Regional depositional trends in Upper Jurassic mudstones: Oxford Clay, Ampthill Clay, Kimmeridge Clay

Decarbonisation and Resource Management Programme

Open Report OR/24/036

BRITISH GEOLOGICAL SURVEY

DECARBONISATION AND RESOURCE MANAGEMENT PROGRAMME

OPEN REPORT OR/24/036

Keywords

Jurassic, Stratigraphy, Depositional Basins, Oxford Clay, Ampthill Clay, Kimmeridge Clay.

Bibliographical reference

WOODS, M A. 2024. Regional depositional trends in Upper Jurassic mudstones: Oxford Clay, Ampthill Clay, Kimmeridge Clay. *British Geological Survey Open Report*, OR/24/036. 29pp.

Regional depositional trends in Upper Jurassic mudstones: Oxford Clay, Ampthill Clay, Kimmeridge Clay

M A Woods

Keyworth, Nottingham British Geological Survey 2024

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Nicker Hill, Keyworth,
Nottingham NG12 5GG
Tel 0115 936 3100

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

BGS Sales
Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP
Tel 0131 667 1000
email scotsales@bgs.ac.uk

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

Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT
Tel 029 2167 4280

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

Geological Survey of Northern Ireland, 7th Floor,
Adelaide House, 39-49 Adelaide Street, Belfast, BT2 8FD
Tel 0289 038 8462
www2.bgs.ac.uk/gsni/

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

UK Research and Innovation, Polaris House,
Swindon SN2 1FL
Tel   01793 444000
www.ukri.org

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

Foreword

This report summarises regional depositional and facies trends in selected Upper Jurassic mudstones (Oxford Clay, Ampthill Clay and Kimmeridge Clay formations) across England and adjacent offshore regions of the southern North Sea. It will provide a broad geological framework for understanding patterns of geochemical data arising from planned future borehole core analysis.

Contents

FIGURES

TABLES

Summary

This report summaries depositional trends for key Upper Jurassic mudstone units (Oxford Clay, Ampthill Clay and Kimmeridge Clay formations) across England and adjacent offshore regions of the southern North Sea.

For each of the selected geological units, this report summarises information about:

- Geological context, basin architecture, depositional setting
- Thickness trends and basin evolution
- Stratigraphy
- Main lithofacies types
- Typical bulk geochemical composition
- Facies trends related to stratigraphical classification
- Lateral variation in lithofacies related to lateral changes in environmental conditions (environmental gradients)

1 Introduction

This report summarises regional depositional and facies trends in selected Upper Jurassic mudstones across England and adjacent offshore regions of the southern North Sea. The selected units comprise the Oxford Clay, Ampthill Clay and Kimmeridge Clay formations (Fig. 1). This work will provide a broad geological framework for understanding geochemical data arising from future borehole core analysis.

Onshore borehole location and BGS registration details are given in Appendix 1.

2 Oxford Clay Formation

2.1 PALAEOGEOGRAPHICAL CONTEXT AND BASIN ARCHITECTURE

In the UK, deposition of the Oxford Clay followed a protracted period of regional extension and thermal uplift that occurred through much of the Middle Jurassic, centred on an incipient triple junction in the North Sea (intersection of Viking Graben, Central Graben & Witches Ground Graben) (Underhill & Partington, 1993; Hendrie et al., 1993). Middle Jurassic deposits are generally varied, including deltaic, freshwater lagoonal and shallow marine settings. Deposition of strongly contrasting mudstone-dominated facies was initiated in the youngest Middle Jurassic and continued into the overlying Upper Jurassic, reflecting the progressive collapse of thermal doming in the North Sea region and drowning of Middle Jurassic palaeogeography by relative sea level rise (Underhill & Partington, 1993; Hesselbo, 2008).

The palaeogeographical setting for Oxford Clay deposition comprises a number of basins, separated by small emergent landmasses and structural highs (Fig. 2). The basins comprise: the Cleveland Basin, East Midlands Shelf (including its offshore extension into the Southern North Sea), Weald Basin and Wessex Basin. The semi-emergent massifs include Cornubia in the south-west, a conjectural Welsh landmass covering parts of central Wales, the Anglo-Brabant Massif extending across southern East Anglia, and the Pennine Landmass with its northern continuation into Scotland (Scottish Landmass) and eastwards into the Southern North Sea (Mid North Sea High) (Fig. 2). The Market Weighton High, occupying a region between the Flamborough Fault Zone (at the southern margin of the Cleveland Basin) and an area just north of the Humber, forms a significant submerged massif between the East Midlands Shelf and the Cleveland Basin across which important lateral facies changes occurred during deposition of the Oxford Clay (Wright, 2021; Fig. 2).

2.2 REGIONAL THICKNESS VARIATION AND BASIN EVOLUTION

Borehole data show that the oldest part of the Oxford Clay Formation (Peterborough Member; see below) shows a progressive pattern of south-westward thickening from the East Midlands Shelf (ca. 15 – 20 m) into the Wessex Basin (+50 m), and a similar pattern can be deduced for the Oxford Clay as a whole (Woods et al., 2022b, fig. 4; Whittaker, 1985, map 16). The entire formation forms a westward thickening wedge of sediment from East Kent (ca. 40 m), across the Weald Basin (90 – 120 m), into the Wessex Basin (ca. 190 m). It is absent across the Anglo-Brabant Massif, thinning rapidly against its flanks, and is also absent across the Market Weighton High (Wright, 2021; Whittaker, 1985). North of the Flamborough Fault Zone, only the youngest part of the Oxford Clay Formation (Weymouth Member; see below) occurs in the Cleveland Basin (Wright, 2021; Whittaker, 1985). On the East Midlands Shelf, the Oxford Clay is ca. 35 m thick in the cored Nettleton Bottom Borehole (Woods et al., 2022c; Appendix 1). Lott & Knox (1994) recorded that coeval strata in the Southern North Sea are dominated by sandstone and siltstone of the Seeley Formation which east of the Dowsing Fault Zone, passes into sandstones and limestones of the Corallian Formation (= offshore equivalent of the Corallian Group; Lott & Knox, 1994). The point of transition from the facies of the Oxford Clay to the Seeley Formation is not known.

The Callovian and Oxfordian, corresponding with the period of deposition of the Oxford Clay, are associated with long-term regional subsidence, with growth faulting limited to the southern flank of the Anglo-Brabant Massif along the northern margin of the Weald Basin. Contemporaneous erosion contributed to thinning of the Oxford Clay at the margins of the Anglo-Brabant Massif and northwards towards the Market Weighton High (Holloway, 1985).

2.3 STRATIGRAPHY, MAJOR FACIES, FACIES TRENDS AND ENVIRONMENTAL GRADIENTS

The Oxford Clay was traditionally divided into Lower, Middle and Upper Oxford Clay, corresponding respectively to the Peterborough, Stewartby and Weymouth members (Fig. 4). Across the East Midlands Shelf, the Oxford Clay forms the lower part of the mudstone-rich Ancholme Group, with its offshore correlative designated the Humber Group (Cameron et al., 1992). In the Cleveland Basin, the sand-rich Osgodby Formation replaces the Peterborough and Stewartby formations, and here the Oxford Clay corresponds exclusively with the youngest Weymouth Member.

2.3.1 Stratigraphical facies trends

The major facies change related to the stratigraphical subdivision of the Oxford Clay is organic content, which is significantly elevated in the Peterborough Member (3 – 16 % Total Organic Carbon (TOC); Kenig et al., 1994), and this is associated with the occurrence of dark laminated mudstone (Fig. 3). Higher in the succession, organic-rich units are much less common, although ‘carbonaceous’ beds have been recorded in the higher part of the Weymouth Member (Cox et al., 1992).

The Stewartby and Weymouth members are both dominated by paler grey-coloured calcareous mudstone, typically more silty, and blocky in texture rather than laminated (Fig. 4). A unit of highly calcareous mudstone/muddy limestone (Lamberti Limestone) occurs in some areas at the top of the Stewartby Member. Overall, the Stewartby and Weymouth members have similar lithologies, although the Weymouth Member is generally less silty (apart from in the Cleveland Basin – see below) and has some thin organic mudstones (Cope, 2006).

In the Peterborough Member, there are frequent oscillations in mudstone facies between organic-rich and organic-poor units, and also silty/sandy mudstone units, that occur over a broad range of frequency from a few millimetres to decimetre-scale (Woods et al., 2022b). Although not investigated in detail, it is likely that some lateral facies variability also exists within the Stewartby and Weymouth members, but with a much lower frequency of organic-rich units.

The occurrence of pyrite is a general feature of the Oxford Clay, but it is abundant in the Peterborough Member, mainly occurring in a dispersed form through the sediment (Hudson & Martill, 1991), but also replacing the shells of macrofossils. In the Upper Oxford Clay (Weymouth Member), dispersed fine-grained pyrite is rare, but more common as replacements of macrofossils (Hudson & Martill, 1991). Cemented concretions are generally distributed through the Oxford Clay and some are iron-rich.

Table 1 (below) summarises average mineral abundances for member subdivisions of the Oxford Clay in the Winterborne Kingston Borehole (Dorset) and Warlingham Borehole (Surrey) based on Baig (1982).

Table 1. Average mineral abundances for member subdivisions of the Oxford Clay based on analyses of samples by Baig (1982) from the Winterborne Kingston Borehole, Dorset (WK) and Warlingham Borehole, Surrey (WA). Dolomite values for the Oxford Clay in the Warlingham Borehole (not recorded in Winterborne Kingston Borehole) are as follows: Peterborough Mbr: 3.67%; Stewartby Mbr: 4.70%; Weymouth Mbr: 10.82%.

Stratigraphy	Borehole	Mineralogy (%)							
		Quartz	Calcite	Pyrite	Total Clays	Illite	Kaolinite	Chlorite	Smectite
Weymouth Member	WK	23.67	39.35	2.25	33.26	14.17	2.79	1.28	15.02
	WA	20.41	26.86	1.04	40.29	26.8	3.10	1.90	8.46
Stewartby Member	WK	19.01	28.43	2.95	47.73	27.83	8.44	3.52	7.93
	WA	18.63	25.95	1.78	47.81	31.68	5.86	3.19	7.04
Peterborough Member	WK	17.75	23.76	3.89	50.28	30.36	10.94	3.91	5.07
	WA	18.06	17.96	1.94	54.43	35.60	7.87	3.23	7.68

2.3.2 Facies trends related to environmental gradients

Recent work on the Peterborough Member (Woods et al., 2022) has shown that there are a number of regional facies trends related to basin architecture and palaeogeography (Fig. 3). The most important of these are:

1) Tendency for organic-rich units to be better developed in the relatively thin successions across the East Midlands Shelf compared to the thicker successions in the Wessex Basin. Times of organic-rich facies development on the East Midlands Shelf correspond with facies in the Wessex Basin that are indicative of oxic marine conditions (e.g. oyster-rich silty mudstone).
2) Stratigraphical thinning and dominance of pale-grey silty mudstone, with common broken-up shell material, on the flanks of the Anglo-Brabant Massif.
3) Development of extensive shelly mudstone facies at the margin of the Weald Basin where syn-sedimentary faulting may have caused mixing of shelly faunas that usually characterise a number of discrete stratigraphical intervals.
4) Development of silt-rich facies at the base of the Peterborough Member in parts of the Wessex Basin (= Mohuns Park Member of Bristow et al., 1995).
5) Tendency for thick successions in the Wessex Basin to show regular repetition of relatively thin mudstone facies units (e.g. blocky/shelly/laminated) rather than persistence of any single facies type over broad intervals.
6) Atypical thin, indurated, calcareous, pyritous and organic-rich facies in the centre of the Weald Basin

Information about regional facies changes for the remainder of the Oxford Clay (Stewartby & Weymouth members) is less detailed. The main trends are (Fig. 3):

1) Presence/absence of one or more hard, calcareous mudstone/muddy limestone units (= Lamberti Limestone) at the top of the Stewartby Member. These have been recorded across the East Midlands Shelf (Penn et al., 1985) and parts of the South Midlands (Cope, 2006) around the margin of the Anglo-Brabant Massif (Shephard-Thorn et al.,1994; Horton et al., 1995; Sumbler, 1996), where they allow mapping of the boundary between the Stewartby and Weymouth members. Across much of the Wessex Basin, particularly Dorset, the absence of the Lamberti Limestone means that the Stewartby and Weymouth members have been mapped as a combined geological unit (Bristow et al., 1995, 1999; Barton et al., 2011). It may occur across some structural highs that transect the Wessex Basin, for example in the Marchwood Borehole [SU 39910 11180] near Southampton, on the Hampshire-Dieppe High, where core and borehole sonic log data suggest a pronounced lithological change at the top of the Stewartby Member (Whittaker et al., 1985, fig. 35).
2) Increased silt content in the Weymouth Member of the Cleveland Basin (Cope, 2006).
3) In near offshore areas of the East Midlands Shelf, the Oxford Clay likely persists as a thin (ca. 30 – 45 m) mudstone unit at the base of the Ancholme Group, but further offshore it equates with sandstone and siltstone forming the lower part of the Seeley Formation (Lott & Knox, 1994). In the Central Graben, strata equivalent to the Oxford Clay Formation are deltaic and coal-bearing (Møller and Rasmussen, 2003).

3 Ampthill Clay Formation

3.1 PALAEOGEOGRAPHICAL CONTEXT AND BASIN ARCHITECTURE

Deposition of the mud-dominated Ampthill Clay across the East Midlands Shelf occurred contemporaneously with the sandstones/siltstones/limestones of the Corallian Group elsewhere in the UK (Figs 1, 5). Seismic stratigraphy suggests the original area of deposition of the Ampthill Clay may have been much greater than its current extent prior to later Jurassic and Early Cretaceous erosion; it may have extended across the Market Weighton Axis and much of the Anglo-Brabant Massif (Chadwick, 1985a; Fig. 5). In the Cleveland Basin, the Ampthill Clay caps a mixed sandstone and oolitic limestone succession that corresponds with the lower and middle parts of the Corallian Group in the Wessex Basin. In the offshore part of the East Midlands Shelf, the Ampthill Clay is represented by the lithologically similar calcareous mudstone facies of the Woodward Formation, although Lott & Knox (1994) also note the occurrence of sandy and silty units.

Apart from a thin (ca. 10 - 15 m) inter-bedded calcareous mudstone/silty mudstone/siltstone succession (West Walton Formation) between the top of the Oxford Clay and the base of the Ampthill Clay, mudstone dominates the succession from the base of the Oxford Clay to the top of the Kimmeridge Clay across the East Midlands Shelf, forming the mud-rich Ancholme Group (Fig. 1).

3.2 REGIONAL THICKNESS VARIATION AND BASIN EVOLUTION

Borehole geophysical log correlations across the onshore East Midlands Shelf suggest that the Ampthill Clay is 55 – ca. 80 m thick, but thinning southwards towards the Anglo-Brabant Massif (ca. 35 m) at Denver Sluice [TF 5911 0106] south of The Wash, and thinning and becoming absent north of the Humber, towards the Market Weighton High (Woods et al., 2022c; Gallois, 1979). In the near offshore, west of the Dowsing Fault Zone, borehole geophysical logs suggest that the Ampthill Clay/Woodward Formation is +80 m thick, thinning eastwards towards the Dowsing Fault Zone to around 40 m.

In the area around The Wash, Gallois & Cox (1977) noted that erosion surfaces developed within the higher part of the formation caused lateral changes in the thickness of sediment packages, and that thinning of the formation was affected by erosion at the base of the Kimmeridge Clay (most notably in the extreme south close to the inferred margin of the Anglo-Brabant Massif).

Gallois & Cox (1977) suggested that this mud-dominated facies should be seen as the ‘normal’ depositional signal for this interval, with the heterolithic facies of the coeval Corallian Group representing shallow-water, near-shore deposits (Holloway, 1985; Chadwick, 1985a).

3.3 STRATIGRAPHY, MAJOR FACIES, FACIES TRENDS AND ENVIRONMENTAL GRADIENTS

The Ampthill Clay was divided into 42 numbered beds by Gallois & Cox (1977), mostly representing the alternation of units of mudstone beds that are calcareous, with relatively less calcareous mudstones. There are also thin organic-rich units (e.g. Bed 22), ironstone (e.g. Bed 16), units of very shelly mudstone (e.g. Bed 24), and silty, phosphatic, pyritic and highly cemented mudstone (‘cementstone’) (Gallois & Cox, 1977, fig. 2). Erosion surfaces within the Ampthill Clay, particularly developed within the upper part of the formation (Beds 30 – 42), responsible for changes in thickness, are associated with concentrations of phosphatic nodules.

3.3.1 Stratigraphical facies trends

Overall, the Ampthill Clay can be approximately divided into three units (Gallois, 1979) as follows:

1) (lower part) slightly silty mudstone
2) (middle part) smooth-textured mudstone
3) (upper part) silty mudstone with erosion surfaces, phosphatic nodules, common oysters

The highest part (3 above) can be inferred to broadly correspond to Beds 30 – 42, but the precise relationship of units (1) and (2) above to the numbered bed stratigraphy of Gallois & Cox (1977) is uncertain.

Gallois and Cox (1977) described compositional details of the Ampthill Clay and these are summarised in Table 2 (below).

Table 2. Summary of compositional data for the Ampthill Clay (from Gallois & Cox, 1977).

Mineralogical component	%
Clay minerals (illite/kaolinite/chlorite)	25 – 60
quartz	7 – 22
Calcium carbonate	<15 - 50

3.3.2 Facies changes related to environmental gradients

Investigation of the Ampthill Clay in the area around The Wash (Gallois & Cox, 1977, Gallois, 1979) suggest that environmental and palaeogeographical factors likely drove the stratigraphical and thickness variation seen in the numbered bed facies units that comprise the formation. Gallois & Cox (1977) regarded these beds as indicating laterally persistent facies signatures between boreholes, synchronous with ammonite biozones. The extent of any lateral facies variation within a given bed or package of bed units was not commented on by Gallois & Cox (1977) or Gallois (1979), and does not appear to have been the focus of any more recent study. Work by Penn et al. (1985), linking the numbered beds within the Ampthill Clay to laterally persistent inflection patterns on borehole geophysical logs that extend from The Wash towards the Humber, tends to suggest lateral persistence of the gross lithofacies character of these units across the East Midlands Shelf. Gallois & Cox (1977, fig. 3) envisaged that the different facies of the Ampthill Clay related to a variety of near-shore to offshore settings, with each facies type occupying a different relative distance from the shore-line. The implication of this model is that relative change in sea level is driving the cyclical vertical stacking of the different lithofacies types.

In the offshore part of the East Midlands Shelf, west of the Dowsing Fault Zone, there is some evidence for facies change in the upper part of the Ampthill Clay based on lateral changes in the character of borehole geophysical logs (Fig. 7), and from observations of lithological components observed during biostratigraphical work (Jan Hennissen, pers comm). The typical geophysical log character of the Ampthill Clay seen in the Nettleton Bottom Borehole persists offshore into Borehole 47/18-1, but further east, towards the Dowsing Fault Zone, there is significant thinning of the inferred Ampthill Clay Formation (Fig. 5, 7), associated with a significant decline in gamma log values and increase in sonic velocity (i.e. low interval transit time). Observations during microfossil biostratigraphical analysis of cuttings from Borehole 47/14B-G1, suggests that this change in the upper part of the Ampthill Clay/Woodward Formation may be a consequence of increased quartz content (Jan Hennissen, pers comm.), suggesting the presence of sandy or silty lithologies. The extent to which these strata should be included as part of the Ampthill Clay, or more accurately reflect the lithology of the Woodward Formation, is an open question.

4 Kimmeridge Clay Formation

Deposition of the Kimmeridge Clay coincided with a significant rise in relative sea level (probably the highest in the Jurassic; Chadwick, 1985a), and it is one of the most widely distributed mudrocks of the British Jurassic (Hesselbo, 2008; Cope, 2006). In the UK, the Kimmeridge Clay has traditionally been regarded as synonymous with the Kimmeridgian stage (= ‘Kimmeridgian *sensu anglico*’), but is actually equivalent to the Kimmeridgian and lower part of the Tithonian of continental Europe (Cope, 2006; Fig. 1). Cope (1993) proposed the name Bolonian (Fig. 1) for strata equivalent to the early Tithonian (= Upper Kimmeridge Clay) that post-date the Kimmeridgian stage as defined in continental Europe, but this has not gained widespread use.

4.1 PALAEOGEOGRAPHICAL CONTEXT AND BASIN ARCHITECTURE

Marine deposition is inferred to have occurred widely across central and southern England, with limited land areas represented by the margins of the Anglo-Brabant Massif in south-east England (mostly confined to the fringes of the East Anglian coast), Cornubia extending across parts of Devon and Cornwall, and an extension of a Scottish landmass reaching southwards into parts of northern England (Fig. 8). Onshore, the main preserved depo-centres in England are the Wessex-Weald basins, the East Midlands Shelf, and the Cleveland Basin, with offshore depositional areas in the Channel and North Sea basins (Fig. 8).

4.2 REGIONAL THICKNESS VARIATION AND BASIN EVOLUTION

The Kimmeridge Clay attains a maximum thickness in excess of 500 m in the Wessex, Weald and Channel basins (Chadwick, 1985a; Barton et al., 2011), and more than 300 m beneath the Vale of Pickering in the Cleveland Basin (Cope, 2006). Across the East Midlands Shelf and the adjacent Southern North Sea, the Kimmeridge Clay is affected by erosion at the base of the overlying Late Jurassic and Early Cretaceous succession (see below), and the preserved maximum thickness is less, at around 180 m (Woods et al., 2022c). Significant local thickening of the Kimmeridge Clay within basins across southern England is related to growth faults that bound intra-basin ‘highs’, with the contrast in preserved stratigraphy between these regions further accentuated by later erosion (see below) that particularly affected the successions deposited across the footwalls of these structures (Chadwick, 1985a).

In the Late Jurassic and Early Cretaceous, a eustatic fall in sea level combined with broad regional uplift and variable patterns of fault-related basin subsidence caused variable erosion of the Late Jurassic succession (Chadwick, 1985b), including the Kimmeridge Clay. Erosion was locally severe across structural highs within basins and structurally prone regions, such as the Cranborne-Fordingbridge High in the Wessex Basin, the London-Brabant Massif and the Market Weighton High (Chadwick, 1985b).

4.3 STRATIGRAPHY, MAJOR FACIES, FACIES TRENDS AND ENVIRONMENTAL GRADIENTS

The Kimmeridge Clay Formation has been informally subdivided into lower and upper parts (Lower Kimmeridge Clay, Upper Kimmeridge Clay), mainly based on differences in ammonite taxa, and traditionally these subdivisions are coeval with the Lower Kimmeridgian and Upper Kimmeridgian substages (*sensu anglico*) (Cox & Gallois, 1981; Fig. 9). As discussed above, differences with how the Kimmeridgian has been defined in continental Europe have led to some workers using the secondary stage term ‘Bolonian’ for the interval equating with the Upper Kimmeridge Clay (e.g., Cope, 1993). Cored boreholes in the Southern North Sea show a good correlation with the onshore Kimmeridge Clay (Cox et al., 1987), and there is no change in offshore lithostratigraphical nomenclature. The comment by Lott & Knox (1994) that the offshore Kimmeridge Clay Formation includes part of the Ampthill Clay appears to refer to how this formation has been seismically defined in relation to cored boreholes, and does not relate to any fundamental difference in the offshore lithological development of these units.

The Kimmeridge Clay was subdivided into 48 numbered beds (KC 1 – 49) by Gallois & Cox (1976) and Cox & Gallois (1979) on the basis of widely recognisable stratigraphical variations in lithofacies seen in borehole cores drilled in eastern England. These beds were traced into the Dorset outcrop (Cox & Gallois, 1981), and the subdivisions extended (KC 50 – 63) to include the youngest strata based on cored borehole material (Gallois, 2000) and outcrop data in Dorset (Gallois & Etches, 2001) that had not previously been available/examined in detail. Penn et al. (1985) showed how Kimmeridge Clay bed subdivisions could be equated with borehole geophysical log inflection patterns across the East Midlands Shelf, allowing individual beds and packages of beds to be correlated between boreholes on the basis of their distinct geophysical log character. Morgans-Bell et al. (2001) pointed out that the ‘beds’ of the Kimmeridge Clay (KC 1 – 63) are better conceptualised as ‘bed groups’ containing multiple bed units bounded by distinct surfaces, and that there is some uncertainty about the chronostratigraphical equivalence of KC bed numbers recognised in different outcrop successions. More recently, Cope (2009) has pointed out, on the basis of ammonite data, that there are problems with how Kimmeridge Clay beds first identified in the stratigraphically thin succession on the East Midlands Shelf have been traced through to the stratotype Dorset succession.

4.3.1 Stratigraphical facies trends

The Kimmeridge Clay comprises a rhythmic repetition of mudstone facies linked to Milankovitch climate cycles and relative sea level change (Huang et al., 2010). Typical facies comprise: medium-dark grey mudstone, dark grey – black laminated mudstone, greyish-brownish black mudstone, medium-grey to creamy-white coccolith limestones and dolomitic limestones (Morgans-Bell et al., 2001; Fig. 9). In the Kimmeridge Clay, the terms ‘stone bands’ or cementstone have been used to describe thin indurated siltstones and primary/secondary limestones. The black-laminated and brownish mudstones are organic-rich (up to 45% TOC) and have been referred to as ‘oil shales’ (Gallois, 2000). Siltstone and silty mudstones occur in the basal and higher parts (where this has not been removed by erosion) of the succession (Fig. 9). Small-scale rhythms range from 0.5 – 1.5 m thick, with larger rhythms 10s of metres thick (Gallois, 2000). In the Lower Kimmeridge Clay, Cox and Gallois (1981) recorded rhythms comprising siltstone passing up into dark grey mudstone and then pale-grey calcareous mudstone (Type A; Gallois, 1994). Higher in the Lower Kimmeridge Clay, and in the Upper Kimmeridge Clay, Cox & Gallois (1981) recorded brownish-grey organic-rich mudstone, passing up into dark grey mudstone and then pale grey calcareous mudstone (Type B; Gallois, 1994), sometimes with stone bands.

Macquaker et al. (1998) used petrographic and SEM analysis of a suite of samples from the Kimmeridge Clay to identify litho-types comprising clay-rich mudstones, silt-rich mudstones, nannoplankton-rich mudstones, laminated mudstones and concretionary carbonates. At a small (decimetre-metre) scale, these authors noted a simple alternation of finer-grained organic-rich laminated mudstones with siltier mudstone; at larger scale (1 – 15 m), both coarsening and fining upward cycles were recognised, related to relative changes in the amount of silt in the small-scale silt-rich units (Macquaker et al., 1998). Concretionary carbonate units were observed to occur at the top of large scale upward coarsening successions, or close to where large-scale upward-fining cycles changed to upward-coarsening cycles (Macquaker et al., 1998). Morgans-Bell et al. (2001) noted the importance of ‘stone bands’ for correlation.

Atar et al. (2019) analysed the petrography of the Kimmeridge Clay of the Cleveland Basin, defining six lithofacies (clastic detritus-rich medium-grained mudstone; organic material and calcareous pellet-rich laminated medium to coarse mudstone; coccolith-dominated medium mudstone; agglutinated foraminifera-bearing, medium to coarse carbonaceous mudstone; biogenic-detritus-dominated fine to medium mudstone; carbonate-cemented coarse mudstone), and showed that different combinations of these facies could be used to define ‘Low Variability Mudstones’ and ‘High Variability Mudstones’, the latter including high TOC mudstone facies and indicating rapid bottom-water environmental fluctuations from oxic to suboxic/anoxic.

Cox & Gallois (1981) detailed the bulk geochemistry of the common lithofacies of the Kimmeridge Clay recognised by them (Table 3).

Table 3. Geochemistry of major lithofacies of the Kimmeridge Clay (after Cox & Gallois, 1981).

Lithofacies-type	Bulk Geochemistry
Dark grey mudstone	*Clay minerals: 45 – 65% Quartz: 10 – 30% Calcium carbonate: 5 – 20% (subject to shell content) Kerogen: <2%

Medium grey mudstone	*Clay minerals: 35 – 55% Quartz: 10 – 15% Calcium carbonate: 20 – 35% Kerogen: <1%
Pale grey mudstone	*Clay minerals: 25 – 45% Quartz: 8 – 15% Calcium carbonate: 25 – 55% Kerogen: <1%
Bituminous mudstone	*Clay minerals: 30 – 50% Quartz: 10 – 20% Calcium carbonate: 10 – 25% Kerogen: 2 – 10%
Oil Shale	*Clay minerals: 30 – 40% Quartz: 10 – 15% Calcium carbonate: 10 – 25% Kerogen: 10 – 45%
Cementstone	*Clay minerals: 10 – 20% Quartz: 2 – 6% Calcium magnesium carbonate: 60 – 90% Kerogen: <1%
*Clay minerals: mostly illite and kaolinite with minor smectite and chlorite	

4.3.2 Facies changes related to environmental gradients

The true extent of lithofacies changes related to environmental gradients across the outcrop and subcrop of the Kimmeridge Clay is unknown. The apparent lateral persistence of the KC bed numbers between the Cleveland Basin, East Midlands Shelf and Wessex Basin (Gallois, 1979; Cox & Gallois, 1981; Gallois, 2021), tends to suggest very low environmental gradients, and little lateral change in general character of particular lithological intervals within the Kimmeridge Clay. However, the possibility that the apparent cyclicity identified in each of the regions is not chronostratigraphically synchronous (Morgans-Bell et al., 2001; Cope, 2009), suggests the potential for at least weak lithofacies gradients. Cox & Gallois (1981, fig. 13) illustrated the correlation of the Kimmeridge Clay between Dorset, Surrey (Warlingham Borehole) and The Wash. The main features affecting the overall character of the succession between these localities are lateral thinning and increased erosion of the higher part of the succession towards The Wash, but the cycles of calcareous mudstone and mudstone with organic-rich horizons is broadly persistent (Cox & Gallois, 1981). A comparison of lithofacies across the Eudoxus – Autissiodorensis zonal boundary between Dorset and the Warlingham Borehole successions suggests lateral changes in the thickness and frequency of ‘oil shale’ facies, and differences in the presence/absence of cementstones (Cox & Gallois, 1981), both likely influenced by more condensed sedimentation at Warlingham. Wignall (1989) commented that the depositional gradient of the basin in which the Kimmeridge Clay accumulated was likely very low, with no evidence of slumping and the persistence of lithofacies patterns over distances of at least 200 km. Only close to the palaeogeographical margin of the Kimmeridge Clay basin, near Boulogne in northern France, is there good evidence for lateral transition of mudstone facies of the Kimmeridge Clay into sandstone (Williams et al., 2001).

Appendix 1 – Onshore borehole location and registration details

Borehole Name	Grid Reference	BGS Registration (SOBI) Number
Marchwood	SU 39910 11180	SU31SE/227
Nettleton Bottom	TF 12520 98200	TF19NW/54
Warlingham	TQ 34760 57190	TQ35NW/1
Winterborne Kingston	SY 84700 97900	SY89NW/1

References

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

ATAR, E, MÄRZ, C, APLIN, A C, DELLWIG, O, HERRINGSHAW, L G, LAMOUREUX-VAR, V, LENG, M J, SCHNETGER, B, and WAGNER, T. 2019. Dynamic climate-driven controls on the deposition of the Kimmeridge Clay Formation in the Cleveland Basin, Yorkshire, UK. *Climate of the Past*, Vol. 15, 1581 – 1601.

BAIG, M A A. 1982. The geochemistry and mineralogy of sediments of the Oxford Clay and Kellaways formations from southern England (Winterborne Kingston and Warlingham boreholes). Unpublished PhD Thesis, University of Southampton, 695 pp.

BARTON, C M, WOODS, M A, BRISTOW, C R, NEWELL, A J, WESTHEAD, R K, EVANS, D J, KIRBY, G A, and WARRINGTON, G W. 2011. Geology of south Dorset and south-east Devon and its World Heritage Coast. *Special Memoir of the British Geological Survey*, 1:50 000 geological sheets 328 (Dorchester), 341/342 (West Fleet and Weymouth), 342/343 (Swanage), and parts of sheets 326/340 (Sidmouth), 327 (Bridport), 329 (Bournemouth), and 339 (Newton Abbot).

BRADSHAW, M J, COPE, J C W, CRIPPS, D W, DONOVAN, D T, HOWARTH, M K, RAWSON, P F, WEST, I M, and WIMBLEDON, W A. 1992. Jurassic. In: COPE, J C W, INGHAM, J K, and RAWSON, P F (Eds). Atlas of Palaeogeography and Lithofacies. *Geological Society Memoir*, No. 13.

BRISTOW, C R, BARTON, C M, FRESHNEY, E C, WOOD, C J, EVANS, D J, COX, B M, IVIMEY-COOK, H C, and TAYLOR, R T. 1995. Geology of the country around Shaftesbury. *Memoir of the British Geological Survey*, 1:50 000 Geological Sheet 313 (England & Wales).

BRISTOW, C R, BARTON, C M, WESTHEAD, R K, FRESHNEY, E C, COX, B M, and WOODS, M A. 1999. The Wincanton district – a concise account of the geology. *Memoir of the British Geological Survey*, 1:50 000 Sheet 297 (England & Wales).

CAMERON, T D J, CROSBY, A, BALSON, P S, JEFFREY, D H, LOTT, G K, BULAT, J, and HARRISON, D J. 1992. The geology of the southern North Sea. *British Geological Survey: United Kingdom Offshore Regional Report*.

CHADWICK, R A. 1985a. Upper Jurassic: late Oxfordian to early Portlandian. 49 – 51 in: WHITTAKER, A (Ed.), *Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy*. (Glasgow & London: Blackie.)

CHADWICK, R A. 1985b. End Jurassic – early Cretaceous sedimentation and subsidence (late Portlandian to Barremian), and the late-Cimmerian unconformity. 52 – 56 in: WHITTAKER, A (Ed.), *Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy*. (Glasgow & London: Blackie.)

COPE, J C W. 2009. Correlation problems in the Kimmeridge Clay Formation (Upper Jurassic, UK): lithostratigraphy versus biostratigraphy and chronostratigraphy. *Geological Magazine*, Vol. 146, 266 – 275.

COPE, J C W. 2006. Jurassic: the returning seas. 325 – 363 in BRENCHLEY, P J, and RAWSON, P F. *The Geology of England and Wales* (2nd Edition). (London: The Geological Society.)

COPE, J C W. 1993. The Bolonian Stage: an old answer to an old problem. *Newsletters on Stratigraphy*, Vol. 28, 151 – 156.

COX, B M, and GALLOIS, R W. 1981. The stratigraphy of the Kimmeridge Clay of the Dorset type area and its correlation with some other Kimmeridgian sequences. *Report of the Institute of Geological Sciences*, 80/4.

COX, B M, and GALLOIS, R W. 1979. Appendix B. Description of the standard stratigraphical sequences of the Upper Kimmeridge Clay, Ampthill Clay and West Walton Beds. 68 – 73 in: GALLOIS, R W, Geological investigations for the Wash Water Storage Scheme. *Report of the Institute of Geological Sciences*, 78/19.

COX, B M, HUDSON, J D, and MARTILL, D M. 1992. Lithostratigraphic nomenclature of the Oxford Clay (Jurassic). *Proceedings of the Geologists' Association*, Vol. 103, 343 – 345.

COX, B M, LOTT, G K, THOMAS, J E, and WILKINSON, I P. 1987. Upper Jurassic stratigraphy of four shallow cored boreholes in the UK sector of the southern North Sea. *Proceedings of the Yorkshire Geological Society*, Vol. 46, 97 – 109.

GALLOIS, R W. 2000. The stratigraphy of the Kimmeridge Clay Formation (Upper Jurassic) in the RGGE Project boreholes at Swanworth Quarry and Metherhills, south Dorset. *Proceedings of the Geologists' Association*, Vol. 111, 265 – 280.

GALLOIS, R W. 2021. The stratigraphy of the Kimmeridge Clay Formation (Jurassic) of the Vale of Pickering, Yorkshire, UK. *Proceedings of the Yorkshire Geological Society*, Vol. 63, https://doi.org/10.1144/pygs2021-004

GALLOIS, R W. 1994. Geology of the country around King's Lynn and The Wash. *Memoir of the British Geological Survey*, 1:50 000 Geological Sheet 145 and part of 129 (England & Wales).

GALLOIS, R W. 1979. Geological investigations for the Wash Water Storage Scheme. *Report of the Institute of Geological Sciences*, 78/19.

GALLOIS, R W, and COX, B M. 1976. The stratigraphy of the Lower Kimmeridge Clay of eastern England. *Proceedings of the Yorkshire Geological Society*, Vol. 41, 13 – 26.

GALLOIS, R W, and COX, B M. 1977. The Stratigraphy of the Middle and Upper Oxfordian sediments of Fenland. *Proceedings of the Geologists' Association*, Vol. 88, 207 – 228.

GALLOIS, R W, and ETCHES, S. 2001. The stratigraphy of the youngest part of the Kimmeridge Clay Formation (Upper Jurassic) of the Dorset type area. *Proceedings of the Geologists' Association*, Vol. 112, 169 – 182.

HENDRIE, D B, KUSZNIR, N J, and Hunter, R H. 1993. Jurassic extension estimates for the North Sea 'triple junction' from flexural backstripping: implications for decompression melting models. *Earth and Planetary Science Letters*, Vol. 116, 113 – 127.

HUANG, C, HESSELBO, S P, and HINNOV, L. 2010. Astrochronology of the late Jurassic Kimmeridge Clay (Dorset, England) and implications for Earth System processes. *Earth and Planetary Science Letters*, Vol. 289, 242 – 255.

HESSELBO, S P. 2008. Sequence stratigraphy and inferred relative sea level change from the onshore British Jurassic. *Proceedings of the Geologists' Association*, Vol. 119, 19 – 34.

HOLLOWAY, S. 1985. Upper Jurassic: early Callovian to Middle Oxfordian. 17 – 18 in: WHITTAKER, A (Ed.), Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy. (Glasgow & London: Blackie.)

HORTON, A, SUMBLER, M G, COX, B M, and AMBROSE, K. 1995. Geology of the country around Thame. *Memoir of the British Geological Survey*, 1:50 000 Geological Sheet 237 (England & Wales).

HUDSON, J D, and MARTILL, D M. 1991. The Lower Oxford Clay: production and preservation of organic matter in the Callovian (Jurassic) of central England. In: TYSON, R V, and PEARSON, T H (Eds), Modern and Ancient Continental Shelf Anoxia. *Geological Society Special Publication*, No. 58, 363 – 379.

KENIG, F, HAYES, J M, POPP, B N, and SUMMONS, R E. 1994. Isotopic biogeochemistry of the Oxford Clay Formation (Jurassic), UK. *Journal of the Geological Society, London*, Vol. 151, 139 – 152.

LOTT, G K, and KNOX, R W O'B. 1994. 7 – Post-Triassic of the Southern North Sea. *Lithostratigraphic nomenclature of the UK North Sea*. Published by the British Geological Survey on behalf of the UK Offshore Operators Association.

MACQUAKER, J H S, GAWTHORPE, R L, TAYLOR, K G, and OATES, M J. 1998. Heterogeneity, Stacking Patterns and Sequence Stratigraphic Interpretation in Distal Mudstone Successions: Examples from the Kimmeridge Clay Formation, UK. 163 – 186 in: SCHIEBER, J, ZIMMERIE, W, and PARVINDER, S S (Eds.), Recent progress in shale research. (Stuttgart: E. Schweizerbart.)

MØLLER J J, and RASMUSSEN, E S. 2003. Middle Jurassic – Early Cretaceous rifting of the Danish Central Graben. *Geological Survey of Denmark and Greenland Bulletin*, 1, 247 – 264.

MORGANS-BELL, H S, COE, A L, HESSELBO, S P, JENKYNS, H C, WEEDON, G P, MARSHALL, J E A, TYSON, R V, and WILLIAMS, C J. 2001. Integrated stratigraphy of the Kimmeridge Clay Formation (Upper Jurassic) based on exposures and boreholes in south Dorset, UK. *Geological Magazine*, Vol. 138, 511 – 539.

PENN, I E, COX, B M, and GALLOIS, R W. 1986. Towards precision in stratigraphy: geophysical log correlation of Upper Jurassic (including Callovian) strata of the Eastern England Shelf. *Journal of the Geological Society*, Vol. 143, 381 – 410.

SHEPHARD-THORN, E R, MOORLOCK, B S P, COX, B M, ALLSOP, J M, and WOOD, C J. 1994. Geology of the country around Leighton Buzzard. *Memoir of the British Geological Survey*, 1:50 000 Geological Sheet 220 (England & Wales).

SUMBLER, M G. 1996. *British regional geology: London and the Thames Valley* (4th edition). (London: HMSO for the British Geological Survey.)

UNDERHILL, J R, and PARTINGTON, M A. 1993. Jurassic thermal doming and deflation in the North Sea: implications of the sequence stratigraphic evidence. *Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*, 337 – 345.

WHITTAKER, A. 1985. *Atlas of Onshore Sedimentary Basins in England and Wales: Post-Carboniferous Tectonics and Stratigraphy*. (Glasgow & London: Blackie.)

WIGNALL, P B. 1989. Sedimentary dynamics of the Kimmeridge Clay: tempests and earthquakes. *Journal of the Geological Society*, Vol. 146, 273 – 284.

WILLIAMS, C J, HESSELBO, S P, JENKYNS, H C, and MORGANS-BELL, H S. 2001. Quartz silt in mudrocks as a key to sequence stratigraphy (Kimmeridge Clay Formation, Late Jurassic, Wessex Basin, UK). *Terra Nova*, Vol. 13, 449 – 455.

WOODS, M A, HENNISSEN, J A I, NEWELL, A J, DUFF, K L, and WILBY, P I. 2022b. Rolling back the ‘mudstone blanket’: complex geometric and facies responses to basin architecture in the epicontinental Oxford Clay Formation (Jurassic, UK). *Newsletters on Stratigraphy*, Vol. 56, 1 – 31.

WOODS, M A, NEWELL, A J, and BURREL GARCIA, L. 2022c. UK Stratigraphical Framework Series: The Ancholme Group of the East Midlands Shelf. *British Geological Survey Open Report*, OR/22/013.

WRIGHT, J K. 2021. The Market Weighton High in the 21st century – new understanding of a long-standing problem. *Proceedings of the Yorkshire Geological Society*, Vol. 64, https://doi.org/10.1144/pygs2021-008?ref=pdf&rel=cite-as&jav=VoR

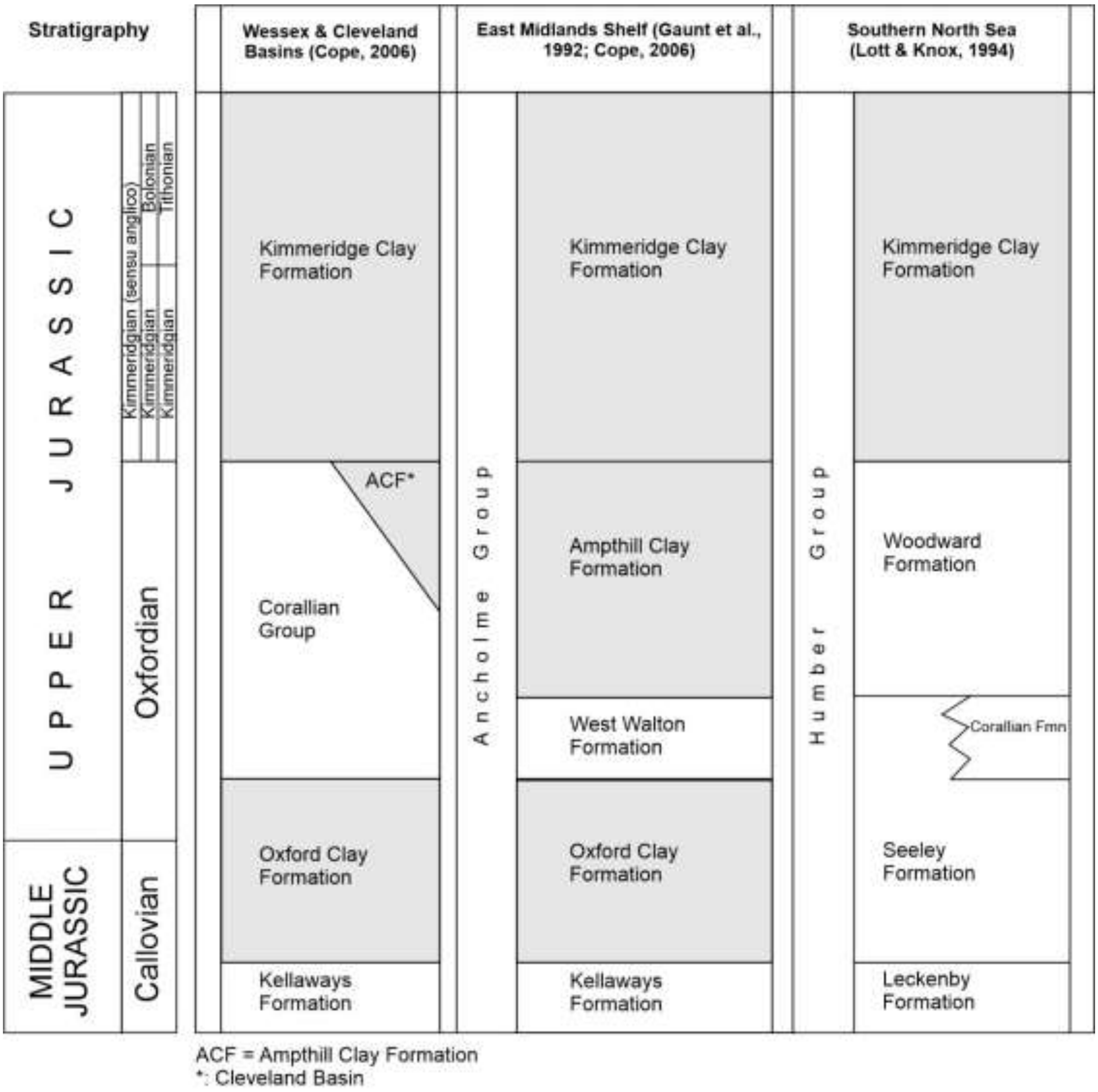


Figure 1. Generalised stratigraphical relationships of Upper Jurassic stratigraphical units. Grey highlight = Upper Jurassic mudstones described in this report.

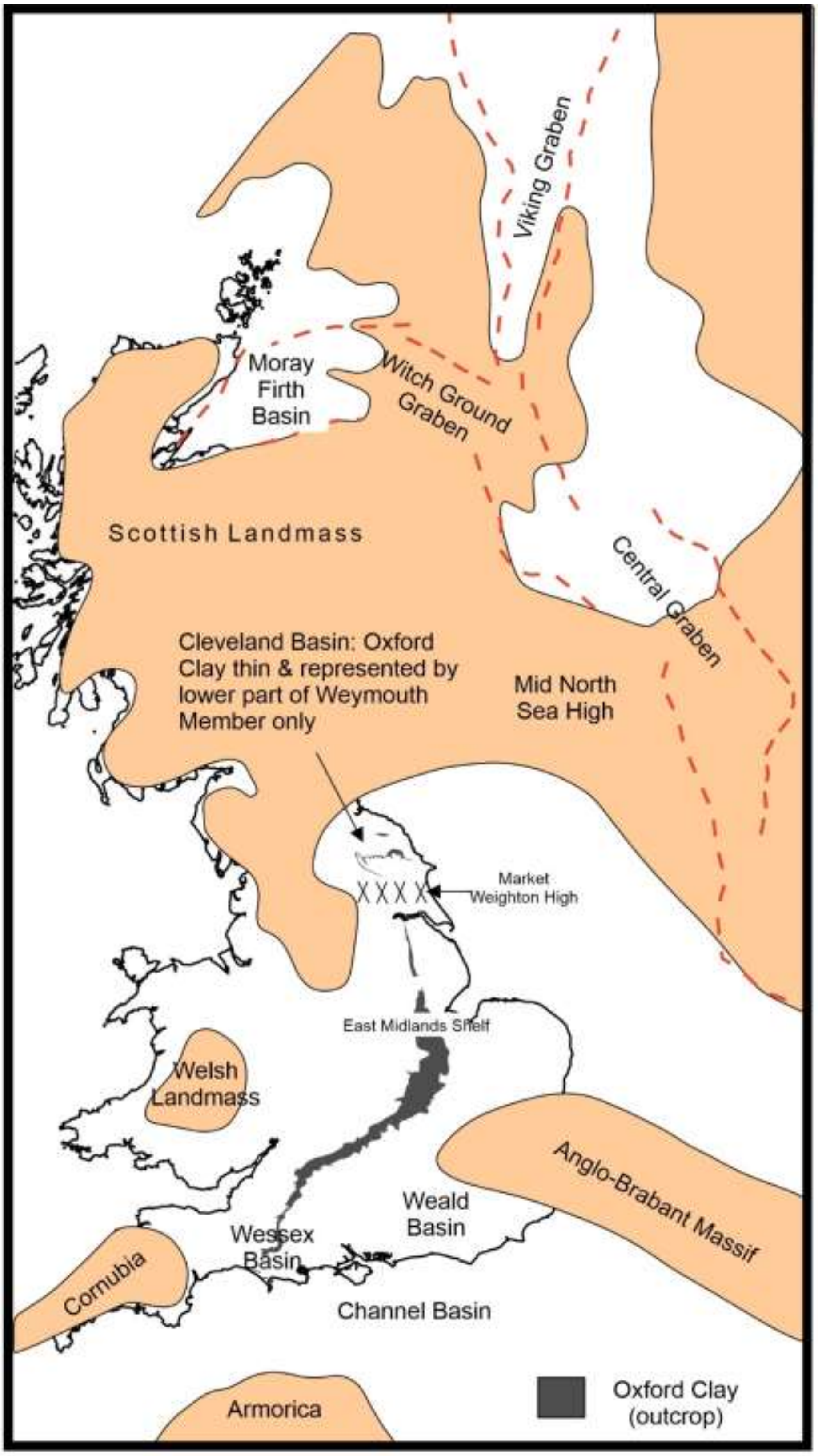
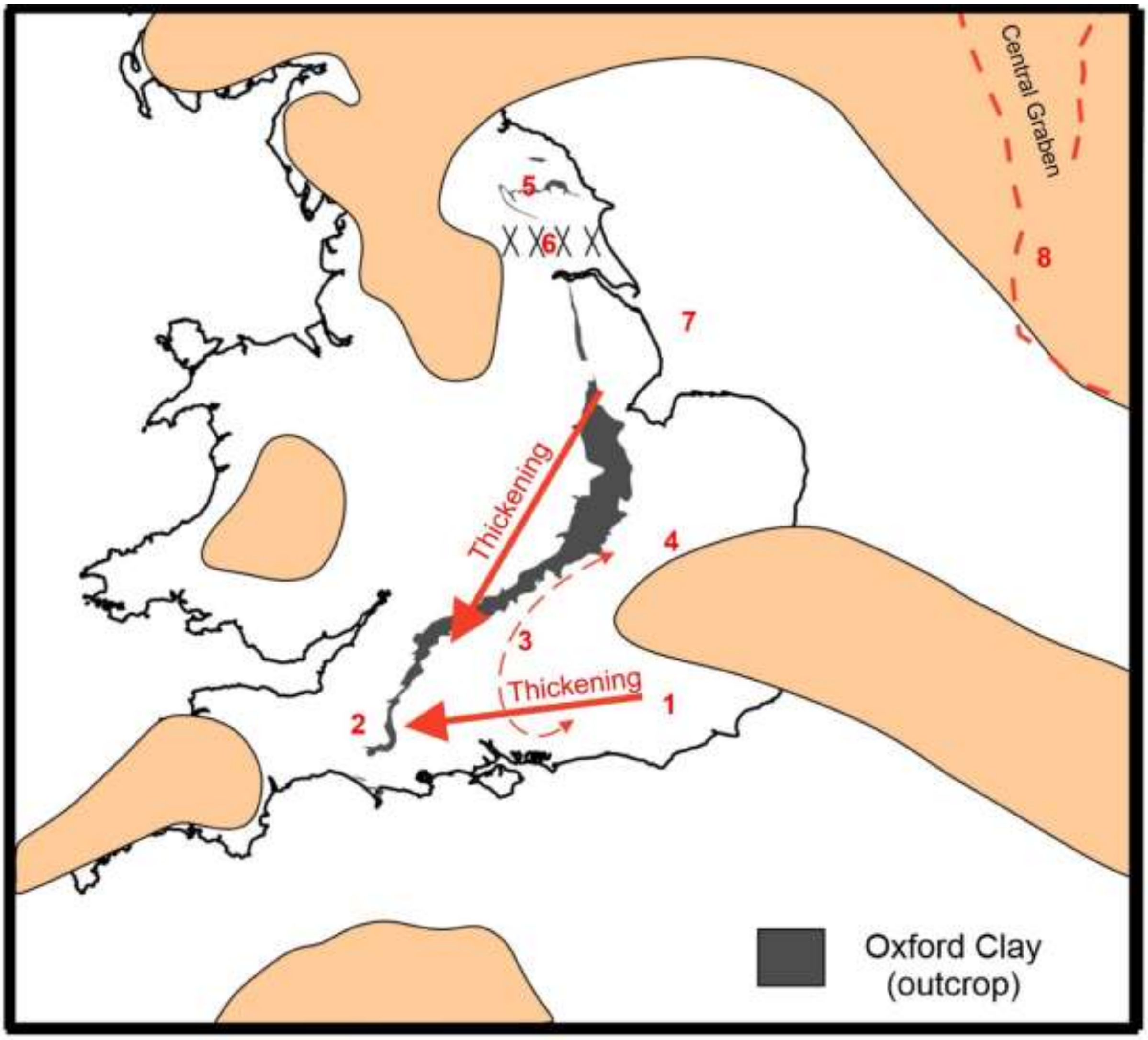
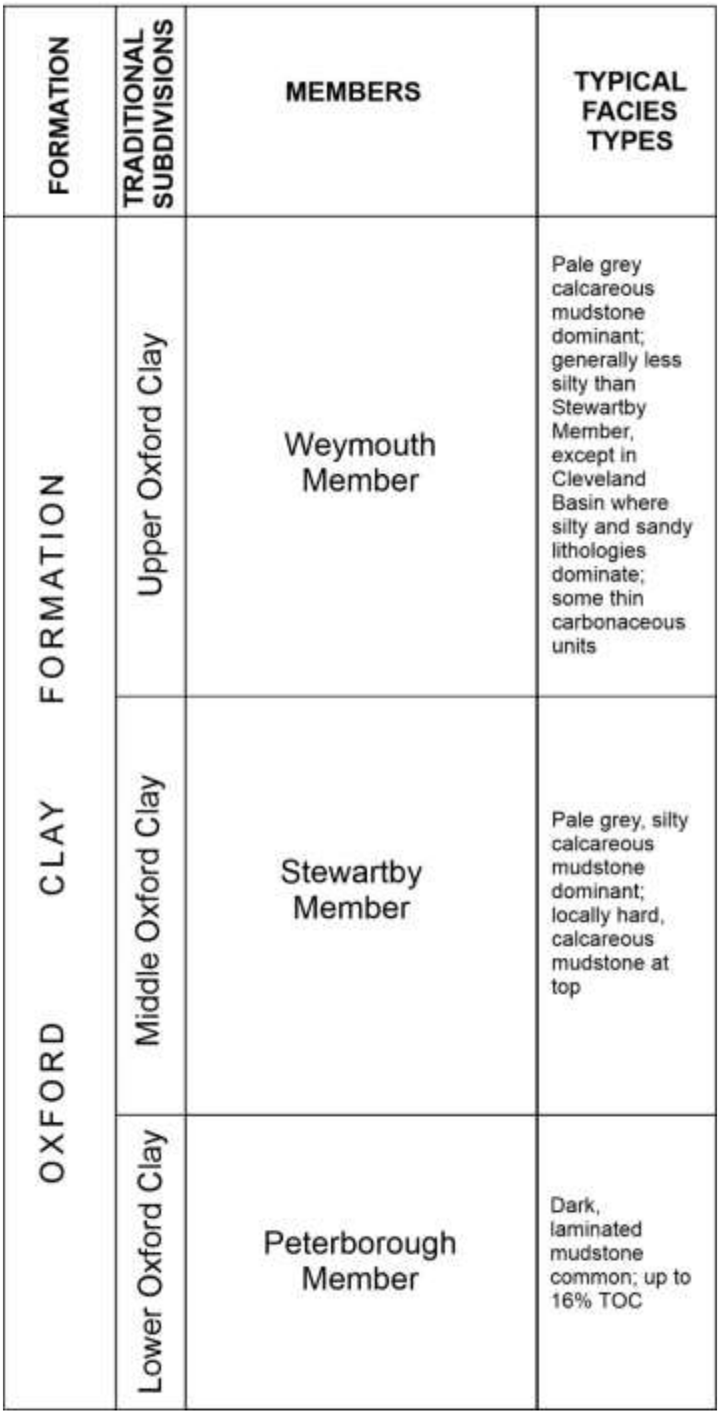


Figure 2. Palaeogeography during deposition of the Oxford Clay Formation. Based on map J8 of Bradshaw et al. (1992).



1: Thin Oxford Clay with atypical thin, indurated, calcareous, pyritous and organic-rich facies
2: Occurrence of silty facies in the lower part of the Oxford Clay across structural highs in the Wessex Basin
3: Development of indurated calcareous mudstone at top of Stewartby Member in areas adjacent to the Anglo-Brabant Massif and across structural highs
4: Thinning of Oxford Clay against Anglo-Brabant Massif with lower part dominated by mudstone with common broken-up shell suggesting higher energy conditions
5: Absence of Peterborough & Stewartby Members in the Cleveland Basin and occurrence of sandy/silty facies of the Weymouth Member
6: Absence of Oxford Clay across Market Weighton High
7: Eastward thinning of Oxford Clay and lateral passage into sandy/silty facies of the Seeley Formation
8: Deltaic facies that are coeval with the Oxford Clay

Figure 3. Thickness and facies trends in the Oxford Clay Formation. Based on map J8 of Bradshaw et al. (1992).



FORMATION	TRADITIONAL SUBDIVISIONS	MEMBERS	TYPICAL FACIES TYPES
OXFORD CLAY FORMATION	Upper Oxford Clay	Weymouth Member	Pale grey calcareous mudstone dominant; generally less silty than Stewartby Member, except in Cleveland Basin where silty and sandy lithologies dominate; some thin carbonaceous units
	Middle Oxford Clay	Stewartby Member	Pale grey, silty calcareous mudstone dominant; locally hard, calcareous mudstone at top
	Lower Oxford Clay	Peterborough Member	Dark, laminated mudstone common; up to 16% TOC

Figure 4. Stratigraphical facies trends in the Oxford Clay Formation

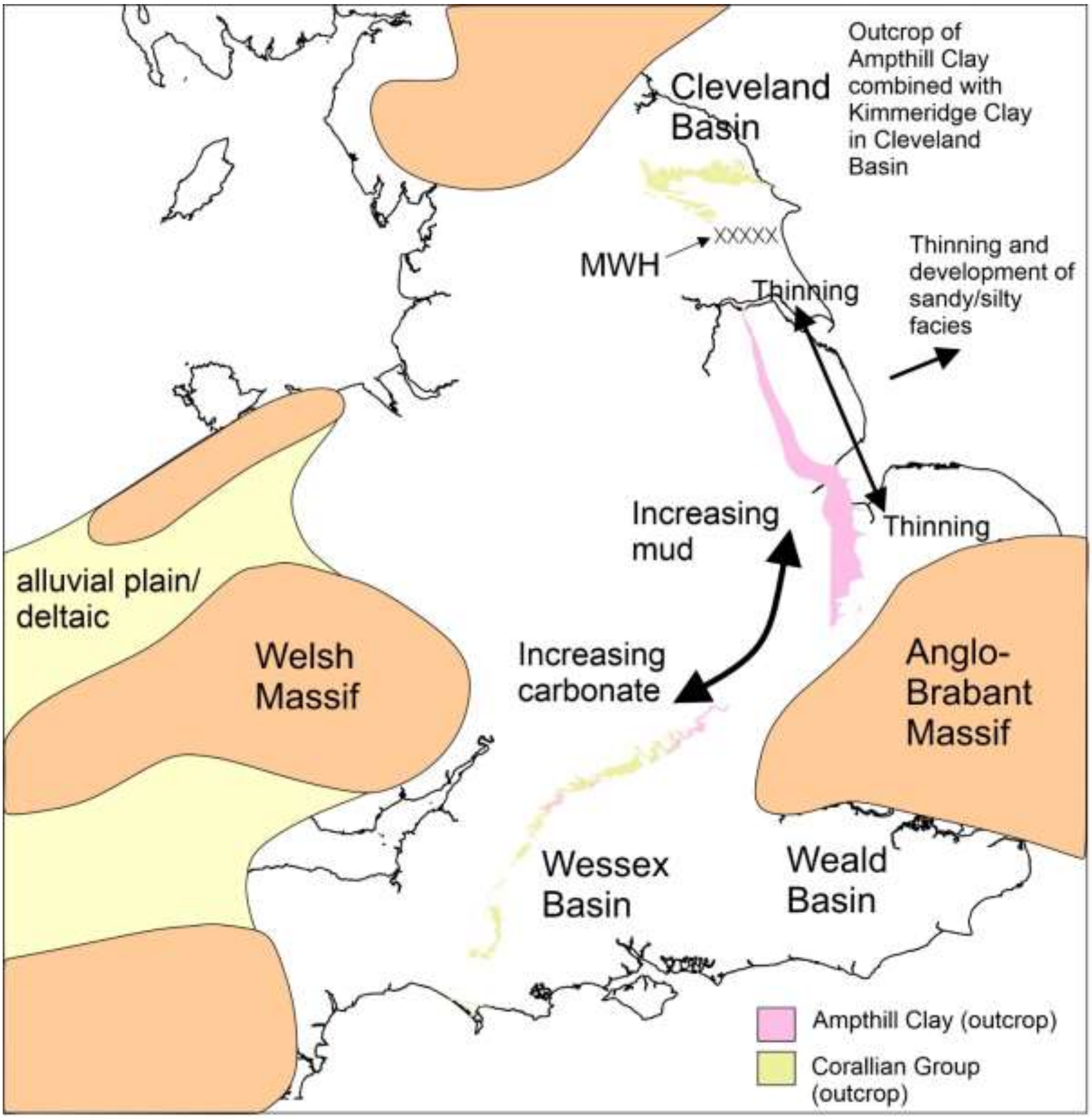
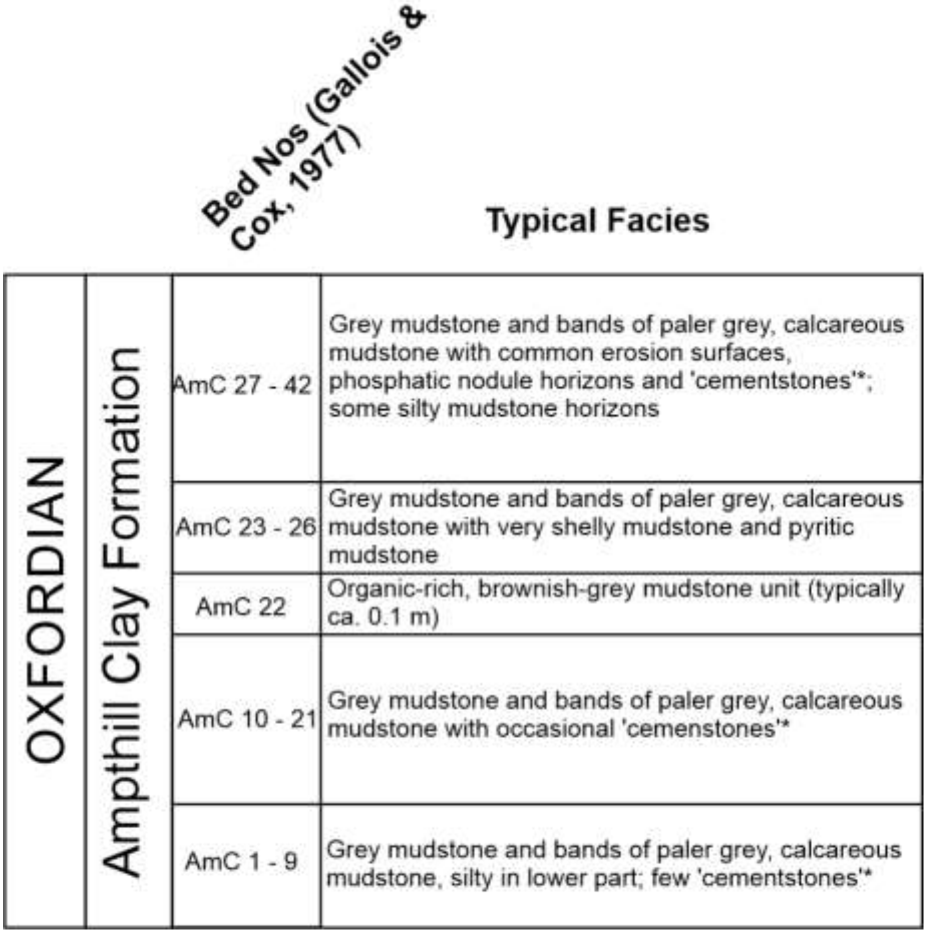
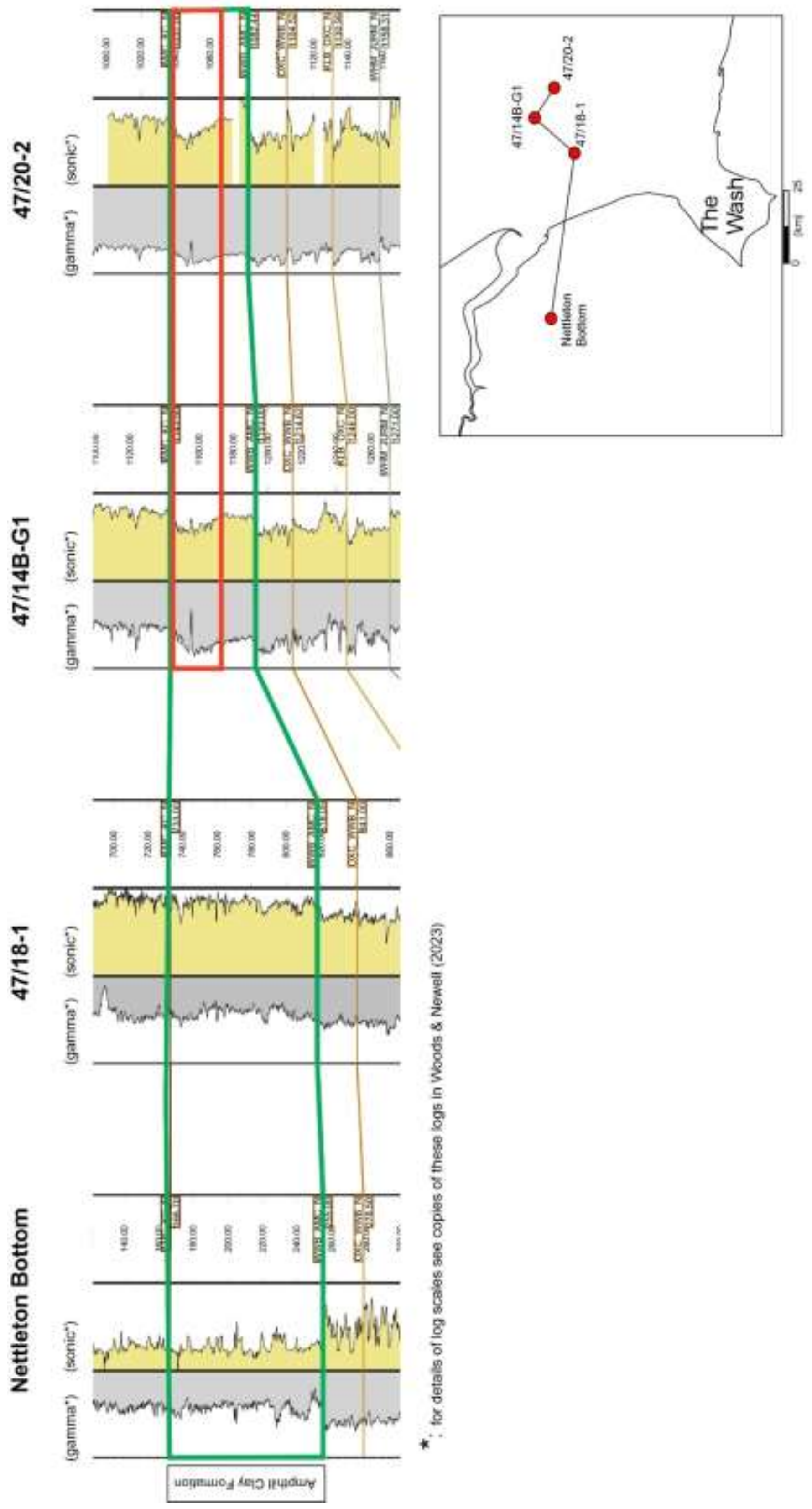


Figure 5. Palaeogeography during deposition of the Corallian Group and laterally equivalent West Walton and Ampthill Clay formations of the Ancholme Group. Based on Map J9 of Bradshaw et al. (1992). MWH = Market Weighton High.



		Bed Nos (Gallois & Cox, 1977)	Typical Facies
OXFORDIAN	Ampthill Clay Formation	AmC 27 - 42	Grey mudstone and bands of paler grey, calcareous mudstone with common erosion surfaces, phosphatic nodule horizons and 'cementstones'*; some silty mudstone horizons
		AmC 23 - 26	Grey mudstone and bands of paler grey, calcareous mudstone with very shelly mudstone and pyritic mudstone
		AmC 22	Organic-rich, brownish-grey mudstone unit (typically ca. 0.1 m)
		AmC 10 - 21	Grey mudstone and bands of paler grey, calcareous mudstone with occasional 'cemenstones'*
		AmC 1 - 9	Grey mudstone and bands of paler grey, calcareous mudstone, silty in lower part; few 'cementstones'*

Figure 6. Stratigraphy and facies variation in the Ampthill Clay Formation.
*cementstones = indurated diagenetic calcareous concretions



*: for details of log scales see copies of these logs in Woods & Newell (2023)

Figure 7. Correlation of the Ampthill Clay Formation across the East Midlands Shelf (green box) showing geophysical log evidence for potential lateral facies change in the upper part of the Ampthill Clay in the offshore part of the East Midlands Shelf (red box). The fall in gamma log values and corresponding increase in sonic velocity in the upper part of the formation in boreholes 47/14B-G1 and 47/20-2 is potential evidence of the lateral development of sandier/siltier mudstone facies.

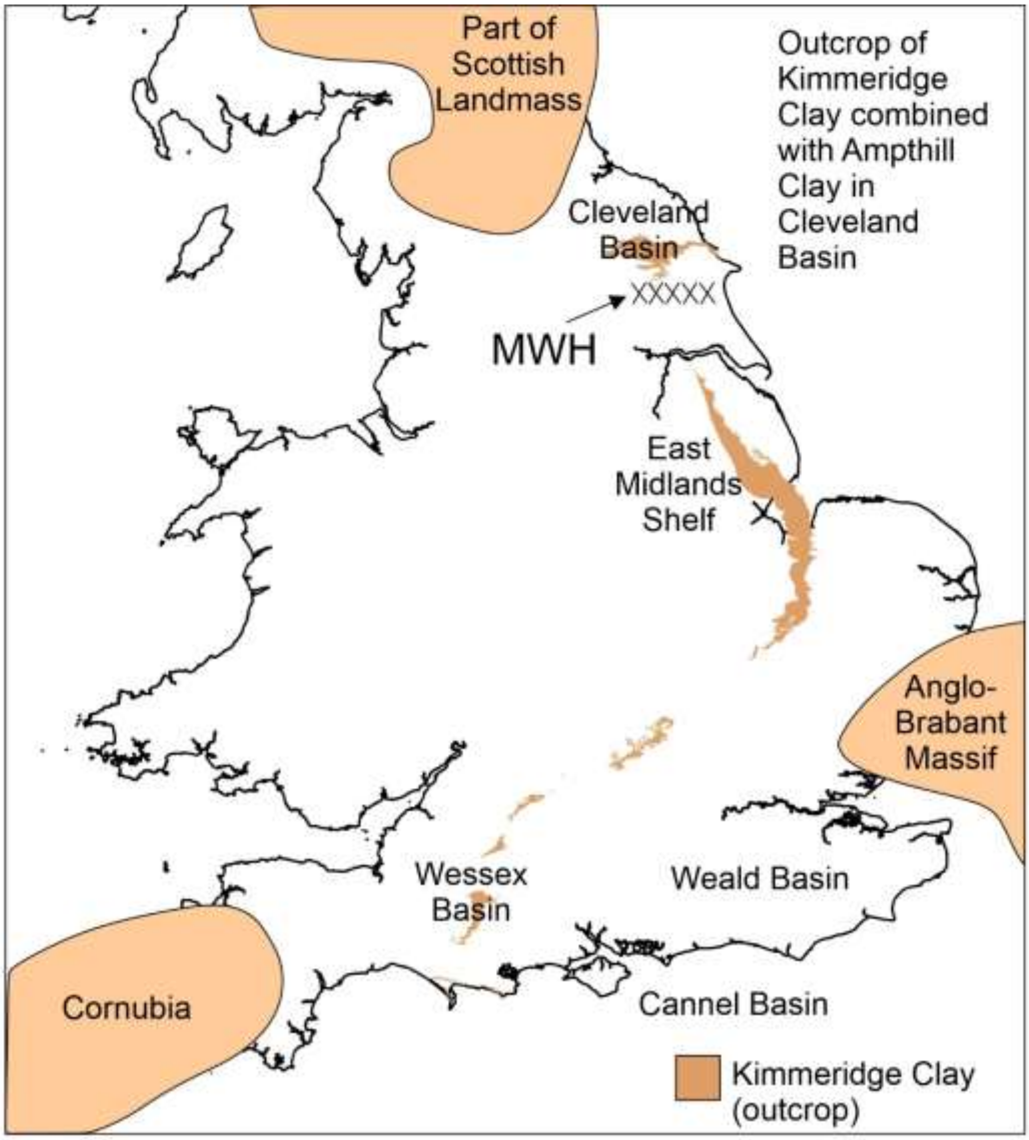
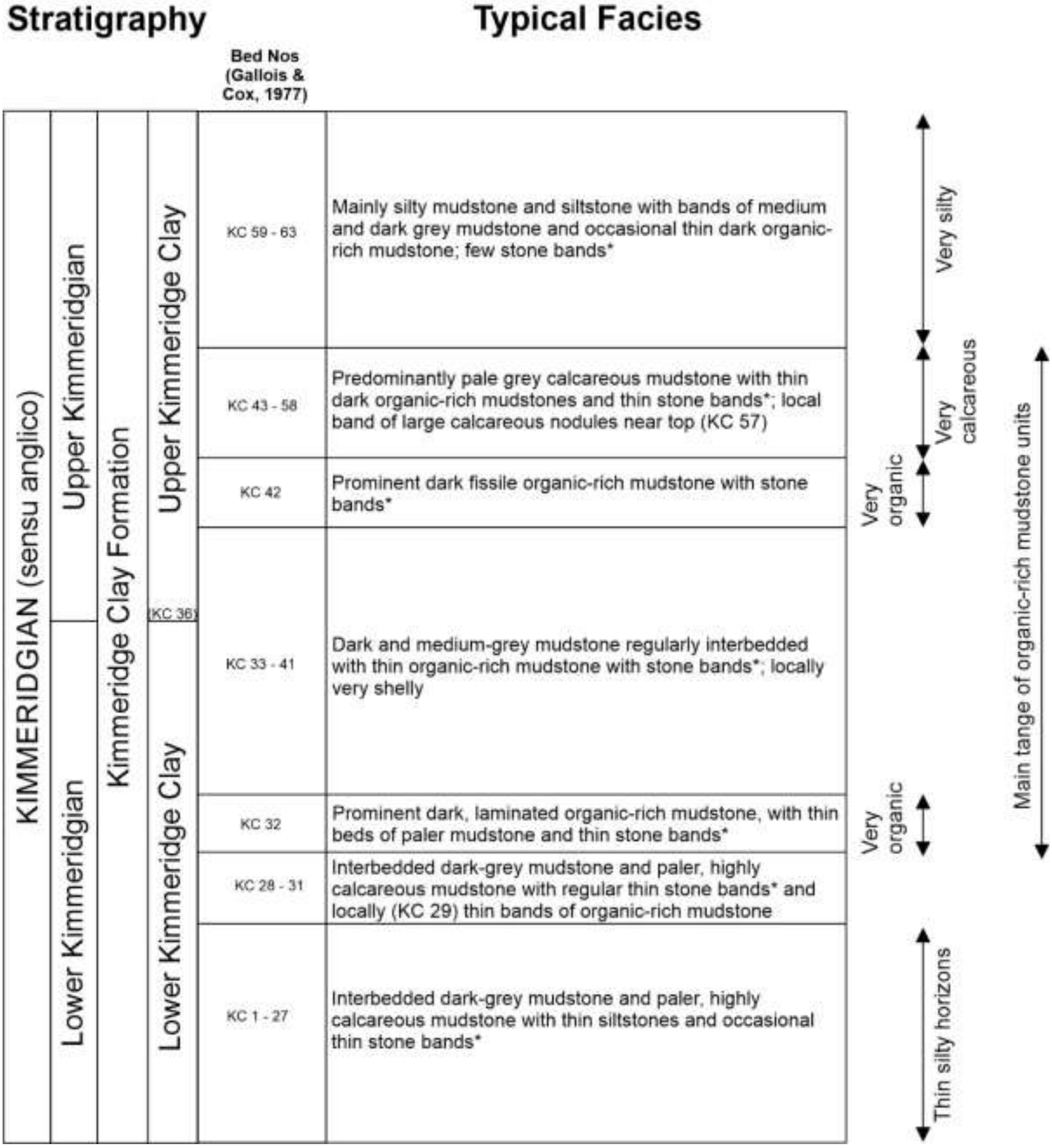


Figure 8. Palaeogeography during deposition of the Kimmeridge Clay Formation of the Ancholme Group. Based on Map J10 of Bradshaw et al. (1992). MWH = Market Weighton High.



Stratigraphy				Bed Nos (Gallois & Cox, 1977)	Typical Facies
KIMMERIDGIAN (sensu anglico)	Upper Kimmeridgian	Kimmeridge Clay Formation	Upper Kimmeridge Clay	KC 59 - 63	Mainly silty mudstone and siltstone with bands of medium and dark grey mudstone and occasional thin dark organic-rich mudstone; few stone bands*
				KC 43 - 58	Predominantly pale grey calcareous mudstone with thin dark organic-rich mudstones and thin stone bands*; local band of large calcareous nodules near top (KC 57)
				KC 42	Prominent dark fissile organic-rich mudstone with stone bands*
	Lower Kimmeridgian		(KC 36) Lower Kimmeridge Clay	KC 33 - 41	Dark and medium-grey mudstone regularly interbedded with thin organic-rich mudstone with stone bands*; locally very shelly
				KC 32	Prominent dark, laminated organic-rich mudstone, with thin beds of paler mudstone and thin stone bands*
				KC 28 - 31	Interbedded dark-grey mudstone and paler, highly calcareous mudstone with regular thin stone bands* and locally (KC 29) thin bands of organic-rich mudstone
				KC 1 - 27	Interbedded dark-grey mudstone and paler, highly calcareous mudstone with thin siltstones and occasional thin stone bands*

Figure 9. Stratigraphy and facies variation in the Kimmeridge Clay Formation.

*stone bands = indurated silstones / coccolithic limestones / diagenetic calcareous or dolomitic concretions