample scale - the vertical resolution of geophysical logs are much larger than the few centimetres-across core samples retrieved. Thus in very heterogeneous formations, average log response over an interval may be very different to the "point" data measurements on core;
- Core treatment history - core porosity measurements generally fall between total and effective porosities, depending on the measurement method and also what was done to prepare it e.g. the degree of cleaning and drying processes applied prior to measurement. Permeability measurements from sidewall core samples (wells 112/15-1 and 110/09a-2) of sandstones are generally considered to less be valid than full cores as a result of drilling mud contamination (because of their smaller size relative to conventional core, which may have mud damage around the outsides).

Comparisons of core-measured and log-interpreted porosities are shown graphically in Appendix 2 along with graphs showing core-measured porosity against core-measured permeability. Tables 5 & 6 show the relationships derived from these graphs (where they were possible to derive).

3.2 VOLUME OF CLAY CURVE (V_{CL})

A Volume of Clay (V_{CL}) curve was interpreted for each well. This gives a continuous, geophysical log-derived volume of clay for the intervals investigated. Input curves were the Gamma Ray (GR) and a combination of the Neutron, Density and Sonic curves where available and of good quality. These curves were used to select end points representing 0% clay and 100% clay for zones of the log, subdivided based on changing log character and curve responses with depth, to create a V_{CL} log scaled from 0 (100% clean reservoir) to 1 (100% clay). Note that data on clay types (for example, evidence of tuffaceous beds) in individual wells or intervals of interest were not explored. This “quick-look”, regional scale study interpretation of clay volume is based on curve responses only. The V_{CL} logs were used in combination with other curves to identify appropriate reservoir cuts off for the calculation of Net to Gross values for the main reservoir formations (section 4.2).

3.3 COAL AND SALT IDENTIFICATION CURVE (V_{COAL} AND V_{SALT})

Coal and salt identification curves (V_{COAL} and V_{SALT}) were interpreted for each well, where “coal or salt indicated” = 1, “no coal or salt indicated” = 0, respectively. This gives an indication of whether evaporites or coal are thought to be present at each depth, based on the log response, and certain cut off values. The cut off values selected were based on a combination of the log responses where the composite log lithology track indicated coal or salt to be present, together with a visual evaluation of curve response with knowledge of expected responses expected in coal, evaporate (halite) and other minerals. Thus slightly different cut offs were used in each well (Table 7, Appendix 3).

The V_{COAL} and V_{SALT} curves were used in combination with other curves to identify appropriate reservoir cut offs for the calculation of Net to Gross values for the main reservoir formations (section 4.2).

3.4 POROSITY CURVES

Porosity curves were interpreted for each well. Input curves included the V_{CL} curves (section 3.2), Neutron, Density and Sonic curves. (Resistivity and Photoelectric Factor curves were used as visual aids to interpretation where required and data appeared to be reading within expected ranges). Areas of poor log quality were identified using primarily the Density Correction and Caliper curves (Table 7, Appendix 3).

Effective Porosity (PHIE) and Total Porosity (PHIT) curves were computed using the Neutron – Density method*. Where Density or Neutron data was unavailable, or its quality was poor, porosity was calculated using the sonic curve. These computations take into account tool measurements and interpretations of clay, mud filtrate and rock matrix properties. Where sufficient data was available, core porosity measurements were used to guide parameter selection, see Section 3.1.

*Using IP variable matrix density logic. IP solves the tool response equations for PHIE (corrected for wet clay volume). PHIT is then back-calculated by adding back in the clay bound water. Intervals that required sonic porosity calculations utilized the Wyllie equation.

The PHIE logs were used in combination with other curves to identify appropriate reservoir cut offs for the calculation of Net to Gross values for the main reservoir formations (section 4.2).

3.5 PERMEABILITY ESTIMATION CURVE

A permeability estimation was derived for the wells for which appropriate core data was available (Section 3.1). The estimates were based on the relationships between core porosity and log porosity, and core porosity and permeability where data was available and a relationship was found to exist. The same statistical method to examine these relationships was used for each well, as follows:

- Because insufficient data often existed to depth shift the core to the logs, the RMA (reduced major axis) method of regression was chosen to describe any relationship between core and log porosity to attempt to minimise depth matching errors.
- The Robust Fit method was used to calculate the regression line in the core porosity-permeability data, because this reduces the effect of outliers in the dataset. This method minimises the sum of the errors in the Y (permeability) direction, rather than the square of the distances (as is the case with the ordinary Least Squares regression method). The resulting curve was clipped at 10,000 mD, to remove any spuriously high permeability values (applied to well 113/27-2).

As explained in Section 3.1, on a hydrocarbon field scale, the normal procedure to derive permeability curves would be more detailed than the method applied here. The permeability estimations here should therefore be regarded as a broad indicator of possible permeability fluctuations with depth and not as absolute values.

4 Outputs & results

4.1 INTERPRETED CURVES

Continuous curves for 8 wells in the Irish Sea were interpreted using Interactive Petrophysics software (IP^{TM}, Version 4.2.2015.61, LR-Senergy) and the methods described in section 3. Curve data were clipped to the Palaeozoic interval. Any small data gaps were filled (to allow software calculation of Net to Gross and curve averages, sections 4.2 – 4.4).

Note that in many cases the base of the Palaeozoic interval was not penetrated. Continuous curves produced were:

- Volume of Clay curve (V_{CL});
- Coal Identification curve (V_{COAL});
- Evaporite Identification curve (V_{SALT});
- Effective Porosity curve (PHIE);
- Total Porosity curve (PHIT) ;
- For some wells a curve of Estimated Permeability (PermEst) exists.

Core data tables are available in Excel form.

Plots of data for each well are available as a "quick-look" output in Appendix 1. (Note that the input data is also displayed in these plots, but is not provided as an output due to data permission constraints). (Note also that an indication of input curve data quality is provided in Table 7, Appendix 3 and curve to core porosity match comments in Table 5, Appendix 2. These can give an indication of the confidence in output curve results).

4.2 NET TO GROSS

Net to Gross (NTG) in this report gives an indication of the amount of reservoir (Net) within an interval of interest (Gross). It is expressed as a fraction from 0 to 1, where a NTG of 0 means that no reservoir has been interpreted within the of interval and a NTG of 1 means that all of the rock within the interval has been interpreted to be composed of 100% reservoir. The NTG equation is shown below.

$$\text{Net to Gross (NTG)} = \frac{\text{Total thickness of reservoir" (net)}}{\text{Total thickness of interval (gross)}}$$

The total thickness of the interval of interest is the Gross. The Net interval is the sum of the thicknesses of those parts of the reservoir that meet a set of cut-off criteria (applied to one or more curves). These parameters (the cut off criteria that define the Net) will, at the field scale, be based on operator preferences or field observations of reservoir productivity that may be refined through time. However, at this "quick-look", regional-scale, generic cut-offs have been applied to give a broad indication of the Net where:

- Clay volume is less than 50% (i.e. where $V_{CL} <0.5$);
- Porosity is more than 5% (i.e. where PHIE > 0.05);
- No coal or salt intervals are identified (i.e. where $V_{COAL} = 0$, or $V_{SALT} = 0$).

Note that permeability cut offs were not applied, due to the roughly-estimated nature of the derived curves and because they were not available for every well.

NTG values were calculated for each stratigraphic unit in each well (and by stratigraphic unit (for all wells) and by well (for all stratigraphic units)).

4.3 AVERAGE POROSITY AND RANGE

Average porosities and ranges were calculated for each stratigraphic unit in each well. These are based on arithmetic average calculations and curve statistics of the interpreted effective porosity (PHIE) curve (section 3.4) over the intervals defined as net reservoir (Net: see NTG, section 4.2).

4.4 AVERAGE ESTIMATED PERMEABILITY AND RANGE

Given the nature of the permeability estimations, simple averages and ranges found over the stratigraphic units investigated for the wells studied are given, based on the estimated (PermEst) curve (Section 3.5) for the intervals defined as net reservoir (Net: see NTG, section 4.2).

4.5 SUMMARY OF PETROPHYSICAL RESULTS

Summary results (based on interpreted curves, Section 4.1) are given for the whole Palaeozoic interval and by individual formation in each well. Main reported results are highlighted in bold type.

Table 1 Notes:

All depths and thicknesses are in metres.

- **Colours on the left side** of the table refer to the "standard " colours of the stratigraphic units used throughout this project;
- **Colours on the right side** of the table are used to help highlight the maximum and minimum values in each column or set of columns. In general the colours are scaled from the highest value shown as brightest green, shading to the lowest value shaded in darkest red, grading midway through yellow, set as the 50 percentile value. Columns for Gross, Net and NTG are scaled as individual columns. The three porosity columns are scaled together, as are the three permeability columns.
- No deviation logs were loaded for this study (they are presented in measured depth (MD) along the borehole) and formation dip is not taken into account. Therefore thickness of intervals in Table 1 is the interval along the borehole that they can be recognised. This is not necessarily their true stratigraphic thickness (depending on formation dip and borehole deviation).

[1]Note that the base of the Palaeozoic succession is not penetrated in any wells. The truncated stratigraphic intervals for which this applies is indicated by '[nb]'(no base) in the Gross column.

[2]Section 4.2 describes the curve cut-offs used to define "Net".

[3]Net to Gross, described in Section 4.2. See also note 1.

[4]Effective porosity (PHIE). Section 3.4 describes the method of deriving the porosities curves. Average is arithmetic average. Average, Minimum and Maximum values are over the Net intervals only, see note 2. Expressed as a fraction.

[5]Estimated permeability (PermEst) Section 3.5 describes the method of deriving the permeability curves. Average is arithmetic average. Average, Minimum and Maximum values are over the Net intervals only, see note 2. Units are millidarcies (mD).

Well	Unit name	Unit code	Top	Base	Gross[1]	Net[2]	NTG[3]	Average PHIE[4]	PHIE Min[4]	PHIE Max[4]	Average PermEst[5]	PermEst Min[5]	PermEst Max[5]
110/02b-9	Cumbrian Coast Group	CCO	2329	2448	119	1	0.01	0.07	0.05	0.09	0.0	0.0	0.1
110/07b-6	Cumbrian Coast Group	CCO	1138	1274	136	0	0.00						
110/09a-2	Cumbrian Coast Group	CCO	1213	1391	178	10	0.06	0.08	0.05	0.12	0.2	0.0	1.4
110/11-1	Cumbrian Coast Group	CCO	2241	2399	158	0	0.00						
112/15-1	Cumbrian Coast Group	CCO	2172	2349	177	7	0.04	0.07	0.05	0.08			
112/25a-1	Cumbrian Coast Group	CCO	1762	2090	328	36	0.11	0.14	0.05	0.43			
112/30-1	Cumbrian Coast Group	CCO	467	540	73	27	0.37	0.08	0.05	0.18			
113/27-2	Cumbrian Coast Group	CCO	1707	1735	28	0	0.00						
110/07b-6	Appleby Group	APY	1274	1440	166	164	0.99	0.19	0.05	0.33	6.9	0.2	82.3
110/11-1	Appleby Group	APY	2399	3158	759	654	0.86	0.09	0.05	0.25			
112/25a-1	Appleby Group	APY	2090	2313	223	93	0.42	0.09	0.05	0.40			
113/27-2	Appleby Group	APY	1735	1778	43	25	0.58	0.09	0.05	0.17	1.6	0.0	24.3
110/11-1	Pennine Coal Measures Group	PCM	3158	3420	262	0	0.00						
110/02b-9	Pennine Coal Measures Group	PCM	2448	2981	533	62	0.12	0.11	0.05	0.26	0.8	0.0	61.4
110/09a-2	Pennine Lower Coal Measures	PLCM	1391	1594	203	26	0.13	0.07	0.05	0.18	0.2	0.0	3.9
110/11-1	Pennine Lower Coal Measures	PLCM	3420	3508	88	1	0.01	0.11	0.07	0.13			
112/30-1	Pennine Lower Coal Measures	PLCM	540	585	45	1	0.02	0.08	0.06	0.09			
113/27-2	Pennine Lower Coal Measures	PLCM	1778	1894	116	12	0.10	0.08	0.05	0.12	0.2	0.0	1.1
110/02b-9	Millstone Grit Group	MG	2981	3459	478	59	0.12	0.09	0.05	0.28	0.9	0.0	175.2
110/07b-6	Millstone Grit Group	MG	1440	1978	538	132	0.25	0.11	0.05	0.30	2.1	0.2	41.2
110/11-1	Millstone Grit Group	MG	3508	4194	686	53	0.08	0.07	0.05	0.27			
112/30-1	Millstone Grit Group	MG	585	1352	767	20	0.03	0.08	0.05	0.20			
113/27-2	Millstone Grit Group	MG	1894	2396	502	29	0.06	0.09	0.05	0.31	367.7	0.0	10000.0
110/07b-6	Bowland Shale Formation	BSG	1978	2433	455	16	0.03	0.07	0.05	0.23	0.7	0.2	16.2
113/27-2	Bowland Shale Formation	BSG	2396	2492	96	0	0.00	0.06	0.06	0.07	0.0	0.0	0.0
112/15-1	Yoredale Group	YORE	2349	2755	406	0	0.00						
112/25a-1	Yoredale Group	YORE	2313	2690	377	16	0.04	0.07	0.05	0.30			
113/27-2	Great Scar Limestone Group	GSCL	2492	2651	160	0	0.00						
112/25a-1	Carboniferous Limestone Supergroup	CL	2690	2776	86	0	0.00	0.05	0.05	0.05			

Table 1 Results of petrophysical calculations listed by formation for each well (Table notes and units are listed on previous page)

4.6 SUMMARY OF CORE POROSITY-PERMEABILITY DATA

Porosity and permeability data, measured from core samples is available as an Excel spreadsheet, contained within the digitised output dataset. Note that these measured values are against depth, and not by formation. However, for a subset of those wells, interpreted stratigraphic units were available, and for these, the core data has been assessed by formation. This is summarised in Table 2 and shown graphically in Figure 2, for all measurement data points (Note: the petrophysical data in Table 1 are displayed for the Net intervals only).

			Core porosity (fraction)				Core horizontal permeability (mD)				Core vertical permeability (mD)			
Well	**Unit name**	**code**	**Number of samples**	**average core poro**	**min core poro**	**max core poro**	**Number of samples**	**average kh perm**	**min kh pem**	**max kh perm**	**Number of samples**	**average kv perm**	**min kv pem**	**max kv perm**
113/26- 1	Cumbrian Coast Group	CCO	6	0.04	0.02	0.07	5	3.06	0.01	15.20				
110/07b- 6	Appleby Group	APY	18	0.11	0.06	0.18	18	0.80	0.19	1.72				
110/09- 1	Appleby Group	APY	1	0.00			0	0.01						
110/12a- 1	Appleby Group	APY	57	0.11	0.05	0.18	32	0.43	0.07	1.62				
110/12b- 2	Appleby Group	APY	73	0.13	0.06	0.21					15	7.90	0.17	71.50
113/27- 2	Appleby Group	APY	5	0.08	0.05	0.12	13	0.42	0.00	1.09				
113/26- 1	Pennine Middle Coal Measures	PMCM	3	0.04	0.02	0.07	3	0.06	0.00	0.12				
110/02b- 9	Pennine Coal Measures Group	PCM	9	0.02	0.00	0.07					9	0.01	0.00	0.13
110/09a- 2	Pennine Lower Coal Measures	PLCM	20	0.06	0.03	0.10	20	0.12	0.02	0.67				
113/27- 1	Pennine Lower Coal Measures	PLCM	14	0.02	0.01	0.03	13	1.07	0.00	9.43				
113/27- 2	Pennine Lower Coal Measures	PLCM	9	0.05	0.02	0.10	13	0.10	0.00	0.22				
110/02b- 9	Millstone Grit Group	MG	6	0.03	0.02	0.03					4	0.05	0.00	0.13
110/03- 2	Millstone Grit Group	MG	6	0.03	0.02	0.04	4	0.01	0.01	0.01	1	0.01	0.01	0.01
110/09- 1	Millstone Grit Group	MG	29	0.06	0.02	0.10	29	0.04	0.01	0.37				
110/11- 1	Millstone Grit Group	MG	7	0.01	0.00	0.01	6	0.01	0.00	0.03	7	0.00	0.00	0.01
113/27- 2	Millstone Grit Group	MG	1	0.01			1	0.00						
112/15- 1	Yoredale Group	YORE	9	0.01	0.00	0.03	5	0.00	0.00	0.00	5	0.00	0.00	0.00

Table 2 Summary of digitised core porosity-permeability measurement data by formation, for the wells studied petrophysically.

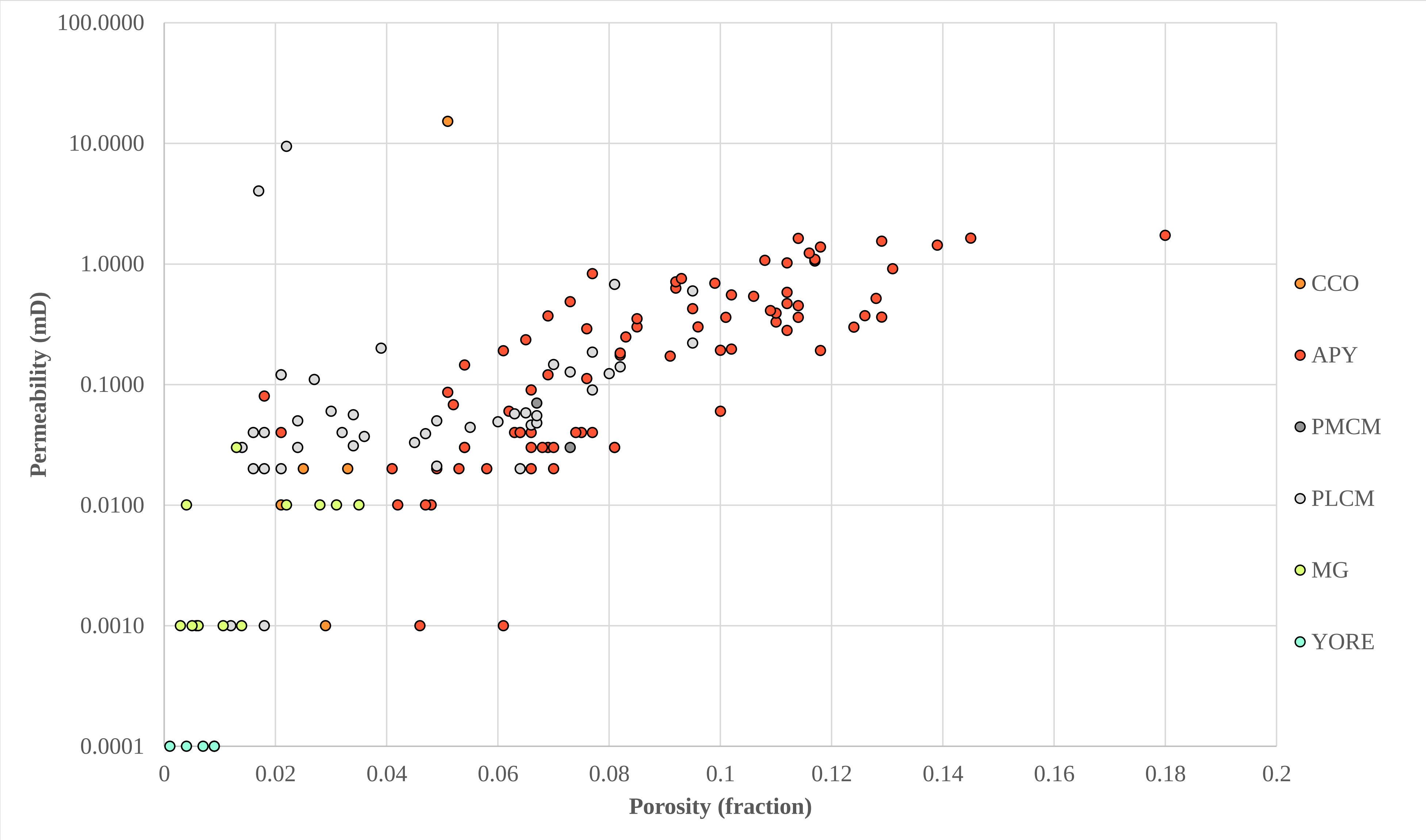


Figure 2 Cross plot of core porosity and permeability measurement data by stratigraphic for the wells examined (for the long names corresponding to unit codes, see Table 2).

4.7 MAP SUMMARISING NET TO GROSS RESULTS (IN TABLE 1)

Height of bars indicate the relative thickness of Permian - Carboniferous rocks in each well (see Table 1, Note 1 about measured depth thickness versus true stratigraphic thickness, and note 2 about how “Net” was defined).

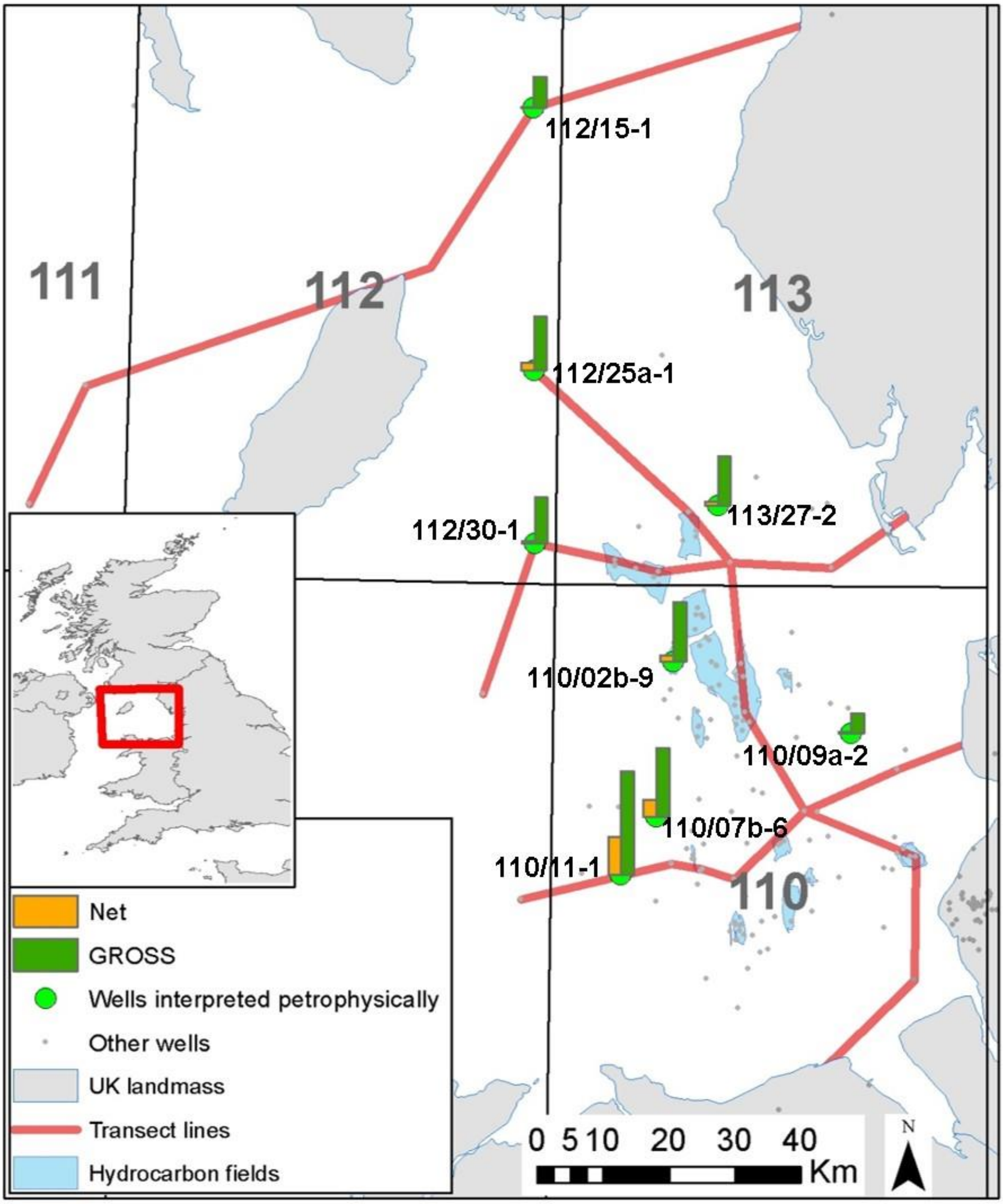


Figure 3 Indication of Gross and Net thickness for whole Permian-Carboniferous interval for each well

5 Conclusions

"Quick-look" volume of clay (V_{CL}), coal identification (V_{COAL}), evaporite identification (V_{SALT}) and effective and total porosity curves were interpreted from geophysical log responses in each of 8 wells across the East Irish Sea (Quadrants 110-113). In addition a permeability estimation curve was derived for those wells with suitable core porosity and permeability measurement data. These curves were used to calculate "quick-look" net to gross (NTG) values and average porosities for the net intervals for each formation in each well. Syntheses of the petrophysical results by well and by stratigraphic unit are shown in Tables 3 & 4 respectively (below). *Given this nature of the study, a full rigorous petrophysical interpretation of each well examined was not within scope. This is explained in the report and should be borne in mind when examining the outputs and results.*

The highest average porosities were found in the Permian aged Appleby Group (19%). This unit also had the highest NTG and second highest average permeabilities of the units examined. Although the highest average permeability is low (6.89 mD), maximum values in the 50-100 mD range are recorded for several wells. The Millstone Grit Group has very high permeabilities recorded in one well (113/27-2), but this is thought to be a comparatively low confidence value and further investigation into its validity is needed. The Cumbrian Coast Group, Pennine Lower Coal Measures and Millstone Grit Group all had reasonable porosities averaging 11-14%, although they have low net to gross values (7-13%).

The Cumbrian Coast Group (Upper Permian) includes some evaporite deposits of no reservoir potential themselves, but these could potentially act as a barrier (trap) to any hydrocarbons beneath them (as per gas shows in 113/27- 2). Most of the other units in the wells examined show heterogeneous properties with low net to grosses. Although the Millstone Grit Group generally has a low net to gross because of its high clay volume, cleaner reservoir intervals with reasonable porosity exist and more study on the permeabilities and distribution of these could potentially be worthwhile. The basal limestones appear cleaner, but have very low matrix porosities and so are not considered to be potential reservoirs unless fractures contribute to their porosity and permeability (not examined here).

Given the relatively few wells interpreted and the distances between them, it has not been possible to discern any regional trends within the units (data shown geographically in Section 4.7, some of which is tabulated below, extracted from Tables 1 & 2). Pharaoh et al. (2016b) consider the results of this study within the context of the wider petroleum system.

			Log derived			Core measured		
Well	**Gross**	**Net**	**N/G**	**Average PHIE**	**Average PermEst**	**Average PHI**	**Average kh perm**	**Average kv perm**
110/02b-9	1130	122	0.11	0.08	0.80	0.02		0.03
110/07b-6	1295	312	0.24	0.12	3.24	0.11	0.80	
110/09a-2	381	36	0.10	0.07	0.17	0.06	0.12	
110/11-1	1953	707	0.36	0.09		0.01	0.01	0.00
112/15-1	583	7	0.01	0.07		0.01	0.00	0.00
112/25a-1	1014	146	0.14	0.09				
112/30-1	885	48	0.05	0.08				
113/27-2	944	67	0.07	0.08	92.38	0.05	0.18	
110/03- 2						0.03	0.01	0.01
110/09- 1						0.03	0.03	
113/26- 1						0.04	1.56	
113/27- 1						0.02	1.07	
110/12a- 1						0.11	0.43	
110/12b- 2						0.13		7.90

Table 3 Synthesis of petrophysical results and core data (data in Table 1 and 2) by well

			Log curve (& core) derived (Table 1) (for net intervals)		Core measured (Table 2) (for parts of the units)			Comments
Stratigraphic unit name	**Top**	**N/G**	**Highest Av PHIE**	**Highest Av PermEst**	**Highest Av PHI**	**Highest Av Perm (Kh)**	**Highest Av Perm (Kv)**	
Cumbrian Coast Group	CCO	0.07	0.14	0.17	0.04	3.06		
Appleby Group	APY	0.72	0.19	6.89	0.13	0.80	7.90	Highest net to gross, highest porosity. Highest permeabilities values in the 50-100 mD range for several wells (see Tables 1 & 2).
Pennine Coal Measures Group	PCM	0.08	0.11	0.79	0.02		0.01	
Pennine Middle Coal Measures	PMCM				0.04	0.06		
Pennine Lower Coal Measures	PLCM	0.09	0.11	0.20	0.06	1.07	0.00	Low NTG (although third highest of the units examined). Reasonable average porosity. Permeabilities appear low. Highest values of 175 mD in 1 well, but with no core data over the PLCM interval in that well (see Table 1).
Millstone Grit Group	MG	0.10	0.11	367.74	0.06	0.04	0.05	Low NTG, but highest permeability (low confidence: high permeabilities seen in log estimates in only 1 well, 113/27-2, with relatively poor core-log data fit)
Bowland Shale Formation	BSG	0.03	0.07	0.75				
Yoredale Group	YORE	0.02	0.07		0.01	0.00	0.00	
Great Scar Limestone Group	GSCL	0.00						Matrix porosities less than 5% therefore not considered to have any 'net' using the cut offs applied
Carboniferous Limestone Supergroup	CL	0.00	0.05					Matrix porosities less than 5% therefore not considered to have any 'net' using the cut offs applied

Table 4 Synthesis of petrophysical results (data in Table 1& Table 2) by stratigraphical unit

Appendix 1 Log plots

Log plots from each well interpreted are presented. These are all shown at the same scale (1:5000) to allow some comparison of the thickness of the intervals and to summarise the data available for each well. They are not intended as a definitive output of the interpretation, the digital data is available as a project output for this purpose. Wells are shown in Quadrant block number order. Log plot tracks are explained from left to right here:

Track 1 (far left): Stratigraphic intervals, (reinterpreted for this project).

Track 2 (1 in from left): Depth in metres, measured depth

Track 3 (2 in from left): core intervals (extracted from BGS core database)

Tracks 1 to 3 are repeated in the reverse order at the far right of the plot.

Track 4: Input curves: Gamma ray (green, e.g. GR), caliper curves (grey, e.g. CALI) and density correction curve (beige, e.g. DRHO). The density correction curve is considered to be out of tolerance outside of the -0.1 to 0.1 range. This can adversely affect porosity derived from the density curve and so often the sonic or other curves may be used to derive porosity instead (Table 8, Appendix 4 summarises the tolerances and quality of data in each well)

Track 5: Input curves: Resistivity curves (red, e.g. ILD, LLD etc)

Track 6: Input curves: Porosity curves, sonic (pink, e.g. DT), density (red, e.g. RHOB) and neutron (green, e.g. NPHI)

Track 7: Interpreted curves: Clay volume (V_{CL}) and coal indicator (V_{COAL}). Variable brown shading helps to highlight cleaner intervals in pale colours and clay-rich intervals in dark brown. Coal intervals are shown in black, as stripes across the full width of the track. Evaporite intervals are shown as turquoise stripes across the full width of the track.

Track 8: Interpreted curves: Effective porosity (PHIE), Total porosity (PHIT). Also includes any discrete core porosity data from core reports, where available.

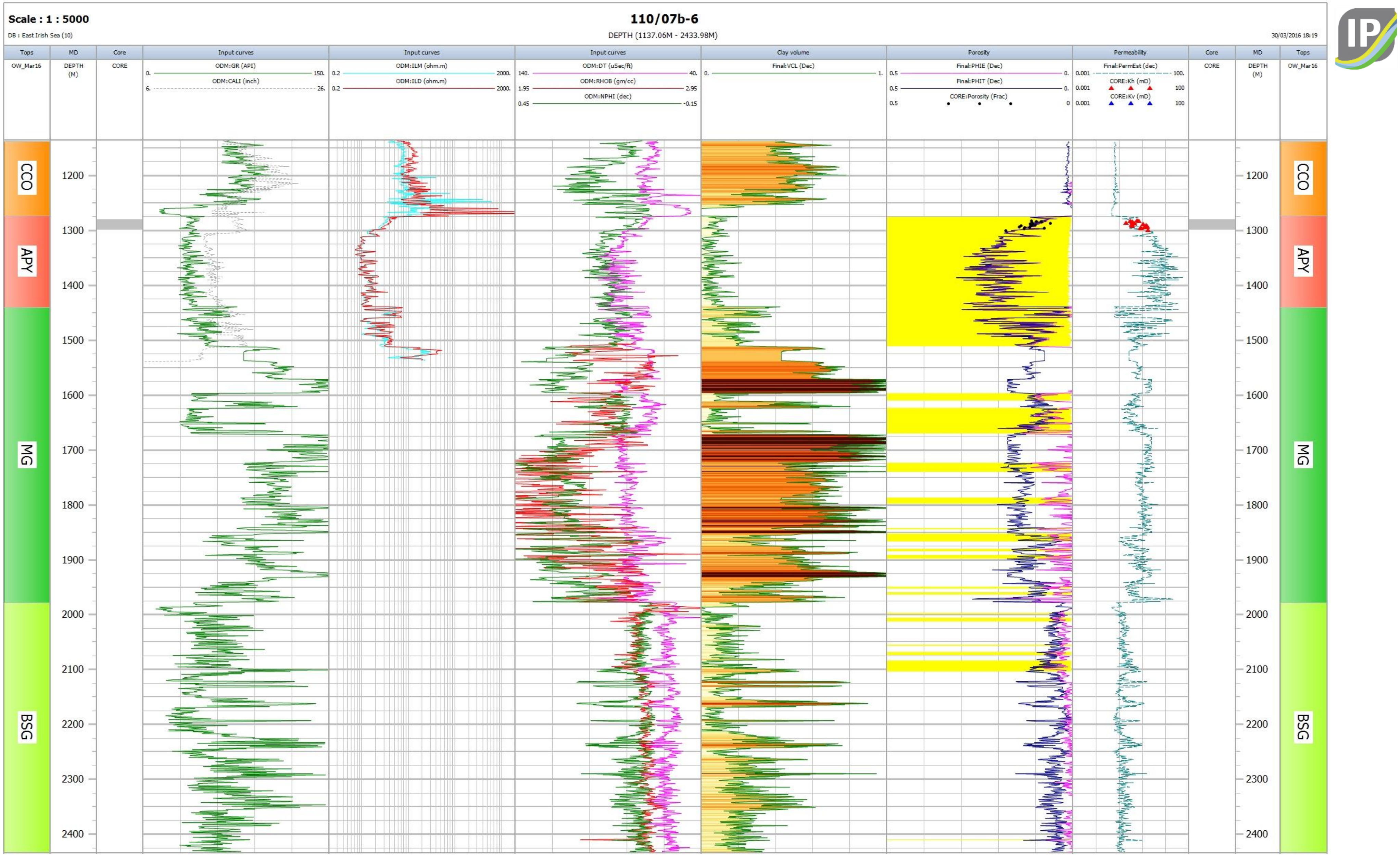
Track 9: Interpreted curves: Permeability (PermEst), estimated where sufficient core poro-perm data exists. Also includes discrete permeability data from core reports, where available.

Yellow shading across the porosity – permeability tracks (8&9) indicates the net intervals. (The definition of Net, used in the calculations is explained in Section 4.2).

Notes for specific wells:

For wells **110/09a-2** and **112/15-1** core poroperm data is shown, but no cored interval. This is because the measurements come from rotary sidewall cores.

Scale : 1 : 5000
110/02b-9
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPT (M)
CORE
ODM:GR (API)
0. 150.
ODM:CALS (inch)
6. 26.
ODM:LLD (ohm.m)
0.2 2000.
ODM:LLS (ohm.m)
0.2 2000.
ODM:DT (uSec/ft)
140. 40.
ODM:RHOB (gm/cc)
1.95 2.95
ODM:NPHI (dec)
0.45 -0.15
Final:VCL (Dec)
0. 1.
Final:PHIE (Dec)
0.5 0.
Final:PHIT (Dec)
0.5 0.
CORE:Porosity (Frac)
0.5 0
Final:PermEst
0.001 100.
CORE:Kh (mD)
0.001 100
CORE:Kv (mD)
0.001 100
CCO
PCM
MG
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400



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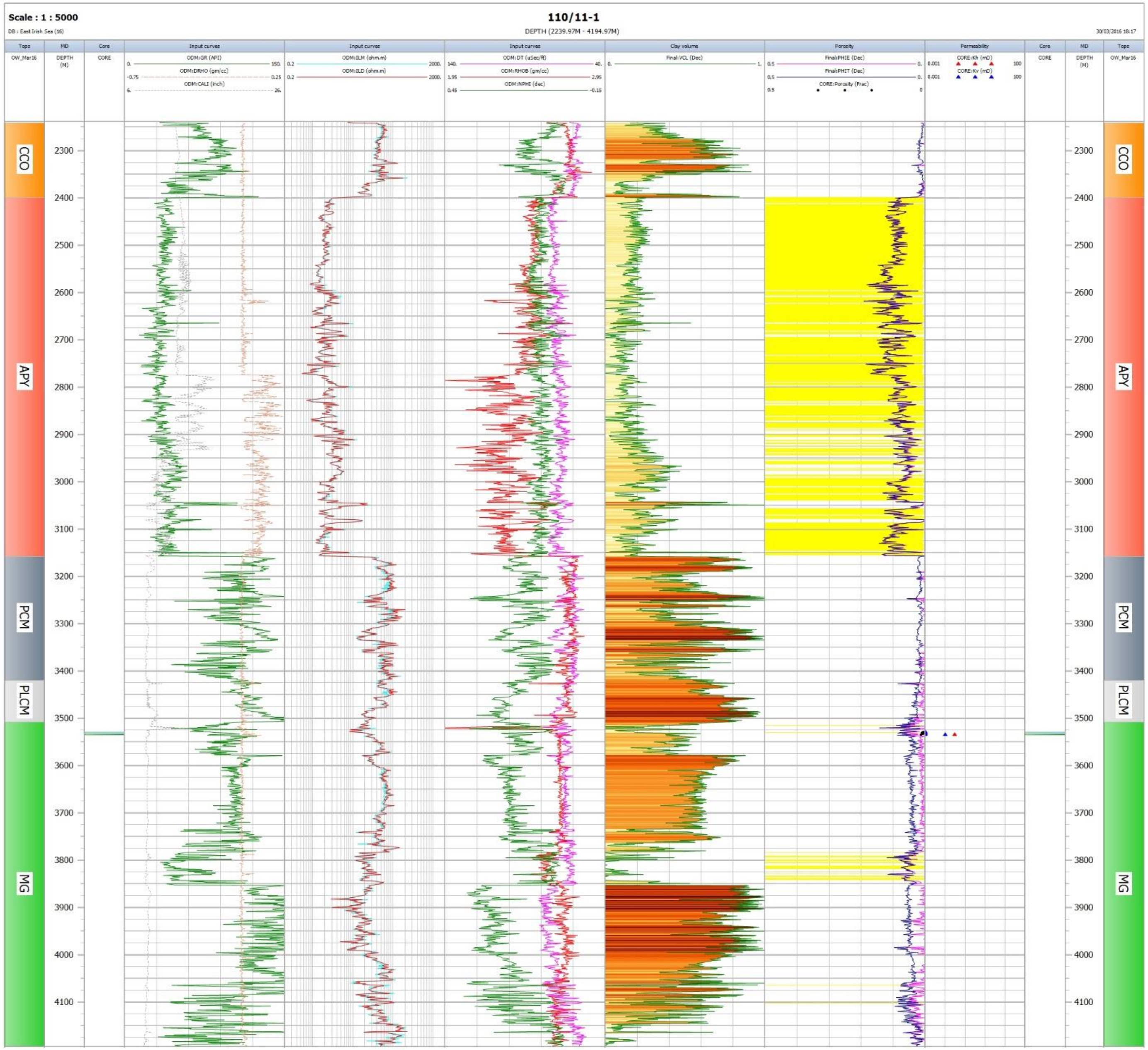
110/07b-6
DEPTH (1137.06M - 2433.98M)
30/03/2016 18:19
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPTH (M)
CORE
ODM:GR (API)
ODM:CALI (inch)
ODM:ILM (ohm.m)
ODM:ILD (ohm.m)
ODM:DT (uSec/ft)
ODM:RHOB (gm/cc)
ODM:NPHI (dec)
Final:VCL (Dec)
Final:PHIE (Dec)
Final:PHIT (Dec)
CORE:Porosity (Frac)
Final:PermEst (dec)
CORE:Kh (mD)
CORE:Kv (mD)
CORE
DEPTH (M)
OW_Mar16
CCO
APY
MG
BSG
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400

Scale : 1 : 5000
110/09a-2
DB : East Irish Sea (79)
DEPTH (1211.98M - 1595.02M)
30/03/2016 18:18
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPTH (M)
CORE
ODM:GR (API)
ODM:DRHO (gm/cc)
ODM:CALI (inch)
ODM:LLD (ohm.m)
ODM:LLS (ohm.m)
ODM:DT (uSec/ft)
ODM:RHOB (gm/cc)
ODM:NPHI (dec)
Final:VCL (Dec)
Final:PHIE (Dec)
Final:PHIT (Dec)
CORE:Porosity (Frac)
Final:PermEst (dec)
CORE:Kh (mD)
CORE:Kv (mD)
CCO
PLCM
1300
1400
1500



Scale : 1 : 5000
110/11-1
DB : East Irish Sea (16)
DEPTH (2239.97M - 4194.97M)
30/03/2016 18:17
Tops
MD
Core
Input curves
Clay volume
Porosity
Permeability
OW_Mar16
DEPTH (M)
CORE
ODM:GR (API)
ODM:DRHO (gm/cc)
ODM:CALI (inch)
ODM:ILM (ohm.m)
ODM:ILD (ohm.m)
ODM:DT (uSec/ft)
ODM:RHOB (gm/cc)
ODM:NPHI (dec)
Final:VCL (Dec)
Final:PHIE (Dec)
Final:PHIT (Dec)
CORE:Porosity (Frac)
CORE:Kh (mD)
CORE:Kv (mD)
CCO
APY
PCM
PLCM
MG
2300
2400
2500
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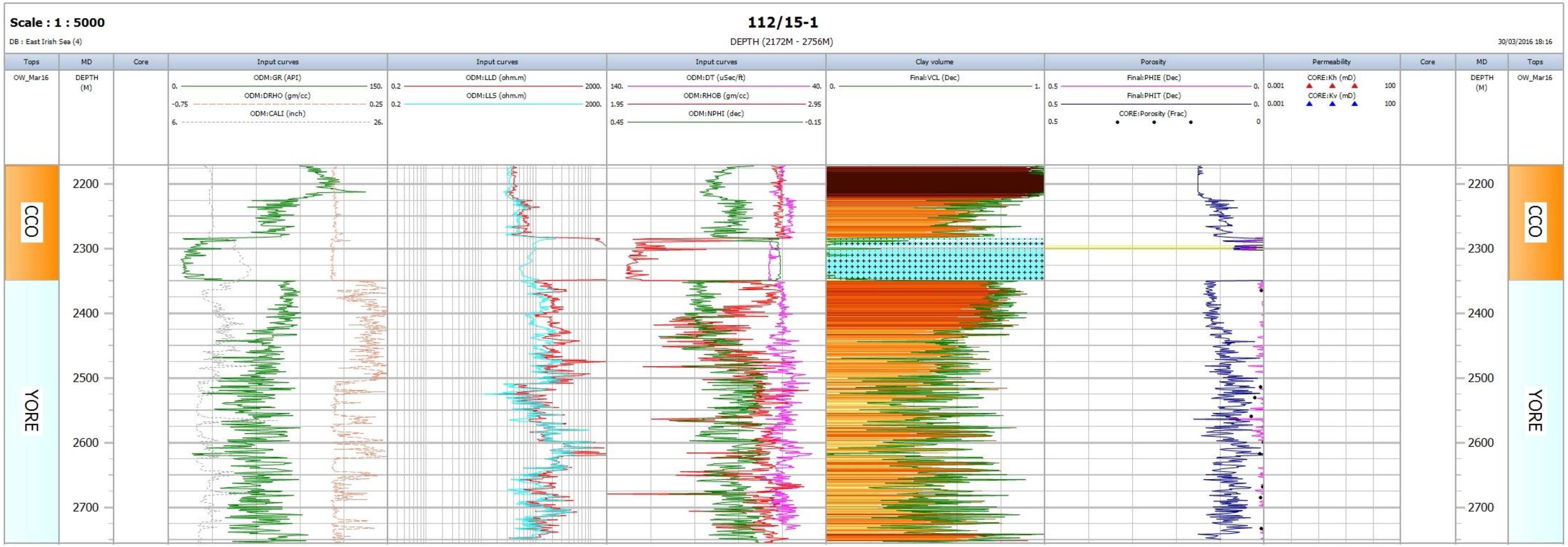
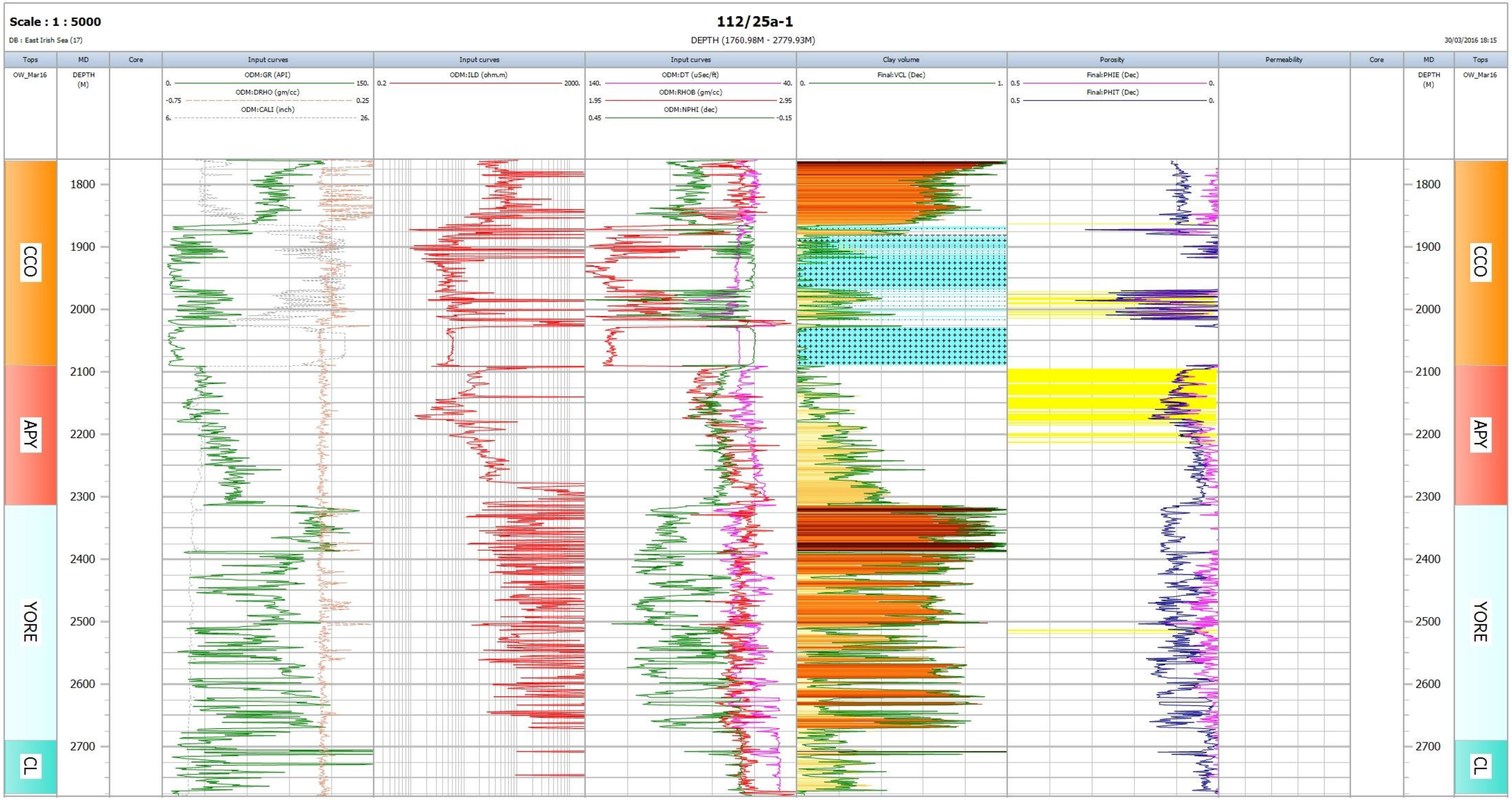
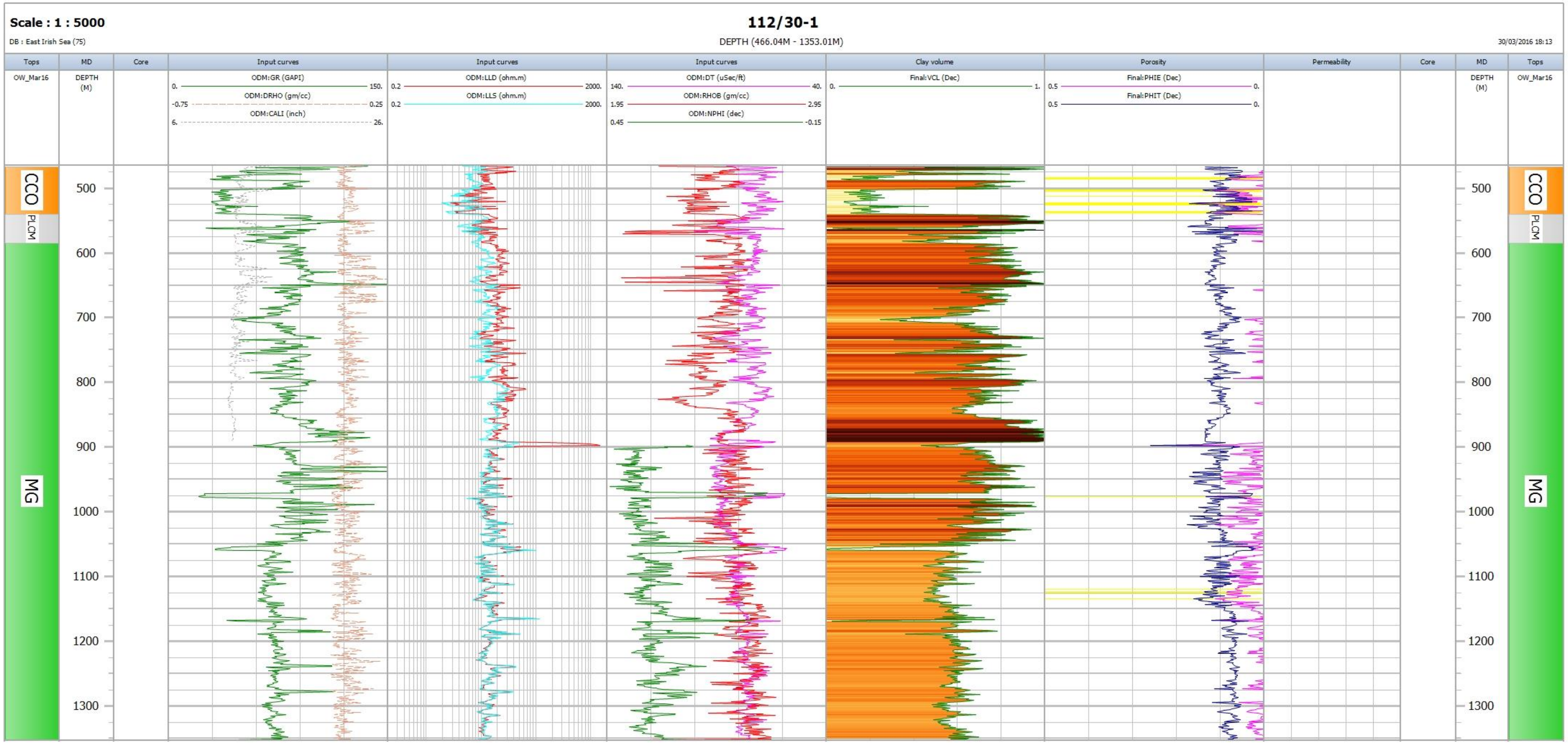
3800
3900
4000
4100



Scale : 1 : 5000
DB : East Irish Sea (4)
112/15-1
DEPTH (2172M - 2756M)
30/03/2016 18:16
Tops
MD
Core
Input curves
Clay volume
Porosity
Permeability
OW_Mar16
DEPTH (M)
ODM:GR (API)
ODM:DRHO (gm/cc)
ODM:CALI (inch)
ODM:LLD (ohm.m)
ODM:LLS (ohm.m)
ODM:DT (uSec/ft)
ODM:RHOB (gm/cc)
ODM:NPHI (dec)
Final:VCL (Dec)
Final:PHIE (Dec)
Final:PHIT (Dec)
CORE:Porosity (Frac)
CORE:Kh (mD)
CORE:Kv (mD)
CCO
YORE
2200
2300
2400
2500
2600
2700



Scale : 1 : 5000
DB : East Irish Sea (17)
112/25a-1
DEPTH (1760.98M - 2779.93M)
30/03/2016 18:15
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPTH (M)
ODM:GR (API)
0.
150.
ODM:DRHO (gm/cc)
-0.75
0.25
ODM:CALI (inch)
6.
26.
ODM:ILD (ohm.m)
0.2
2000.
ODM:DT (uSec/ft)
140.
40.
ODM:RHOB (gm/cc)
1.95
2.95
ODM:NPHI (dec)
0.45
-0.15
Final:VCL (Dec)
0.
1.
Final:PHIE (Dec)
0.5
0.
Final:PHIT (Dec)
0.5
0.
DEPTH (M)
OW_Mar16
CCO
APY
YORE
CL
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700



Scale : 1 : 5000
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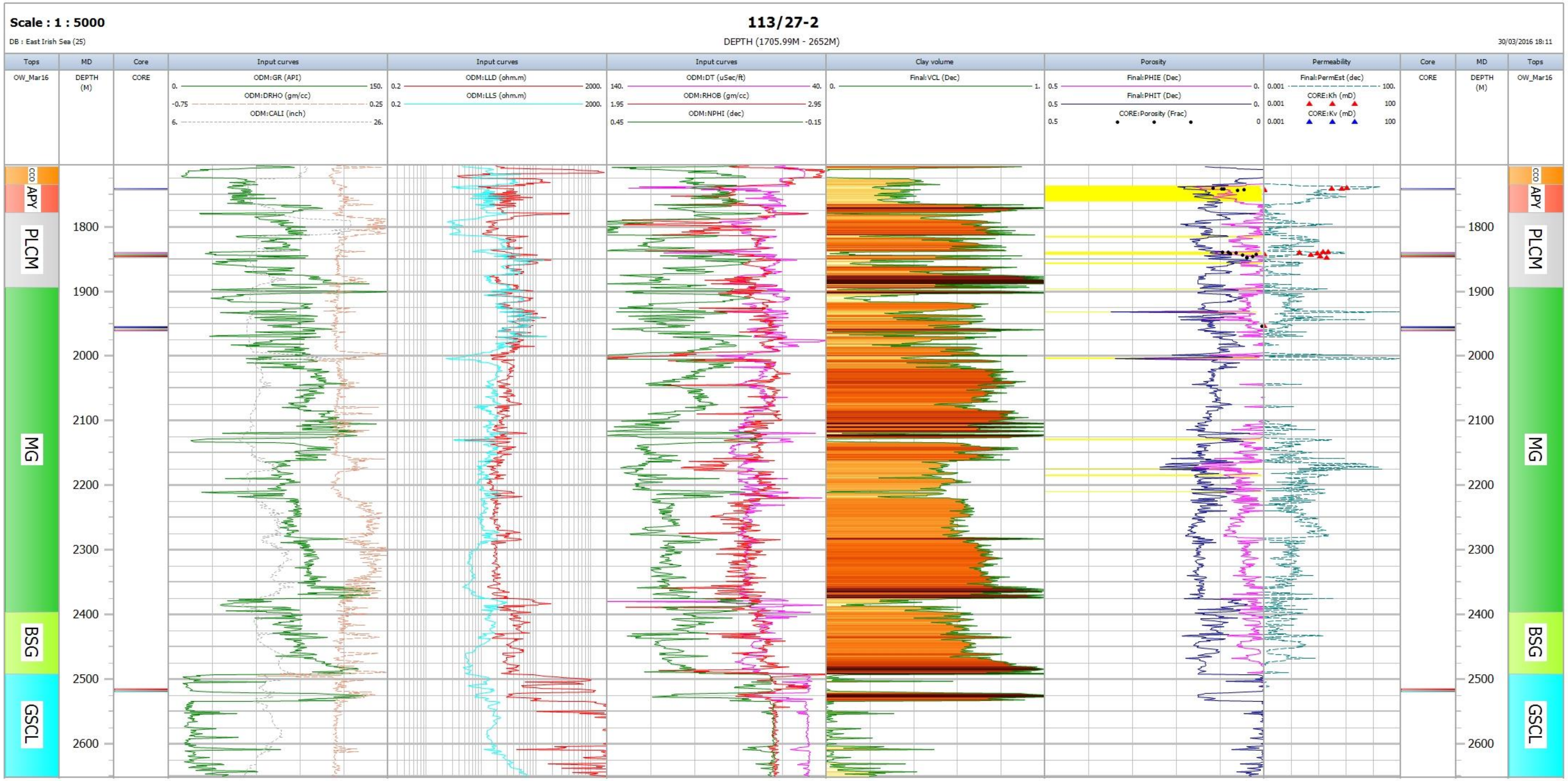
112/30-1
DEPTH (466.04M - 1353.01M)
30/03/2016 18:13
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPTH (M)
ODM:GR (GAPI) 0. 150.
ODM:DRHO (gm/cc) -0.75 0.25
ODM:CALI (inch) 6. 26.
ODM:LLD (ohm.m) 0.2 2000.
ODM:LLS (ohm.m) 0.2 2000.
ODM:DT (uSec/ft) 140. 40.
ODM:RHOB (gm/cc) 1.95 2.95
ODM:NPHI (dec) 0.45 -0.15
Final:VCL (Dec) 0. 1.
Final:PHIE (Dec) 0.5 0.
Final:PHIT (Dec) 0.5 0.
DEPTH (M)
OW_Mar16
CCO
PLCM
MG
500
600
700
800
900
1000
1100
1200
1300



Scale : 1 : 5000
DB : East Irish Sea (25)
113/27-2
DEPTH (1705.99M - 2652M)
30/03/2016 18:11
Tops
MD
Core
Input curves
Input curves
Input curves
Clay volume
Porosity
Permeability
Core
MD
Tops
OW_Mar16
DEPTH (M)
CORE
ODM:GR (API)
ODM:DRHO (gm/cc)
ODM:CALI (inch)
ODM:LLD (ohm.m)
ODM:LLS (ohm.m)
ODM:DT (uSec/ft)
ODM:RHOB (gm/cc)
ODM:NPHI (dec)
Final:VCL (Dec)
Final:PHIE (Dec)
Final:PHIT (Dec)
CORE:Porosity (Frac)
Final:PermEst (dec)
CORE:Kh (mD)
CORE:Kv (mD)
CORE
DEPTH (M)
OW_Mar16
APY
PLCM
MG
BSG
GSCL
1800
1900
2000
2100
2200
2300
2400
2500
2600

Appendix 2 Core and curve data used for permeability estimations

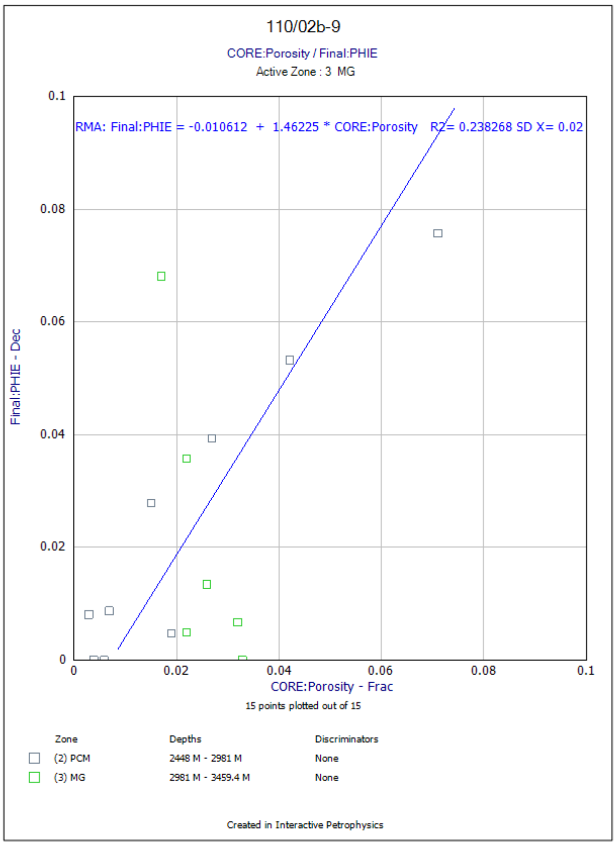
See section 3.5 for explanations. Depth shifting the core data was not possible (except for well 110/07b-6 where the composite log indicated the amount of shift required (+7 ft, +2.13 m). For each well that data was available for, the relationship between core porosity and log porosity, and core porosity core permeability is shown in cross plots. Relationship equations derived from the cross plots and used for the permeability estimation curve (PermEst) are shown together with their statistics (Table 5 and Table 6).

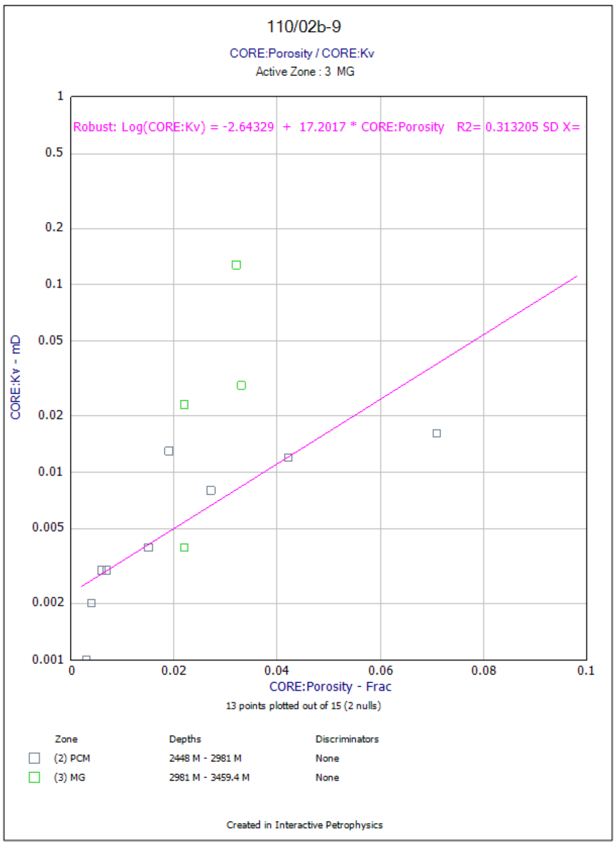
CROSS PLOTS AND SUMMARY STATISTICS OF RELATIONSHIPS USED FOR PERMEABILITY ESTIMATIONS

For each well that data was available for, core porosity is plotted against log porosity (left) and core porosity is plotted against permeability (right). The equations of the lines (where a relationship was found to exist) are summarised in Table 5 and Table 6. Usually core porosity falls between PHIT and PHIE and so either one was chosen for the relationship, depending on the best match. Further explanations of potential mismatches can be found in Section 3.1

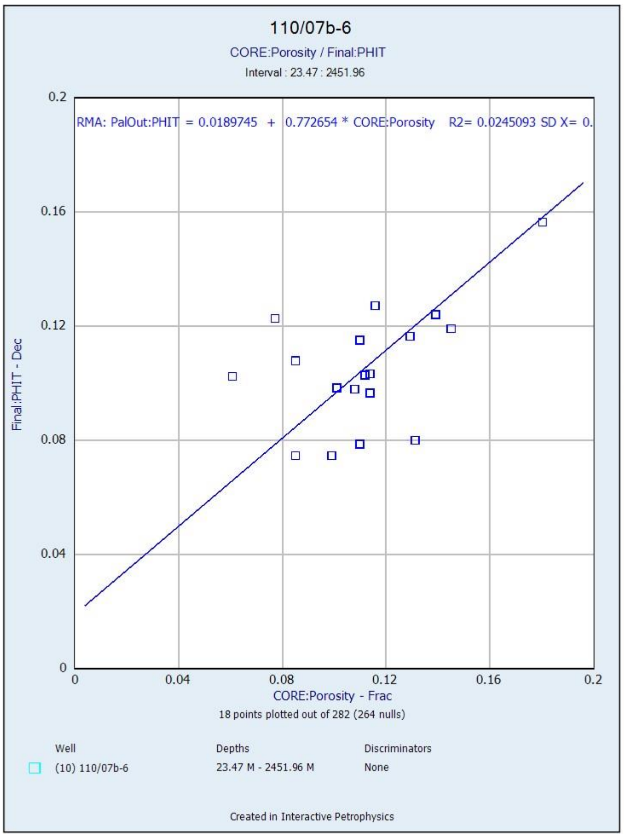
WELL 110/02b-9

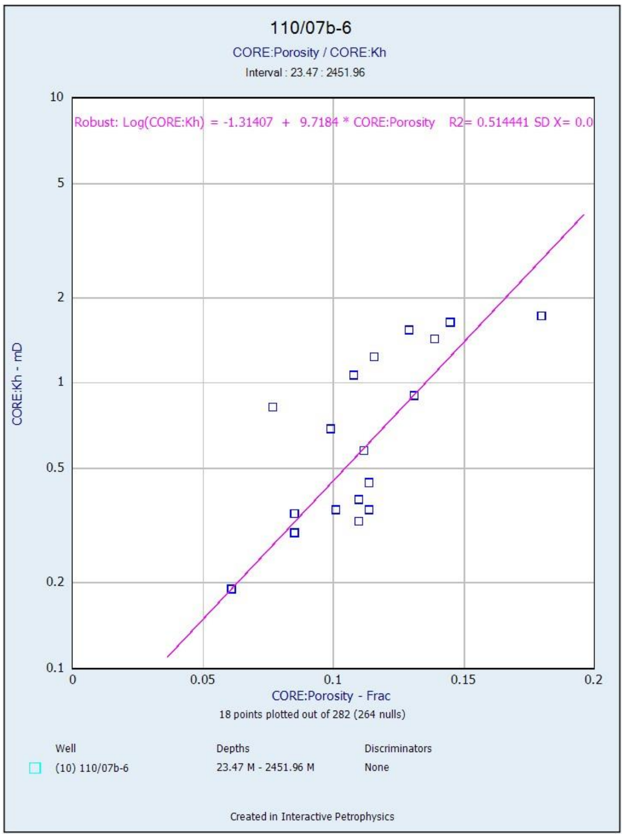
Note that the poroperm relationship for this well is with vertical, not horizontal permeability as no Kh values were available for the Palaeozoic interval.



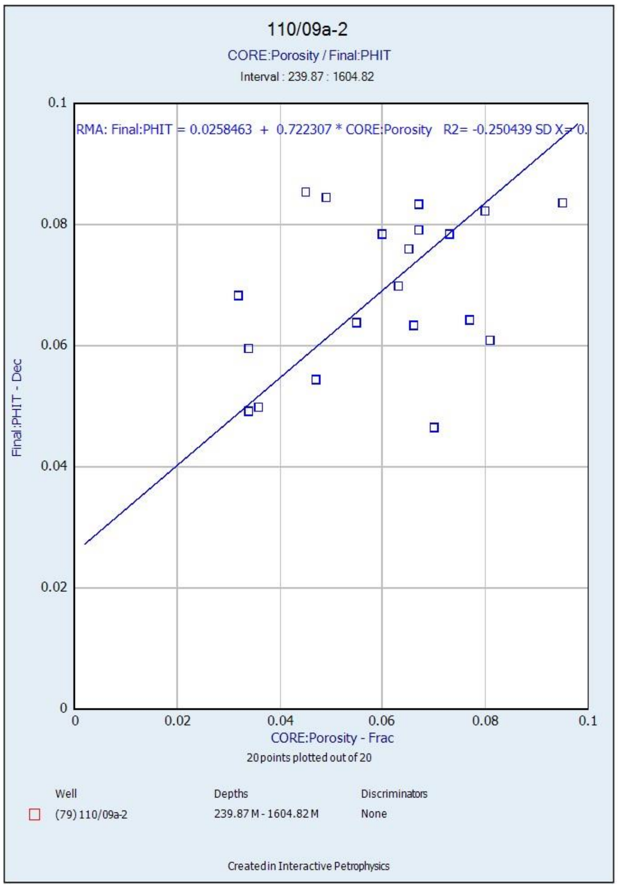


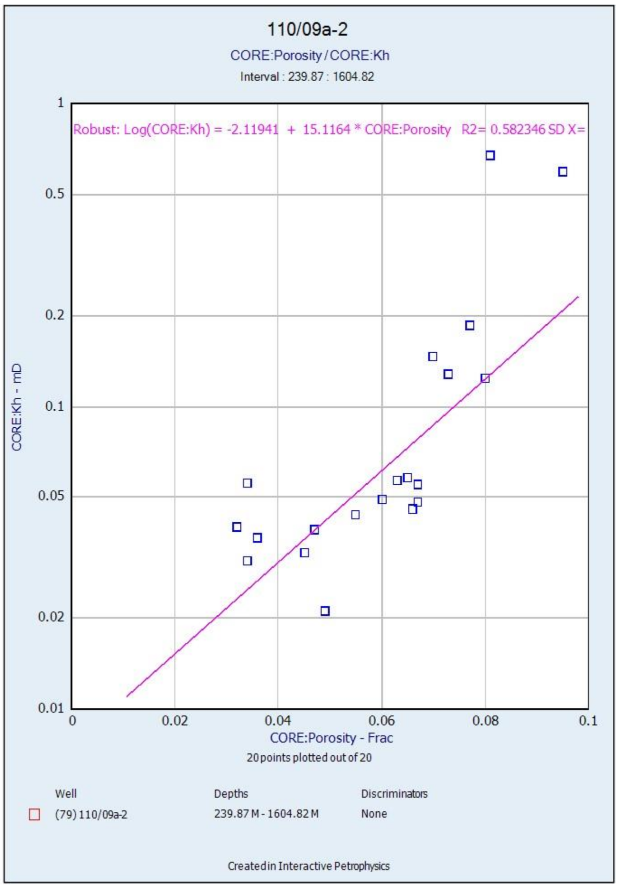
WELL 110/07b-6





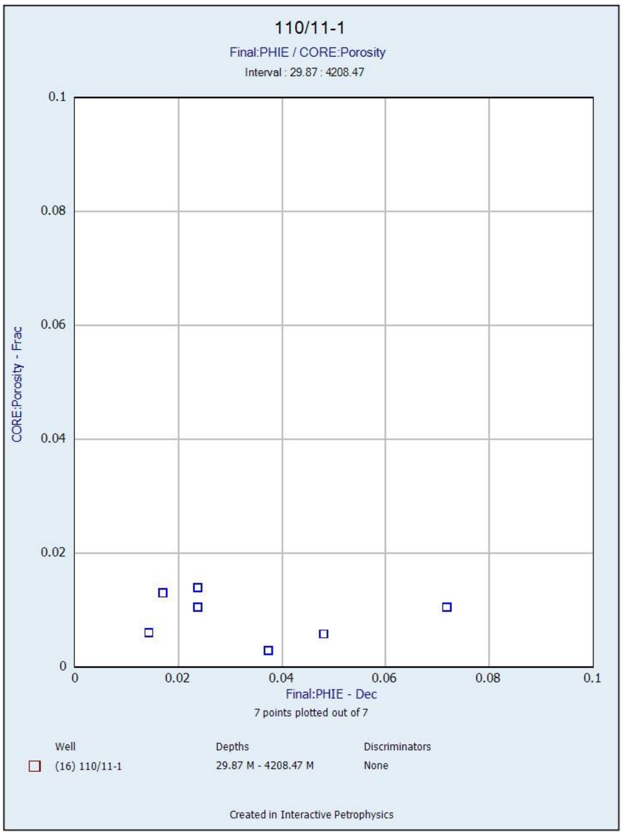
WELL 110/09a-2

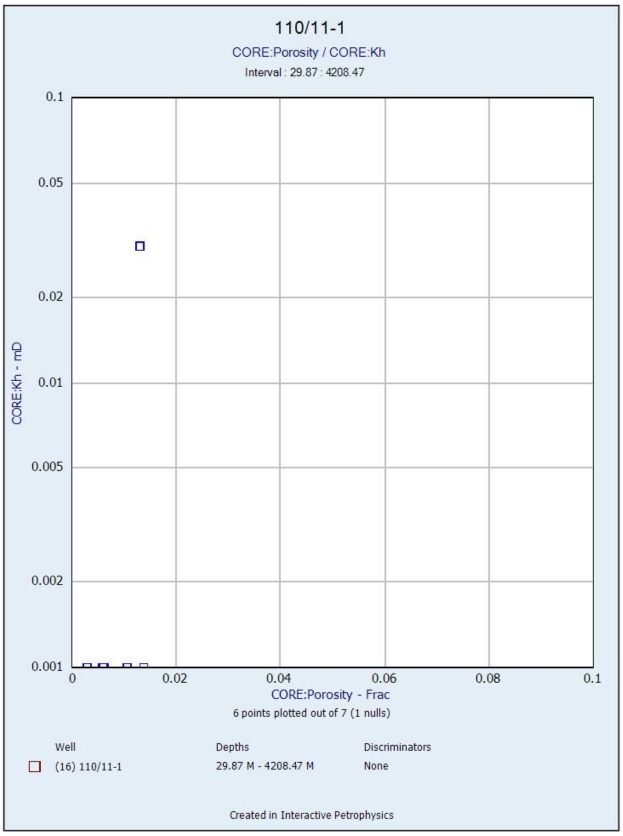




WELL 110/11-1

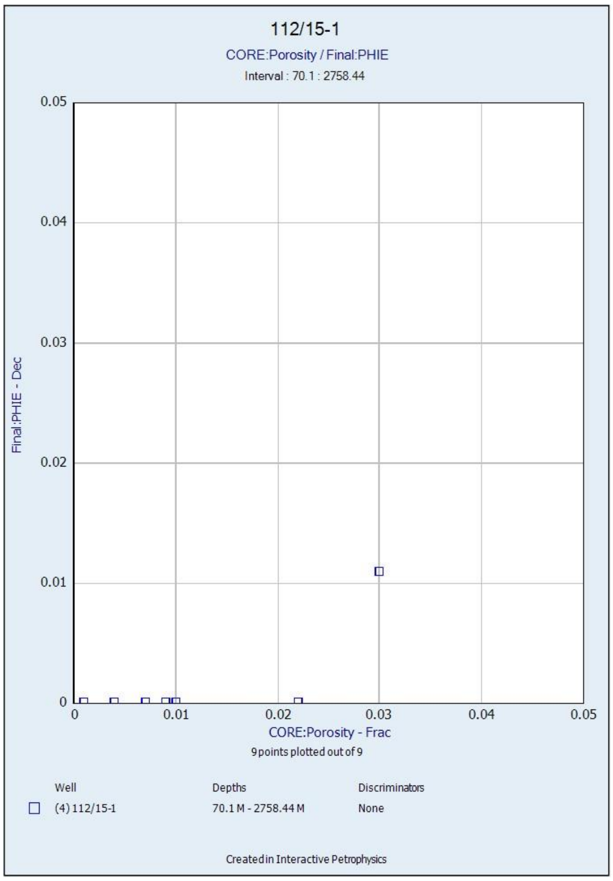
No relationships determined

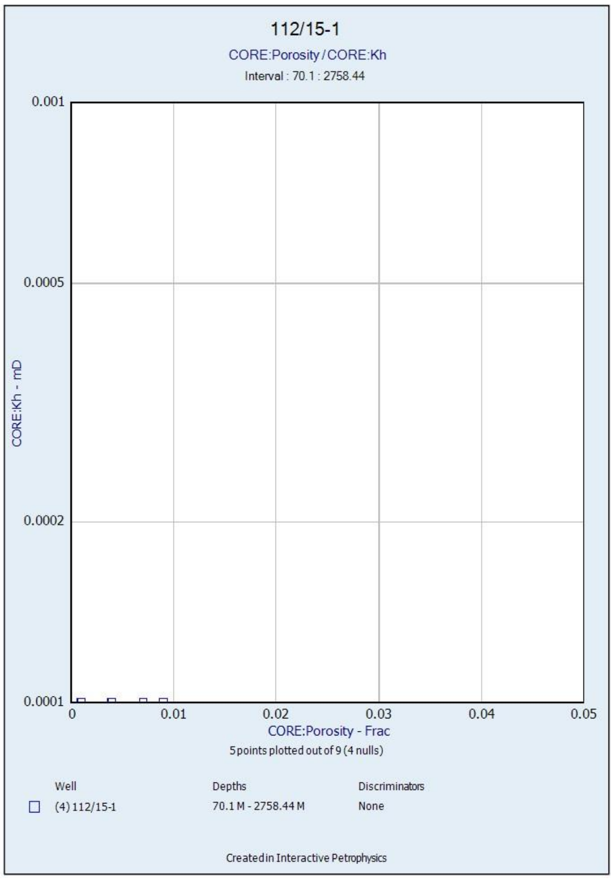




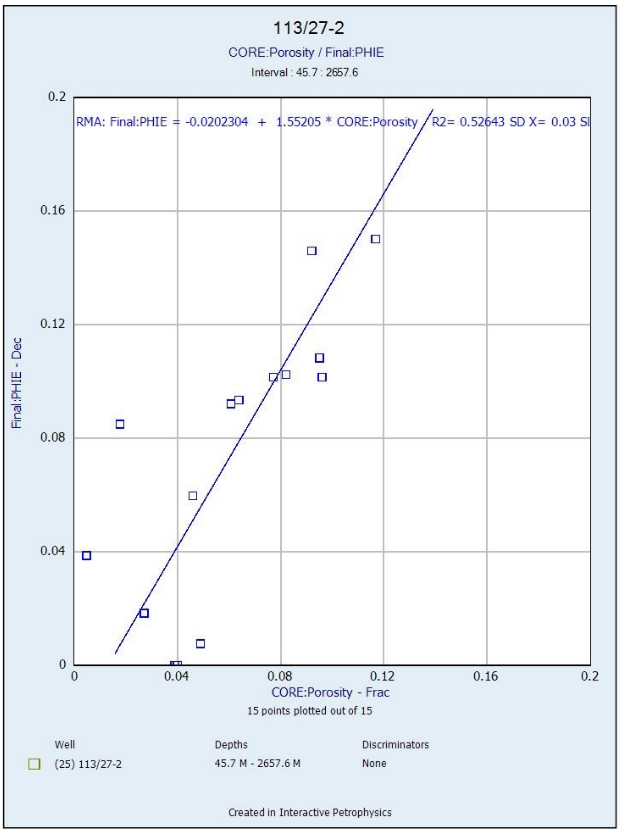
WELL 112/15-1

No relationships determined

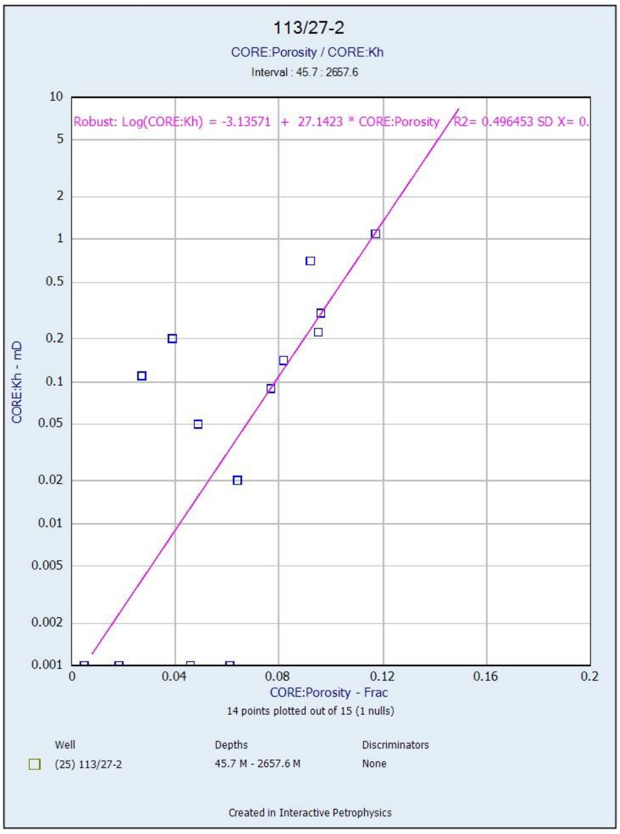




WELL 113/27-2



113/27-2
CORE:Porosity / Final:PHIE
Interval : 45.7 : 2657.6
RMA: Final:PHIE = -0.0202304 + 1.55205 * CORE:Porosity R2= 0.52643 SD X= 0.03 SI
Final:PHIE - Dec
0.2
0.16
0.12
0.08
0.04
0
0
0.04
0.08
0.12
0.16
0.2
CORE:Porosity - Frac
15 points plotted out of 15
Well
Depths
Discriminators
(25) 113/27-2
45.7 M - 2657.6 M
None
Created in Interactive Petrophysics



113/27-2
CORE:Porosity / CORE:Kh
Interval : 45.7 : 2657.6
Robust: Log(CORE:Kh) = -3.13571 + 27.1423 * CORE:Porosity R2= 0.496453 SD X= 0.
CORE:Kh - mD
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0
0.04
0.08
0.12
0.16
0.2
CORE:Porosity - Frac
14 points plotted out of 15 (1 nulls)
Well
Depths
Discriminators
(25) 113/27-2
45.7 M - 2657.6 M
None
Created in Interactive Petrophysics

Well	# of points	Comments on core porosity - curve porosity relationship	Core porosity - Curve porosity (PHI) relationship: RMA method — Relationship: Porosity Curve (Final:PHI) =	Core porosity points (Core:porosity) =	R^2	Core porosity statistics: SD	Mean	Max	Min	PHI curve statistics: SD	Mean	Max	Min
110/02b-9	15	Insufficient data points to core depth shift. Looks reasonable fit over PCM- OK fit to PHIE. MG poor fit. Used combined data to derive estimate relationship - therefore poorer match outside PCM interval.	Final:PHIE=-0.010611994 +1.46225343*CORE:Porosity	0.007257288+0.683875982 *Final:PHIE	0.24	0.02	0.02	0.07	0.00	0.03	0.02	0.08	0.00
110/07b-6	18	Core depth shift described as 7ft (2.1336m) on comp log. Adjusted core data depths accordingly. Good match to PHIE and PHIT.	Final:PHIT=0.018974471+0.772654239*CORE:Porosity	-0.024557518 +1.294239971*Final:PHIT	0.02	0.03	0.11	0.18	0.06	0.02	0.11	0.16	0.07
110/09a-2	20	Rotary sidewall cores. Not sufficient for depth shifting. Log poro data within a similar range but exact match not great (better than for some wells…)	Final:PHIT=0.025846342+0.722306922*CORE:Porosity	-0.035783046 +1.384453022*Final:PHIT	-0.25	0.02	0.06	0.10	0.03	0.01	0.07	0.09	0.05
110/11-1	7	Poor match to PHIT or PHIE. Insuff data to core depth shift. Insufficient match to form poroperm relationship. Therefore no PermEst curve produced.											
112/15-1	9	Sidewall cores. Insufficient data for core-depth shift. Poroperm so low that no relationship visible.											
113/27-2	15	Poor to PHIT. Use PHIE, but still not great fit.	Final:PHIE=-0.020230358 +1.552046041*CORE:Porosity	0.013034638+0.644310783 *Final:PHIE	0.53	0.03	0.06	0.12	0.01	0.05	0.07	0.15	0.00

Table 5 Summary statistics of core porosity – curve porosity relationships (Section 3.5 summarises the method)

	Core porosity - log of Core permeability relationship: Robust fit method												
	#of points	Equation applied to porosity curve to derive permeability estimator (PermEst) curve	Relationship			Core porosity statistics				Log of core permeability stats			
Well			Log of core permeability points (Log (Core:K)) =	Core porosity points (Core:porosity) =	R^2	SD	Mean	Max	Min	SD	Mean	Max	Min
110/02b-9	13	**10^(-2.643290997 + 17.201710581*Final:PHIE)**	Log(CORE:Kv)=-2.643290997+17.201710581*CORE:Porosity	0.153664427+0.058133753*Log(CORE:Kv)	0.31	0.02	0.02	0.07	0.00	0.57	-2.10	-0.90	-3.00
110/07b-6	18	**10^(-1.795291305+13.49483332 *Final:PHIT)**	Log(CORE:Kh)=-1.795291305+13.49483332*CORE:Porosity	0.133035456+0.074102434*Log(CORE:Kh)	0.51	0.03	0.11	0.18	0.06	0.30	-0.19	0.24	-0.72
110/09a-2	20	**10^(-2.119408607 + 15.116384339*Final:PHIT)**	Log(CORE:Kh)=-2.119408607+15.116384339*CORE:Porosity	0.140206055+0.066153385*Log(CORE:Kh)	0.58	0.02	0.06	0.10	0.03	0.40	-1.15	-0.17	-1.68
110/11-1	6	**No poro-perm relationship seen.**											
112/15-1	5	**No poro-perm relationship seen.**											
113/27-2	14	**10^(-3.135712624 + 27.142254654*Final:PHIE)**	Log(CORE:Kh)=-3.135712624+27.142254654*CORE:Porosity	0.115528819+0.036842923*Log(CORE:Kh)	0.50	0.03	0.06	0.12	0.01	1.12	-1.42	0.04	-3.00

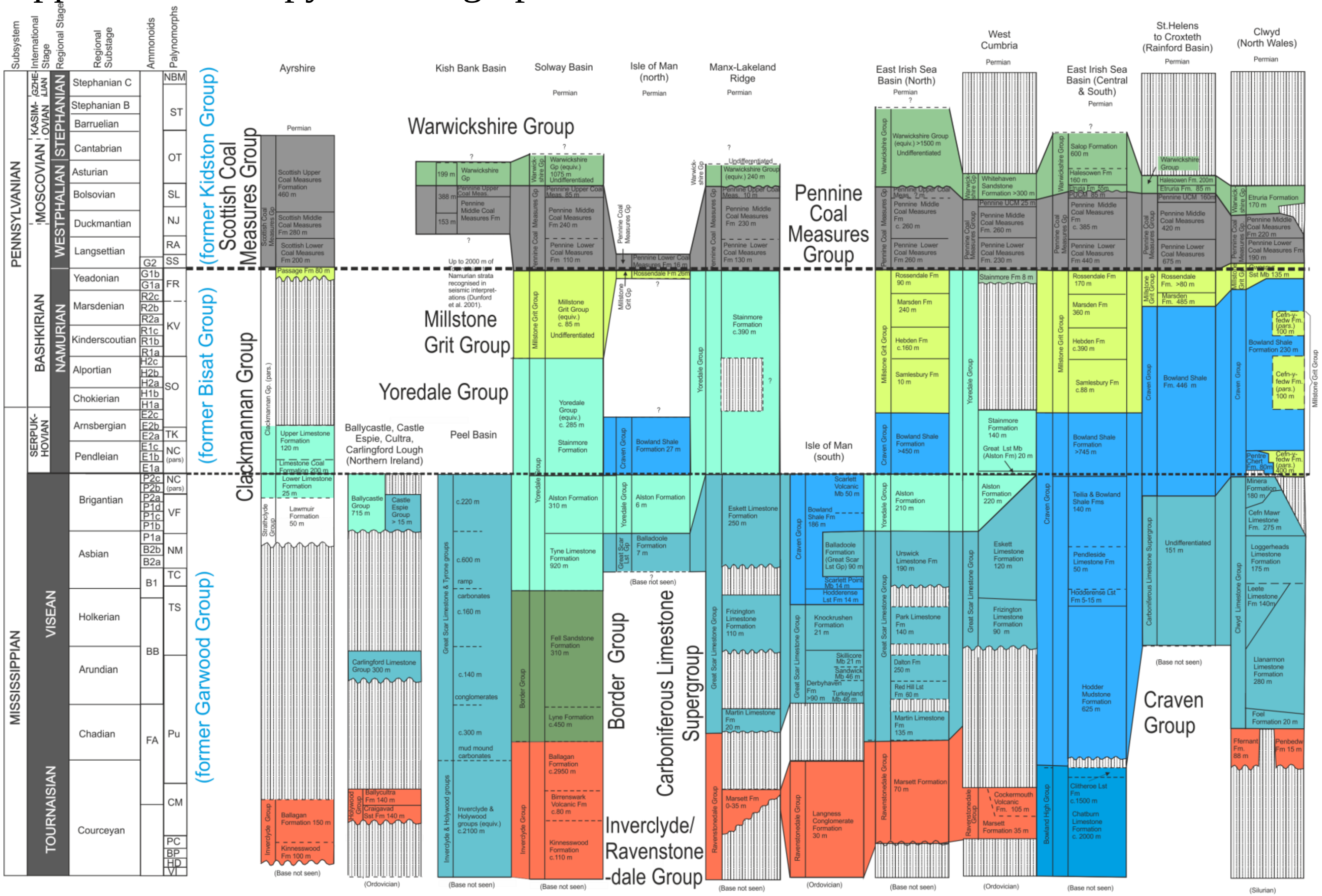
Table 6 Summary statistics of core porosity – permeability relationships (Section 3.5 summarises the method)

Appendix 3 Table of well information and log quality and interpretation comments

				# of core samples			Thickness (m, MD)		salt ID			Coal ID			
Well	Interpreted wells	Core data displayed	# curves in ODM	porosity	kh	kv	Carboniferous	Permian-Carb	N	D	S	N	D	S	**Interpretation/data quality comments for report.** • *Notes: Tension curves were generally not available (because the files were composites).* • *It was assumed that appropriate borehole corrections had already been applied to all curves.* • *DRHO in tolerance was assumed to be -0.1 to 0.1* • *Calliper logs were compared to bit size to identify washouts or zones of potential poor pad-tool contact.* • *All curves were compared to their expected responses and to the company composite pdf logs where available.*
110/02b-9	x	x	8	15	0	13	1011	1130							No DRHO curve, only CALS. A few washouts, esp large one across evaporite base CCO.
110/07b-6	x	x	14	18	18	0	1042	1295							No DRHO curve, No CALI over basal part of log (MG, BSF), so difficult to determine log quality there particularly. Curves look generally OK though - but perhaps not so great ND across MG, - didn't use ND for VCl and used sonic for poro over that interval. Washouts over CCO interval. No Res curves beneath top MG.
110/09a-2	x	x	12	20	20	0	209	381							CALI and DRHO show data quality appears not too bad. A few washouts and DRHO spikes but data generally OK cf some other wells examined.
110/11-1	x	x	16	7	6	7	1036	1953							Poor quality density over lower half of APY (DRHO out of tolerance, hole washouts on CALI). From CALI, looks to be slight corkscrew hole around PLCM depths but doesn't seem to adversely affect log. Washouts around 3520m appear to be affecting ND responses in top BSG, or could be friable coaly band (not reported as such on comp log).
112/15-1	x	x	12	9	5	5	406	583							Hole rugosity appears to be affecting data quality, DRHO spikes to out of tolerance over much of the YORE, especially the top half, used sonic for porosity (although sonic also adversely affected by bad hole, but perhaps less so than density). GR spike to 8k GAPI at 2666m removed. Maybe some coals in YORE, but difficult to identify given poor quality ND data (pyrite and carbonaceous material reported throughout YORE on comp) - pyrite affecting dens and res curves too. Generally appears to be no reservoir in this well.
112/25a-1	x		10				378	1016	0.05	2.2	72				Some areas where DRHO is out of tolerance (upper CCO and few areas in YORE). Very large washouts (Caliper open to max extent) in CCO evap - probably poor quality data over those intervals. Neut-Dens-Sonic salt ID parameters set (slightly exaggerated) to satisfactorily pick up salt and null porosity (D:2.2, N:0.05, S:72)
112/30-1	x		12				829	885						100	~ 5m data gap probably due to run splicing at ~891 - 896 m. Data invalid over this interval. No NPHI or MSFL data above this interval. Hole rugosity appears to be affecting data quality, DRHO spikes to out of tolerance over much of the interval of interest, used sonic for porosity (although sonic also adversely affected by bad hole, but perhaps less so than density).
113/27-2	x	x	19	15	14	0	713	944				0.35	2.05	80	Areas of hole washout affecting log quality (DRHO out of tolerance across similar zones) - especially upper third of PLCM and basal third of MG (plus a few other spots higher in MG and in BSG). ND used to calibrate GR values for VCL where data good, but not used in calc (due to poor hole conditions).
110/09-1		x	13	30	30	0	118	449							
110/12a-1		x	3	57	32	0	60	945							
110/12b-2		x	0	73	0	15	152	826							
113/26-1		x	18	9	8	0	648	722							
113/27-1		x	3	14	13	0	320	477							
110/03-2		x	11	6	4	1	194	249							

Table 7 Table of well information and log quality and interpretation comments

Appendix 4 Copy of stratigraphic chart from Wakefield et al., 2016.



References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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