UK Stratigraphical Framework Series: The Ancholme Group of the East Midlands Shelf

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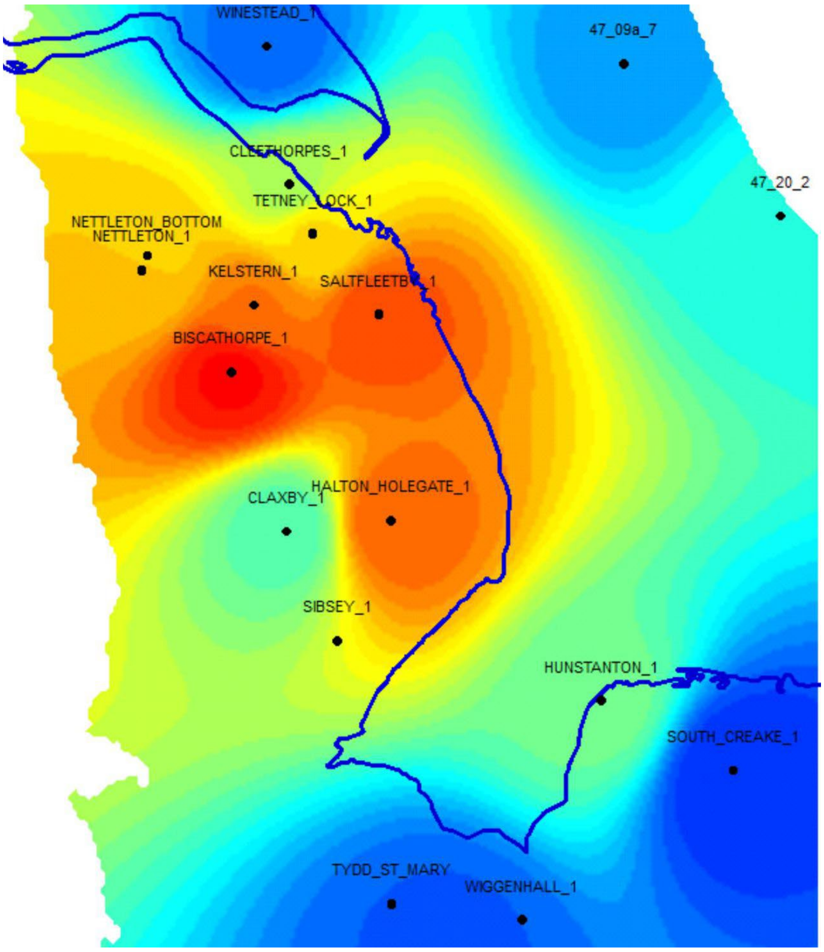

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UK Stratigraphical Framework Series: The Ancholme Group of the East Midlands Shelf

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Keywords

Ancholme Group, Oxford Clay, West Walton Formation, Ampthill Clay, Kimmeridge Clay, Stratigraphy, Correlation, Geophysical Logs.

Front cover

Total thickness of the Ancholme Group (Kellaways Formation omitted), reflecting the combined effects of depositional variation and post-depositional erosion.

Bibliographical reference

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Foreword

This report provides a high-level overview of the stratigraphy of the Ancholme Group (Oxford Clay, West Walton Formation, Ampthill Clay, Kimmeridge Clay) of the East Midlands Shelf, and is intended to provide a broad geological context for any future investigations of this interval.

Contents

FIGURES

TABLES

Summary

This report forms part of the UK Stratigraphical Framework Series (UKSFS) and provides an overview of the stratigraphy of the Ancholme Group (combined Kellaways Formation, Oxford Clay Formation, West Walton Formation, Ampthill Clay Formation, Kimmeridge Clay Formation) of the East Midlands Shelf. The work is based on interpretation of borehole geophysical logs and published records of cored boreholes. The emphasis of the report is on establishing criteria that allow the confident subdivision of the Ancholme Group (a predominately marine mudrock succession) into its component parts.

1 Introduction

1.1 BACKGROUND TO THE REPORT SERIES

This report on the Ancholme Group forms part of the UK Stratigraphical Framework Series (UKSFS) which aims to generate new information on the structure, stratigraphy and facies (lithology) trends within UK bedrock geology units (formations or groups) of sedimentary origin. The emphasis of the report series is primarily (but not exclusively) on onshore UK geology and on stratigraphical trends across the entire areal distribution of the rock unit, at both outcrop and in the subsurface. The reports thus make extensive use of borehole data where these are available, for example, in the post-Devonian sedimentary basins of the UK where there has been a long history of exploration for groundwater, hydrocarbons, coal and other mineral resources.

The over-arching aim of the UKSFS is to create concise stratigraphical frameworks that can provide regional understanding of key UK stratigraphical units and can form the context and basis for further site-specific work where and when this is required. An emphasis on surface to subsurface correlations should make the reports and associated datasets applicable to many sectors where the subsurface understanding is important (e.g. hydrogeology, deep geothermal energy, geological containment of hydrogen, carbon dioxide and radioactive waste).

Where input datasets allow, the specific technical aims of the report series are to:

- Interpret borehole data and produce a robust set of stratigraphical markers using all available evidence (e.g. core, cuttings, biostratigraphy, chemostratigraphy and geophysical logs).
- Create structure maps of the stratigraphical unit fitted to verified borehole markers and other data (e.g. available depth-converted seismic picks and outcrop lines) where available.
- Create thickness maps of stratigraphical units and any key internal subdivisions using verified borehole markers and correcting for borehole inclination and structural dips where required. Attempt to understand trends within the thickness maps and the role of basin structure in controlling depositional trends.
- Classify boreholes for lithology (facies) using combinations of core, cuttings and geophysical logs and use this information to provide greater insight into patterns, trends and subsurface heterogeneity of the rock unit.

The emphasis of the report series is on the concise delivery of new stratigraphical data and associated datasets at the UK scale. The reports do not aim to summarise all published information on a particular rock unit or specifically address issues around stratigraphical nomenclature which are covered in BGS stratigraphical formational reports (e.g. Barron et al. 2012), BGS Memoirs and in the BGS Lexicon of named rock units (www.bgs.ac.uk).

Most of the raw data (where publicly released) and information shown in the figures are available as spatial data files (Table 1).

Data	Data source	Projection
OS Terrain 50	Ordnance Survey 50 m digital terrain model	OSGB 1936/BNG
Well markers	This project	OSGB 1936/BNG
Outcrop erosion outlines	BGS DigMapGB-50	OSGB 1936/BNG
Jurassic faults	BGS Tectonic Map UKCS	OSGB 1936/BNG

TABLE 1: Raw & spatial data availability

2 Ancholme Group: geological background

The Ancholme Group (Gaunt et al.,1992) is a marine mudstone-dominated succession developed between Norfolk and Humberside, largely restricted to a region of Mid/Late Jurassic sedimentation bordering the North Sea Basin known as the East Midlands Shelf (Cope, 2006; Bradshaw 1992; Fig. 1). The Ancholme Group combines the Kellaways, Oxford Clay, West Walton, Ampthill Clay and Kimmeridge Clay formations (Gaunt et al.,1992; Fig. 2) that cannot easily be distinguished at outcrop and separately mapped. The West Walton and Ampthill Clay formations are mud- and silt-rich time equivalents of the Corallian Group (Fig. 2), a carbonate- and sand-rich facies that elsewhere usually provides clear lithological and topographical separation of the Oxford Clay and Kimmeridge Clay. Locally, in Cambridgeshire and north Norfolk, thin (ca. 2.5 – 10.5 m), muddy, oolitic limestones occur at the horizon of the West Walton Formation, named the Upware Limestone and Elsworth Rock members. The Upware Limestone is currently regarded as a local facies of the West Walton Formation, whilst the Elsworth Rock is classified as part of the Corallian Group. The occurrence of these facies suggests a transition into shallower water conditions away from the East Midlands Shelf, as described by Barron (2015), and re-establishment of the typical Late Jurassic succession with Corallian Group separating the Oxford Clay and Kimmeridge Clay formations.

In the near offshore from the East Midlands Shelf, south of the Market Weighton Block (Fig. 1), the Humber Group represents a lateral equivalent of the Ancholme Group. The Humber Group is comprised of (in ascending stratigraphical order): Leckenby, Oxford Clay, Seeley and Woodward formations (= West Walton & Ampthill Clay formations), and Kimmeridge Clay Formation (Cope, 2006; Cameron et al., 1992; Lott & Knox, 1994; Fig. 2). Further offshore, and northwards towards the Cleveland Basin (Fig. 1), sandy/oolitic limestone facies of the Corallian Formation are developed (Cameron et al., 1992; Kent et al.,1980, fig. 15; Lott & Knox, 1994). This unit is partly coeval with the onshore Corallian Group, and its development appears to be controlled by palaeogeography and related structure in the southern North Sea (Cameron et al., 1992, fig. 73),

Deposition of the mud-rich succession of the Ancholme Group suggests a persistently deeper water setting across the East Midlands Shelf and immediately adjacent parts of the southern North Sea Basin, un-interrupted by the relatively shallower-water conditions that accompanied deposition of the Corallian Group (Hesselbo, 2008) elsewhere across southern England and the Yorkshire (Cleveland Basin) area.

Most information about the stratigraphy of the largely drift-obscured outcrop of the Ancholme Group has come from boreholes drilled for ground investigations, hydrocarbons exploration and British Geological Survey mapping projects.

2.1 KEY OUTCROP REFERENCE SECTIONS AND BOREHOLES

The Ancholme Group is mapped at outcrop in the region around Kingston-upon-Hull, but borehole evidence shows that it occurs widely in the subsurface beneath Lincolnshire and Norfolk, with extensive near surface drift-obscured occurrences in the vicinity of The Wash. The key reference sections and boreholes for the Ancholme Group and its component formations where recognised on the East Midlands Shelf are listed in Table 2, and many are represented by extensive collections of sample material in BGS archives.

Locality	Key Ancholme Group Stratigraphy	Information Source(s)
Admirals Farm Borehole [NGR TF 5624]	Kimmeridge Clay Fmn (KC 2 – 16)	Gallois (1979, 1994)
Alandale Borehole [NGR TA 0025]	Ampthill Clay Fmn West Walton Fmn (Brantingham Mbr)	Gaunt et al. (1994)
Balaclava Farm Borehole [NGR TF 5523]	Kimmeridge Clay Fmn (KC 1 – 12) Ampthill Clay Fmn (AmC 33 – 42)	Gallois & Cox (1977) Gallois (1979, 1994)
Bardney 1 Borehole [NGR TF 1168]	West Walton Fmn (WWF 1 – 4) Oxford Clay Fmn (Peterborough, Weymouth, Stewartby Mbrs) Kellaways Fmn	Penn et al. (1986)
Brigg 1 Borehole [NGR TA0306]	Ampthill Clay Fmn (AmC 1 – 17) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough Mbr, Stewartby Mbr, Weymouth Mbr) Kellaways Fmn	Penn et al. (1986)
Dam Road Borehole [NGR TA 0222]	Kimmeridge Clay Fmn Ampthill Clay Fmn	Penn et al. (1986)
Daseley's Sand Borehole [NGR TF 5531]	Ampthill Clay Fmn (AmC 40 – 42)	Gallois & Cox (1977) Gallois (1979, 1994)
Denver Sluice Borehole [NGR TF 5901]	Kimmeridge Clay (KC 1 – 36) Ampthill Clay Fmn (AmC 1 – 40) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Gallois & Cox (1977) Gallois (1979, 1994) Penn et al. (1986)
Donington-on-Bain Borehole [NGR TF 2381]	Kimmeridge Clay (KC 1 – 49) Ampthill Clay	Penn et al. (1986)
East Clough Borehole [NGR SE 9724]	Ampthill Clay Fmn West Walton Fmn (Brantingham Mbr)	Gaunt et al. (1992)
Emorsgate Borehole [NGR TF 5320]	Kimmeridge Clay Fmn (KC 6 – 18)	Gallois (1979, 1994)
Gayton Borehole [NGR TF 7219]	Kimmeridge Clay Fmn	Penn et al. (1986)
Gedney Drove End Borehole [TF 4629]	Ampthill Clay (AmC 1 – 27?) West Walton Fmn (WWF 1 – 16) Ampthill Clay Fmn (AmC 1 – 29)	Gallois & Cox (1977) Gallois (1979, 1994) Penn et al. (1986)
Helpringham Borehole [NGR TF 1738]	Oxford Clay Fmn (Peterborough & basal Stewartby Mbrs) Kellaways Fmn	Penn et al. (1986)
Hook Drain Borehole [NGR TF 5712]	Kimmeridge Clay (KC 1 – 24) Ampthill Clay Fmn (AmC 32 – 42)	Gallois & Cox (1977) Gallois (1979, 1994)
Hunstanton Borehole [NGR TF 6942]	Kimmeridge Clay Fmn (KC 37 – 47)	Penn et al. (1986) Gallois (1994)
Hunstanton No. 1	Kimmeridge Clay Fmn (KC 1 – 47)	Penn et al. (1986)

	Ampthill Clay Fmn (AmC 1 – 40) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Weymouth & Stewartby Mbrs) Kellaways Fmn	
Lordsbridge Borehole [NGR TF 5712]	Ampthil Clay Fmn (AmC 19 – 39)	Gallois & Cox (1977) Gallois (1979)
Lowfield Lane Borehole [NGR SE 9626]	West Walton Formtion (Brantingham Mbr) Oxford Clay Fmn	Gaunt et al. (1992)
Marshland St James [NGR TF 5408]	Kimmeridge Clay Fmn Ampthill Clay Fmn (AmC 30 – 42)	Gallois & Cox (1977) Gallois (1979)
New Common Marsh Borehole [NGR TF 5223]	Kimmeridge Clay Fmn (KC 14 – 19)	Gallois (1979)
Nettleton Bottom Borehole [NGR TF1298]	Kimmeridge Clay Fmn (KC 1 – 42) Ampthill Clay Fmn (AmC 1 – 42) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Weymouth & Stewartby Mbrs) Kellaways Fmn	Penn et al. (1986)
Nettleton 1 Borehole [NGR TF 1298]	Kimmeridge Clay Fmn (1 – 44) Ampthill Clay Fmn (1 – 42) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Weymouth, Steartby Mbrs) Kellaways Fmn	Penn et al. (1986)
North Runcton Borehole [NGR TF 6416]	Kimmeridge Clay Fmn (KC 1 – 47)	Penn et al. (1986) Gallois (1994)
North Wootton Borehole [NGR TF 6424]	Kimmeridge Clay Fmn (KC 1 – 47) Ampthill Clay Fmn (AmC 1 – 42)	Gallois & Cox (1977) Gallois (1979, 1994) Penn et al. (1986)
Offshore Borehole CSU 71/65 [NGR TF 5846]	Lower Kimmeridge Clay; Upper Kimmeridge Clay (KC 34 – 44; elegans – hudlestoni zones)	Gallois & Cox (1974) Gallois (1994)
Offshore Borehole CSU 71/66 [NGR TF 6144]	Upper Kimmeridge Clay (wheatleyensis – pectinatatus zones; KC 42 – 47))	Gallois & Cox (1974) Gallos (1994)
Offshore Borehole CSU 72/77 [NGR TF 6348]	Upper Kimmeridge Clay (KC 45 – 49; pectinatatus Zone)	Gallois & Morter (1979) Gallois (1994)
Old Podike Bank [NGR TF 5605]	Kimmeridge Clay (KC 16 – 29)	Gallois (1979)
Ongar Hill Borehole [NGR TF 5724]	Ampthill Clay Fmn (AmC ?36 – 40)	Gallois & Cox (1977) Gallois (1979, 1994)
Osgodby Borehole [NGR TF 0792]	Ampthill Clay Fmn West Walton Fmn Oxford Clay Fmn	Gaunt et al. (1992)
Parson Drove Borehole [NGR TF 3710]	West Walton Fmn (WWF 1 - ?11) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Penn et al. (1986)

Pierrepont Farm Borehole [NGR TF 5723]	Kimmeridge Clay Fmn (KC 1 – 16) Ampthill Clay Fmn (AmC 42)	Gallois (1979, 1994)
Racecourse Road Borehole [NGR TF 5521]	Kimmeridge Clay Fmn (KC 19 – 28)	Gallois (1979, 1994)
Sibsey 1 Borehole [NGR TF 3650]	Kimmeridge Clay (KC 1 – 7) Ampthill Clay (AmC 1 – 42) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Penn et al. (1986)
South Cave [NGR SE 9332]	Ampthill Clay Fmn West Walton Fmn Oxford Clay Fmn	Gaunt et al. (1992)
Spalding Borehole [NGR TF 2414]	West Walton Fmn (WWF 1 – 10) Oxford Clay Formation (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Penn et al. (1986)
Spice Chase Borehole [NGR TF 5512]	Ampthill Clay Fmn (AmC 17 – 40)	Gallois & Cox (1977) Gallois (1979)
Stowbridge Borehole [NGR TF 6006]	Kimmeridge Clay Fmn (KC16 – 35)	Gallois (1979, 1994)
Symington Farm Borehole [NGR TF 5425]	Kimmeridge Clay Fmn (KC 1 – 12) Ampthill Clay (AmC 40 – 41)	Gallois & Cox (1977) Gallois (1979, 1994)
Terrington St John Borehole [NGR TF 5414]	Kimmeridge Clay Fmn (KC 1 – 18) Ampthill Clay Fmn (AmC 41 – 42)	Gallois & Cox (1977) Gallois (1979, 1994)
Tetney Lock Borehole [NGR TA 3300]	Kimmeridge Clay (KC 1 – 44) Ampthill Clay (AmC 1 – 42) West Walton Fmn (WWB 1 – 16) Oxford Clay Fmn (Peterborough Mbr, Stewartby Mbr, Weymouth Mbr) Kellaways Fmn	Penn et al. (1986)
The Grange Borehole [NGR TF 5813]	Kimmeridge Clay Fmn (KC 18 – 25)	Gallois (1979, 1994)
Tilney Fen Side Borehole [NGR TF 5411]	Ampthill Clay Fmn (AmC 26 – 41)	Gallois & Cox (1977) Gallois (1979)
Tilney A11 [NGR TF 5717]	Kimmeridge Clay Fmn (KC 18 – 30)	Gallois (1979)
Tydd St Mary Borehole [NGR TF 4317]	Ampthill Clay Fmn (AmC 1 – 4) West Walton Fmn (WWB 1 – 16) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Gallois (1994)
Ulceby Cross Borehole [NGR TF 4173]	Kimmeridge Clay Fmn (1 – 45) Ampthill Clay Fmn (AmC 1 – 42) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Weymouth, Stewartby Mbrs) Kellaways Fmn	Penn et al. (1986)
Vale of Ancholme, north Lincolnshire (Type area of the Ancholme Group)	Kimmeridge Clat Fmn Ampthill Clay Fmn	Gault et al. (1992)

[NGR SE 9715]	West Walton Fmn (Brantingham Mbr) Oxford Clay Fmn Kellaways Fmn	
Vinegar Middle Borehole [NGR TF 6025]	Kimmeridge Clay Fmn (KC 12 – 19)	Gallois (1979, 1994)
Walkers Marsh Borehole [NGR TF 5225]	Ampthill Clay Fmn (AmC 36 – 42) Kimmeridge Clay Fmn (KC 1 – 10)	Gallois & Cox (1977) Gallois (1979, 1994)
West Walton Highway Borehole [NGR TF 4913]	Ampthill Clay Fmn (AmC 1 – 16) West Walton Fmn (WWB 1 – 16) Oxford Clay Fmn (Weymouth Member)	Gallois & Cox (1977) Gallois (1979, 1994) Penn et al. (1986)
Wiggenhall St Peter Borehole [NGR TF 6013]	Kimmeridge Clay Fmn (KC 1 – 32) Ampthill Clay Fmn (AmC 1 – 42) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs), Kellaways Fmn	Gallois & Cox (1977) Gallois (1979)
Winstead Borehole [NGR TA 2724]	Kimmeridge Clay Fmn (KC 1 – 6) Ampthill Clay Fmn (AmC 1 – 42) West Walton Fmn (WWB 1 – 16) Oxford Clay Fmn (Stewartby Member) Kellaways Fmn	Penn et al. (1986)
Wisbech 1 [NGR TF 4008]	Ampthill Clay Fmn (AmC 1 - ?7) West Walton Fmn (WWF 1 – 16) Oxford Clay Fmn (Peterborough, Stewartby, Weymouth Mbrs) Kellaways Fmn	Penn et al. (1986)
Worlaby Borehole E [NGR SE 9915]	Ampthill Clay Fmn West Walton Fmn (inc. Brantingham Mbr) Oxford Clay Fmn	Gaunt et al. (1992)

Table 2: Key outcrops and boreholes on the East Midlands Shelf.

2.2 LITHOSTRATIGRAPHY

The following tables (Tables 3 – 7) summarise lithostratigraphical information for component formations of the Ancholme Group. For the Kellaways, Oxford Clay and Kimmeridge Clay these details are abbreviated, as much of the information about these comes from successions in areas beyond the geographical range of the Ancholme Group, and will be the focus of future detailed reports.

Formation	Member	Typical features	Thickness on East Midlands Shelf
Kellaways	Kellaways Sand	Patchily indurated calcareous, pale grey, sandstone/siltstone, with thin beds of mudstone.	3 – 5 m
	Kellaways Clay	Mudstone, smooth in basal part, becoming silty & sandy upwards with nodules of argillaceous limestone	Up to 8 m

Table 3: Lithostratigraphy of the Kellaways Formation. Kellaways Formation likely predominantly represented by Kellaways Sand on East Midlands Shelf (Page, 1989).

Formation	Member	Typical features	Marker-beds	Marker-bed features	Thickness on East Midlands Shelf
Oxford Clay	Weymouth Member	Mainly pale-grey, blocky, calcareous mudstone with thin carbonaceous mudstone units. Generally weakly silty but some thin calcareous siltstones present.	Pans Hill Siltstone (locally in south Midlands; Horton et al., 1995)	Ca. 0.3 – 0.5 m thick brownish-grey calcareous siltstone (Mariae Zone, upper Scarburgense Subzone)	2 – 23 m (affected by variable erosion at base of West Walton Formation)
	Stewartby Member	Pale – medium grey, typically smooth-textured, variably silty blocky calcareous mudstone. Generally silty and calcareous in upper part with limestone in some areas (Lamberti Limestone).	Lamberti Limestone (present mainly in south Midlands; Cope, 2006) Trochocyathus Band .	Pale grey or cream-coloured, soft, silty limestone or calcareous siltstone/mudstone Typically, about 0.3 m thick. Horizon with common remains of the solitary button-shaped coral *Trochocyathus magnevillianus*.	12 – 22 m
	Peterborough Member	Common laminated, organic-rich mudstone & subordinate beds of pale/medium-grey mudstone. Horizons of concretionary limestone.	Acutistriatum Band Comptoni Bed	Hard calcareous mudstone that may contain concretionary limestone nodules. Characterised by the ammonite *Kosmoceras acutistriatum*. About 0.3 m thick. Coarse, gritty shelly pyritic mudstone that may contain concretionary limestone nodules. Characterised by the ammonite *Binatisphinctes comptoni.*	0 – 21 m

Table 4: Lithostratigraphy of the Oxford Clay Formation.

Formation	Typical features	Member	Typical features	Marker-beds	Thickness on East Midlands Shelf
West Walton	Typically, rhythmic alternations of dark grey, silty mudstone (rich in fine-grained shell and plant material) with pale grey mudstone and cementstone horizons.	Upware Limestone (local occurrence in Cambridgeshire)	Cross-bedded ooidal limestones and coral rag.	Subdivided by Gallois & Cox (1977) into 16 numbered beds (WWF 1 – 16)	West Walton Formation: typically 15 m; up to 20 m Elsworth Rock: 2.5 – 10.5 m Upware Limestone: up to 11 m Brantingham Member: up to 18m
		Brantingham (restricted occurrence in Humber area)	Sandstones, calcareous siltstone and thin, lenticular, sandy & silty limestones, with minor thin mudstones		

Table 5: Lithostratigraphy of the West Walton Formation.

Formation	Typical features	Marker-beds	Thickness on East Midlands Shelf
Ampthill Clay	Smooth or slightly silty, pale to medium grey calcareous mudstone. Topmost beds are typically pale grey marls with cementstone and in the beds 30 – 42, erosion surfaces and phosphatic nodules	Subdivided by Gallois & Cox (1977) into 42 numbered beds (AmC 1 – 42)	50 – 90 m

Table 6: Lithostratigraphy of the Ampthill Clay Formation.

Formation	Typical Features	Informal Subdivisions (based on changes in ammonite fauna)	Members	Typical Features	Marker-Beds	Thickness on East Midlands Shelf
Kimmeridge Clay	Mudstones (calcareous or kerogen-rich or silty or sandy); thin siltstone and cementstone beds; locally sands and silts	Upper Kimmeridge Clay (= Upper Kimmeridgian /Bolonian)	Elsham Sandstone	Medium – coarse-grained, bioturbated sandstone with clayey or calcareous matrix. Shelly & lignitic. Equivalent to the basal part of the Kimmeridge Clay	Subdivided by Cox & Gallois (1979) and Gallois (1994) into 14 numbered beds (KC 36 – 49)	Kimmeridge Clay Fmn up to 175 m (variably eroded at unconformable upper surface of formation)
		Lower Kimmeridge Clay (= Lower Kimmeridgian/ Kimmeridgian)			Subdivided by Gallois & Cox (1976) into 35 numbered beds (KC 1 – 35)	

Table 7: Lithostratigraphy of the Kimmeridge Clay Formation.

2.3 BOUNDARIES OF STRATIGRAPHICAL UNITS

Features that define the stratigraphical limits of the Ancholme Group and its component formations are as follows (Fig. 3):

- Base Ancholme Group / Base Kellaways Formation: Typically, a shelly mudstone resting on the limestone of the Cornbrash Formation.
- Base Oxford Clay Formation: Appearance of dark, silty mudstone above sandstones of the underlying Kellaways Formation (Cox et al., 1992).
- Base West Walton Formation: Typically, the inter-burrowed surface of dark grey, silty mudstone resting on pale grey, smooth-textured mudstones of the Oxford Clay Formation (Weymouth Member).
- Base Ampthill Clay Formation: Base of mudstones, resting on darker siltier mudstone, or limestone (Upware Limestone) of the West Walton Formation. Locally, also base of mudstones on limestone of Elsworth Rock Member (Corallian Group).
- Base Kimmeridge Clay Formation: An erosive non-sequence with phosphatic pebbles marking an upward change to darker-coloured mudstones. Generally, a marked colour change and break-of-slope at outcrop.
- Top Ancholme Group/Top Kimmeridge Clay: Unconformable junction of mudstones with uppermost Jurassic/Lower Cretaceous limestones and sandstones.

2.4 BIOSTRATIGRAPHY

The standard biostratigraphical classification of the component formations of the Ancholme Group is based on ammonites, the preserved remains of which are generally abundant, although other types of fossils (e.g. brachiopods, bivalves, crinoids) can also be useful for recognising discrete intervals of strata (marker-beds) within the succession. The chronostratigraphical and biozonal classification of the component formations of the Ancholme Group is shown in Fig. 4.

2.5 GEOPHYSICAL LOG SIGNATURES AND REGIONAL CORRELATION

The correlations for a selection of boreholes investigated as part of this study (Fig. 5) are illustrated in Figure 7, and the geophysical log features and trends that allow their interpretation are discussed below. Selected cored and/or geophysically logged boreholes (Fig. 8) across the East Midlands Shelf and adjacent offshore areas provide a basis for understanding the stratigraphy and correlation of the Ancholme Group.

In conjunction with borehole core where available, gamma and sonic geophysical logs provide the most useful means of interpreting the sub-surface stratigraphy of the Ancholme Group. Gamma logs respond primarily to mud-content, and in the Ancholme Group are useful for indicating intervals with high organic content, or units with increased sand/silt. Sonic logs respond to changes in lithology and cementation, intervals that are sandy/silty and/or more calcareous generally having faster interval transit times compared to adjacent mudstone-/organic-rich units.

A cross-plot of gamma-ray and sonic transit time for the Nettlecombe Bottom Borehole (Fig. 6) shows that the Oxford Clay, West Walton and Ampthill Clay/Kimmeridge Clay (undifferentiated) can be readily distinguished based on these properties. In contrast the Ampthill Clay and Kimmeridge Clay show a large degree of overlap in their gamma ray and sonic properties and distinguishing these units from geophysical logs requires additional criteria.

2.5.1 Kellaways Formation

Typically indicated by a sharp downward change from high gamma and slow sonic log values in the basal part of the Oxford Clay to low gamma and fast interval transit times in the sand-rich part of the upper part of the Kellaways Formation. The lower, more clay-rich part of the formation produces a sharp reversal in the above trend (high gamma, slow sonic), with another sharp reversal (low gamma, high sonic) where the base of the Kellaways Clay Member contacts the Cornbrash Formation (Fig. 8).

2.5.2 Oxford Clay Formation

Overall the Oxford Clay is thin on the East Midlands Shelf, reflecting both attenuation of the succession (Woods et al., in press), and variable erosion of the top of the succession by the overlying West Walton Formation.

The base of the Oxford Clay corresponds with a sharp increase in gamma log values and interval transit time on sonic logs, corresponding with the presence of organic-rich mudstones in the lower part of the Oxford Clay (Peterborough Member). Gamma log values decline in the Stewartby and Weymouth members, as these successions become more calcareous with a significantly lower organic mudstone content (Cox et al., 1992). A limestone-rich interval at the top of the Stewartby Member (Lamberti Limestone) corresponds with a sharply developed low gamma response and fast sonic inflection. The top of the Oxford Clay is represented by a more marked decline in gamma log values, sometimes accompanied by sharp oscillations in both gamma and sonic log signatures that marks the base of the West Walton Formation (Fig. 8).

2.5.3 West Walton Formation

The characteristically thin rhythmic siltstone/mudstone units of the West Walton Formation (Gallois & Cox, 1977) are responsible for a general decline in gamma log values above the top of the Oxford Clay, often associated with high-frequency oscillation in both gamma and sonic log signatures. The top of the West Walton Formation marks a major shift to mudstone-dominated lithologies at the junction with the overlying Ampthill Clay. This boundary is associated with a sharp increase in gamma log values and increase in interval transit time on sonic logs. This feature is very clear on the logs illustrated in Figure 8, and as such is selected as the correlation datum for alignment and comparison of the borehole successions shown in Figure 7.

2.5.4 Ampthill Clay Formation

Core data from the Nettleton Bottom and Denver Sluice boreholes, where the Ampthill Clay has been classified according to the bed numbers of Gallois & Cox (1977, 1979) shows that there is a very consistent relationship between this stratigraphy and gamma log inflections in the lower and upper part of the formation. The same inflection patterns can be traced into uncored successions (e.g. Hunstanton 1, Fig. 8), providing high confidence for their high-resolution lithostratigraphical interpretation. At the base of the Ampthill Clay, above the marked increase in gamma and increase in interval transit time that marks the base of the formation, beds AmC 5 – 6, 7 – 14, 15 and 17 are associated with a distinctive pair of sharp peaks and troughs (Fig.8). Above this it is difficult to identify any laterally persistent trends, but at the top of the formation there is a reasonably consistent broad trough (drop) in the gamma log, usually associated with some thin units with low interval transit time. In cored successions this inflection is variably identified as AmC40 or AmC42, corresponding with an interval of silty and highly calcareous mudstone with erosion surfaces and cementstone horizons that is typically developed in the highest part of the Ampthill Clay (Gallois & Cox, 1979; Gallois, 1994).

2.5.5 Kimmeridge Clay

The most problematic boundary to consistently pick in the Ancholme Group is the junction of the Ampthill and Kimmeridge Clay formations. The broad low gamma trough serves as a reasonably good guide to the position of the top of the Ampthill Clay, but this feature is not associated with any conspicuous shift in the average character of the geophysical logs (Fig.8). Two useful guides for discriminating log sections in these mudstone formations are: 1) the serrated character of the gamma log in the Ampthill Clay generally shows fewer high amplitude oscillations than the serrated log in the Kimmeridge Clay. This presumably reflects the slightly broader range of lithologies in the Kimmeridge Clay (which usually includes both organic-rich mudstones and frequent thin stone bands), and the strongly cyclic arrangement of facies units that typically characterise this formation (Gallois, 1994; Cope, 2006; Weedon, 1999); 2) the gamma logs in the Kimmeridge Clay typically show a series of sharp steps, where segments of the signature reduce in value before slowly building in the overlying succession. Based on core data, these steps seem particularly associated with beds KC17, KC29 and KC44. Again, these steps probably relate in some way to the pervasive cyclicity that has been reported for the formation.

On the East Midlands Shelf, the top of the Ancholme Group is represented by an unconformity with Late Jurassic, Cretaceous or Quaternary strata, typically corresponding with sharp changes in the overall character in both gamma and sonic logs compared to the immediately underlying Kimmeridge Clay.

2.6 STRUCTURE AND REGIONAL THICKNESS TRENDS

A structural contour plot for the top of the Kellaways Formation across the East Midlands Shelf shows a consistent eastward offshore dip (Fig. 9), with gradients steeper in the north and shallower and more north-easterly in the south. The total thickness pattern of the Ancholme Group across the region (Fig. 10) is complicated by variable post-depositional erosion of the Kimmeridge Clay Formation. The pattern of thicker strata forms an arcuate area running along the coast and inland south of the Humber (Fig. 9), with thinning north towards the Humber, eastwards into the North Sea, and south towards The Wash. Northward thinning potentially indicates increasing influence of the Market Weighton Axis. The southern margin of this structure was somewhat variable, and at times is thought to have broadly coincided with faults close to the line of the Humber (Brough Faults, Flixborough Faults; Gaunt et al., 1992). Southward thinning around The Wash probably reflects increasing proximity to the Anglo-Brabant Massif (Fig. 1; Cameron et al., 1992, fig. 72). The pattern of apparent thinning to the edge of the North Sea Basin may be caused by lack of data. Cameron et al. (1992, fig. 72) suggested that relatively thick Humber Group strata (+300 m) might extend offshore from Lincolnshire, before the succession begins to thin further offshore towards the Sole Pit Trough. A potentially better indication of depositional thickness trends is provided by the thickness plot of the combined Oxford Clay, West Walton and Ampthill Clay formations (Fig. 11). This plot shows a consistent region of thicker strata between the northern edge of The Wash and south of the Humber, and probably indicates the palaeogeographical extent of the deepest parts of the East Midlands Shelf, between shallower regions marginal to the Market Weighton High further to the north, and the flanks of the Anglo-Brabant Massif to the south (Fig. 1).

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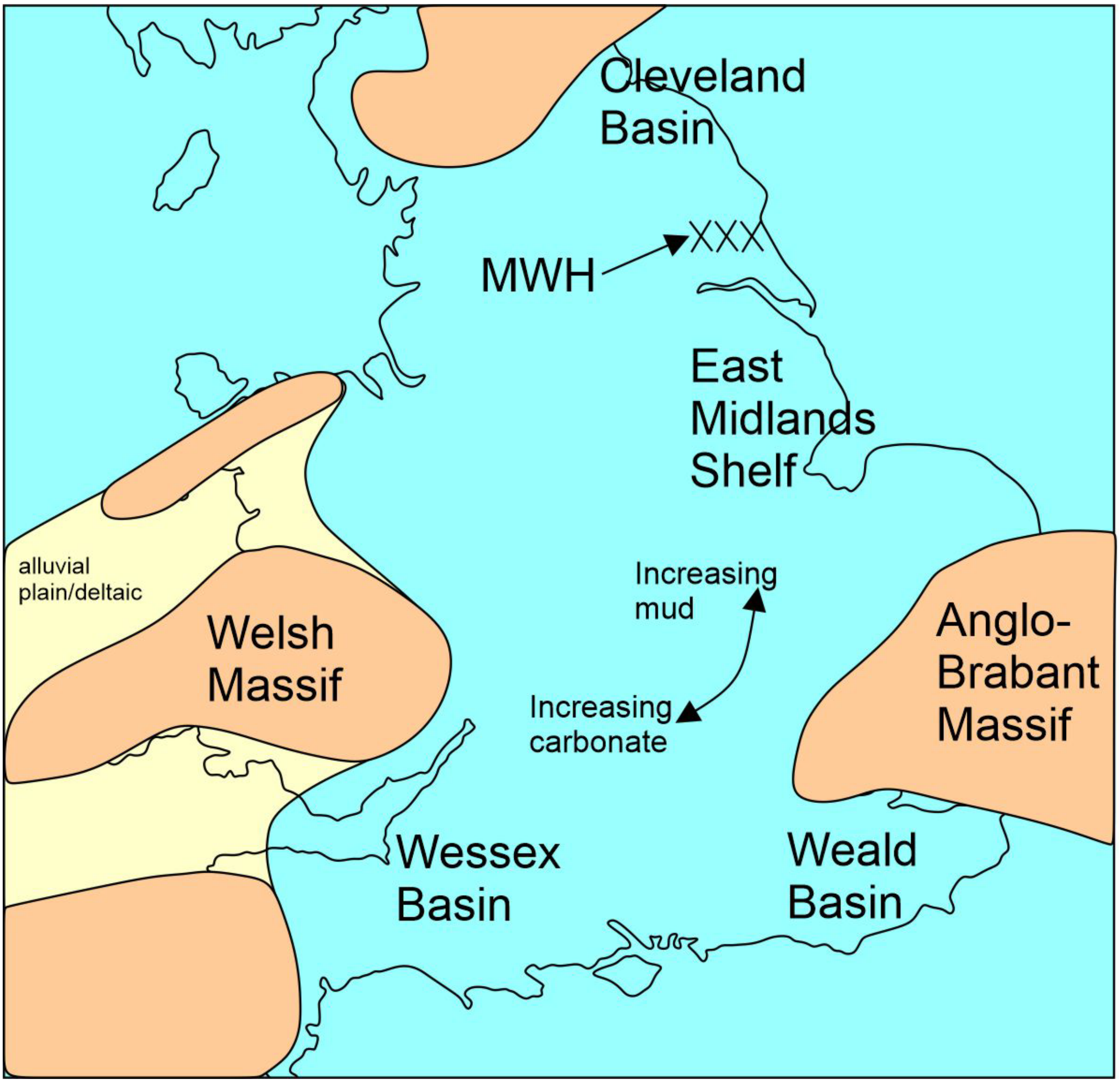
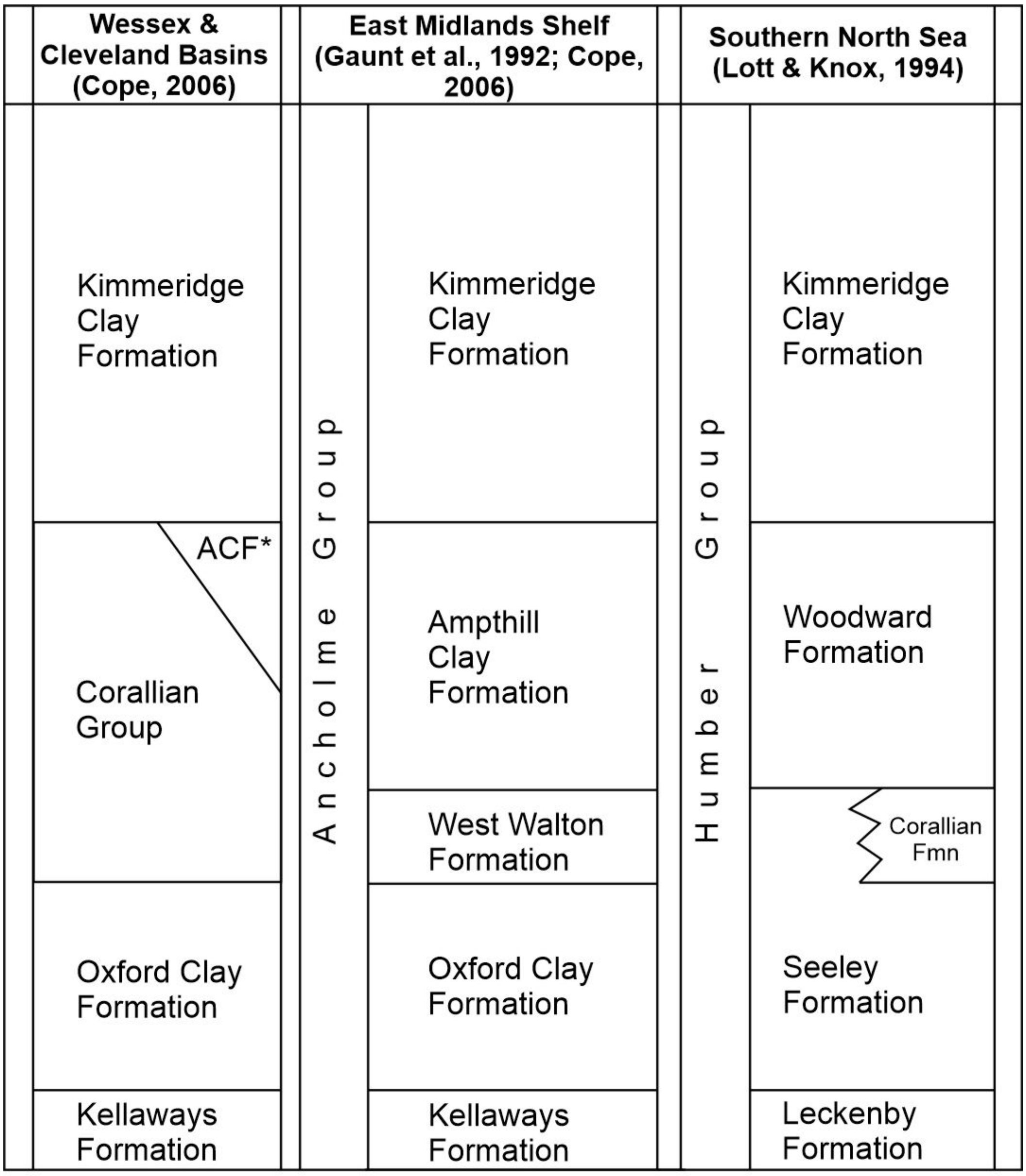


Figure 1. Mid Oxfordian palaeogeography reflecting conditions during deposition of the Corallian Group and laterally equivalent West Walton and Ampthill Clay formations of the Ancholme Group. Based on Map J9 of Bradshaw et al. (1992). MWH = Market Weighton High.



ACF = Ampthill Clay Formation
*: Cleveland Basin

Figure 2. Correlation of the Ancholme Group of the East Midlands Shelf with laterally equivalent successions in southern and northern England and the Southern North Sea. The Corallian Formation is a locally developed offshore oolitic limestone and/or sandstone developed between the Seeley Formation below and the Woodward Formation above. Across the offshore East Midlands Shelf the Corallian Formation rapidly transitions into mixed sandstone/siltstone mudstone facies of the upper part of the Seeley Formation, represented in the onshore East Midlands Shelf by the West Walton Formation.

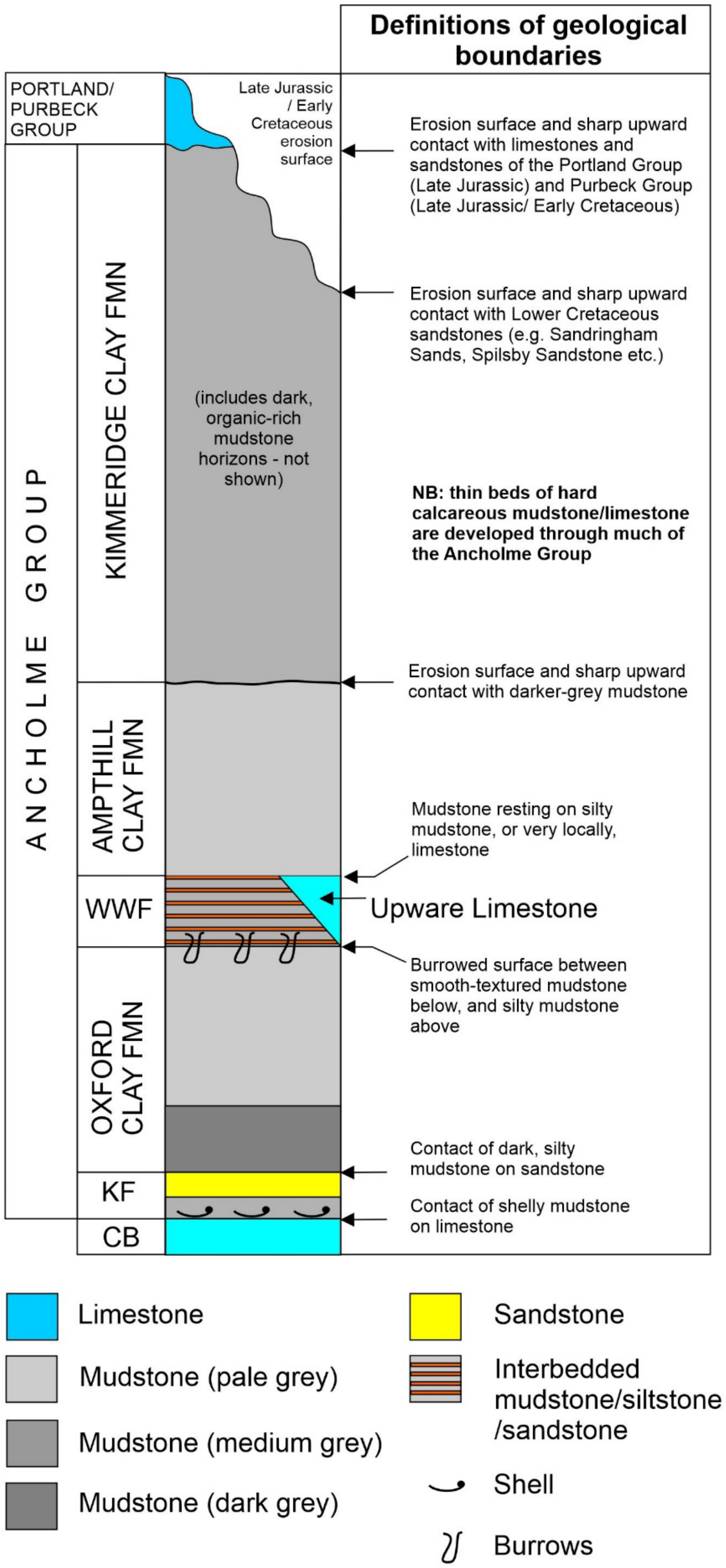
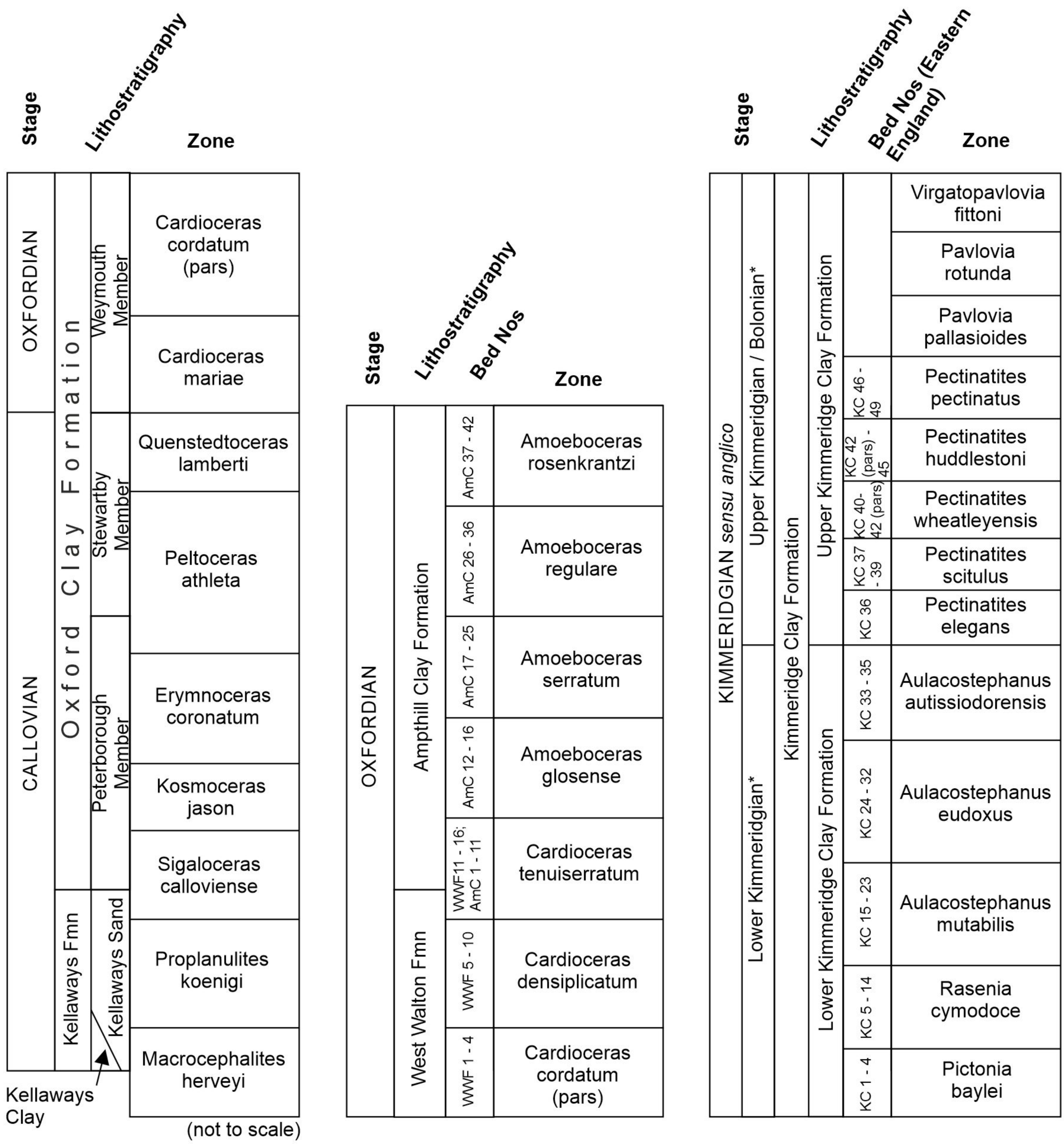


Figure 3. Ancholme Group lithostratigraphy and key criteria for recognition of component formation boundaries. (not to scale).
CB: Cornbrash Formation; KF: Kellaways Formation; WWF: West Walton Formation; FMN: Formation



WWF = West Walton Formation standard bed numbers
AmC = Ampthill Clay standard bed numbers
KC = Kimmeridge Clay standard bed numbers (Eastern England)

NB: The Kimmeridgian of European successions equates with only the Lower Kimmeridgian *sensu anglico*, creating a gap between the top of the Kimmeridgian *sensu stricto* and the base of the Portlandian. Cope (1993) suggested using the term Bolonian for this interval, although adoption of this stage nomenclature is not universal, with many UK workers using the term Kimmeridgian to refer to the whole of the Kimmeridge Clay Formation.

Figure 4. Biostratigraphical and chronostratigraphical subdivision of the Ancholme Group, including relationship of marker-bed numbers to biozones for the West Walton, Ampthill and Kimmeridge Clay formations. Based on information from Gallois & Cox (1977), Penn et al. (1986), Morgans-Bell et al., (2001), Cope (2006).

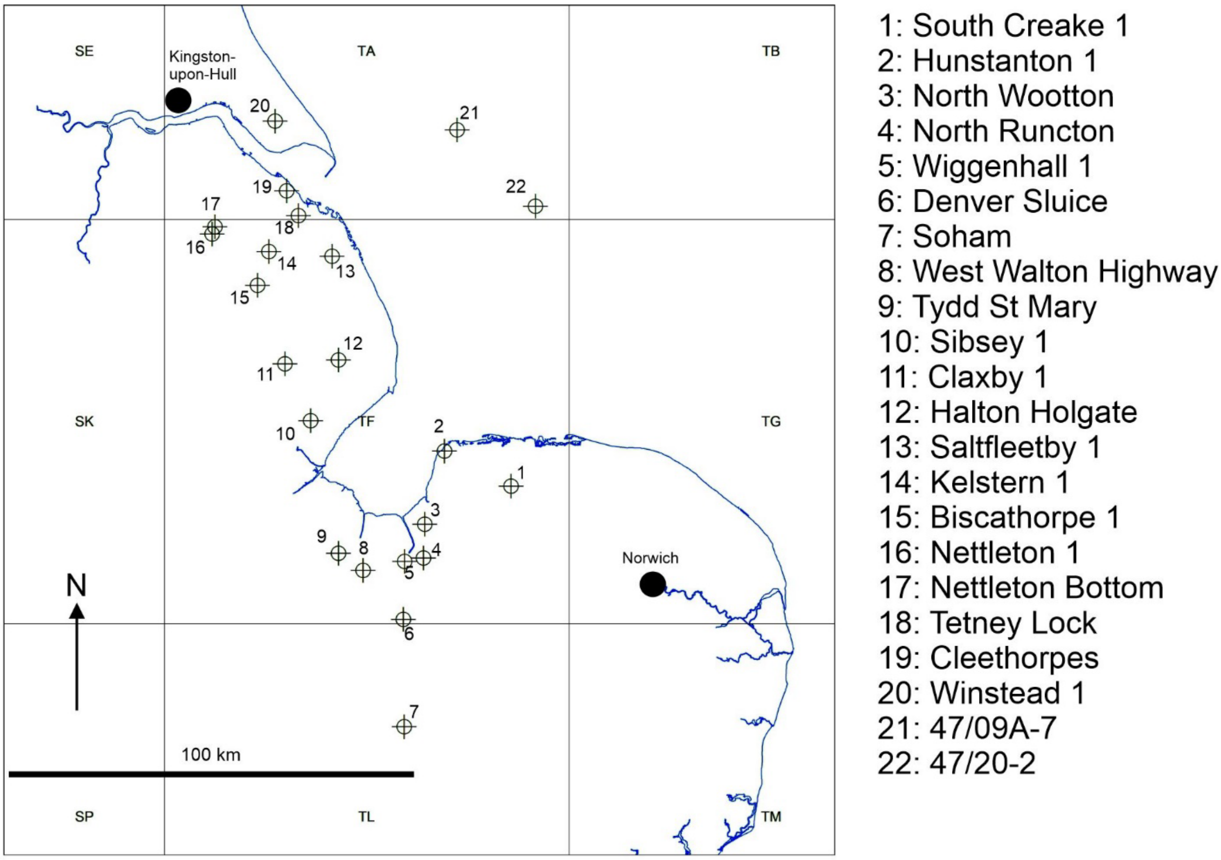


Figure 5. Boreholes with geophysical logs investigated as part of this work.
TL = letters denoting British National Grid 100 km grid square.

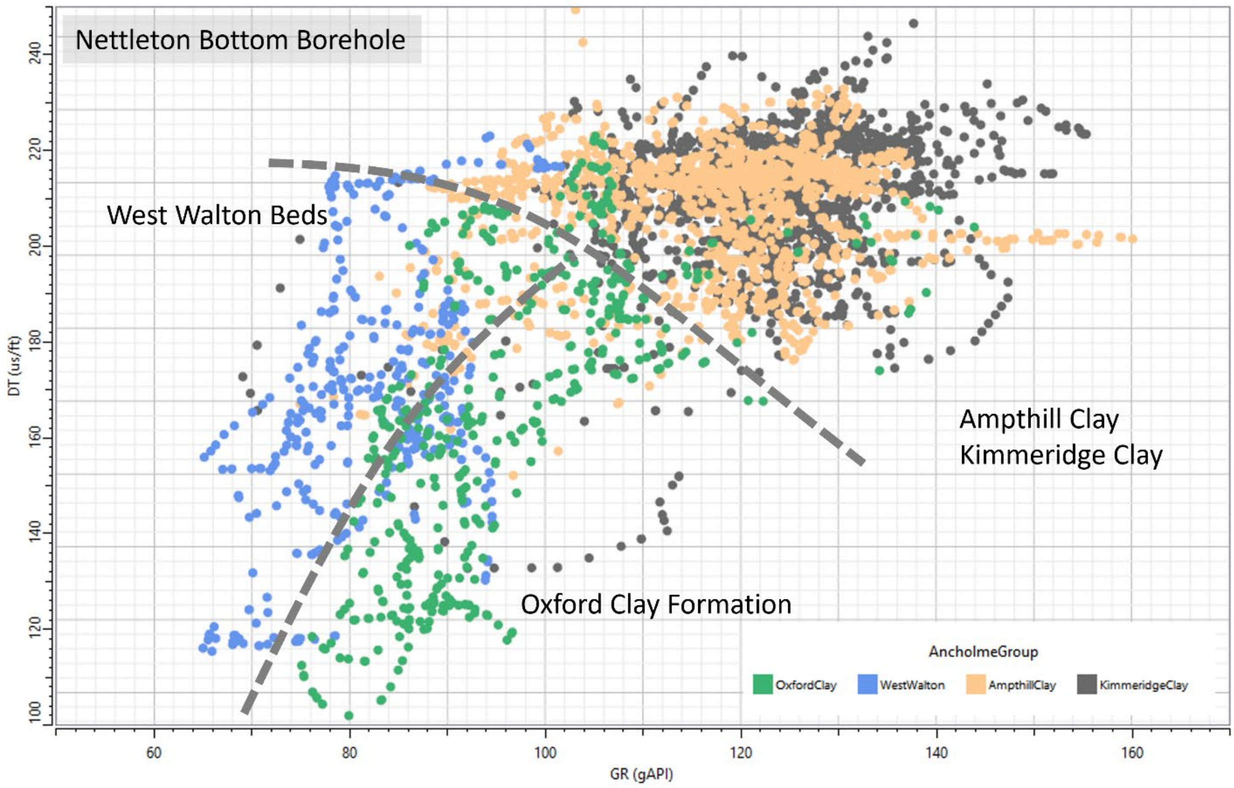


Figure 6. Cross-plot of gamma-ray (GR) and sonic transit time (DT) for the Nettleton Bottom Borehole with points coloured by lithostratigraphical subdivisions of the Ancholme Group (excluding Kellaways Formation). The plot shows the relatively clear segregation of the Oxford Clay, West Walton and Ampthill Clay/Kimmeridge Clay based on the gamma-ray and sonic log properties. The Ampthill Clay and Kimmeridge Clay are strongly overlapping.

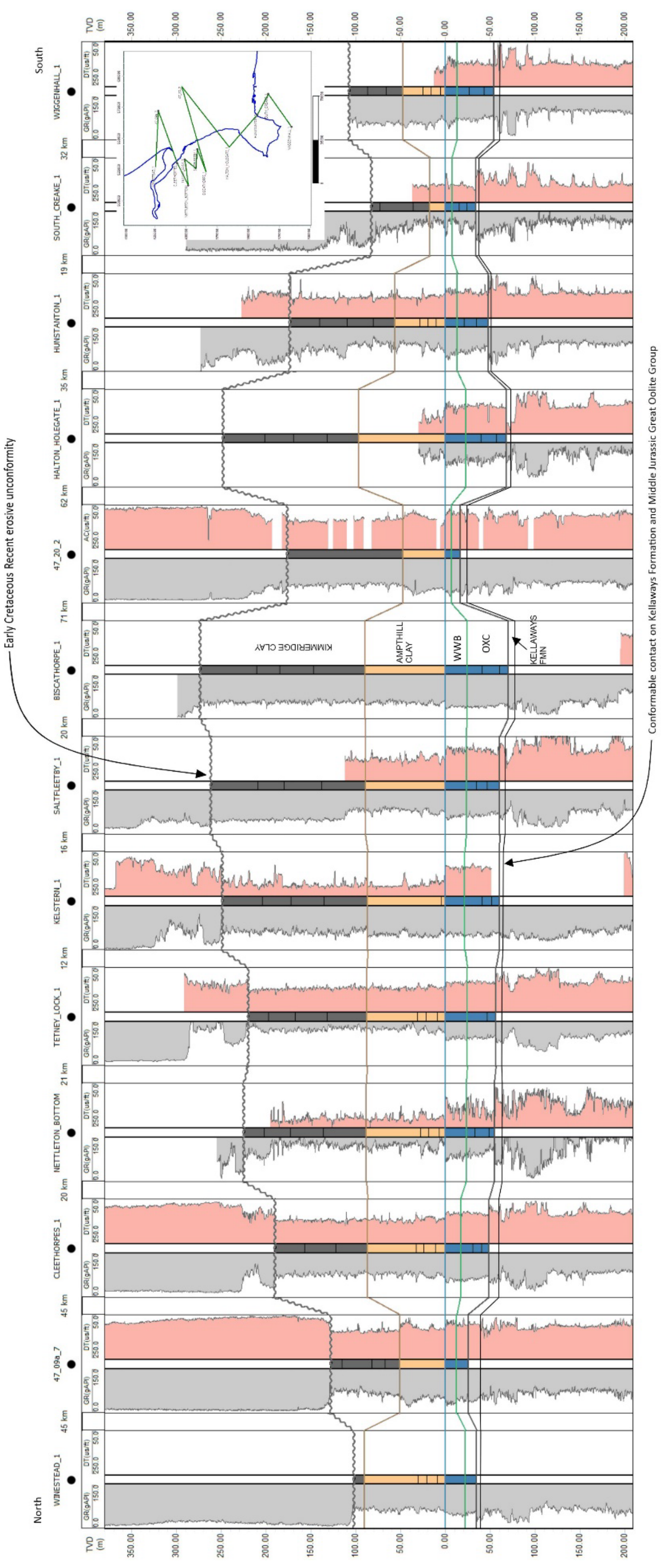


Figure 7. Geophysical log correlation of the Ancholme Group in selected boreholes across the East Midlands Shelf

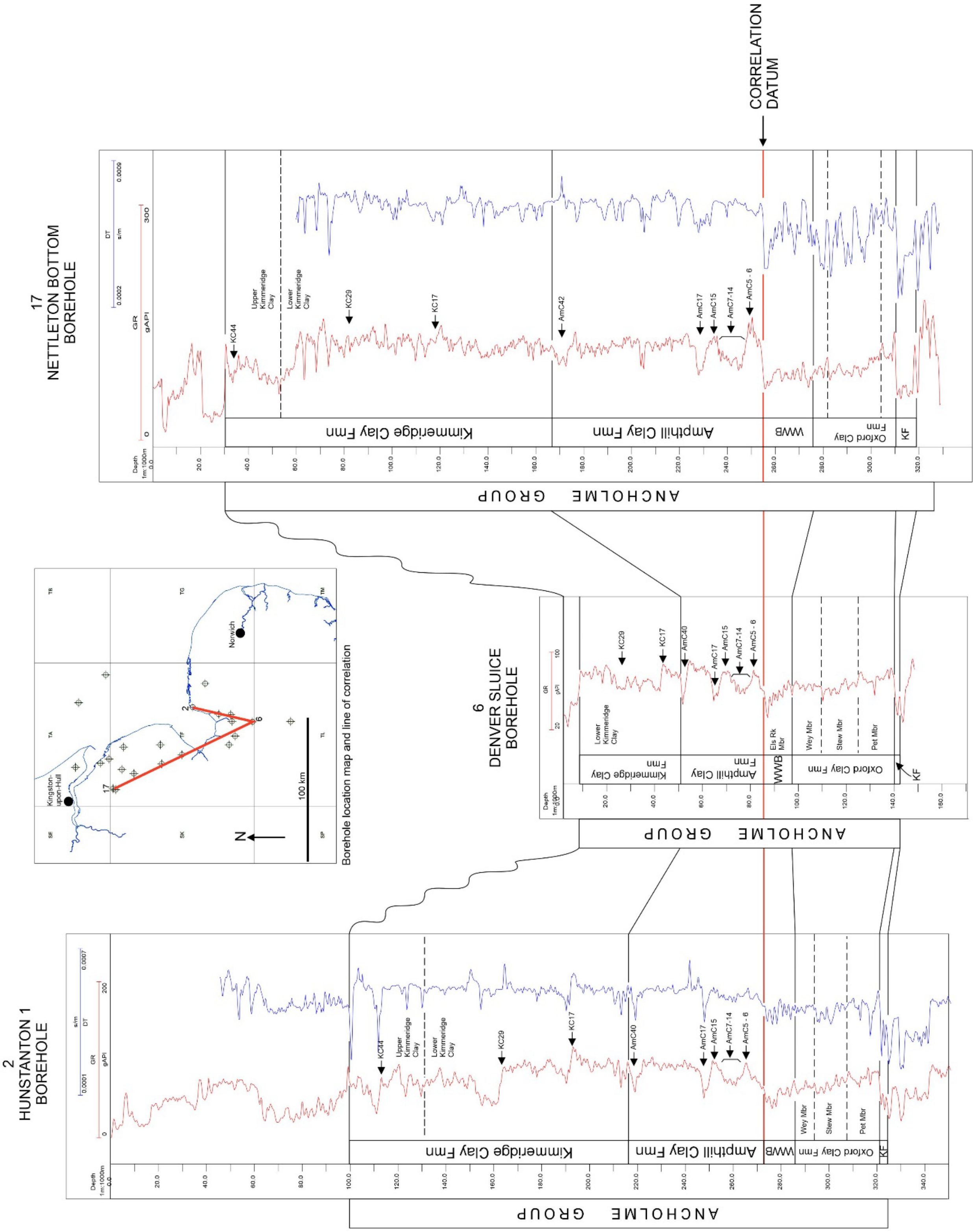


Figure 8. Gamma and sonic logs for key boreholes in the Ancholme Group showing typical inflection patterns in the with respect to selected marker beds. Borehole numbers correspond with those used in Figure 5.

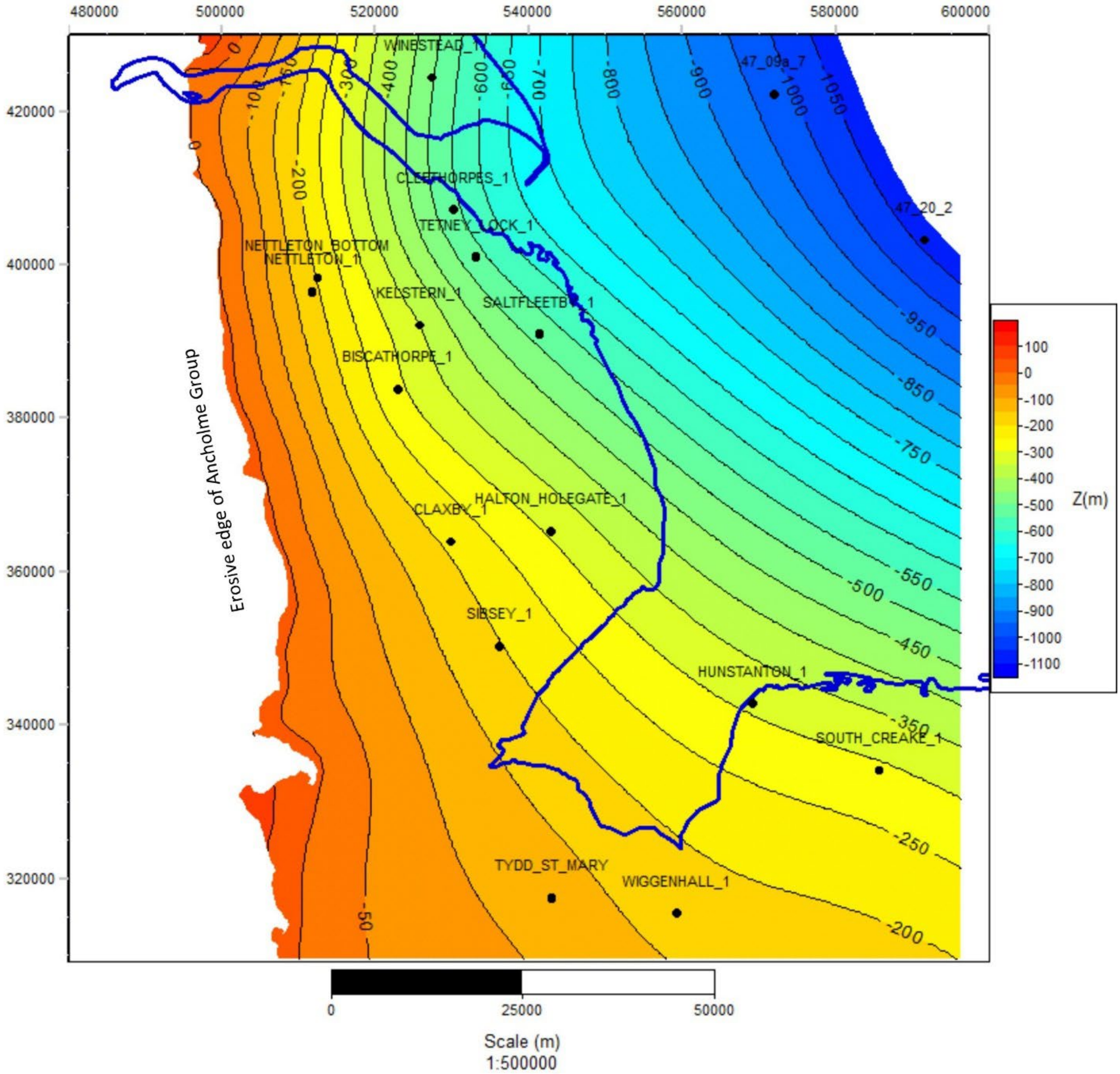


Figure 9. Structural contours for the top of the Kellaways Formation illustrating the regular offshore dip of the Ancholme Group.

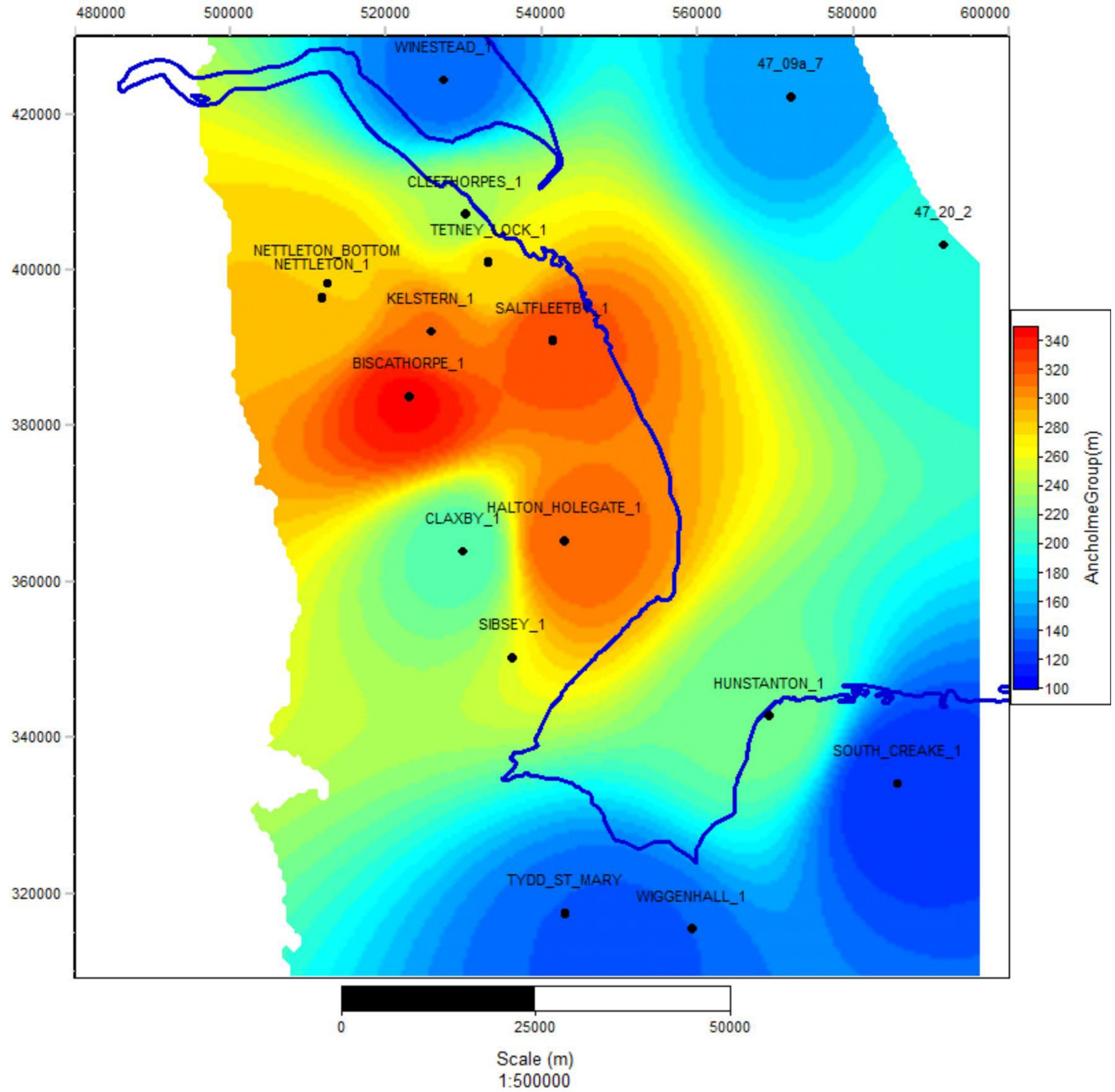


Figure 10. Total thickness of the Ancholme Group (Kellaways Formation omitted), reflecting the combined effects of depositional variation and post-depositional erosion.

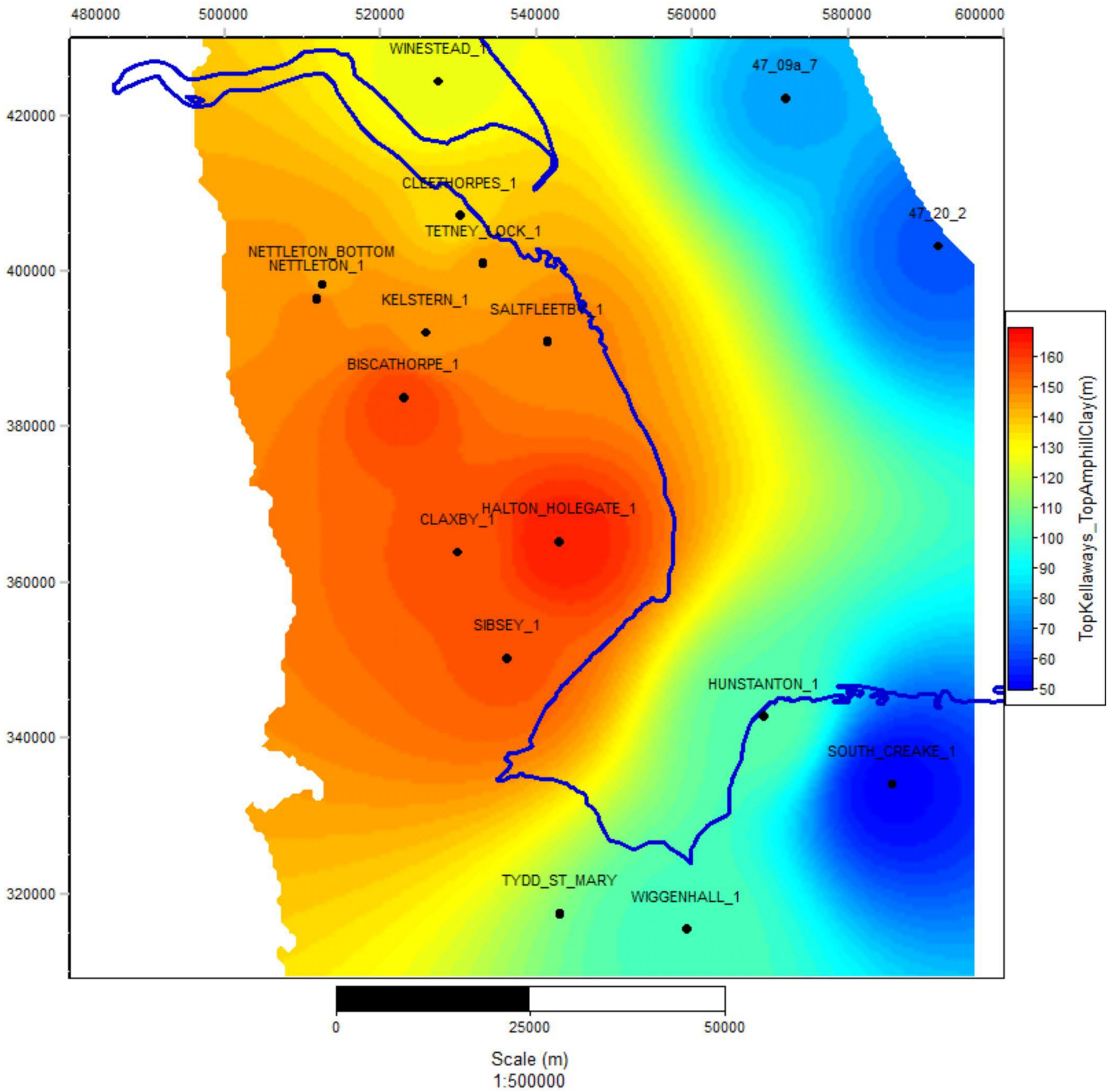


Figure 11. Thickness of the combined Oxford Clay, West Walton and Ampthill Clay formations within the Ancholme Group. This map potentially gives a clearer picture of depositional trends for the Ancholme Group as it removes the impacts of post-depositional erosion that affect the preserved thickness of the Kimmeridge Clay Formation.