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Early Jurassic Earth System and Timescale scientific drilling project (JET) – Operational Report & Explanatory Notes

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Early Jurassic Earth System and Timescale scientific drilling project (JET) – Operational Report

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Abstract

This report documents the drilling operations of the Early Jurassic Earth System and Timescale scientific drilling project (JET, ICDP Project: 5065). The wells 5065_1_A, 5065_1_B, 5065_1_A were drilled in 2019-2021 with the support of the International Continental Scientific Drilling Program (ICDP) and the UK Natural Environment Research Council (NERC). Alternatively, the site is known as Prees 2 (Holes A – C). Prees 1 was a nearby hydrocarbon exploration well drilled by Trend Petroleum in 1972–1973.

The project aims to construct a fully integrated and astronomically calibrated timescale for the Early Jurassic, a time in Earth history during which important physical, chemical, and biological elements of the modern Earth system were initiated. The JET drilling campaign supplements the earlier Llanbedr (Mochras Farm) borehole (1967 – 1969) in NW Wales – usually known as Mochras – which recovered a 1.3 km thick succession comprising the Rhaetian (Upper Triassic), Hettangian, Sinemurian, Pliensbachian and Toarcian (Lower Jurassic) stages (Woodland, 1971; Hesselbo et al., 2013). Using the combined framework of Prees and Mochras, internal and external forcing factors on the Earth system will be documented and quantified for major palaeoenvironmental events, such as the Late Triassic mass extinction and the Early Toarcian Oceanic Anoxic Event, and for the more stable 'background' state.

The principal well 5065_1_C (Prees 2C) was drilled to a total depth of 651.42 mbs (metres below surface) and recovered core from the Branscombe Mudstone and Blue Anchor formations of the Mercia Mudstone Group, the Westbury and Lilstock formations of the Penarth Group, and the Redcar Mudstone Formation of the Lias Group. A core recovery of 99.7% was achieved. Drilling commenced at 32.92 mbs after installation of the conductor casing, with continuous 97 mm diameter core produced to the base. Wells 5065_1_A and 5065_1_B (Prees 2A and 2B) provide core for the upper interval of Lias between 22.5 mbs and 37 mbs, although with poorer core recovery due to the complicating presence of near-surface subglacial fractures.

For Well 5065_1_C, drill core was documented onsite, and sub-sampled every meter for bulk organic carbon isotopes ($\delta^{13}C_{org}$), total organic carbon (TOC) analyses, and carbonate content. The core was subsequently transported to the BGS Core Scanning Facility, Keyworth, Nottingham, for in-depth analyses of the whole round core with radiographic imaging and multisensory core logging (MSCL-S) (density, magnetic susceptibility and natural gamma), and split core XRF scanning (Itrax). Wireline logs were run in-hole to provide a comprehensive and integrated dataset for the well. This operational report provides an overview of the JET geoscientific drilling operations and available datasets. The initial summary core description and interpretations are presented in the scientific report 'Initial results of coring at Prees, Cheshire Basin, UK (ICDP JET Project); towards an integrated stratigraphy, timescale, and Earth System understanding for the Early Jurassic' (Hesselbo et al., 2023).

Referencing articles

Hesselbo, S. P., Al-Suwaidi, A., Baker, S. J., Ballabio, G., Belcher, C. M., Bond, A., Boomer, I., Bos, R., Bjerrum, C. J., Bogus, K., Boyle, R., Browning, J. V., Butcher, A. R., Condon, D. J., Copestake, P., Daines, S., Dalby, C., Damaschke, M., Damborenea, S. E., … Zhao, K. (2023). Initial results of coring at Prees, Cheshire Basin, UK (ICDP JET project): towards an integrated stratigraphy, timescale, and Earth system understanding for the Early Jurassic. In Scientific Drilling (Vol. 32, pp. 1–25). Copernicus GmbH. https://doi.org/10.5194/sd-32-1-2023

Supplementary material

BGS Core Scanning Facility. (2022). Prees-2C Core Scanning Dataset. NERC EDS National Geoscience Data Centre. (Dataset). https://doi.org/10.5285/91392f09-25d4-454c-aece-56bde0dbf3ba

Wonik, T. (2023) Downhole logging data of the ICDP Scientific Drilling Project "Early Jurassic Earth System and Time Scale (JET)". GFZ Data Services, https://doi.org/10.5880/ICDP.5065.001

https://www.icdp-online.org/projects/by-continent/europe/jet-uk/public-data (Site & Drilling Data)

Location of the JET drill site

The JET geoscientific drill site is located on the Prees Jurassic outlier, within the southern part of the Cheshire Basin (Figure 1, Table 1).

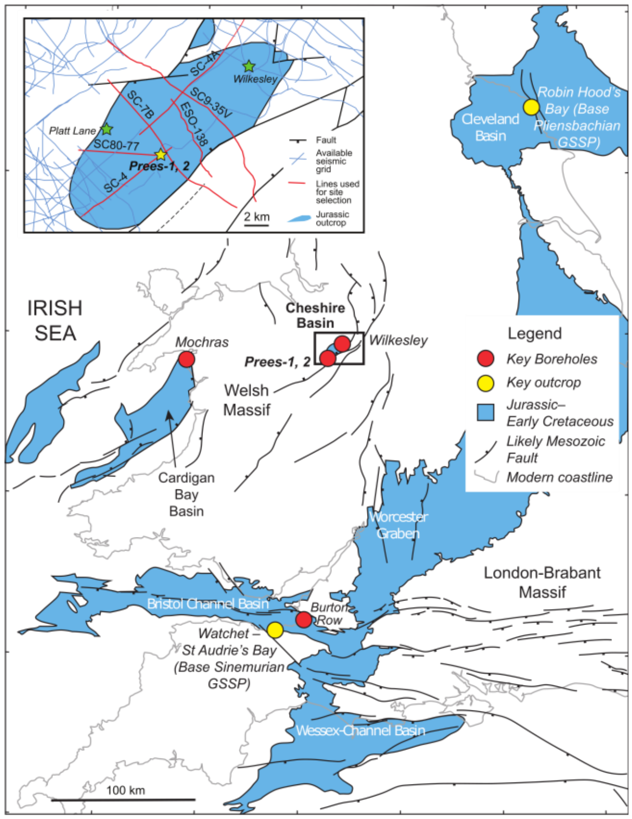

Figure 1: Geological map of Jurassic–Lower Cretaceous strata in the southern UK area, showing location of the drill sites Prees 1 and ICDP drill site 5065_1 (Prees 2) (main map and inset) in relation to the Mochras, Burton Row, Platt Lane, and Wilkesley boreholes, and outcrop Lower Jurassic GSSP sections. The Prees Jurassic outlier (main map and inset) sits in the southern part of the Cheshire Basin. Main figure modified from BGS 1:1,500,000 series tectonic map of Britain, Ireland and adjacent areas, Sheet 1 (Pharaoh, 1996). Inset modified from the UK Onshore Geophysical Library [ukogl.org.uk]. Green stars in inset give offset well locations.

Table 1 Location and Identifiers of boreholes from ICDP Drilling Project JET (= Prees 2)

Borehole ICDP Combined-ID	BGS Borehole Identifier (SOBI); contractors' label; alternative hole name	IGSN https://doi.org/10.60510/	Latitude decimal WGS84	Longitude decimal WGS84	UK National Grid Reference
5065_1_A	SJ53SE/52; MDG06; Prees 2A	ICDP5065EH10001	52.905933	-2.662053	SJ 55569 34483
5065_1_B	SJ53SE/51; MDG06A; Prees 2B	ICDP5065EH20001	52.905996	-2.661980	SJ 55574 34490
5065_1_C	SJ53SE/53 Prees 2C	ICDP5065EH30001	52.905887	-2.662201	SJ 55559 34478

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(alphabetic order, see site reports for detailed responsibilities, **bold: Principal investigators and proponents**)

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2 alternating drilling supervisors (Zenith Energy)

1 offsite assistance (Zenith Energy)

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Andy Sloan

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Operations Engineer

Contract manager, offsite assistance

4 Toolpusher

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Dr. Santiago Aldaz (ICDP-OSG)

Health and Safety Management and Environmental Management

On-site and Off-site personnel from Zetland Group (3)

2. Introduction

The latest Triassic to Early Jurassic was a time in Earth history when important physical, chemical, and biological elements of the modern Earth system were initiated, such as the first phases of Atlantic Ocean opening, and the rapid evolution of marine planktonic primary carbonate producers. At the same time, other crucial elements of the Earth system had distinctly Mesozoic characteristics, such as generally warm climate states, the presence of extensive epicontinental seaways susceptible to water mass stratification and anoxia, and short-lived episodes of massive flood basalt volcanism. However, the diverse Lower Jurassic biostratigraphic, cyclostratigraphic, magnetostratigraphic and chemostratigraphic schemes have, for the most part, remained poorly integrated with each other and have lacked accurate numerical calibration.

The major goal for this ICDP project was then to produce a new global standard stratigraphy for these 25 million years of Earth history and carry out a research programme to investigate the causes and effects of fundamental changes in the Earth system at this time. Planning for the project originally focussed on re-drilling at Llanbedr (Mochras Farm) on the edge of Cardigan Bay, Wales (Hesselbo et al. 2013), and developing an integrated stratigraphy for the cored material there. Subsequently the project focus shifted to an alternative site at Prees, Shropshire, in the Cheshire Basin, where practical environmental and logistical considerations indicated a greater reward-to-risk ratio.

2.1. The Llanbedr (Mochras Farm) borehole

The Llanbedr (Mochras Farm) borehole, hereafter referred to as Mochras, was drilled and logged through 1967–1970. The borehole recovered a 1300 m thick succession of marine mudstone of Early Jurassic age that was found to be biostratigraphically complete at the ammonite zonal level (Woodland 1971; Dobson and Whittington 1987; Copestake and Johnson 2014). The borehole proved to be of great value, but although original recovery is calculated as 97.6% for the Jurassic, only 59.1% is preserved as core slabs at the National Core Repository, the remainder being either kept as discrete fossil specimens, or placed into bags of coarse chippings (~20 mm) representing 5' (~1.5 m) (Hesselbo *et al.* 2013). Unfortunately, this means that any signal of orbital cycles at the precession scale has been lost from the lower part of the cored interval, with intact core slabs largely restricted to the Pliensbachian and Toarcian stages. Similarly, there are no downhole wireline logs for the lower half of the Jurassic succession (Hettangian and Sinemurian stages).

Since the ICDP-funded workshop that took place in Oxford in March 2013, substantial work has been carried out on the remaining core slabs from the original Mochras borehole as part of the ramping-up research leading to the drilling operations at Prees, and has focussed on the Pliensbachian and Toarcian stages; this work was facilitated principally by funding from Shell, through a grant held at Oxford University, through no-cost academic access provided by the British Geological Survey, and through funding from the UK Natural Environmental Research Council.

2.2. Planning and environmental constraints and land access

The project team was successful in raising significant funds to support drilling operations for a new Mochras borehole which was projected to reach ~1900 m depth. However, it was also clear that coring of the full Lower Jurassic succession at Mochras was at the very limits of affordability, given the constraints of planning and environmental requirements since the site lies within the Snowdonia National Park and adjacent to a Special Area of Conservation. Additionally, access to our preferred site was problematic.

As a result, an alternative drill site was proposed. The new site, at Prees in Shropshire, UK (Figure 1), promised results as good as, or even potentially superior to, those that would have been achieved at Mochras within the available financial resources.

3. Geological Setting

3.1. Broad geological context

The drilled site at Prees is in the Cheshire Basin, and represents a similar overall depositional setting to Mochras (Evans et al. 1993; Tappin et al. 1994; Warrington, 1997, Plant et al. 1999a, Figure 1), being sited within an SW-NE oriented half-graben called the Wem-Audlem Sub-basin, ~3.2 km NW of the bounding faults of the Wem–Red Rock fault system on its SE margin (Evans et al. 1993; Mikkelsen and Floodpage 1997).

3.1. Offset wells: the Wilkesley and Prees 1 boreholes

Two boreholes drilled previously in the Cheshire Basin provided a solid stratigraphic background to this project: Wilkesley (UK National Grid Reference: SJ 363864 341438), drilled in 1959–1960 to a depth of 1608 m and in its upper part recovering a succession from the Lower Jurassic to the Lower Triassic (Poole and Whiteman 1966), and Prees 1 (UK National Grid Reference SJ 355727 334474, WGS84: Latitude 52.905865, Longitude -2.659703) drilled in 1972–1973 by Trend Petroleum for Shell to a depth of 3733 m and penetrating Jurassic to Silurian strata (Plant et al. 1999). Wilkesley was drilled to prove salt deposits within the Triassic, and Prees 1 was an exploration well for hydrocarbon resources in possible Triassic and Permian sandstone reservoirs. A shallow borehole at Platt Lane (SJ 351400 336450), drilled for the British Geological Survey in 1959 to 113 m, provides additional core and data around the Triassic-Jurassic boundary. Jurassic and Upper Triassic strata were not cored in Prees-1, and although the Hettangian at Wilkesley was fully cored, the core was subsequently broken up, with hand samples only being retained at 1ft (~30 cm) intervals. In total, six exploration wells have been drilled for conventional oil and gas targets in the Cheshire Basin, and all have proven to be dry (Mikkelsen and Floodpage 1997; Plant et al., 1999).

The Hettangian and lowermost Sinemurian in the Wilkesley borehole comprises medium to dark grey calcareous mudstone with silty mudstone and argillaceous limestone (Poole and Whiteman 1966, p. 47). Based on the Prees 1 well completion log, together with our examination of cuttings from Prees 1, the entire Lower Jurassic succession at Prees was inferred to comprise calcareous mudstone and siltstone with subordinate limestone, a very similar lithological succession to Mochras. Marine calcareous fossils are common in the Hettangian at Wilkesley, including ammonites, and these have previously allowed a highly resolved ammonite biostratigraphy to be constructed (Donovan in Poole and Whiteman 1966; Bloos and Page, 2000; Plant et al., 1999).

The burial history of the basin-fill around Prees has been previously examined; based on formation densities and sonic log data, the thickness of strata eroded from above the preserved Lower Jurassic succession is estimated as ~2.0 km (Evans et al. 1993; Chadwick et al. 1999). The maximum temperature reached by the base of the Lower Jurassic during the Paleocene is estimated by modelling to be 80°C (Chadwick et al., 1999; Plant et al. 1999).

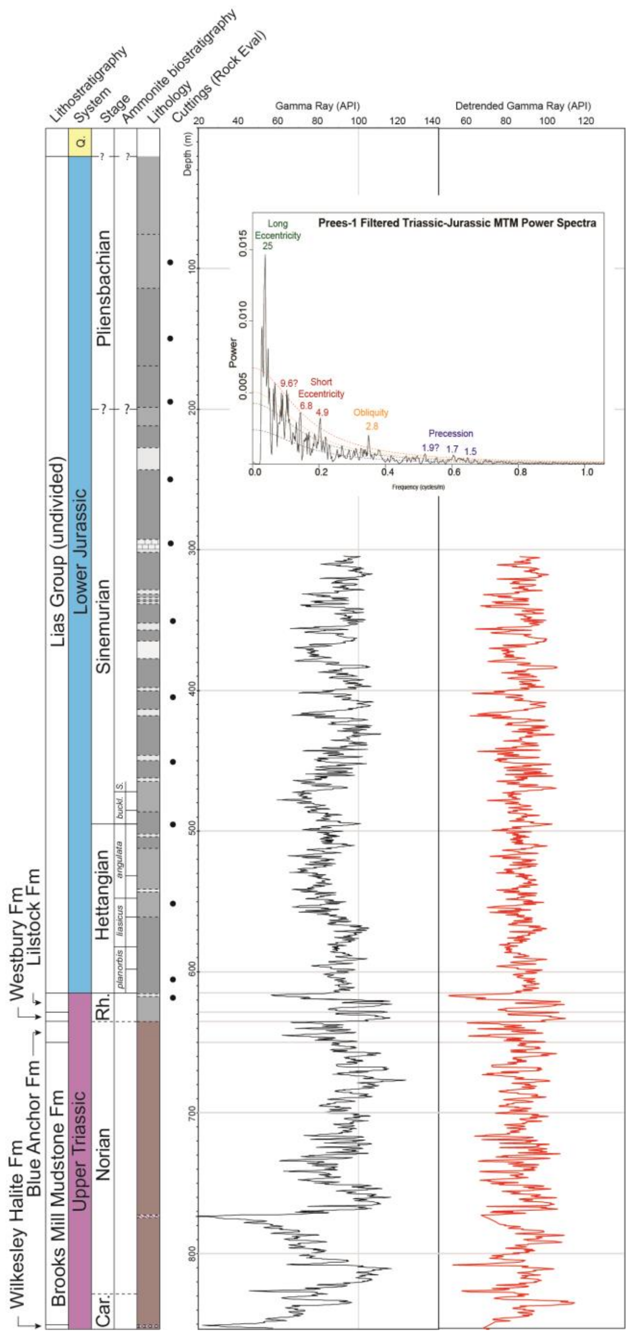

Figure 2. Stratigraphy of the Prees-1 borehole to 850 m below surface. The lithology is from the Prees-1 completion log. All lithologies are mudstone except at 300 m (micritic limestone), 773 m (anhydrite) and 851 m (halite). Multiple downhole logs are available from 300 m below surface to TD; the total gamma ray is shown as an example. Ammonite biostratigraphy is from the nearby Wilkesley borehole core and applied to the Prees section by correlation of the near identical gamma-ray signatures of the two holes. Thicknesses of Holocene and Pleistocene deposits are locally very variable. Car. = Carnian; Rh. = Rhaetian; Q. = Quaternary; buckl. = bucklandi ammonite Chronozone; s. = semicostatum ammonite Chronozone. For spectral analysis the gamma ray dataset was trimmed to remove very high or low values occurring at the very top of the hole. The data were then detrended using a bandpass filter with a frequency base of 0.025 removing periods over 40 m and smoothed using a lowness filter.

3.2. Pilot study data

Prior to submitting the November 2018 addendum to the 04/2015 Full JET Proposal to the ICDP, we carried out Rock Eval analyses at the Oxford University Earth Sciences laboratory (see Behar et al. 2001 for method), the results of which are included in Hesselbo et al. (2023). The Prees 1 borehole Jurassic strata have an average T_{max} of 434°C and an interquartile range (IQR) 436–433°C (n = 11). Wilkesley has a narrowly higher T_{max} of 435.5°C with an IQR of 436–434.25 (n = 5). Both Prees and Wilkesley show slightly higher average T_{max} values than Mochras (429°C, IQR 431–427°C, n = 910). The range of values across the three wells is small and the differences in average T_{max} almost within uncertainty; this indicates practically the same to very marginally deeper burial for Prees 1 and Wilkesley boreholes compared to Mochras. The average T_{max} temperature recorded for Wilkesley just surpasses the 435°C immature to mature transition, equivalent to vitrinite reflectance (R0) values of 0.6.

We further tested the Lias mudstone lithology in the Prees outlier for magnetostratigraphy by analysing samples from the Hettangian of the Wilkesley borehole. These samples were examined in the Oxford University Palaeomagnetism Laboratory where progressive AF demagnetization was applied (Figure 3). The two samples shown have stable magnetizations with contrasting polarity. The intensities are like those of the Mochras core, but the data are as clean as the best data from Mochras (cf. Xu *et al*. 2018). Because the Wilkesley core is up/down oriented, but azimuthally unoriented, only the inclinations (vertical plane) are meaningful. We conclude that the prospects for a viable high-resolution magnetostratigraphy from a new Prees core are excellent.

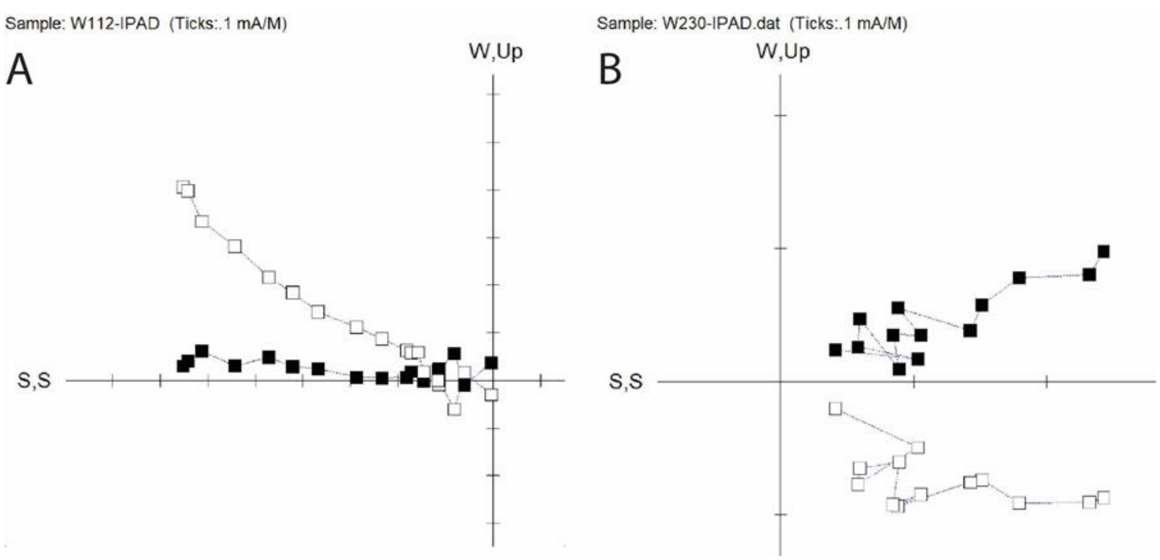

Figure 3. Orthogonal vector diagrams illustrating the alternating field (AF) demagnetization of two samples from the Sinemurian and Hettangian of the Wilkesley core. The closed and open symbols are projections onto horizontal and vertical planes, respectively; open symbols indicate polarity in this case. The sample in panel A (112' depth, mid Bucklandi Chronozone) is reversed polarity and the sample in panel B (230' depth, mid Angulata Chronozone) normal.

4. Scientific objectives

The science programme and scientific objectives of JET were initially submitted to ICDP in January 2011. Recognising the potential for realising a transformative understanding of climate changes between extremes, the ICDP funded a workshop to plan future drilling at Mochras, which was held in Oxford in March 2013. The report from that workshop summarizes the scientific objectives (Hesselbo et al., 2013). The JET science programme divides into two inter-related parts: a new integrated age model for Early Jurassic time and a combined data gathering and modelling analysis of the Early Jurassic Earth System. Scientific outcomes to date are described in Hesselbo et al. (2023) to which the reader is referred for further detail.

5. Strategy

5.1. Prees site selection

To meet the scientific goals of the project and on the basis of outcrop and evidence from wells summarised above (Section 2) as well as from seismic data, we selected the site at Prees to have a succession with the same characteristics as Mochras, specifically (1) a stratigraphically expanded, hemipelagic marine record with excellent biostratigraphic control, and; (2) low thermal maturity.

The criteria that guided site selection were (1) accessibility with the drill site located adjacent to a major road, (2) proximity to the Prees 1 well, and (3) minimum environmental and regulatory constraints.

The ages and thickness of the Jurassic section at Prees in comparison to other key Lower Jurassic sequences, including Mochras, are included in Figure 4.

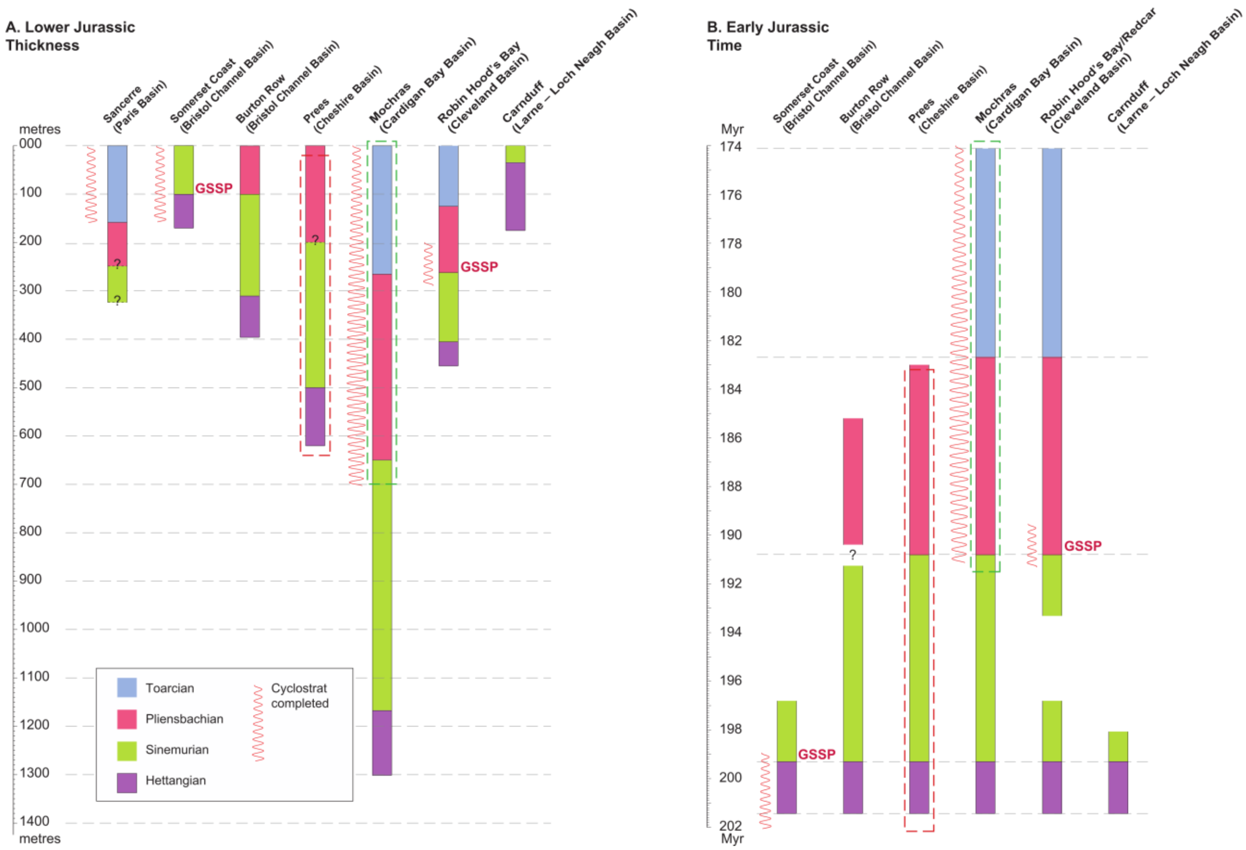

Figure 4. Comparisons of possible drill sites and key Lower Jurassic sequences in depth (A) and time (B). Note that Prees has the most expanded Lower Jurassic succession known in England. At Mochras, preserved core slabs have already allowed an integrated age model to be constructed for the Toarcian and Pliensbachian stages (box with green dashed lines; Ruhl et al. 2016; Pienkowski et al. 2023); therefore, the principal focus at Prees is the Hettangian–Lower Pliensbachian section (box with red dashed lines). Note that at Prees the youngest outcrop is Late Pliensbachian in age, but at the drill site the youngest strata are mid Pliensbachian. Additionally, Prees preserves a sedimentary sequence in which the Triassic-Jurassic boundary can be readily recognized and so provides an important new record of this first-order mass extinction. Burton Row in Somerset was considered and rejected as an alternative site, based on relatively reduced thickness and likely hiatuses. A recent fully cored borehole drilled at Carnduff in N. Ireland (Boomer et al. 2020) is also available for study and will provide additional constraint on Hettangian cyclostratigraphy. The Sancerre Borehole, Paris Basin, (Zhang et al. 2023) is shown for comparison.

5.2. Selecting the optimal location for the drilling operations

The optimal location for the drilling operations at Prees was informed using legacy seismic data. The Prees site lies in a region characterised by relatively good seismic coverage. These surveys include a 1970s vintage low-fold dynamite grid, and a denser grid of vibroseis acquired in the late 1970s and 1980s (Mikkelsen and Floodpage, 1997). The Leibniz Institute for Applied Geophysics (LIAG) team have closely examined the relevant seismic lines (Figures 1, 5, 6) and re-processed where possible.

Line SC-7B is oriented NW-SE, passing 0.5 km from Prees-1 (Figures 1, 5). The interpreted trace of the Wem Fault is shown dipping to the NW, together with an interpreted SE dipping antithetic fault. The thickest Jurassic succession occurs at the projected location of the Prees 1 well, where it is not affected by seismically imageable faults. This reflection profile shows that the Jurassic and, probably, Upper Triassic occupy a sag basin sitting on top of the Permian-Triassic half graben structure. Due to uncertainties in our time-depth conversion the precise level at which this change in tectonic style occurs is not yet known; however, the Upper Triassic lithostratigraphy is complete (i.e. all formations and members of the Rhaetian age Penarth Group are present) and the lowermost Hettangian shows a good succession of the earliest species of the ammonite *Psiloceras* (Bloos and Page, 2000), and therefore we are confident that any missing strata related to the change in subsidence style is restricted to a level in the Upper Triassic, likely at the base the Branscombe Mudstone or lower (Figure 5). Interpretation of Line SC-7B is supported by interpretation of line SC9-35V which is parallel and lies ~4 km to the NW. Line ESO-138, also examined, is of poor quality and does not yield any additional constraint on Jurassic stratigraphy or structure.

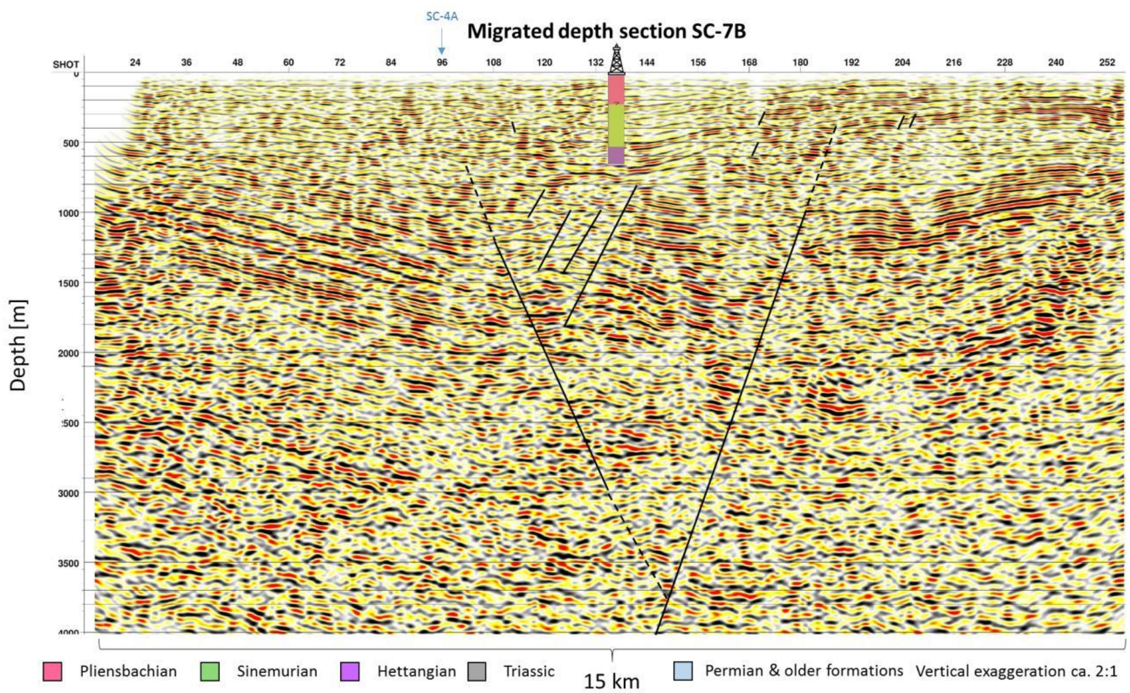

Figure 5. Migrated and depth converted section of profile SC-7B orientated NW (left) –SE (right) (Figure 1 inset). The relevant upper section of the Prees 1 borehole is projected onto the seismic line. The stratigraphic units are colour coded to match Figure 4. Note the change in subsidence style equivalent to a depth of about 800 m at Prees, using assumed time-depth parameters, which likely corresponds to a level within the Upper Triassic. The Wem fault is projected to break surface at about shot point 192.

Line SC-4 is a SW-NE oriented line along the axis of the basin, with Prees 1 situated at the NE end (Figures 1 and 6). This profile confirms the general tilt of the Jurassic in a NE direction along the axis of the basin, suggesting that any drill site situated towards the SW will have a less complete section at the top of the Pliensbachian. Line SC80-77 also approaches the Prees 1 location at its eastern end, with the profile being oblique across the basin structure. This line confirms that a reduced thickness of Jurassic strata occurs to the NW of the proposed drill site and also confirms the antithetic geometry of the subsidiary fault shown in Figure 5.

In summary, seismic reflection data confirmed that a new site located as close as is practical to the original Prees 1 well was likely to yield a thick Lower Jurassic succession of Pliensbachian and older strata.

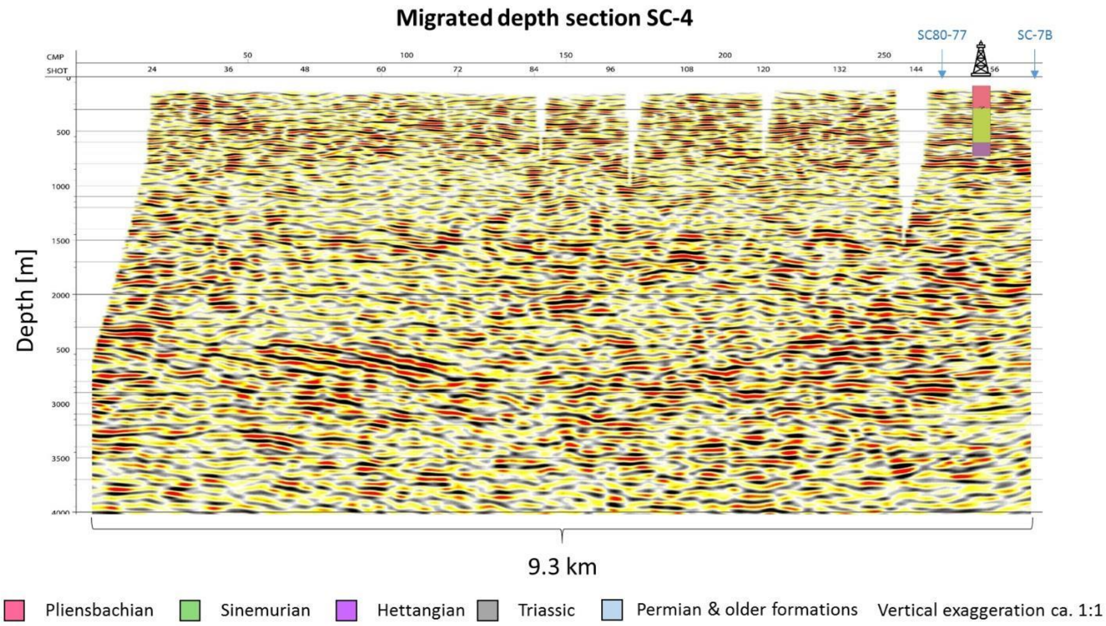

Figure 6. Migrated and depth converted section of profile SC-4 oriented SW (left) –NE (right) (Figure 1 inset). The Prees 1 borehole is located at shotpoint number 150. The stratigraphic units of Prees 1 are colour coded to match Figures 4 and 5. Note the clear post-depositional dip of strata to the NE (right) and thus likely removal of the top of the Jurassic succession to the SW. Well log correlation between Prees 1 and Wilkesley also shows a thinning of the Jurassic succession across the 10 km that separates Prees 1 from Wilkesley in a NE direction.

5.3. JET_5065_1 drilling strategy

Three wells were drilled on the geoscientific borehole drilling program site; 5065_1_A (Prees 2A;), 5065_1_B (Prees 2B;) and the principal borehole 5065_1_C (Prees 2C). 5065_1_A and 5065_1_B provide core for the Quaternary and upper interval of the Lower Jurassic (Lias Group) to 37 mbs, and 5065_1_C provides core of the Lower Jurassic to Triassic sections from the base of the conductor casing at 32.92 mbs to 651.42 mbs. Various depth reference points were used because of the different drill rigs and contractors used, therefore all depths within this report are quoted as meters below surface (mbs) for consistency. The meters below surface (mbs) depths are referenced from ground level and quoted as the measured depth due to the near-verticality of the wells.

5065_1_A and 5065_1_B were the first wells drilled on the site and used the Comacchio 305 rotary rig. The 5065_1_A well was drilled to 32.2 mbs and encountered topsoil and glacial deposits to ~25 mbs. The Lias Group was intersected at the base of the well between 25 mbs to 32.2 mbs. Two sampling methods were used 1) the window sampling method in the superficial deposits to 13 mbs, and 2) rotary coring with a PDC drill bit and the Geobore S rotary wireline coring tool between 13 mbs – 32.2 mbs, producing a core diameter of 102 mm. The core recovery from 5065_1_A was insufficient, therefore an additional well, 5065_1_B, was drilled ~ 9 m to the north-east to provide a continuous core section. The 5065_1_B well was drilled to a total depth of 37 mbs, with core retrieved from 22.5 mbs – 37 mbs (95% core recovery - 13.8 m recovered core, 14.5 m drilled depth). The cores from 5065_1_A and 5065_1_B are stored at the National Geological Repository (NGR). A summary of the strata encountered by 5065_1_A and 5065_1_B is given in Table 2.

Table 2: Summary of strata encountered from 5065_1_A (0– 32.2 mbs) and 5065_1_B (0– 37 mbs).

Geological Strata		Maximum Depth Below Ground Level to Base of Strata (m)	Strata Thickness (m)
Topsoil		0.35	< 0.35
Glaciofluvial Deposits	Medium dense sand, and dense silty sand	11.30	~ 11.0
Glacial Till	Stiff sandy, slightly gravelly clay (locally with granular horizons)	25.00	~ 5.50
Lias Group	Mudstone	>37.00	>12.0

The principal 5065_1_C well was drilled using Marriott Drilling Group (MDG) Rig 18 with a Micon SK 5 1/2” B heavy duty wireline coring string and PDC core bit. Continuous 97 mm core was collected from below the conductor shoe at 32.92 mbs (top of core one) to 651.42 mbs. All drilled depths were originally quoted from the rotary kelly bushing (RKB), located 4.58 m above ground level (“Rig Floor”); however, these are converted to mbs within this report for consistency. The core was extracted from the well in 6-m segments, marked up and then cut into 1 m sections on-site. The cores from 5065_1_C are also stored at the National Geological Repository (NGR).

The 5065_1_C well was drilled in three main stages. Stage one involved drilling between 32.92 mbs and 241.42 mbs using a 6 3/8” (161.9 mm) coring bit. The second stage widened the previous section between 32.62 and 240.42 mbs with a 9.5” (241.3 mm) Push Type PDC Reamer for casing installation. Stage three drilled between 241.42 mbs to 651.42 mbs with 6 3/8” (161.9 mm) core bit.

All wireline logging operations were conducted by Robertson Geo within a 161.9 mm uncased borehole. The original wireline depths were referenced from ground level.

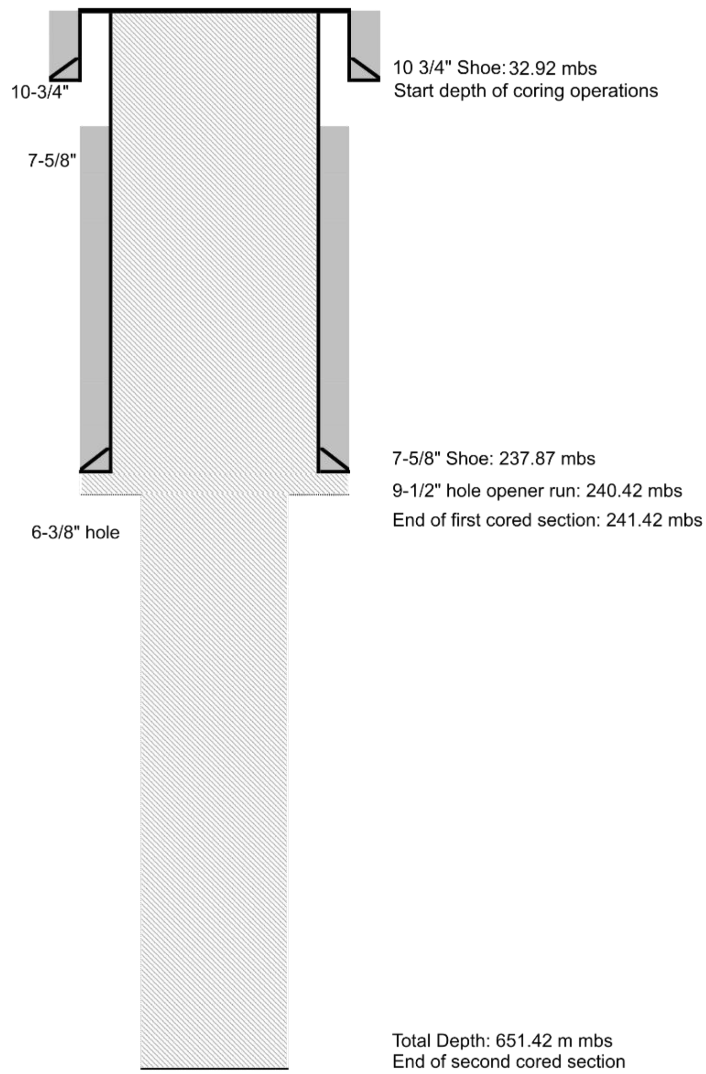

Figure 7. 5065_1_C (Prees-2C) well schematic illustrating the casing points and final borehole diameter after the completion of drilling operations (courtesy of Marriott Drilling Group).

6. Preparations

The operations of the JET geoscientific borehole drilling program consisted of the drill site preparations (site investigation, construction of the drill platform), the drilling operation phase (coring, wireline logs, well abandonment) and later laboratory analysis of the core at the BGS core scanning facilities. The timings of the JET geoscientific borehole drilling program are outlined in Table 3.

Table 3. JET geoscientific borehole drilling program operations by time.

Date	Task
05/06/2019 to 15/07/2019	Phase one site investigation by WSP
16/12/2019 to 19/02/2020	Phase two site investigation by TerraConsult
16/12/2019 to 20/12/2019	Drilling of 5065_1_A (Prees-2A; MDG06 - Comacchio 305 rotary rig)
08/01/2020 to 10/01/2020	Drilling of 5065_1_B (Prees- 2B; MDG06A - Comacchio 305 rotary rig)
11/08/2020 to 23/09/2020	Construction of the main drill site (Zetland Group)
07/10/2020 to 21/10/2020	Installation of conductor casing to 32.92 mbs (Rig 14)
04/11/2020	Rig 18 accepted onsite
05/11/2020	Spud date of 5065_1_C (Prees-2C) / start of drilling operations of Rig 18
07/11/2020	First core on deck
07/11/2020 to 15/11/2020	Drilling of intermediate section (32.92 mbs – 241.42 mbs)
16/11/2020 to 17/11/2020	Downhole logging operations
17/11/2020 to 26/11/2020	Hole opening to 9.5” and installation of 7.625” casing
27/11/2020 to 27/12/2020	Drilling of final section to well TD (241.42 mbs – 651.42 mbs)
28/12/2020 to 29/12/2020	Downhole logging operations
29/12/2020 to 01/01/2021	Well abandonment
02/11/2020 to 11/12/2020	Core description and XRF Scanning at British Geological Survey, Keyworth, UK (during drilling)
01/06/2021 to 27/08/2021	XRF Scanning at British Geological Survey
01/06/2021 to 28/08/2021	Sampling party at British Geological Survey, Keyworth, UK (Covid restricted)
03/07/2022 to 07/07/2022	Sampling party at British Geological Survey, Keyworth, UK (Open, but with Covid-related limitations)
05/09/2022 to 07/09/2022	Sampling party at British Geological Survey, Keyworth, UK (Open)

6.1. Site Investigation

The site investigation work was carried out in two phases, the first investigation was by WSP and a second later investigation by SM Associates on behalf of the drilling contractors Marriott Drilling Group. The phase one work programme is detailed in report 70059777/11410 prepared by WSP, and phase two within report 4634/01 Issue 1 prepared by TerraConsult Ltd. The site investigations were undertaken to provide preliminary geotechnical information on the ground conditions for the construction of a drilling platform. The investigations included rotary drilling, dynamic sampling, ground water monitoring and contaminant testing.

The first phase involved the drilling of six exploratory shallow boreholes (BH1 - BH6), which were subjected to dynamic cone penetrometer tests, ground contamination, and particle size analysis. Further in situ testing and ground observations were carried out in phase 2 and involved:

- The drilling of 5065_1_A and 5065_1_B using a tracked drilling rig. Dynamic sampling was used to the rockhead, and thereafter rotary coring with the Geobore S rotary wireline tool with air/water flush. The borehole was backfilled with bentonite:cement grout on completion.
- Four additional dynamic (windowless) sample holes with plastic liners
- Installation of three groundwater monitoring wells (51 mm internal diameter HDPE)
- Six trial pits using a wheeled hydraulic excavator
- In situ California Bearing Ratio (CBR) tests using the plate bearing test method
- Sampling and testing of soils
- Groundwater monitoring

6.2. Site Overview

After the site investigations were complete, drill site construction was managed by the Zetland Group. The site was located on gently sloping arable land adjacent to the A49 trunk road north of Prees, Shropshire, and covered a surface area of approximately 100 m x 60 m (Figure 8).

The site preparations involved stripping the topsoil after clearance from the ecological nesting bird survey. The top soil was placed on the southern boundary for subsequent restoration under archaeological watching brief. An area of containment was created using perimeter containment ditches and geomembranes, and plastic track matting was laid down across the site area to provide traction for site traffic. A concrete slab was formed and cast around the drill cellar.

The site was split into the active area where the primary drilling operations were located. The active area was sealed to prevent land contamination, and contained the drill rig, water, cuttings, mud tanks, mixing tanks, fuel, generators and the chemical trailer. The inactive area was unsealed, and contained the pipe baskets and the catwalk where drill pipe was laid out. The drilled core was transported from the catwalk to the mudloggers cabin where it was washed, described and cut into 1 m segments.

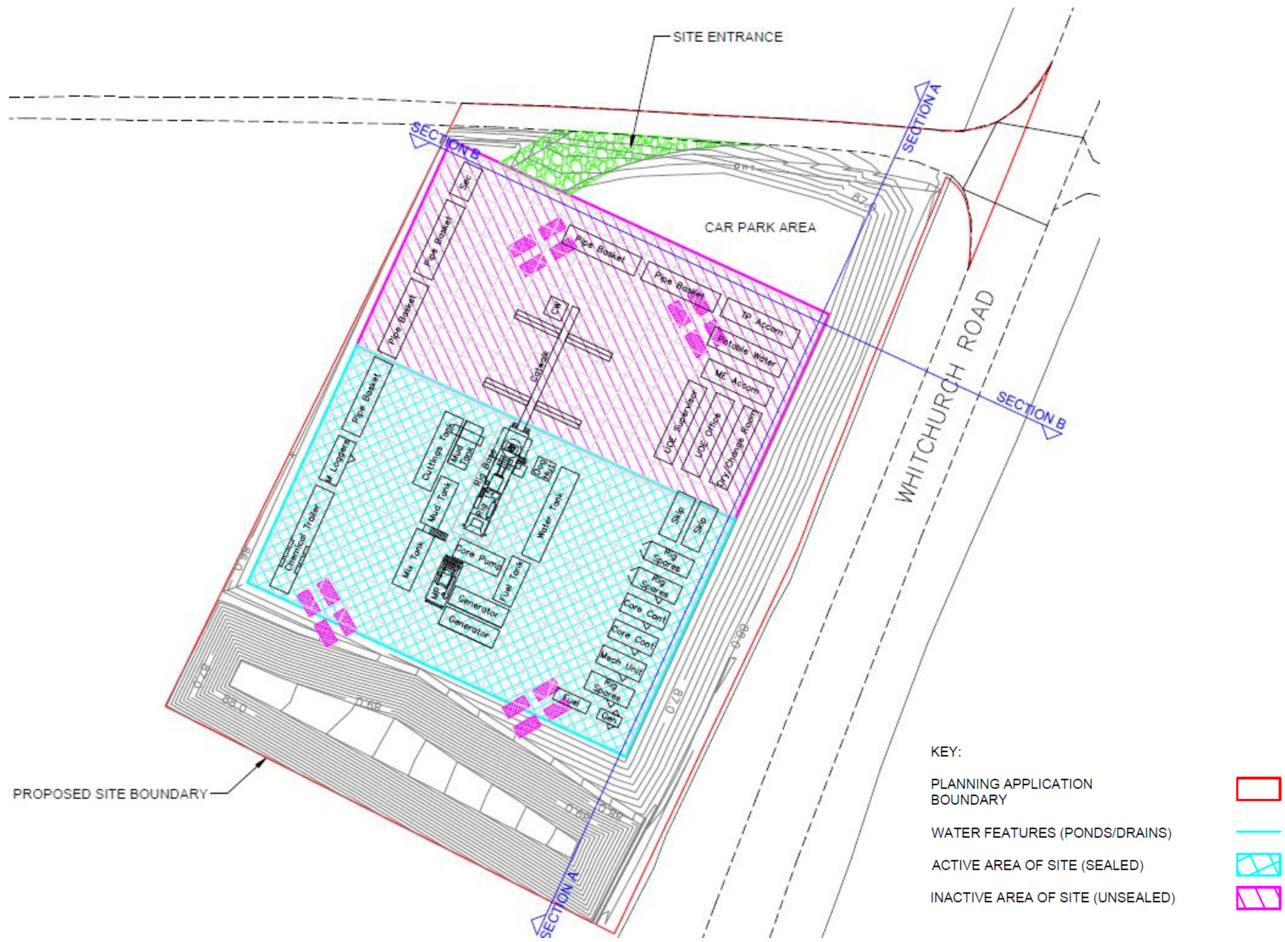

Figure 8. JET geoscientific borehole drilling program site, illustrating the active sealed, inactive unsealed areas and the location of site offices (figure courtesy of Zetland Group*).*

6.3. Installation of conductor casing

The 5065_1_C conductor casing was installed by Marriott Drilling Group with the use of MDG drilling Rig 14. A 17” conductor hole was drilled with an auger to 32.92 mbs, and then lined with 10 ¾” conductor casing. The conductor was drilled down to 32.92 m to be in competent unfractured formation for borehole stability and then cemented to surface to provide isolation and well stability.

7. Technical operations

7.1. Drilling equipment

Marriott Rig 18 consists of a WEI DS 100 SLANT hydraulic semi-trailer mounted fitted with independent hydraulic stabilizers for trailer & substructure. This equipment was manufactured in 2013 and first commissioned in 2019. The rig's top drive was a WEI DS100 S, with a 220,000 lbs pull-up capacity, 3,000 psi, a maximum rotary speed of 180 rpm, and a maximum continuous torque of 21,700 ft-lbs. Draw works were supported by a WEI hydraulic ram with 220,000 lbs capacity. Rig Engine was a Caterpillar C-18 with 447 kW (600 HP) and the rig generators consisted of two Caterpillar C-15 ACERT (635 kVA).

The mud pumps consisted of two Drillmec 7TS-600 Triplex c/w Caterpillar C-18 ATACC motors with a md working pressure equal to 5,000 psi. The two mud tanks had a capacity of 127 bbl each.

The presence of gas or having a kick was deemed unlikely, but as a precaution, an annular diverter was used on the 10 ¾" casing and a 13 5/8" BOP on the 7 5/8" intermediate casing. In the upper section, above the wellhead, a DSA and drilling spool with minimum 6" diameter outlet was installed together with a 13 3/8" annular diverter system to cater for any influxes during drilling of the upper section. In the lower section, above the wellhead there was a DSA from 11" 5m to 13 5/8" 5m then to a full 13 5/8" 5m BOP system along with standard choke and surface equipment.

7.2. Drilling

The 5065_1_C drilling operations started on 5th November 2020 and were completed by 1st January 2021. The end depth of 5065_1_C is 651.42 mbs.

7.2.1. Drilling crew

Marriott Drilling Group was the drilling contractor for 5065_1_C. Drilling operations were carried out 24h/day with on average 15 rig personnel. The University of Exeter and Zenith Energy supervised the drilling operations on a daily basis. The University of Exeter was the well operator.

7.2.2. Start - up

The drilling operations began with a 9.5" diameter tri-cone drill bit to drill through the cement plug in the lower part of the conductor casing. The top of the conductor cement was tagged at 30.02 mbs and drilled out to 32.92 mbs, until the Lias Group was encountered. The well was circulated clean before the coring operations started.

Technical casing (7.625") was installed to the bottom of the conductor casing shoe to create the correct annular spacing for the coring operations. This was required to reduce risk of damage to the drill rods and allow efficient transport of cuttings to the surface.

7.2.3. Description of core drilling

The Wireline Core Barrel SK 5 ½" B was used for the coring operations, with the bottom hole assembly consisting of a 6.375" core head, 6.375" stabilizer, core barrel (6 m), adaptor coupling, locking coupling, 6.375" stabilizer, 2 x 6 m core pipe and a 6.375" stabilizer.

The triple core barrel assembly (outer core barrel, inner core barrel, core liner) was used to maximize core recovery with minimal disturbances. The triple tube core barrel assembly provided a core diameter of 97 mm, with the use of 101.4 mm clear plastic core liners. For core extraction, the drill string was lifted to break the core. The catching assembly was lowered down the well, with the overshot attached onto the latch head of the inner tube. The inner tube was then extracted out of the well.

7.2.4. Interval 1: Core Drilling 32.92 mbs – 241.42 mbs

The first section of 5065_1_C (32.92 m – 241.42 mbs) took nine days to complete, with an average ROP of 1.28 m/hr and one drill bit change. The whole section was drilled first with a 6.375" drill bit and later opened up to 9.5" after the wireline log operations.

Parameters recorded whilst drilling were total depth, bit depth, ROP, weight on bit, hookload, RPM, standpipe pressure, rotary torque, electromagnetic flowmeter, pump strokes per minute, pit levels for the active system, trip tank sensor, total gas sensor, FID chromatograph and H_2S detection.

7.2.5. Casing

After the first section had been drilled, the coring string was pulled out of hole and laid down. The technical casing that was previously installed between 0 and 32.92 mbs was removed. Nine logging runs were undertaken by Robertson Geo. The well was subsequently widened for the casing operations using a 9.5" hole opener. The 7 5/8" casing was run in hole and landed off the hanger at 0.07 mbs, with the casing shoe at 237.87 mbs. The annulus between the casing and formation was cemented using stinger cementing technique, where 4" drill pipe inner string was run in hole and stung into the float collar.

7.2.6. Problems

Poor core recovery on core runs 1, 4 and 5 between 37.5 mbs and 54.5 mbs (73 – 88 %) were caused by the presence of near-surface subglacial fractures. These fractures did not cause any further issues for core recovery in the subsequent core runs. The unconsolidated nature of the upper section also caused core jamming (sample stuck within the inner core barrel), which potentially caused material to be flushed away.

The 6.375" pilot bit was lost downhole during the hole opener run and required a fishing operation to remove it from the well. The fish was successfully recovered to surface with no damage to the threads and drill bit, with all drill cones recovered. The fishing operation resulted in 16.5 hour delay.

7.2.7. Interval 2: Core Drilling 241.42 mbs – 651.42 mbs

After the cementing operations and BOP tests, the cement and float shoe was drilled out with a 6.5" tri-cone drill bit. The hole was circulated clean and then the assembly pulled out of hole. The coring BHA was subsequently picked up to re-commence the coring operations.

The second interval between 241.42 m - 651.42 mbs took 31 days to complete, with two drill bit changes and an average ROP of 1.35 m/hr. The whole section was drilled with 6.375" drill bits with water based KCl Pure-Bore drilling fluid (biodegradable polysaccharide), which acts as a shale encapsulator to de-crease hydration of clays and disintegration whilst drilling. Additional inputs to the mud included biocide

2090A, caustic potash, citric acid and sodium bicarbonate. From 295.42 mbs onwards, barite was added to increase the mud weight to 9.7 ppg. Loss of circulation material, composed of $CaCO_3$ and mica, was used between 604.49 m – 609.42 mbs to minimise losses. A core recovery of 99.9% was obtained during the section run.

7.2.8. Problems

Technical problems included mud pump failure that caused the downhole mud circulation to stop during core run # 106 (603.42 – 605.39 m mbs). This resulted in 0.09 m of core and liner to sustain significant heat damage, with poor core recovery and ~0.6 m of rubble. Further, on the 18 06/12/2020 (443.29 mbs) the Rig 18 top drive failed, which resulted in 11 days, 8 hours of non-productive time (272 hours). Core catcher issues occurred during the recovery of cores 94 and 101, which resulted in only partial core recovery due to core slip. An estimated 3.27 m of core was left in hole during core run 100, although much subsequently recovered. The issue was subsequently resolved once a new batch of core catchers were run.

Formation problems included mud losses (10 - 12 bbl/hr, 0.5 L/s) that were encountered whilst coring between 604.49 – 609.42 mbs. The losses were linked to vertical and subvertical fractures observed in the core (Core # 107). To stem the losses, the flow rate was reduced and the active system was dosed with lost circulation material (LCM). The dynamic losses decreased to 4 – 6 bbl/hr but no static losses were observed. An LCM pill was subsequently pumped at the base of the well and allowed to soak into the formation, reducing the dynamic losses to 2-3 bbl/hr. An additional LCM pill was pumped downhole, and the mud weight was reduced from 9.6 to 9.5 ppg with the input of unweighted premix to the mud system. The measures further reduced the losses to 1-2 bbl/hr. Coring resumed, and losses dropped to 0.3 bbl/hr. The mud weight was further reduced to 9.4 ppg to continue drilling with an increased pump rate.

7.2.9. Drill bits

Five diamond drill bits were used during the coring operations between 32.92 m and 651.42 mbs (Table 4). The maximum lifespan of a drill bit was 156 m (to TD, bit #8) and the minimum 58.2 m (bit #6). Bit #6 was changed after 58.2 m due to a decreased ROP (0.5 – 0.7 m/hr). Subsequent analysis on surface showed the drill bit to be in good condition, but with some balling (cuttings sticking to the bit) evident around parts of the cone. Bit #2 that drilled 73.5 m showed wear and damage to 90 % of the cutters and was blackened due to heat build-up. The average drilled interval for a bit was 114 m.

Two tricone drill bits (bit #1, bit #5) were used to drill out the cement after the casing operations, whilst the PDC hole opener (bit #4) was used to widen the upper section of the well to install casing (Table 4).

Table 4. 5065_1_C (Prees-2C) drill bit record.

Bit Number	Drill bit description	Diameter (inch)	Depth from (mbs)	Depth (mbs) to	Total (m)
1	Security TCl 619753	9.5	30.02	32.92	2.9
2	Micon Core 67951	6.375	32.92	106.39	73.5
3	Micon Core 67952	6.375	106.39	241.42	138.11
4	Mill Tooth (Pilot bit) PDC Hole Opener	6.25 9.5	241.42 32.62	241.42 240.42	0 207.8
5	Mill Tooth	6.5	213.42	241.42	24
6	Micron PDC	6.375	241.42	299.62	58.2
7	Micron TSD 67955	6.375	299.62	495.16	144.63
8	Micron TSD 679567	6.375	495.16	651.42	156.26

7.2.10. Drilling activities after TD (total depth)

Once TD had been reached, further efforts were made to reduce the losses before the well was abandoned. During hole cleaning, losses of 60 bbl/hr were noted, but these quickly dropped to 0 bbl/hr and were followed by gains that subsequently reduced to 0 bbl/hr (fracture charging). A 40 bbl LCM pill was pumped downhole and the drill string was then pulled out of hole. The rig was subsequently set up for wireline logging operations.

After the logging operations were complete, the well was abandoned by running in hole with cement stinger tubing to construct two cement plugs.

7.2.11. Borehole deviation

The borehole survey was carried out by Robertson Geo using the Borehole Geometry Wireline Tool (I002044). The borehole is near vertical with a maximum inclination of 1.9° at 180 m. The borehole drifts ~14 m to the south over a vertical distance of 611.5 m. It should be noted that due to the casing of the upper ~33 m in this depth interval, only the inclination of the borehole could be determined with the triaxial accelerometers present in the probe used. The azimuth of the borehole is determined with triaxial fluxgate magnetometers, which do not provide meaningful data in the steel-cased area. Therefore, the borehole azimuth was interpolated in the cased area (Figure 9 left) and the representation of the borehole trajectory therefore only begins below 33 m (Figure 9 middle and right).

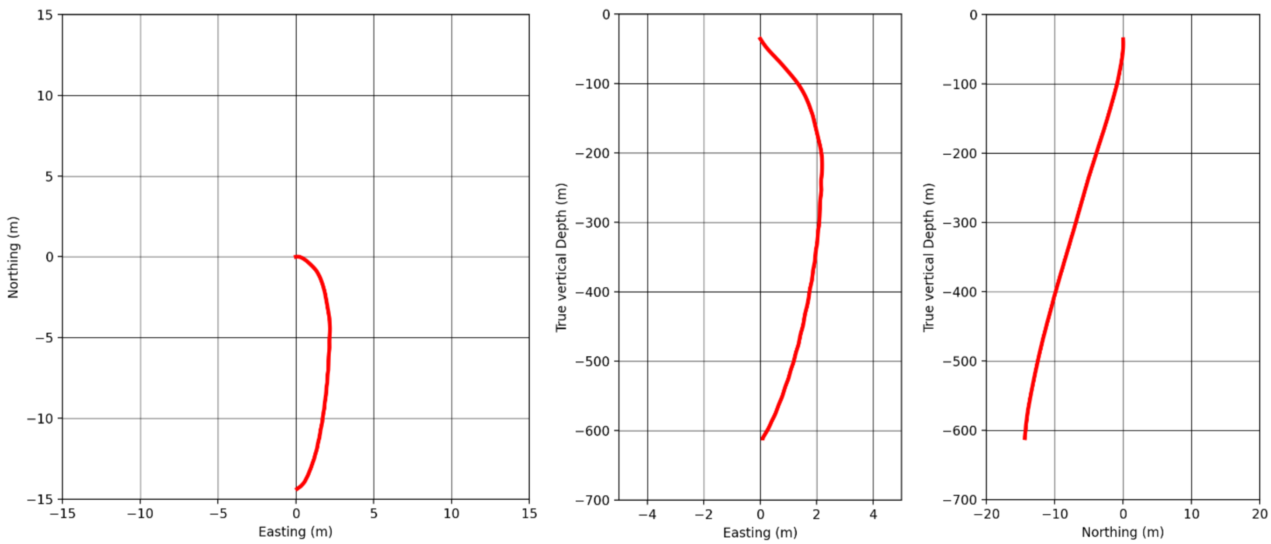

Figure 9. 5065_1_C borehole deviation survey. Trajectories calculated using the minimum curvature method.

8. Scientific operations

8.1. On site drill core workflow

The 6 m inner core barrels were recovered on wireline and placed on the rig pipe handling system. The core liner was then transported to the mudlogging unit and placed on a rack for sawing into one metre lengths. Each core segment was marked indicating the top and bottom of each core on the liner. The convention used was a white end cap for the bottom and blue end cap for the core top and the liner marked with two coloured lines in accordance with ICDP protocol (Figure 10). Each one metre core length was then washed manually within the core liner to flush the drilling mud, and washed a second time whilst undergoing inspection, geological description and initial sampling. The length of each recovered core was recorded and correlated with the drilled depth. The working half of the core was selected for onsite sampling. The core was placed back into the liner and into 1 m drill core boxes for transport to the BGS for core scanning.

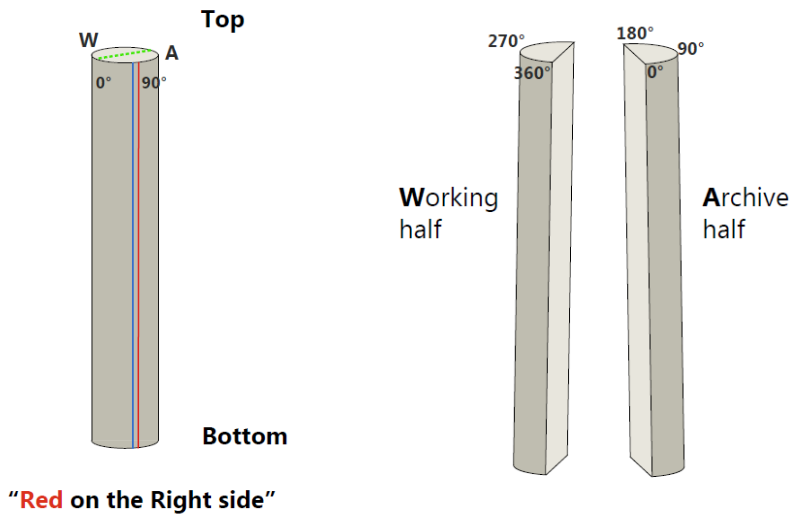

Figure 10. ICDP core marking conventions used during the JET geoscientific drilling to indicate the core top and working (W) and archive(A) halves (Harms, 2021).

8.2. On site sampling

Bulk rock samples of approximately 20–50 g weight were taken from the bottom end of each 1 m core section during coring operations for rapid data generation to aid more detailed sample requests. A total of 625 samples with an average spacing of ~1 m was sampled. All samples were marked with a BGS SSK number, which is the unique identifier for the BGS Core Repository and is used to track samples in the BGS data system. Currently, BGS does not register IGSN numbers. The entities 'hole', 'core', and 'section' do have IGSNs with the ICDP namespace.

8.3. Core curation

Core curation at the BGS National Core Repository was carried out in synchrony with drilling, and all whole round sections that were shipped from the drill site were curated with the designation of the future archive halves. Once whole round core scanning was completed, the core sections were cut in half, re-boxed and working halves curated. Curation was finalised in August 2021. The following labelling system was used to ensure reliable core position and orientation:

Core boxes:

- ICDP-style core section number (e.g., 5065_1_C_10_3) (Expedition_Site_Hole_Core_Section) handwritten
- ICDP-style core section number placed on cardboard strip in core box alongside core
- BGS IGSN-compatible core box number (e.g. CB00354103) and ICDP section number on stickers on core box lid

Ahead of any core scanning work the core was washed to remove drill mud. Although this was mostly done at the drill site, the top c. 50 m were washed at the BGS core store by flushing the core in the liner with tap water as core was partly strongly fractured and could not effectively be removed and replaced into the liner after washing.

End caps, especially in the deeper part of the core, were checked for good fit on the liner and electrical insulation tape replaced and/or added where it had been missed on the drill site. Triangular broken liner segments partly puncturing the end caps were cut off where necessary.

8.4. Downhole investigations

The original project plan was for LIAG to travel from Hannover to Prees with its borehole logging equipment and carry out the planned measurements. Due to the Covid pandemic, this plan had to be discarded and the company Robertson Geo, based in Deganwy, UK, was contracted to carry out the borehole measurements. This was done in two campaigns in November and December 2020, each two days long (see Table 5). Since the susceptibility measurements obtained in the first campaign showed that the probe used was too insensitive for our purposes (and the measurements were thus unusable), the measurement in the lower section of the borehole was not contracted. In the first campaign, a Focused Electric Log probe was used to determine resistivity. Given the very saline mud, Robertson Geo used a Dual Induction probe in the lower section of the borehole at our request. The other probes used were identical for both campaigns and were deployed in the same order.

8.5. Downhole geophysical logs

Downhole geophysical data were acquired from 33 m to 240 m depth on November 16th/17th, 2020, and for the remainder of the hole after drilling was completed (December 28th/29th, 2020). The probes successfully run to ~240 m were: Spectral Gamma Ray (SGR), Density (DEN), Neutron Porosity (NP), Focused Electric Log (FEL), 4-Arm Caliper (CAL), Mud Temperature/Conductivity (TEMPSAL), Full Wave Sonic (SONIC), Acoustic Televiewer (BHTV).

Probes successfully run from 240 m to the bottom of the hole were: Spectral Gamma Ray, Density, Neutron Porosity, Dual Focused Induction (IND/RES), 4-Arm Caliper, Mud Temperature/Conductivity, Full Wave Sonic, Acoustic Televiewer.

The logs were processed by the Leibniz Institute for Applied Geophysics (LIAG) and merged into one overall composite file. Additional information on the processing is provided with the dataset (Wonik, 2023) and in the Appendix of this report.

Table 5: Summary of 5065_1_C (Prees-2C) downhole logging operations carried out by Robertson Geo. The numbers in brackets refer to the part numbers from the Robertson Geo slimhole probe catalogue.

Logging Campaign 1: 33 – 240 mbs Loggers Depth (16/11/2020 to 17/11/2020)
Run 1, log 1#: Temperature and conductivity with gamma ray (I002055) Run 1, log 2#: Borehole geometry, 4-arm caliper with gamma ray (I002044) Run 1, log 3#: Spectral gamma ray (I017478) Run 1, log 4#: High resolution acoustic televiewer (I002192 - no gamma ray) Run 1, log 5#: Full waveform triple sonic (I013861 - no gamma ray) Run 1, log 6#: Magnetic susceptibility with gamma ray (I002095) Run 1, log 7#: Focused Electric (GuardLog) with gamma ray (I002078) Run 1, log 8#: Formation density with gamma ray (I002013) Run 1, log 9#: Dual neutron (porosity) with gamma ray (I002029)
Logging Campaign 2: 230 – 651 mbs Loggers Depth (28/12/2020 to 29/12/2020)
Run 2, log 1#: Temperature and conductivity with gamma ray (I002055) Run 2, log 2#: Borehole geometry, 4-arm caliper with gamma ray (I002044) Run 2, log 3#: Spectral gamma ray (I017478) Run 2, log 4#: High resolution acoustic televiewer (I002192 – no gamma ray) Run 2, log 5#: Full waveform triple sonic (I013861 – no gamma ray) Run 2, log 6#: Dual focused induction with gamma ray (I002087) Run 2, log 7#: Formation density with gamma ray (I002013) Run 2, log 8#: Dual neutron (porosity) with gamma ray (I002029)

9. Site 5065_1 operational dataset and availabilities

The datasets related to the drilling operations are summarised in Table 6, available at different locations. Metadata related to the drilling operations are publicly available at the ICDP JET project website (https://www.icdp-online.org/projects/by-continent/europe/jet-uk/public-data). The core photos and analytical data were produced at the BGS and will be available through the BGS website once the moratorium has ended (November 2024). The datasets generated are primarily related to the principal 5065_1_C well, with the methodology explained within the explanatory remarks (Appendix A). The geotechnical cores of 5065_1_A (TD: 32.2 mbs) and 5065_1_B (TD: 37 mbs) are thus far not studied in detail. The downhole logging data are published online at the GFZ data services.

Table 6: Summary of the JET_5065_1 (Prees 2) datasets, availabilities and/or citations.

Deposit	Data
Core and drilling operations summary Data availability https://www.icdp-online.org/projects/by-continent/europe/jet-uk/public-data	JET_5065_Expedition.csv JET_5065_Sites.csv JET_5065_Holes.csv JET_5065_1_B_Cores.csv JET_5065_1_C_Cores_DepthMariott.csv JET_5065_1_C_Cores_DepthZenith.csv JET_5065_1_B_Sections.csv JET_5065_1_C_SectionSplit.csv JET_5065_1_C_ICDP_CombinedID-BGS_Core-boxNumber JET_5065_1_A_SiteInvestigationReportFeb2020.pdf JET_5065_1_B_KeyLogbook.pdf JET_5065_1_C_ ZenithDailyDrillingReports.zip JET_5065_1_C_DailyDrillerReportsZenith_Summary.csv JET_5065_1_C_DrillingLog.pdf JET_5065_1_C_DrillBits.csv JET_5065_1_DrilleringLog_Technic.csv READ ME
Downhole logging dataset Data citation: Wonik, T. (2023) https://doi.org/10.5880/ICDP.5065.001	JET_5065_1_BL_CompositeLogs.zip JET_5065_1_BL_LoggingData.zip JET_5065_1_BL_DataDescription.pdf JET_5065_1_BL_LoggingTools_Robertson.xlsx

Deposit	Data
Prees-2C (JET_5065_1_C) Core Scanning Dataset Data citation: BGS Core Scanning Facility. (2022). Prees 2C Core Scanning Dataset. NERC EDS National Geoscience Data Centre. https://doi.org/10.5285/91392f09-25d4-454c-aece-56bde0dbf3ba	Including data from ITRAX and MSCL measurements. A low-resolution dataset of d13C measurement is published in Hesselbo et al. (2023) - supplementary material (datafile 6)
Core photographs and Radiographic Images: Data citation: shall be made available to the public by the National Geoscience data centre in Nov 2024. https://www.bgs.ac.uk/geological-data/national-geoscience-data-centre/	*internal data for science team members, ICDP project website include:* JET_5065_1_C_SectionImages_LR (1 zip file) = (ITRAX Optical Images; Type: CS) JET_5065_1_C_SectionImages_HR (6 zip files) = (Corebox Photographs; Type: BW) JET_5065_1_C_RadiographicImages (1 zip file)
Lithology and Stratigraphy: Data citation ad availability: Stratigraphic Column: Hesselbo et al. (2023) Lithology (1st Nov 204): https://www.icdp-online.org/projects/by-continent/europe/jet-uk/public-data	Summary Stratigraphic column (Hesselbo et al., 2023) JET_5065_1_C_Lithology_Logs (1 zip file; Scans of lithological logs)

10. Conclusion

The principal well 5065_1_C (Prees 2C) was drilled to a total depth of 651.42 mbs (metres below surface) and recovered core from the Branscombe Mudstone and Blue Anchor formations of the Mercia Mudstone Group, the Westbury and Lilstock formations of the Penarth Group, and the Redcar Mudstone Formation of the Lias Group. A core recovery of 99.7% was achieved. Drilling commenced at 32.92 mbs after installation of the conductor casing, with continuous 97 mm diameter core produced to the base. Wells 5065_1_A and 5065_1_B (Prees 2A and 2B) provide core for the upper interval of Lias between 22.5 mbs and 37 mbs, although with poorer core recovery due to the complicating presence of near-surface subglacial fractures. Downhole logs were successfully acquired for the full depth for well 5065_1_C. All cores are in the National Core Repository at the British Geological Survey, Keyworth, Nottingham, UK.

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13. Appendices

A: JET Explanatory Remarks on JET Operational Data Set

Appendix A

Explanatory Remarks on JET Operational Data Set

1. Core and drilling operations summary

Dataset availability: https://www.icdp-online.org/projects/by-continent/europe/jet-uk/public-data.

Summary: The dataset summarises the JET geoscientific drilling operations, core curation at the National Geological Repository (NGR), ICDP naming conventions and depth scales.

Included files:

- JET_5065_Curation_All_Data
- JET_5065_Expedition.csv
- JET_5065_Sites.csv
- JET_5065_Holes.csv
- JET_5065_1_B_Cores.csv
- JET_5065_1_C_Cores_DepthMariott.csv
- JET_5065_1_C_Cores_DepthZenith.csv
- JET_5065_1_B_Sections.csv
- JET_5065_1_C_SectionSplit.csv
- JET_5065_1_A_SiteInvestigationReportFeb2020.pdf
- JET_5065_1_B_KeyLogbook.pdf
- JET_5065_1_C_ ZenithDailyDrillingReports.zip
- JET_5065_1_C_DailyDrillerReportsZenith_Summary.csv
- JET_5065_1_C_DrillingLog.pdf
- JET_5065_1_C_DrillBits.csv
- JET_5065_1_C_DDR_Technic.csv

1.1 Core curation

The JET scientific drilling project samples use two sets of identifiers that are related to 1) sample curation at the National Geological Repository and 2) ICDP naming conventions.

1.1.1 ICDP Combined_ID

Samples from the JET scientific drilling project are marked with an ICDP Combined_ID, which is a hierarchical unique identifier that tracks the relationship between samples. The convention uses relative depth, with samples recorded relative to the distance from the section top. This relative depth scale allows depth corrections to be performed at a later stage in the project, for example conversions from the curated depth recorded at the time of drilling to the measured corrected core depth (MCCD) based on a depth model.

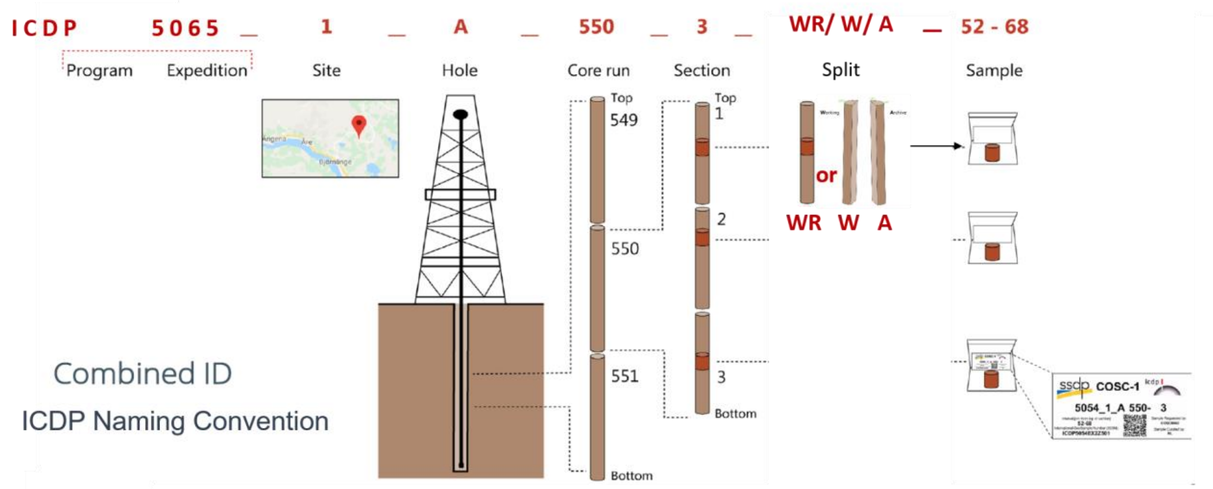

Figure A1. Example for the naming convention used in ICDP. The combined_id is used in ICDP to name any site, hole and drilled or cored material. The ICDP expedition code for the JET project is 5065 (altered after Harms, 2021).

The ICDP expedition code for the JET project is 5065. The project has one site (5065_1) with three holes (5065_1_A; 5065_1_B; 5065_1_C), which are summarised within "**JET_5065_Holes.csv**". The coordinate system for decimal latitude and longitude is WGS84. The platform type "R" stands for land-based drilling rig. (5065_1_A, 5065_1_B, and 5065_1_C are also referred to in published papers as Prees 2A, 2B and 2C, respectively.)

Core runs were typically 6 m in length, although variations occurred due to the drilling operations and core catcher. The core runs for the wells are summarised in the following files:

PREES-2B: "**JET_5065_1_B_Cores.csv**"
PREES-2C: "**JET_5065_1_C_Cores_DepthMariott.csv**"
"**JET_5065_1_C_Cores_DepthZenith.csv**"

Each 6 m core run was cut onsite into 1 m sections for storage at the National Geological Repository, located at the headquarters of the British Geological Survey, Keyworth. The storage location, section identifiers and depths of each core box are available within "**JET_5065_1_C_SectionSplit.csv**".

Onsite sampling involved taking samples from the full cylindrical core material (whole round, WR), whilst subsequent sampling and description was done on the split core (vertically cut) into a working (W) and archive (A) half, where the archive half is only used for non-destructive measurements. The sample interval is the distance of the sample in centimeters from the top of the section. An example for a combined_id of a sample is: 5065_1_C_50_3: 21:22, which is a core sample collected from Prees-2C (5065_1_C) from core run 50, section 3, and a distance of 21 – 22 cm from the section top. Samples taken from the core are summarized within "**JET_5065_1_C_Samples.csv**".

1.1.2 UK BGS Identifier

The cores stored at the National Geological Repository are marked by a core box number that starts with 'CB'. These core box numbers are equivalent to the sections defined in the ICDP system. Each core box and ICDP naming convention equivalents are provided in "**JET_5065_1_C_ICDP_CombinedID-BGS_CoreboxNumber.csv**". The original whole round cores were marked as 'CB00354XXX'. When split, the working half was marked with codes starting with 'CB00355XXX', while the archive half retained the core box number of the whole round. Samples were measured in the same way as the ICDP convention, where the top offset and bottom offset of a sample was noted in relation to the top (0 cm) of the core section. For example, a 2 cm-long sample from 40 cm down Section 5065_1_C_1_1, would be noted with a top offset of 40 and bottom offset of 42. These samples are registered in the BGS system with a SSK (Sub Sample Keyworth) series registration number, which are then linked to the borehole and depth in a spreadsheet.

1.1.3 IGSN

Following the FAIR data principle, each hole, section split, sample and cutting is registered with an International Generic Sample Number (IGSN). This number is registered through an agent and allows for the sample to be findable via the IGSN data base. For further details on the ICDP – IGSN please see Conze et al. (2016).

1.1.4 Depths: Driller's depth and depth corrections

The original depth model for the core is based on the drillers' depth (metres below rig floor – mbrf) for each ~6 m core run, and converted into metres below surface (mbs) by applying a measured 4.58 m offset between rig floor and surface. The meters below surface (mbs) depths are quoted as measured depth (MD) due to the near-verticality of the wells. Driller's depth assumed the top depth of each core run to be equivalent to the length of the drill string in the hole at the beginning of the core run. In the majority of cases the extracted amount of core was nearly equivalent to the drilled interval, but depending on the effectiveness of the core catcher, deviations of a few to a few tens of centimetres occurred. Where material from a previously incompletely extracted core run (e.g. Core 94) was recovered in the successive core run (Core 95), this leads to an apparent core gap above the longer core (between cores 94 and 95) and an apparent core overlap below (between cores 95 and 96). All data produced directly from the drilling with the original labelling follows this previous depth model (e.g. curated core sections at the BGS and core depth recorded by Zenith and Marriott within files: "**JET_5065_1_C_Cores_DepthMariott.csv**"; "**JET_5065_1_C_Cores_DepthZenith.csv**". Minor mismatches may occur in the original driller's depth model due to inconsistencies at the wellsite with multiple service contractors, however these have been standardised in the following mccd scale.

The new scale denoted mccd (metres corrected core depth) was devised based on the amount of extracted core. Depth ranges of core sections cut from the core runs are calculated incrementally and were anchored to the final depth frame by means of the depth of the core run top (see Hesselbo et al. (2023) for further details on the mccd depth model). It is recommended to use the mccd depth for any evaluation, visualization and publication of datasets. The core depth model is provided within "**JET_5065_1_C_Integrated_Depth_Model.csv**"

The MCCD core depth scale is independent of the wireline depth scale, with variations typically showing ± 50 cm based on correlations in gamma ray on the depth shifted wireline depth.

1.2 Drilling operations summary

1.2.1 Drilling reports

The drilling reports outline drilling operations in detail and are supplementary to the Early Jurassic Earth System and Timescale scientific drilling project (JET) – Operational Report (JET Scientific Team, in revision). Information includes drilling parameters, mud data, drill progress and rig data.

The driller reports for hole 5065_1_A is contained within the site investigation report "**JET_5065_1_A_SiteInvestigationReportFeb2020.pdf**" prepared by TerraConsult Ltd. The borehole is referred to as MDG06 within the contractor report.

The driller report for hole 5065_1_B is contained in supplementary file "**JET_5065_1_B_KeyLog-book.pdf**". The borehole is referred to as MDG06A within the contractor report.

The Zenith driller reports for hole 5065_1_C are contained within "**Zenith Daily Drilling Reports.zip**". These reports provide an operation summary and information on the drilling mud on a day by day basis.

A summary of the Prees-2C drilling parameters are provided in "**JET_5065_1_C_DrillingLog.pdf**", which include the rate of penetration (ROP), hookload, weight on bit (WOB), torque, standpipe pressure and total gas.

2 Dataset: Downhole logging

Dataset citation: Wonik, T. (2023) Downhole logging data of the ICDP Scientific Drilling Project "Early Jurassic Earth System and Time Scale (JET)". GFZ Data Services, https://doi.org/10.5880/ICDP.5065.001

Summary: The data relates to the downhole logging operations of 5065_1_C (Prees-2C) that was drilled onshore in the Cheshire Basin, Shropshire, UK in 2020 as part of the ICDP funded JET Project with expedition number 5065. The dataset was funded through the Leibniz Institute for Applied Geophysics (LIAG), Hannover, Germany.

Files included:

- JET_5065_1_BL_CompositeLogs.zip
- JET_5065_1_BL_LoggingData.zip
- JET_5065_1_BL_DataDescription.pdf
- JET_5065_1_BL_LoggingTools_Robertson.xlsx

2.1 Downhole logging

Downhole geophysical data were acquired from 33 m to 240 m depth on November 16th/17th, 2020, and for the remainder of the hole after drilling was completed (December 28th/29th, 2020). The probes successfully from ~240 m to 33 m were: Spectral Gamma Ray (SGR), Density (DEN), Neutron Porosity (NP), Focused Electric Log (FEL), 4-Arm Caliper (CAL), Mud Temperature/Conductivity (TEMPSAL), Full Wave Sonic (SONIC), Acoustic Televiewer (BHTV).

Probes successfully run from the bottom of the hole up to 240 m were: Spectral Gamma Ray, Density, Neutron Porosity, Dual Focused Induction (IND/RES), 4-Arm Caliper, Mud Temperature/Conductivity, Full Wave Sonic, Acoustic Televiewer. Further details on the downhole logging is available within the JET Operational Report (JET Scientific Team, in revision).

2.2 Pre-processing of downhole geophysical logs

After the respective compilation of the raw data measured in the two campaigns, the data were merged into one overall composite file. To achieve this, the following processing steps were carried out:

Step 1:

The reference depth for all measurements of a campaign is based on the depth of the first gamma ray measurement. This means that in both campaigns the GR data of the SALTEMP probe were chosen as the respective master curve.

Since each probe, except for the SONIC and BHTV, was equipped with its own GR sensor, the depth difference between the respective measurements can be determined by comparing the GR data and the GR master curve. This results in the following depth shifts for the measurements of campaign 2, for example, by means of optical determination:

CAL = -2.6 m, SGR = 0 m, IND = -0.4 m, DEN = 0 m, and NP = -0.4 m.

The depth difference in the BHTV of -0.5 m was obtained by comparing the clearly imaged pipe shoe with the caliper data. The depth difference in the SONIC data (-0.3 m) was determined by comparison with prominent GR anomalies.

Step 2:

The influence of the steel piping on the data does not have to be considered, as almost all measurements of campaign 1 were stopped at the pipe shoe at 33 m. The few data measured above a depth of 33 m are not used further. Two exceptions are the measurement of the inclination of the borehole and the temperature and conductivity of the fluid, which are not influenced by the casing.

In campaign 2, data from some of the probes were registered to a depth of about 230 m, i.e. about 7 m into the cased area of the borehole (pipe shoe at 237 m). The data above 237 m could be neglected, as in campaign 1 measurement data were recorded down to a depth of 240 m in the "open hole" condition.

Step 3:

Although the respective cable tension was not recorded for any probe, it is easy to determine where each probe lifted off from the deepest point of the borehole (240 m or ~650 m). Data from greater depths are not included.

Step 4:

Data affected by the approach to the casing is not used in the composite file. The following serves as an example: due to the design of the FEL probe, the drill string disturbs resistivities up to several metres before the tool reaches the casing shoe.

Since the water level in the borehole was almost at the ground surface during both visits, the effect of a dry borehole did not have to be considered or corrected in the data. (e.g. SALTEMP, SGR).

Step 5:

Some remarks on the determination of VP, VS and VP/VS from SONIC data are necessary. The probe records the full sonic wave-train at all three receivers simultaneously. This can be displayed either as a variable density log (VDL) or as a waveform ("wiggle"). The waveform data were exported for use in Robertson Geo's GeoCAD® software package to calculate the compressional (P) and shear (S) velocities. This calculation was carried out by Robertson Geo. A check of the picked first arrival of the p- and s-waves was possible using the pdf and WellCAD® files provided and gave clear and very good results. This is also due to the uniformity of the layers drilled through and the calibre of the borehole, which was true to size except for a few depth intervals.

Step 6:

Robertson Geo recorded all measurements (except BHTV) at a sampling rate of 1 cm, regardless of the tool used. This very dense sampling rate does not do justice to the sensors that are built into the borehole probes. The SGR probe serves as an example for this statement: by means of an SGR probe, the gamma rays from the formation are counted in a detector system. The cylindrical detector used here has the following dimensions: diameter 3.8 cm and height 15 cm. It is therefore obvious that the vertical resolution of this probe is at least in the decimetre range. The data of all probes except the BHTV were recalculated with a sampling rate of 10 cm, also to achieve an initial smoothing for better readability of the measurement curves.

Despite this first form of data smoothing, some measurement curves are still too noisy. This applies in particular to the NP (porosity), SGR (K, U, Th) and SONIC curves (VP, VS and VP/VS), which were additionally smoothed with a moving average filter of length 5 points.

Step 7:

Splicing between the measurements of the two campaigns was carried out separately for each trace at a depth between 230 m and 240 m. Each best splice point is determined visually. The final resistivity curve is composed of the values of the curve R_Long (IND) in the lower borehole section and the resistivity data of the FEL tool in the upper interval. We assume that the results with the deep radius of investigation of the Dual Focused Induction probe reflect the resistivities of the undisturbed formation better than the results with the "medium" radius.

The results of three probes are not spliced, but listed as individual measurements in the composite file: TEMPSAL, CAL and BHTV. The mud present in the two borehole sections when logging took place differs in its composition: in the upper section the mud has an average conductivity of about 80,000 uS/cm, whereas in the lower depth interval the mud conductivity was clearly "sweeter" with about 17,000 uS/cm. The BHTV measurements were not spliced because they already generated very large files in the individual intervals due to the data density of the ultrasonic imaging of the borehole wall. Splicing would only complicate the handling and evaluation of the BHTV measurements in one very large file.

All Robertson Geo probes were fully tested and calibrated at the Robertson Geo Deganwy site a few weeks prior to their deployment. The available protocols of the calibration measurements show a very good reproducibility of the data.

In summary, the quality of the data can be described as good to very good, although no environmental corrections were carried out. Different measurements require different corrections to be made to the log measurements to fit the standard conditions for which the tool has been characterised. For example, resistivity and density measurements usually require correction for changes in borehole diameter. In this borehole, however, the diameter is nearly true to size except for the two sections 580-610 m and 630-640 m and thus borehole corrections are not necessary over long distances. However, some narrower negative anomalies in the density curve indicate that caliber breakouts were not corrected. To compensate for the effects of borehole diameter, the SONIC, IND and NP probe use an array of multiple sensors. The NP probe uses dual detectors and a ratio method to provide a porosity measurement that compensates for, but is not independent of, the borehole diameter.

3 Dataset: Prees-2C Core Scanning Dataset

Citation: BGS Core Scanning Facility. (2022). Prees-2C Core Scanning Dataset. NERC EDS National Geoscience Data Centre. (Dataset). https://doi.org/10.5285/91392f09-25d4-454c-aece-56bde0dbf3ba

Summary: The core scanning dataset contains optical images, radiographic images, geophysical and geochemical property data obtained using a Geotek rotating X-ray computed tomography core scanner (RXCT), a Geotek multi-sensor core logger (MSCL-S) and a Cox Analytical Systems XRF core scanner (Itrax MC) at the Core Scanning Facility (CSF) at the British Geological Survey (BGS).

3.1 Whole round radiographic imaging

Radiographic images of the whole round core in the liner were taken with a Geotek X-ray computed tomography (RXCT) core scanner immediately after the core was curated. The RXCT has a rotating source detector arrangement that allows the core to remain undisturbed during scanning. X-ray images were generated at three angles, 0, 45 and 90 degrees, using “standard” imaging speed, resulting in a scanning time of c. 7 minutes per meter of core section and a total time of c. 30 minutes for (1) scanning at three angles, (2) handling and loading of core, (3) setup of the analysis, (4) analysis, and (5) unloading the core from the core scanner. The three angles give the user information on how structural features propagate through the core, as some may not be visible on some orientations. Sections shorter than c. 60 cm were not scanned due to physical constraints of the instrument. Scanning conditions were set to 130 kV and 500 µA with nominal resolution of c. 70 µm per pixel. Radiographic images were processed / scaled for enhancement of features, resulting in false greyscale information but with clear indication for high density features, cracks and structures in the core section. For this reason, intensity values between different images are not comparable. The raw .tiff imagery have been retained by BGS and can be requested from enquiries@bgs.ac.uk.

The processed image outputs are available under “**RAD_Processed_Images_JPG**”. The scaled images are included as .jpg files with their associated .xml files containing the metadata. The scaled images are labelled with the BGS core box ID and acquisition angle, i.e., _A0, A45 and A90. Each core box ID relates to a depth range listed within “**Prees_Depth_Model.xlsx**”.

3.2 Whole round multi sensor core logger (MSCL-S) scanning

Immediately after radiography, the core was logged for density, magnetic susceptibility, and natural gamma ray emission at 2 cm increments using a Geotek multi-sensor core logger (MSCL-S). Core liners were not opened prior to MSCL-S core scanning. Density (Den1) was determined using gamma ray absorption of gamma rays emitted from a Caesium (Cs) source. The sensor was calibrated on a fortnightly basis using an aluminium check-piece fitted into a section of the liner used for drilling at Prees. Standard calibration and measurement protocols for the MSCL-S followed the Geotek *MSCL Manual 1Nov16*. The integration time of the gamma ray was set to 10 s. Spatial resolution of the density gamma detector is c. 2 cm. Magnetic susceptibility (MS1) was measured using a Bartington magnetic susceptibility loop with 135 mm internal diameter and integration volume of c. 11 cm diameter. The integration time was set to 10 s. The magnetic susceptibility loop was zeroed before the beginning of each logging day. Natural gamma ray emission (NGAM) was measured by three spectrally resolved gamma ray detectors, one positioned above the core track and two placed laterally with an integration volume of c. 30 cm and an integration time of 30 s. Only absolute count rates were determined due to the limited integration time, thus making estimates of K, U and Th concentrations unreliable. Peak drift of the natural gamma detectors was monitored and calibrated on a fortnightly basis following the standard Geotek calibration protocol (*Geotek MSCL Manual 1Nov16*). A natural gamma background spectrum was acquired using an aluminium check-piece fitted into a section of liner as used for drilling at Prees. The resulting background spectrum was subtracted from the measured spectrum of the core to remove any environmental radiation effects.

The MSCL-S data outputs were aggregated into "**MSCL_S_Raw.csv**" and appended with three core depths: (a) Section Top Depth mbs = top depth labelled on BGS core box, (b) Section Top Depth mccd = corrected top depth according to the revised Prees depth model (refer to "**Prees_Depth_Model.xlsx** and **Prees_Depth_Model_Description.docx**") and (c) Depth mccd = corrected top depth + section depth.

The MSCL-S data was further processed and the outputs were aggregated into "**MSCL_S_Processed.csv**". Density measurements affected by cracks, rubbled core, and gaps in the core, as well as measurements corresponding to the ends of core liner and end caps were manually removed. Data within a section were moved by 2, 4 or very rarely 6 cm upwards when density measurements indicated that the rock has slid to the bottom of the core liner, leaving additional empty space at the top of the liner. Magnetic susceptibility data were corrected using density data assuming an average density of 2.5 g/cm^3 for intact core and integration volume of the detector of equating to a sphere of 11 cm diameter. Natural gamma ray emission data were equally corrected, assuming a density of intact core of 2.5 g/cm^3 and detector integration volume equating to a sphere of 30 cm diameter.

To monitor potential instrumental drift and determine repeatability of the analysis, three 30 cm-long check-pieces of natural materials (dolomite, granite, shale) were logged before and after each logging day. The check-piece data outputs were aggregated into "**MSCL_S_CheckPieces.csv**". The average density for the check-pieces is 2.17 ± 0.01 g/cm^3 (2sd) for dolomite, 2.62 ± 0.02 g/cm^3 (2sd) for granite and 2.82 ± 0.02 g/cm^3 (2sd) for shale. The average magnetic susceptibility for the check-pieces is -0.3 ± 0.8 SI * 10^{-5} (2sd) for dolomite, 6.0 ± 0.8 SI * 10^{-5} (2sd) for granite and 47.6 ± 1.6 SI * 10^{-5} (2sd) for shale. MS measurements underwent minor daily drifts of up to c. 1.5 SI * 10^{-5} between morning and afternoon runs. The average natural gamma ray for the check-pieces is 118 ± 8 cps (2sd) for shale, 197 ± 8 cps (2sd) for granite and 9 ± 6 cps (2sd) for dolomite. Due to the large integration volume of the gamma ray detectors, measurements are slightly influenced by adjacent check-pieces, but also by the natural heterogeneity of the check-pieces. However, no significant drifts in detector response could be detected.

3.3 Preparation for split core scanning

After completion of MSCL-S core scanning, the whole round core sections were transferred to the BGS core store for cutting into the archive and working halves. After cutting, the archive and working half cores were rinsed with tap water to remove residual drill mud and cutting residue, covered with paper tissues to soak up salty brine rising to the core surface, and left to dry overnight. The archive and working half cores were then photographed in the BGS core store using a Phase One 645DF camera fitted with a Schneider Blue Ring 55 mm lens and a Phase One P45+ digital back. Each archive halve was transferred to the CSF for XRF core scanning. Initially, the halve core sections were XRF scanned without any surface treatment, but salt present in the pore space of the core caused significant analytical problems from c. 80 m core depth downwards, necessitating further cleaning of the core. The archive halve core sections were washed in batches of 5, using spray bottles filled with tap water and sponges to wipe off residual cutting mud and any salt that had precipitated on the cut surface. Surfaces were sprayed with abundant water until obvious salt crusts had dissolved, were then further cleaned using sponges applied parallel to the sedimentary strata to prevent cross contamination with minimal mud residues, and sprayed with an excess of water again. Surplus liquid from the washing that ponded in the bottom of the liner was discarded and the section was then covered with two layers of paper tissue and a cardboard stripe, weighed down to ensure contact between the tissue and the wet core surface. The core sections were then left to rest for c. 1h, and then uncovered, the core segments levelled, and finally loaded into the ITRAX when the surface had dried. At core depth of c. 610 m and greater, salt formation on the core surface became even more severe and a revised cleaning protocol was adopted. For these core sections the core was washed as described above, covered and left for at least half an hour. They were then uncovered, washed again and covered for at least 15 minutes before levelling and transfer into the ITRAX. Analyses were then done one section at a time and as soon as possible after the surface had visibly dried to prevent formation of salt deposits.

3.4 Split core X-ray fluorescence (XRF) and optical imaging

X-ray fluorescence (XRF) measurements and optical images were collected using an Itrax MC core scanner (Cox Analytical Systems). Before core scanning, fragments of the split core were aligned with a levelling tool to ensure optimal alignment of the detector. XRF was measured at 1 cm step-size and 10 s integration time. For each core section, an initial surface scan was performed to compute the trajectory of the XRF detector and to acquire a standard resolution optical image (210 µm per pixel). A 100 s reference scan on a glass sample (NIST-610) was performed every 5th core section to monitor the stability of the analysis. The glass was cleaned on a weekly basis with alcohol (ethanol or propanol) to prevent build-up of contaminants. Replicate scans of core sections were done every 10th section or nearest to the tenth, in case the target section was substantially shorter than 1 m. These replicate scans served to quantify instrument repeatability and, when taken more than a few hours apart, to judge the bias arising from the build-up of salt on the core surfaces. The core interval between 183 m to 188 m depth was scanned both in December 2020 and June 2021 to check for long-term stability of the measurements. The Itrax MC core scanner automatically produces an XRF sumspectra for each core section, which was peak-fitted using the processing software Q-Spec version 8.6. A single fitting template has been used to fit the whole Prees core succession. The spectral XRF files and associated fitting template will be retained by BGS and can be requested from enquiries@bgs.ac.uk. In this software, the mean square error (MSE) indicates the goodness-of-fit of the mathematical model compared to the measured energies. MSE values are shown in the final data compilation file and can be used to identify region of poor fit.

Regarding the Prees XRF data, a value below 2.5 is taken to be acceptable for 10s integration, where higher values indicate a suboptimal fit, principally due to salt, cracks and gaps, but also significantly different rock chemistry, e.g., carbonate nodules or sulphides.

The fitted XRF data were output as elemental peak areas (counts) and were aggregated into "**ITRAX_Raw.csv**" and appended with core depth mbs = depth labelled on BGS core box. The XRF data was further processed and XRF data points were discarded if they derived from the very top and bottom of each run where the detector's trajectory included air and end caps. Furthermore, sampling points were deleted where there were significant (> 1mm) gaps between rock segments due to fracturing of the surfaces, where total count rates were below 100,000 cps (unless they were comparatively coarse grained, silicate rich intervals), and where Cl peak areas were above 100,000 counts. The processed XRF outputs were aggregated into "**ITRAX_Processed.csv**" and appended with core depth mccd = corrected top depth according to the revised Prees depth model (refer to "**Prees_Depth_Model.xlsx** and **Prees_Depth_Model_Description.docx**").

The data from core interval 183 m to 188 m that was scanned twice, once in December 2020 and once in June 2021, is aggregated into "**ITRAX_Overlap_Section.csv**". Both blocks of data are pasted next to each other with the same (uncorrected) depth scale applied. Element signatures of the 5 m scanned showed excellent reproducibility of general patterns, and 2 rsd reproducibility of 5 to 9 % for individual sample points for Al, Si, K, Ca, Ti, Mn and Fe. Cr, V, Rb, Sr, Zr and Ni reproduced to between 15 and 25 % 2 rsd for individual sample points and showed minor shifts in absolute values. Other elements show much larger scatter, mostly because the signal is at – or close to – the detection limit of the method. Additionally, fragments of core may have shifted a few millimetres between the two measurement campaigns, affecting particularly elements bound to sulphides which often occur in smaller (sub-centimetre) aggregates and layers, and can thus easily be shifted with respect to the track of the detectors.

The data from the replicate scans is aggregated into "**ITRAX_Replicates.csv**". Replicate scans of the core performed every tenth section where the core was not shifted between analyses showed a much better degree of reproducibility, with median relative differences between individual measurements of 1 % or less for Al, Si, S, K, Ca, Ti, and Fe. Median differences of 2 % for Sr and Mn, 4 % for Cr and Zr, 7 % for Cr and 10 % for Ni. The principal impediment for highly reproducible data was the formation of sodium chloride precipitates on the core surface which caused attenuation of the signal, especially for light major elements. This effect amounted to relative signal reductions (per 100,000 Cl counts) of c. 18 % for Al, 16 % for Si, 15 % for K, 12 % for Ca, 11 % for Ti, and 7 % for Fe. Minor observed differences in attenuation response over time and between sections and complete loss of signal where salt development was severe limited the ability to confidently correct for the salt bias to sample spots where Cl peak area is below 100,000 counts.

The data from the glass sample (NIST-610) is aggregated into "**NIST-610_Result.csv**". Repeat measurements of the glass show 2 sd reproducibility of peak areas of 350 counts or greater for low concentration elements indicating limits of quantification (6 sd of background) equivalent to a peak area of c. 300

counts for integration times of 10 s. With increasing peak areas, relative uncertainty of glass measurements decreases, approaching 2 % (2 rsd) for the highest concentration element (Si). Over the period of measurements for the entire core (November 2020 to August 2021) signal intensity of the glass averaged 101,000 ± 2,000 cps (n = 670, 2 sd). Minor signal drift was observed, with monthly averages for the glass ranging from 99,600 to 101,300 cps.

The image outputs are available under "**Optical_Images**". The images are labelled with the BGS core box ID. Each core box ID relates to a depth range listed within "**Prees_Depth_Model.xlsx**".

4 Dataset: Core photographs and Visual Core Descriptions

Dataset citation: to be made publicly available with BGS data: https://www.bgs.ac.uk/geological-data/national-geoscience-data-centre/ (Borehole: Prees 2C)

Summary: The core photographs and Visual Core Description dataset contain the core photographs taken at the time of curation at the National Geological Repository and subsequent visual core description. These two datasets were used in the creation of the summary stratigraphic column for 5065_1_C (Hesselbo et al., 2023).

Files included: marked in bold in text (naming of the files might change to BGS naming convention)

4.1 Core photography

Core photographs were taken for both the archive and working halves using a semi-automated layout on a scanning station at the British Geological Survey core repository using a digital camera. Data were immediately uploaded into the BGS system for quality control. The image outputs are available in low resolution under "JET_**CS_5065_1_C_All.zip**" (ITRAX Optical Images) and in high resolution under "JET_**BW_5065_C_002 – 114.zip**" (6 Files; Corebox Images).

4.2 Visual core descriptions (VCD)

A preliminary visual core description was carried out on site in Prees, which was based on only a superficial examination of the whole round core material inspected during initial curation and cleaning from drilling mud and fluids. This description is superseded by detailed core description of the archive half that was carried out from June to August 2021 at the BGS National Core Repository. These are available in file JET_5065_1_C_Lithology_Logs.zip containing scanned VCD descriptions "**5065_1_C_2_1_VCD.pdf — 5065_1_C_114_7_VCD.pdf**". A digital summary is not available. A detailed graphic log is under construction and a summary graphic log is published in Hesselbo et al. (2023).

The visual core descriptions, combined with the carbonate content from the pXRF dataset (Hesselbo et al., 2023) and grey scale time series extracted from optical images (https://doi.org/10.5285/91392f09-25d4-454c-aece-56bde0dbf3ba) provide the basis for the stratigraphic column in Hesselbo et al. (2023).

5 Data files: Bulk organic carbon isotopes ($\delta^{13}C_{org}$), total organic carbon (TOC) and portable X-Ray Fluorescence (*p*XRF)

Dataset citation: Included as supplementary data files in Hesselbo et al (2023): Data File 4 (d13Corg, TOC, CaCO3) and Data File 5 (pXRF)). Date file 6 presents the Ca/CaCO3 calibration curve used to calculate TOC.

Summary: Bulk organic carbon isotopes ($\delta^{13}C_{org}$), total organic carbon (TOC) and portable X-Ray Fluorescence (*p*XRF) of 5065_1_C (Prees-2C). The dataset provides a low resolution (~1 m) and a higher resolution (~0.20 m) chemostratigraphic record for the entire core.

Files included: TBC

5.1 Bulk organic carbon isotopes ($\delta^{13}C_{org}$) and Total Organic Carbon (TOC)

Bulk rock samples of approximately 20-50 g weight were taken from the bottom end of each 1 m core section during coring operations for rapid data generation to aid more detailed sample requests. A total of 625 samples with an average spacing of ~1 m was sampled.

Bulk rock samples were crushed and ground at the BGS, generating subsamples of different size fraction. Coarse material was retained for palynological work and fine-grained powders were split into subsamples for decarbonation and subsequent organic carbon (c-org) isotope analysis, and subsamples for bulk geochemical analysis. The C-org samples were decarbonated and analysed for TOC and organic carbon isotope ratios at the BGS, yielding a chemostratigraphic record of approximately 1 m resolution for the entire core. The TOC data was subsequently corrected for the carbonate content of the samples from pXRF data outline in section 4.2. The low resolution $\delta^{13}C_{org}$ data are contained within “**JET_5065_Low-resolution_d13C.csv**”.

5.2 Portable X-Ray Fluorescence (pXRF)

Finely powdered bulk rock splits were analysed for bulk geochemical composition at the University of Exeter Penryn campus using an Olympus portable XRF scanner in geochem mode, employing a 40 kV and a 10 kV beam for 60 s each. These data are contained within “**JET_5065_Lowresolution_pXRF.csv**”. The pXRF Ca data were used to estimate carbonate content and calibrated by determination of CO_2 emissions of a subset of 24 samples, using at Sercon 20-22 gas source isotope ratio mass spectrometer at University of Exeter, Penryn Campus. The calibration of pXRF Ca to carbonate content is provided within “**JET_5065_Lowresolution_pXRF_Calibration.csv**