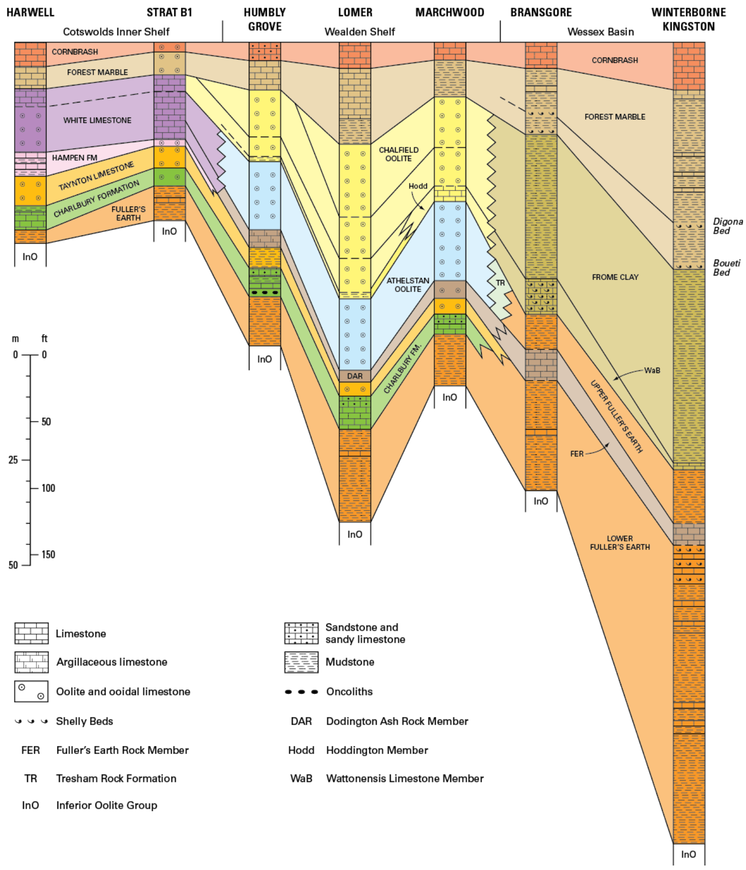
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

A gamma-ray correlation of boreholes and oil wells in the Bathonian Stage succession (Middle Jurassic) of the Wealden Shelf subcrop

Geology and Landscape Programme

Open Report OR/11/048



BRITISH GEOLOGICAL SURVEY

GEOLOGY and LANDSCAPE PROGRAMME

OPEN REPORT OR/11/048

A gamma-ray correlation of boreholes and oil wells in the Bathonian Stage succession (Middle Jurassic) of the Wealden Shelf subcrop

R J Wyatt

Keywords

Bathonian, Middle Jurassic. Lithological Correlation, Wealden Shelf subcrop.

Bibliographical reference

WYATT R. J. 2011. A gamma-ray correlation of boreholes and oil wells in the Bathonian Stage succession of the Wealden Shelf subcrop. *British Geological Survey Open Report*, OR/11/048. 26pp.

Keyworth, Nottingham British Geological Survey 2011

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 the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

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

Foreword

This report is the work of Mr R J Wyatt, a former BGS employee. It is based on studies carried out by him on BGS and other data since his retirement. It is published by BGS in order to put valuable data into the public domain, and to initiate a debate on the stratigraphy of this important succession. Preparation of the figures and report have been undertaken by BGS staff, including Henry Holbrook and Elaine Cross.

Contents

Summary

An analysis of the gamma-ray logs of some forty-three oil wells and boreholes in Sussex and Hampshire demonstrates that the Middle Jurassic (Bathonian) succession at depth there is an extension of the corresponding Cotswold Shelf succession at outcrop in Gloucestershire and the western part of Oxfordshire. The latter extends from the margin of the London Platform landmass to the edge of the Worcester Basin and is characterised by facies belts that prograded basinwards in time. In most respects the Wealden succession replicates the stratigraphy of the Cotswolds Shelf and also exhibits a similar progradation of facies belts

from the London Platform landmass to the margin of the contiguous Wessex Basin. The current stratigraphical nomenclature of the Wealden Shelf is reviewed and adjustments to it are introduced to harmonise with that of the Cotswolds Shelf.

1 Introduction

The correlation of the Middle Jurassic (Bathonian) strata at outcrop between Oxford and Sherborne in Dorset has been comprehensively reviewed in recent years (e.g. Penn and Wyatt, 1979; Sumbler, 1984, 1991; Wyatt, 1996; Wyatt and Cave, 2002). The following account updates the stratigraphy of the corresponding carbonate shelf succession at depth in the Weald and east Hampshire, and correlates it with that of the outcrop.

The method adopted has been analysis of gamma-ray log traces from some forty-three oil wells and boreholes in the study area, the former all declassified (Figure 1). Interpretation of the gamma-ray logs has been augmented by inspection of the few short runs of rock core drilled within the region, mainly in the reservoir rocks (Chalfield Oolite and Athelstan Oolite). However, two fully cored successions are available, namely Humbly Grove No. 3 Well (Figure 2), near Basingstoke, and BGS Warlingham Borehole, near Croydon (Figure 5). Another lengthy core run in Storrington No. 2 Well terminated just above the top of the Fuller's Earth Formation. These three successions are regarded as reference sections.

The results of this analysis indicate that a consistent and correlatable succession, identified in terms of the units recognised at outcrop in Gloucestershire and Oxfordshire (Cotswolds Shelf of Martin (1967)), can be traced throughout what the author terms the Wealden Shelf. As might be expected, chipping samples indicate that some units exhibit different facies from those of the type area in the South Cotswolds; others, however, maintain outcrop lithologies, notably the oil reservoir rock formations (Chalfield Oolite and Athelstan Oolite).

The paucity of cored rock and the uncertainties posed by the unreliability of cutting sample descriptions inhibit valid attempts at facies analysis. Thus, the lithological identities of the component formations in the succession are necessarily generalised. The author asserts, however, that each rock unit has, for the most part, a consistent and recognisable gamma-ray log signature by which it can be identified and correlated with corresponding units elsewhere.

The results of the gamma-ray analysis are presented in the form of eight traverses in an Appendix, herein referred to as Traverse 1, etc. These traverses comprise a number of wells or boreholes, each given a National Grid Reference and a BGS registration number. The stratigraphical interpretation of the gamma-ray traces in each traverse are correlated, such that the complete web of eight traverses (Figure 1) serves to summarise the regional characteristics of the Bathonian Stage succession in the study area.

Certain aspects of the stratigraphy of the Bathonian Stage in the Cotswolds remain controversial. For example, i) the validity of the Hampen Formation type section (Sumbler and Barron, 1996; Wyatt, 2010); ii) the questionable status and lateral extent of the Charlbury Formation (Sumbler, 1999; Wyatt, 1999). However, the present study relies on the author's interpretation of the Cotswolds succession as the basis for its correlation with the corresponding succession in Hampshire and the Weald. It should be noted here that the Upper Rags Member has recently been re-defined as the Corsham Limestone Formation (Barron et al., 2011).

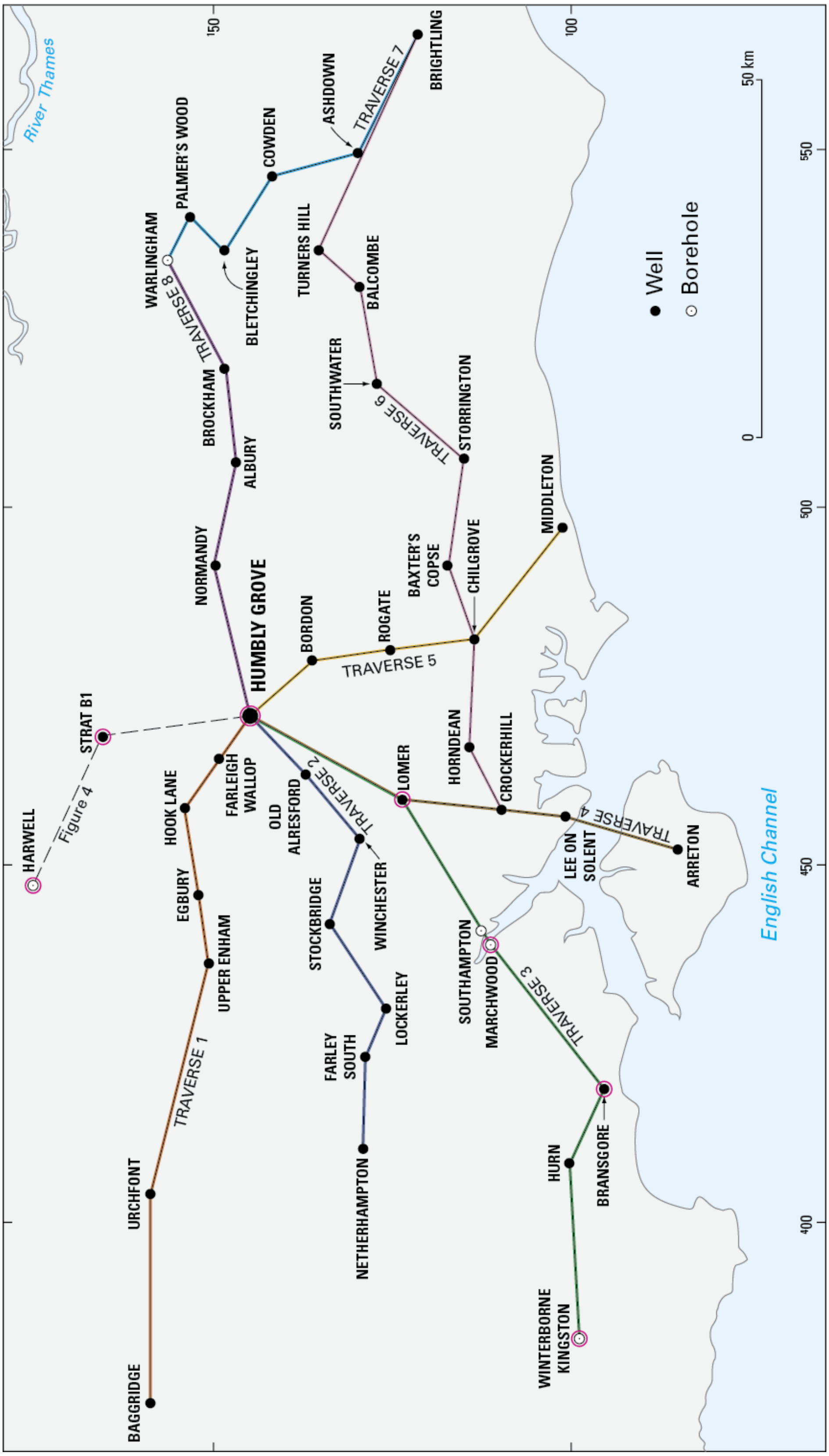


Figure 1: Location of selected boreholes and oil exploration well sites and lines of traverses. Boreholes and well sites ringed in red refer to Figure 4.

2 History of research

The earliest focussed account was that of Taitt and Kent (1958), who described the stratigraphy of the Henfield and Portsdown boreholes (drilled in 1936-7); they included annotated graphic logs of the complete Great Oolite Group successions in both boreholes. Falcon and Kent (1960), in summarising the geological results of petroleum exploration in southern England, made only brief reference to the stratigraphical succession. Martin (1967) defined the Wessex Basin and Cotswold Shelf provinces of the Bathonian in southern England and clearly illustrated the transition between the two in a graphic log correlation traverse, which included the western part of the present study area. He identified and named rock units in this area by comparison with those characteristic of the Oxfordshire outcrop. However, the author believes this nomenclature to be inappropriate, preferring comparison with that of the south Cotswolds where the lithological succession and palaeogeographical environment are more comparable (Figure 3). Worssam and Ivimey-Cook (1971) comprehensively described the stratigraphy and palaeontology of the Bathonian succession in Warlingham Borehole, near Croydon; this being one of only two cored successions in the Wealden Shelf (the other is Strat B1 Borehole) which feature a marginally nearer shoreline facies than that represented in the bulk of the study area. A detailed account of the lithostratigraphical succession in the Humbly Grove Oilfield group of wells and its palaeoenvironmental interpretation was published by Sellwood et al. (1985); they included a lithostratigraphical correlation diagram across the Wealden Shelf.

3 Stratigraphical nomenclature in the Humbly Grove oilfield and correlation with the outcrop in the Cotswolds

The fully-cored succession in Humbly Grove No. 3 Well (Figure 2) was selected as the primary reference section for the Bathonian Stage in the Wealden Shelf. This provides a satisfactory hub from which several geophysical log traverses could be constructed and interpreted (Figure 1). Furthermore, the comprehensive account of the stratigraphy in the Humbly Grove Oilfield group of wells by Sellwood et al. (1985) offers a sound basis for regional correlation. The stratigraphical nomenclature applied to this group of wells by Sellwood et al. (1985) includes several new local names replacing those defined at outcrop in the Cotswolds. The author asserts that it is now possible to harmonise the Humbly Grove succession with that of the Middle Jurassic outcrop in the Bath district (Barron et al., 2011) and to amend the nomenclature accordingly (Table 1).

Sellwood et al. (1985) retained the terms Cornbrash and Forest Marble formations (Figure 2) that cap the Great Oolite Group succession, in which the local lithologies are comparable to those at outcrop. For convenience, the Upper Cornbrash Member is included in this account although it is of Callovian age. Lithologically, the Lower Cornbrash Member resembles that found in the outcrop, consisting of lime-muddy, locally slightly ooidal, shelly, bioturbated limestone with sporadic mudstone partings. The underlying Forest Marble Formation consists of a variable succession of bioclastic argillaceous and bioclastic limestone, lime mudstone, siltstone and calcareous mudstone, the last commonly containing lignite debris. Unlike the outcrop, however, there is no basal, shell-fragmental, ooidal, coralline limestone unit.

COTSWOLD SHELF		HUMBLY GROVE OILFIELD	
CHALFIELD OOLITE FORMATION	Combe Down Oolite Member	GREAT OOLITE FORMATION	Herriard Member
			Hoddington Member
ATHELSTAN OOLITE FORMATION			Humbly Grove Member
Dodington Ash Rock Member		HESTER'S COPSE FORMATION	Dolomite Unit
TAYNTON LIMESTONE FORMATION			Wackestone Unit
CHARLBURY FORMATION	Eyford Member		Sandstone Unit
		? Fuller's Earth Rock Unit	
FULLER'S EARTH FORMATION		Lower Fuller's Earth	

Table 1: Harmonization of the nomenclature between the outcrop and Humbly Grove Borehole

Although Sellwood *et al.* (1985) adopted the then current name Great Oolite Limestone Formation from the south Cotswolds outcrop (now the Chalfield Oolite Formation of Wyatt and Cave, 2002), they identified three local members within it, namely the Herriard, Hoddington and Humbly Grove members in descending order (Table 1). The Herriard Member, which predominantly comprises bioclastic ooid-limestone and ooidal limestone, is now confidently recognised by the author as the Combe Down Oolite Member of the outcrop, which is of similar lithology. As confirmation, about midway down the member there is a bed of ooidal limestone with argillaceous intercalations, the sharp base of which rests upon an ooid-limestone bed capped by lime-muddy burrowfills. This feature is considered to represent a break in sedimentation that probably correlates with the regionally widespread hardground at a similar horizon in the Combe Down Oolite Member at outcrop (Wyatt, 1996). A similar burrowed horizon is recorded in Normandy Well of Traverse 8, 21 km ENE of Humbly Grove No. 3 Well. The term Hoddington Member is retained for the thin, widely persistent argillaceous unit at the base of the Chalfield Oolite Formation throughout the Wealden Shelf, but has no counterpart in the Cotswolds Shelf. The Humbly Grove Member, lying between the Chalfield Oolite Formation above and the Dodington Ash Rock Member below, corresponds stratigraphically to the Athelstan Oolite Formation of the mid Cotswolds and is of similar lithology; it can therefore carry the same name in the Humbly Grove Oilfield.

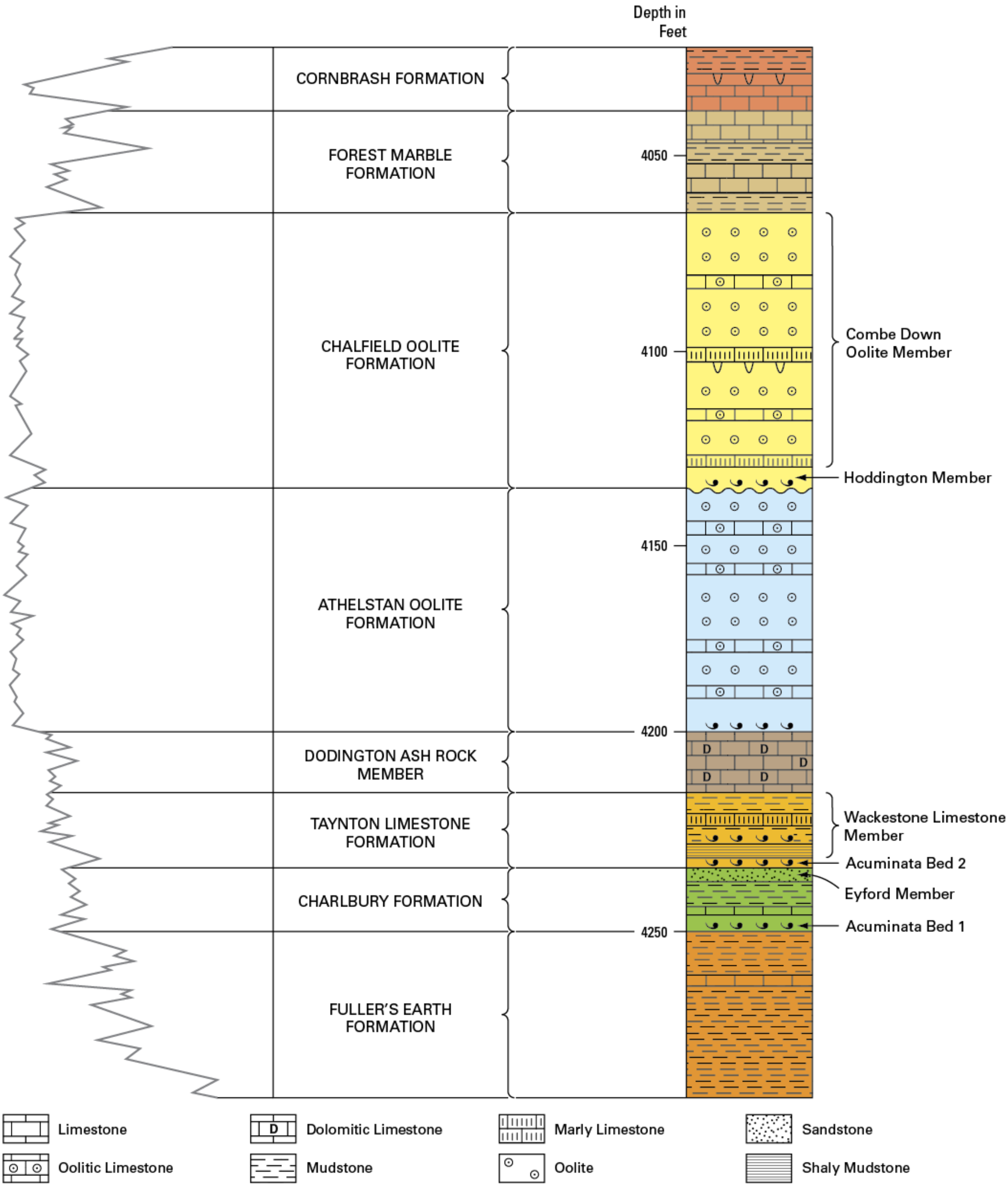


Figure 2: Stratigraphy of Humbly Grove No. 3 Well (based on cored succession) correlated with the matching gamma-ray log of Humbly Grove No. 1 Well.

The strata between the Humbly Grove Member and the ?Fuller's Earth Rock of Sellwood et al. (1985), were named the Hester's Copse Formation and divided into Dolomite, Wackestone and Sandstone units in descending order, each reflecting its dominant lithology (Table 1). The Dolomite Unit, comprising dolomitic, argillaceous, bioturbated, lime-muddy limestone, most closely resembles lithologically the Dodington Ash Rock Member of the Fuller's Earth Formation in the South Cotswolds, although the latter is not dolomitic. The dolomitic element of the Dolomite Unit seems to be localised in the Humbly Grove Oilfield because, elsewhere in the Wealden Shelf, the unit is widely represented by fine- to medium-grained, shell-detrital, variably slightly ooidal limestone.

Sellwood *et al.* (1985) interpret the underlying Wackestone Unit, comprising mudstone interbedded with lime-muddy, ooidal limestone beds, as representing an interbedded fore-shoal/back-shoal/tidal channel facies; this appears, like the Dolomitic Unit, to be restricted to the Humbly Grove area. For the most part in the Wealden Shelf it is represented by fine- to medium-grained, bioclastic, commonly ooidal limestones which, stratigraphically and lithologically are best correlated with the Taynton Limestone Formation at outcrop. It is proposed that the Wackestone Unit of Sellwood *et al.* (1985) be redesignated the Humbly Grove Wackestone Member of the Taynton Limestone Formation. The absence of strata representing the Hampen Formation and the Minchinhampton Beds of the Cotswolds Shelf (except in Warlingham Borehole; Figure 5; Appendix) implies a non-sequence between the Dodington Ash Rock Member and the Taynton Limestone Formation.

The Sandstone Unit of the Hester's Copse Formation (Sellwood et al., 1985), together with their underlying ?Fuller's Earth Rock, are here taken in the Humbly Grove Oilfield to correspond to the Charlbury Formation of Wyatt (1996) in Gloucestershire (Table 1). The Sandstone Unit is considered to be the local equivalent of the Eyford Member, which the author regards as the topmost unit of the Charlbury Formation, and the sole representative of the formation between Cirencester and Stow-on-the-Wold. Sumbler (1999) disputes the validity of the Charlbury Formation and regards the strata at this level at depth in Gloucestershire as part of the Taynton Limestone Formation, which pass west between Cirencester and Stow-on-the-Wold into the Eyford Member of the Fuller's Earth Formation, although Wyatt (1999) contests this interpretation. The top surface of the Eyford Member at Humbly Grove is a planar hardground upon which lies an oyster-rich bed that corresponds to Acuminata Bed 2 marker bed north of Bath; this supports the author's identification of the Eyford Member in the Wealden Shelf. The thin, regionally persistent, dark grey, shaly mudstone that rests directly upon this marker bed and which forms the basal bed of the Taynton Limestone Formation, is thought to be the counterpart of the lower portion of the Sevenhampton Beds of Richardson (1929) as re-interpreted by Wyatt (2009). Capping this shaly mudstone, there is another oyster-rich bed, a shell-fragmental limestone with sporadic ferruginous ooids; it lies at the horizon of the Echinata Bed at outcrop, where it correlates with the base of the Taynton Limestone Formation. It should be noted that Martin (1967) designated strata characterised by sandy mudstones and limestones his 'Passage Beds', which can now be assigned to the Charlbury Formation.

In Humbly Grove No. 3 Well, the ?Fuller's Earth Rock of Sellwood et al. (1985) consists mainly of mudstone with intermittent beds of variably bioclastic limestone; a limestone bed at the base is slightly oncoidal. In the Humbly Grove Oilfield as a whole, Sellwood *et al.* (1985) describe a more representative succession in which mudstones with sporadic fine-grained sandstone layers containing black ooids pass down into a 30 cm-thick bioturbated, argillaceous, shell-fragmental bed containing abundant oncoids; the latter rests upon a basal oyster-rich limestone layer. At outcrop in the North Cotswolds, corresponding beds, forming the Charlbury Formation, are dominated by oodal, shell-fragmental limestone with some argillaceous, sandy limestone beds and subordinate mudstone beds. At the base there are ferru-ooidal, argillaceous, oyster-rich limestone and lime-mudstone beds containing abundant dark-skinned ooids and oncoids. Although lacking the dominance of ooidal, shell-fragmental limestone, the succession in the Humbly Grove Oilfield shows similarities to that of the outcrop, particularly in the presence of dark-skinned oncoidal beds at the base. Thus, the ?Fuller's Earth Rock of Sellwood et al. (1985) is designated here the Charlbury Formation. A thin oyster-rich bed at the base of the formation is interpreted as equivalent to Acuminata Bed 1 marker bed of the Cotswolds Shelf.

The underlying Lower Fuller's Earth (Clay) of Sellwood et al. (1985) is mudstone dominated, with thin beds of fine-grained silicate-sandstone and bioclastic limestone. These beds correspond to Units 2 and 3 of the Lower Fuller's Earth Member south of Bath (Penn and Wyatt, 1979). Throughout the Wealden Shelf the Fuller's Earth is consistently represented by these two units only; therefore, in this region we may justifiably designate these beds the Fuller's Earth Formation. The thick unnamed limestone bed within this formation in Humbly Grove No. 3 Well is probably equivalent to a similar limestone bed at about this horizon in many wells in the Wealden Shelf (Figure 6; Traverse 7).

It is proposed from the evidence cited above that a satisfactory correlation between the Bathonian succession at outcrop in the Cotswolds and that in the Humbly Grove Oilfield can be recognised. Much of the succession in the latter comprises lithologies similar to those of the outcrop, and it is stratigraphically comparable. It is asserted herein that the Humbly Grove Oilfield succession corresponds approximately to that of the central part of the Cotswold Shelf (ramp), just seaward of the White Limestone Formation lagoonal facies belt (Figure 3).

It is possible also to correlate the Humbly Grove Oilfield succession with the more proximal portion of the Cotswold Shelf in Oxfordshire, where lateral facies changes merit a modified stratigraphy as shown in Southrop Borehole (Figure 3). Comparable facies changes occur between Humbly Grove Well No. 3 and Harwell Borehole, as illustrated in Figure 4. A lithostratigraphical classification of the Bathonian succession in the Cotswold Shelf, extrapolated into the Wealden Shelf, is shown in the Appendix.

The extension of the correlation (Traverse 1) between Humbly Grove No. 3 Well and Upper Enham Well westward towards Urchfont and further on towards Baggridge No. 1 Borehole (just south of Bath) is inferred over a distance of about 40 km. However, taking as a model the correlation of the corresponding Bathonian traverse at outcrop, terminating at Baggridge (Penn and Wyatt, 1979), the interpretation here offered in the extended traverse from Urchfont is considered to be valid. That being so, a tie to the distal part of the Cotswold Shelf is recognised and it is suggested that the Wealden Shelf forms an eastward extension of the Cotswolds Shelf to the south of the London Platform landmass. At Urchfont, the Twinhoe Member of the Chalfield Oolite Formation is not represented, presumably for the same reason as to the north of Bath, i.e. by its lateral passage northwards into the Bath Oolite Member (Penn and Wyatt, 1979). The Hoddington Member, as such, is not present at Baggridge, but the argillaceous basal beds of the Combe Down Oolite Member there are considered to be its equivalent.

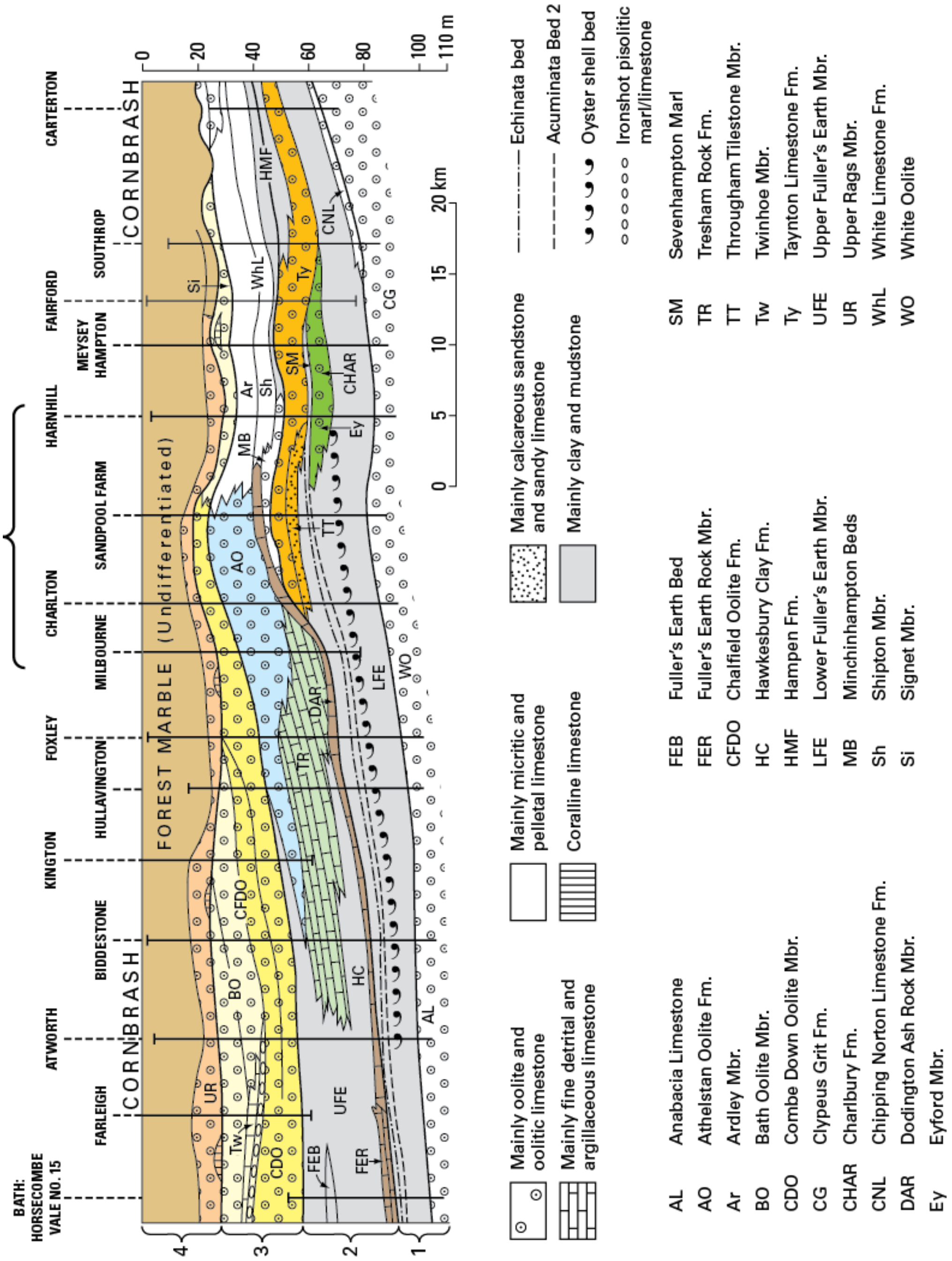


Figure 3: Diagrammatic section to show the lithostratigraphy of the Bathonian succession between Bath and Carterton, near Burford. The four major regressive units are numbered. Cored borehole sequences are shown as bold sticks. (The bracket indicates the approximate limits of the succession in the Cotswolds Shelf that correlates with that of the Humbly Grove Oilfield; after fig. 2 in Wyatt, 1996).

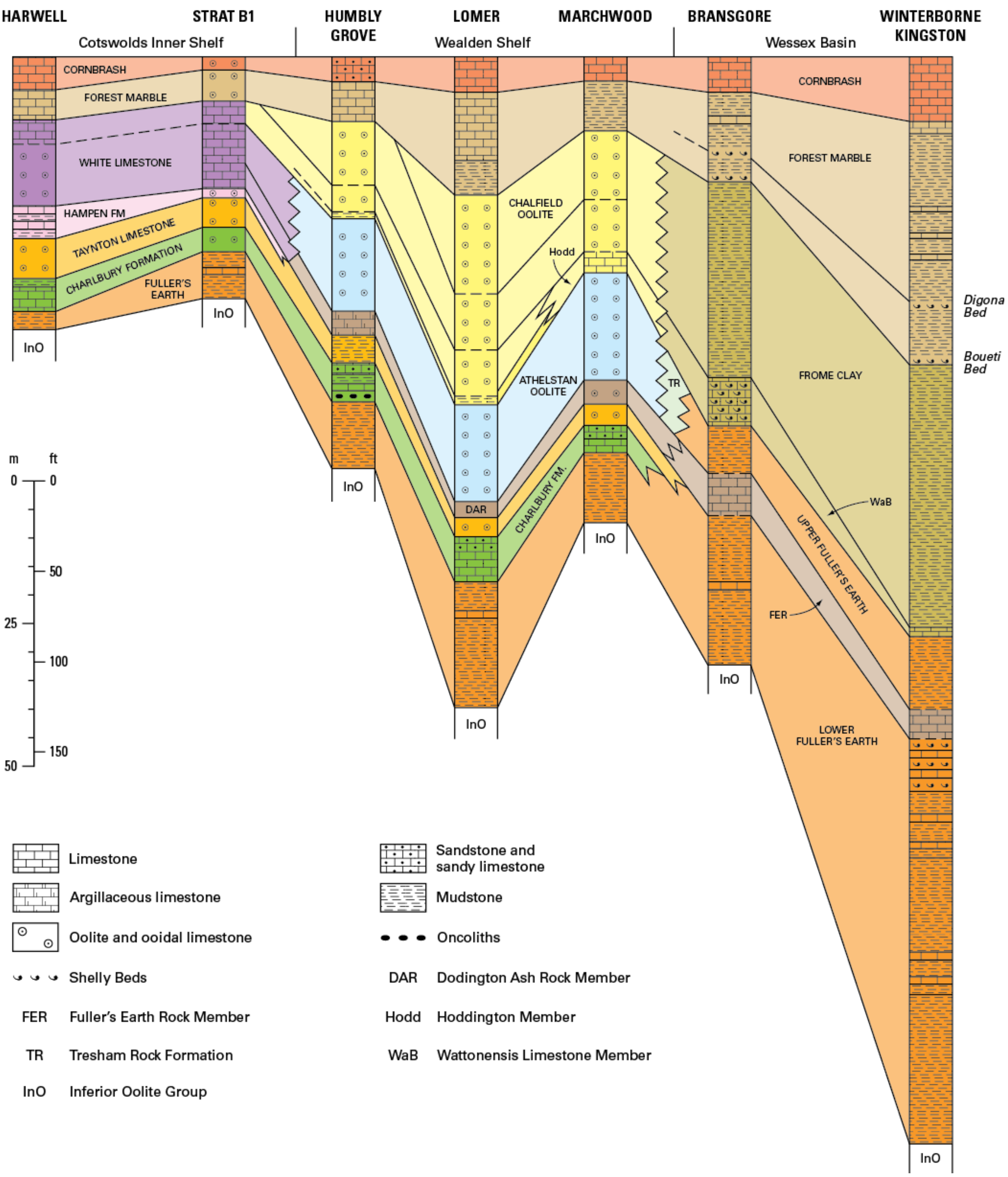


Figure 4: Graphic log correlation between Harwell Borehole and Humbly Grove No. 3 Well, thence via Traverse 3 to Winterborne Kingston Borehole, to illustrate the transition from the Cotswolds Inner Shelf to the Wessex Basin. See Figure 1 for location of boreholes and wells, and line of Traverse 3.

3.1 WARLINGHAM BOREHOLE

The Bathonian succession in the Wealden Shelf, as reviewed above, is more or less consistent throughout the study area. It corresponds approximately to the central and distal parts of the Cotswolds Shelf at outcrop. The proximal portion of the Cotswolds Shelf is represented only in Strat B1 Borehole and, marginally, in Warlingham Borehole (Figure 5).

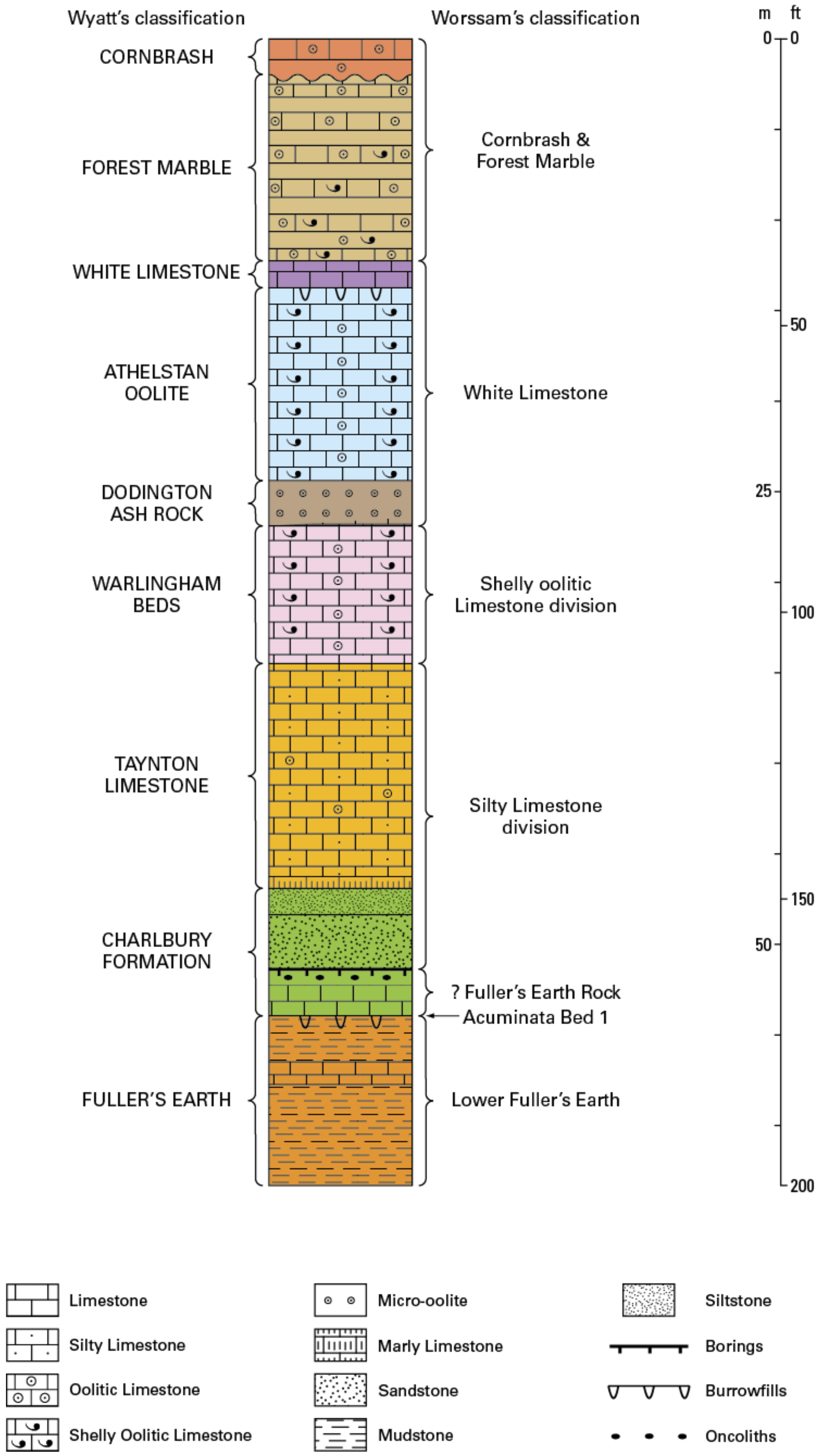


Figure 5: Graphic log of Warlingham Borehole, contrasting Worssam's (1971) classification with that of the author's revised classification.

Beneath the Cornbrash and Forest Marble formations in the Warlingham Borehole, which correspond to these formations elsewhere in the Wealden Shelf, there is a 1.27 m (4 ft 2 in) thick unit of pale grey, porcellanous limestone with burrows in the top, at the base of which there is a thin lime-mudstone layer, the mud from which infills burrows in the underlying Athelstan Oolite (Figure 5); this unit is deemed to be equivalent to the topmost Bladon Member of the White Limestone Formation in the Cotswolds Shelf, probably in its 'Upper Epithyris Bed' facies (Sumbler, 1984). Within the Wealden Shelf, this unit is inferred here to equate to the lowest part of the Combe Down Oolite Member.

The Athelstan Oolite Formation in Warlingham Borehole is characteristically represented by shell-fragmental ooid-limestones and ooidal limestones. The Dodington Ash Rock Member below comprises fine, even-grained micro-ooid-limestones similar to those in the upper part of the member at outcrop near Minchinhampton in the Cotswolds.

Beneath the Dodington Ash Rock Member, Worssam's 'Shelly oolitic limestone division' (in Worssam and Ivimey-Cook, 1971) comprises 8.23 m (27 ft) of fine-grained, shell-detrital, ooidal limestone, with a 0.1 m (4 in) coarse-grained bed at the base. This unit is stratigraphically and lithologically equivalent to the Minchinhampton Weatherstones in the Cotswolds, but because of their lack of continuity with the unit in the Cotswolds (see Traverse 8) I propose the local informal name Warlingham Beds for this unit. As in the Cotswolds, these beds are rapidly overstepped and cut out by the Dodington Ash Rock Member in the Wealden Shelf, just south of Warlingham Borehole (see Appendix).

The upper part of Worssam's 'Silty limestone division below, comprising silty and finely sandy limestone, oolitic in part', is probably the local representative of the Taynton Limestone Formation. At the base of these beds there is a layer of lime-muddy limestone which gives rise to a high gamma-ray spike, equivalent to that characteristic of most wells in the Wealden Shelf, where it usually identifies a marker bed of dark grey, shaly mudstone. Worssam (in Worssam and Ivimey-Cook, 1971) includes in the silty limestone division the underlying 4.06 m (13 ft 4 in) of silicate-siltstone and silicate-sandstone beds, and a basal 0.86 m (2 ft 10 in) thick bed of lime-muddy, fine-grained, slightly ooidal limestone which is welded to the top of the bed beneath and fills borings in it. I interpret these latter beds to be equivalent to the Eyford Member of the Charlbury Formation at outcrop, which there comprises silicate-sandstones and sandy limestones. The thick lime-muddy bed at the base of the member gives rise to a high gamma-ray spike, equivalent to that characteristic of most wells in the Wealden Shelf, where it identifies a marker bed of dark grey, shaly mudstone. This member, in the Wealden Shelf, rests upon the bored hardground capping the remainder of the Charlbury Formation, which was designated the ?Fuller's Earth Rock by Worssam (in Worssam and Ivimey-Cook, 1971). The succession in the Fuller's Earth Formation at Warlingham accords with that elsewhere in the Wealden Shelf, consisting predominantly of mudstones; it includes a thick unnamed limestone bed midway down the formation, which persists widely across the shelf.

4 Gamma-ray analysis of wells in the Wealden Shelf

Having established the stratigraphical relationship between the Bathonian succession at outcrop and that of the Humbly Grove Oilfield, together with revision of the nomenclature in the latter, it is possible to extrapolate the carbonate ramp succession of the Cotswolds Shelf eastwards into the Wealden Shelf (Appendix), using the cored succession and corresponding gamma-ray log of Humbly Grove No. 3 Well as an authentic primary reference section.

4.1 CORNBRASH AND FOREST MARBLE FORMATIONS

The limestone beds of the Lower Cornbrash Member produce a characteristic gamma-ray log signature of relatively low values which, for the most part, is consistent throughout the subcrop. The varied lithologies and successions of the underlying Forest Marble Formation give rise to variable signatures, with gamma-ray counts from low in the limestone beds to high in the mudstone. Consequently, the Forest Marble can generally be differentiated from the overlying Cornbrash. However, where limestone locally dominates in the Forest Marble, the similarity of their gamma-ray counts may make it difficult to differentiate these formations.

It is difficult to define the limits of the Cornbrash Formation in Southampton Borehole from the gamma-ray log. However, comparison with that of Marchwood Borehole nearby suggests that the upper half of the interval between the base of the Kellaways Formation and the top of the Chalfield Oolite belongs to the Cornbrash Formation, despite its uncharacteristically large thickness.

In the transition zone from shelf to basin in traverses 3 and 4, the Forest Marble Formation becomes significantly thicker and dominated by mudstones, characterised by high gamma-ray values; the shelly Boueti Bed at the base corresponds to a muted low gamma-ray spike, whilst the shelly Digona Bed above produces a much more dominant spike. The interval between the two beds equates to the Upper Rags Member of the Forest Marble at outcrop in the Bath area (Bristow, et al., 1999), now termed the Corsham Limestone Formation (Barron et al., 2011).

4.2 CHALFIELD OOLITE FORMATION

The Chalfield Oolite Formation comprises three members, of which the uppermost is the Bath Oolite Member, present in the western part of the Wealden Shelf only. The member is characterised by whitish, shell-detrital, ooidal limestones which are locally pisoidal in part. The underlying Combe Down Oolite Member is predominantly pale cream, bioclastic ooid-limestone and ooidal limestone. Both members have similar, uniformly very low gamma-ray signatures which can only be satisfactorily differentiated by a slightly higher gamma-ray spike at the base of the Bath Oolite Member. The basal, thin Hoddington Member, comprising interbedded lime-muddy limestone and mudstone, invariably displays a significantly higher gamma-ray count and clearly separates the Combe Down Oolite Member from the underlying Athelstan Oolite Formation.

4.3 FROME CLAY FORMATION

The Chalfield Oolite Formation passes laterally into the Frome Clay Formation at the shelf margin as illustrated in traverses 2 and 3, and in Figure 4; the latter formation is characteristic of the Wessex Basin. Mudstones predominate and are represented, for the most part, by fairly uniform high gamma-ray counts. The uncharacteristically variable gamma-ray signature in Farley South Well reflects its location at the critical shelf margin transition zone (compare the gamma-ray logs of Farley South No. 1 Well and Lockerley Well).

The Hoddington Member of the Chalfield Oolite Formation passes laterally at the shelf margin in traverses 2 and 3 into its equivalent at outcrop, i.e. the informally-named Wattonensis Beds. These beds, comprising alternating lime-muddy limestone and shelly mudstone, are characterised by a significantly lower gamma-ray signature than contiguous beds; they are regarded as a thin basal unit in the Frome Clay Formation (Bristow, et al., 1999). These beds are herein formalised as the Wattonensis Limestone Member of the Frome Clay Formation in the Wessex Basin.

4.4 ATHELSTAN OOLITE FORMATION

Lithologically, the Athelstan Oolite Formation is comparable to the Combe Down Oolite Member of the Chalfield Oolite Formation, both being composed of ooidal limestones and ooid-limestones, and both producing a uniform gamma-ray signature of very low values. The gamma-ray signatures of these two units, together with that of the Bath Oolite Member of the Chalfield Oolite Formation, produce a prominent low-value gamma-ray block which stands in clear contrast to those of the remaining lithological units of the Bathonian Stage and which demarcate the Humbly Grove oil reservoir rocks. Indeed, the base of the low-value gamma-ray block provides a satisfactory datum from which to interpret the underlying succession.

4.5 TRESHAM ROCK FORMATION

As in the Cotswolds Shelf, the Athelstan Oolite Formation passes laterally into the Tresham Rock Formation towards the margin of the Wealden Shelf. It is present in traverses 1, 2 and 4 and inferred in traverse 3. The formation comprises fine-grained, locally slightly ooidal limestones with some interbeds of lime-muddy limestone. These beds produce a fairly uniform gamma-ray trace with values intermediate between the Chalfield Oolite Formation and the Hoddington Member.

4.6 TAYNTON LIMESTONE FORMATION AND DODINGTON ASH ROCK MEMBER

The gamma-ray counts of the Taynton Limestone Formation are generally rather lower than the overlying ooid-/ooidal-limestone formations and commonly display rather variable log signatures. However, in Traverse 6 between Chilgrove and Brightling wells, the gamma-ray logs closely match those of the Chalfield Oolite and Athelstan Oolite formations above. The Taynton Limestone Formation is uncharacteristically thick (24.38m: 80 ft) in Netherhampton Well (Salisbury), at the margin of the Wessex Basin. It suggests a localised and transitory advance of the Taynton Limestone Formation bioclastic, ooidal limestone facies into the basin. In much of the subcrop it is difficult, in terms of the gamma-ray logs, to differentiate the Dodington Ash Rock Member from the Taynton Limestone Formation, because they are lithologically similar. This is particularly evident in Traverse 7, between Warlingham Borehole and Brightling Well; only a discreet glance at corresponding geophysical log traces has enabled them to be differentiated! On the contrary, the two units can, on the basis of the gamma-ray signatures, confidently be separated in traverses 1 and 2. At the base of the Taynton Limestone Formation a regionally persistent marker bed of dark grey, shaly mudstone produces a prominent high gamma-ray spike that is present in most wells in the study area.

4.7 CHARLBURY FORMATION

The topmost unit of the Charlbury Formation comprises the fine-grained silicate-sandstones and silicate-siltstones of the Eyford Member that give rise to only marginally lower values than those of the Taynton Limestone Formation. However, it can be differentiated from the latter by the high gamma-ray spike noted above, and by the distinctive lithology recorded in cutting samples.

Gamma-ray counts in the mudstones of the lower part of the Charlbury Formation are similar to these silicate-sandstones, partly attributable to the presence of layers of silicate-sandstone within the mudstone. However, with downward progression into calcareous, oncoidal mudstones, gamma-ray values steadily become moderately high at the base of the formation. As a whole, the Charlbury Formation, where well developed, has a readily identified signature.

4.8 FULLER'S EARTH FORMATION

Gamma-ray counts from mudstones throughout the Fuller's Earth Formation are relatively uniform and are significantly greater than those of mudstones higher in the succession. However, in much of the south-eastern part of the Wealden Shelf they include a widely persistent bed of limestone which generates a moderately low gamma-ray signature (Traverse 7). The Dodington Ash Rock Member passes westwards at the shelf margin in traverses 2 and 3 into the Fuller's Earth Rock Member which lies within the upper part of a considerably expanded Fuller's Earth Formation that is characteristic of the Wessex Basin. It comprises lime-muddy limestone with subordinate calcareous mudstone beds and is identified by an interval of lower gamma-ray log values.

5 Regional stratigraphical framework: a resumé

It has been demonstrated above that the Middle Jurassic (Bathonian) succession in the Wealden Shelf constitutes an eastward extension of the Cotswolds Shelf, the latter being a classic example of a carbonate platform (or ramp), which extends from the margin of the London Platform landmass to the edge of the Worcester Basin. This platform is characterised by facies belts, aligned approximately parallel to the shelf margin, that prograded steadily basinwards in time (Wyatt, 1996). That portion of the Wealden Shelf covered in this study corresponds predominantly to the median and distal parts of the Cotswolds Shelf (Figure 3) and, in most respects, replicates the stratigraphy of the latter and the progradation of facies belts, in this case into the contiguous Wessex Basin (Figure 4). This interpretation enhances the basic premise of Martin (1967), who relied upon a much smaller database. These facies belts range from the open marine mudstones of the Wessex Basin (Fuller's Earth and Frome Clay formations), through the foreshoal silicate-sandstones and oncoidal limestones and mudstones at the basin margin (Charlbury Formation), the mobile shoals of ooid-limestones and ooidal limestones at the distal shelf margin (Chalfield Oolite, Athelstan Oolite and Taynton Limestone formations), to the variegated limestone/mudstone back-shoal and tidal channel deposits (Forest Marble Formation). Nearer shore proximal deposits are represented by the lagoonal White Limestone Formation present in Strat B1 Borehole and Warlingham Borehole, and the clastic, shallow-sea mudstones and limestones of the Hampen Formation in Strat B1 Borehole only.

The facies changes within individual stratigraphical units as they approach the margin of the Wealden Shelf (Figure 4) are also broadly similar to those of the Cotswolds Shelf. Thus, the Chalfield Oolite Formation passes laterally into the Frome Clay Formation (traverses 2 and

3); whilst its basal Hoddington Member passes into the Wattonensis Limestone Member of the Wessex Basin (traverses 2 and 3). The Athelstan Oolite Formation changes into the Tresham Rock before the latter passes into the Upper Fuller's Earth of the basin (traverses 2, 3 and 4). The Dodington Ash Rock Member becomes the Fuller's Earth Rock of the basin (traverses 1 to 4), whilst the Taynton Limestone Formation passes laterally into the Lower Fuller's Earth (traverses 1 to 4); but, unlike the Cotswolds Shelf, there is no intermediate silicate-sandstone/sandy limestone facies (Througham Formation) between the two. The absence of the latter indicates the remoteness of the Wealden Shelf from the probable arenaceous sediment source in the Midlands (Wyatt, 2009). The Charlbury Formation passes into the Lower Fuller's Earth of the Wessex Basin (traverses 1 to 4); again, there is no intermediate representative of the commercially important Cotswolds slate of the outcrop (the Eyford Member there). The Fuller's Earth Formation extends throughout the Wealden Shelf, as it does at outcrop.

In the Cotswolds Shelf, Wyatt and Cave (2002) have concluded that the Forest Marble Formation oversteps the underlying Chalfield Oolite Formation north-eastwards, to leave only the basal portion of the latter represented in Oxfordshire by the Signet and Bladon members of the White Limestone Formation. The author infers that, similarly, in the Wealden Shelf the Forest Marble Formation oversteps the Chalfield Oolite Formation eastwards, finally coming to rest upon the Athelstan Oolite Formation. This is apparent in traverses 1 and 8, between Hook Lane Well and Warlingham Borehole; also in Traverse 6, between Marchwood Borehole and Turner's Hill Well (Figure 6). The eastward limits of the Bath Oolite and Combe Down Oolite members of the Chalfield Oolite Formation are shown in Figure 7. In only two localities, namely Warlingham Borehole near Croydon and Strat B1 Borehole near Reading, is the Bladon Member of the White Limestone Formation represented. In Warlingham Borehole, a highly attenuated remnant of the Hoddington Member of the Chalfield Oolite Formation could well be represented by the 0.1m mudstone bed at the base of the Bladon Member. Although, in most respects, the Forest Marble Formation in the Wealden Shelf has similar diverse lithologies to those of the Cotswold Shelf, it lacks the persistent basal Upper Rags Member of the latter, which comprises bioclastic limestones and oolites with coralline patch reefs at the base.

The non-sequence in the Cotswolds Shelf between the Dodington Ash Rock Member and underlying strata, which eliminates any representative of the *Subcontractus* Zone in the western part of this shelf, is replicated throughout the Wealden Shelf (Appendix). Only in Warlingham Borehole are there strata, the Warlingham Beds, that are of *Subcontractus* Zone age.

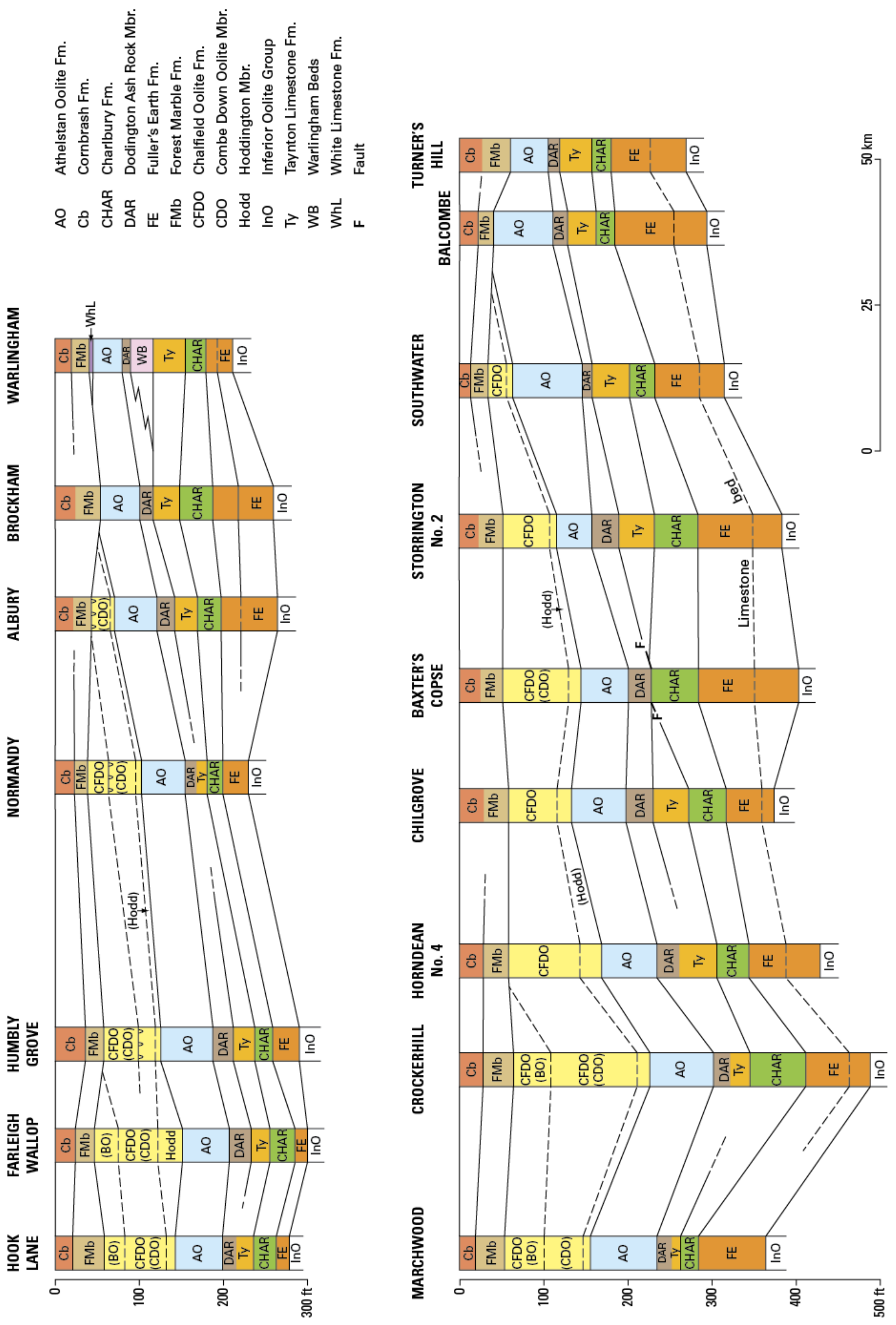


Figure 6: Correlation of summary logs to illustrate the overstep of the Chalfield Oolite Formation by the Forest Marble Formation. See Figure 1 for location of traverses.

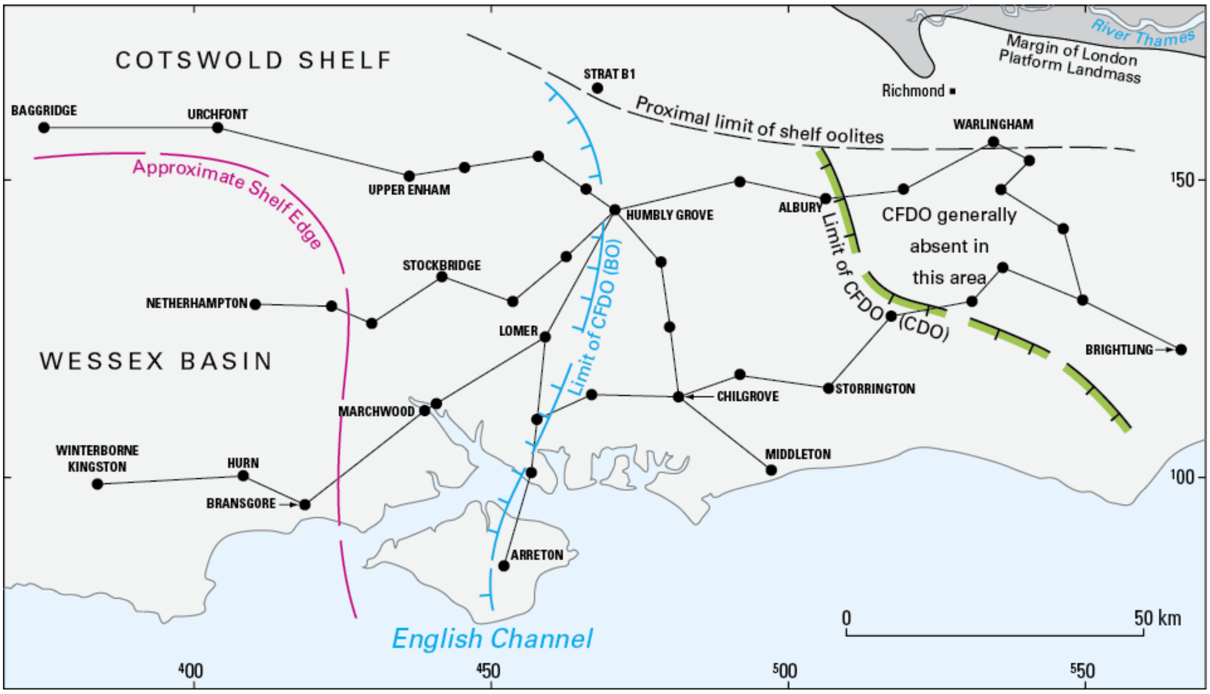


Figure 7: Map indicating the limits of the members of the Chalfield Oolite Formation, illustrating their overstep by the Forest Marble Formation. (CFDO is the Chalfield Oolite Formation; BO is the Bath Oolite Member; CDO is the Combe Down Oolite Member. For clarity, only a few boreholes and wells are named).

References

BARRON, A J M, SHEPPARD, T H, GALLOIS, R W, HOBBS, P R N, and SMITH, N J P. 2011. Geology of the Bath district. *British Geological Survey Sheet Explanation*, Sheet 265 (England and 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 for 1:50 000 Geological Sheet 297 (England and Wales)*.

BRITISH GEOLOGICAL SURVEY. In press. Bath. England and Wales Sheet 265. Bedrock and Superficial Geology. 1:50 000. (Keyworth, Nottingham: British Geological Survey).

FALCON, N L, and KENT, P E. 1960. Geological Results of Petroleum Exploration in Britain 1945-1957. *Memoir of the Geological Society of London*, **2**.

MARTIN, A J. 1967. Bathonian Sedimentation in Southern England. *Proceedings of the Geologists' Association*, **78**, 473-488.

PENN, I E, and WYATT, R J. 1979. The stratigraphy and correlation of the Bathonian strata in the Bath-Frome area. *Report of the Institute of Geological Sciences*, **78/22**, 25-88.

RICHARDSON, L. 1929. The country around Moreton in Marsh. *Memoir of the Geological Survey of Great Britain.* Sheet 217 (England and Wales).

SELLWOOD, B W, SCOTT, J, MIKKELSEN, P, and AKROYD, P. 1985. Stratigraphy and sedimentology of the Great Oolite Group in the Humbly Grove Oilfield, Hampshire. *Marine and Petroleum Geology*, **2**, 44-55.

SUMBLER, M G. 1984. The stratigraphy of the Bathonian White Limestone and Forest Marble formations of Oxfordshire. *Proceedings of the Geologists' Association*, **95**, 51-64.

SUMBLER, M G. 1991. The Fairford Coral Bed: new data on the White Limestone Formation (Bathonian) of the Gloucestershire Cotswolds. *Proceedings of the Geologists' Association,* **102**, 55-62.

SUMBLER, M G, and BARRON, A J M. 1996. The type section of the Hampen Formation (Middle Jurassic, Great Oolite Group) at Hampen Cutting, Gloucestershire. In: *Proceedings of the Cotswolds Naturalists' Field Club,* **40**, 118-128.

SUMBLER, M G. 1999. Correlation of the Bathonian (Middle Jurassic) succession in the Minchinhampton-Burford district: a critique of Wyatt (1996). *Proceedings of the Geologists' Association,* **110**, 53-64.

TAITT, A H , and KENT, P E. 1958. Deep boreholes at Portsdown (Hampshire) and Henfield (Sussex). *Technical Publication BP Co. Ltd, London.*

WORSSAM, B C, and IVIMEY-COOK, H C. 1971. The Stratigraphy of the Geological Survey Borehole at Warlingham, Surrey. Bulletin of the Geological Survey of Great Britain. No. 36, 1-111.

WYATT, R J. 1996. A correlation of the Bathonian (Middle Jurassic) succession between Bath and Burford, and its relation to that near Oxford. *Proceedings of the Geologists' Association,* **107**, 299-322.

WYATT, R J, 1999, *reply to* SUMBLER, M G. 1999. Correlation of the Bathonian (Middle Jurassic) succession in the Minchinhampton-Burford district: a critique of Wyatt (1996). *Proceedings of the Geologists' Association,* **110**, 53-64.

WYATT, R J. 2009. The status and local stratigraphical context of the Hampen Formation type section (Bathonian, Middle Jurassic). *Proceedings of the Geologists' Association,* **120**, 126-132.

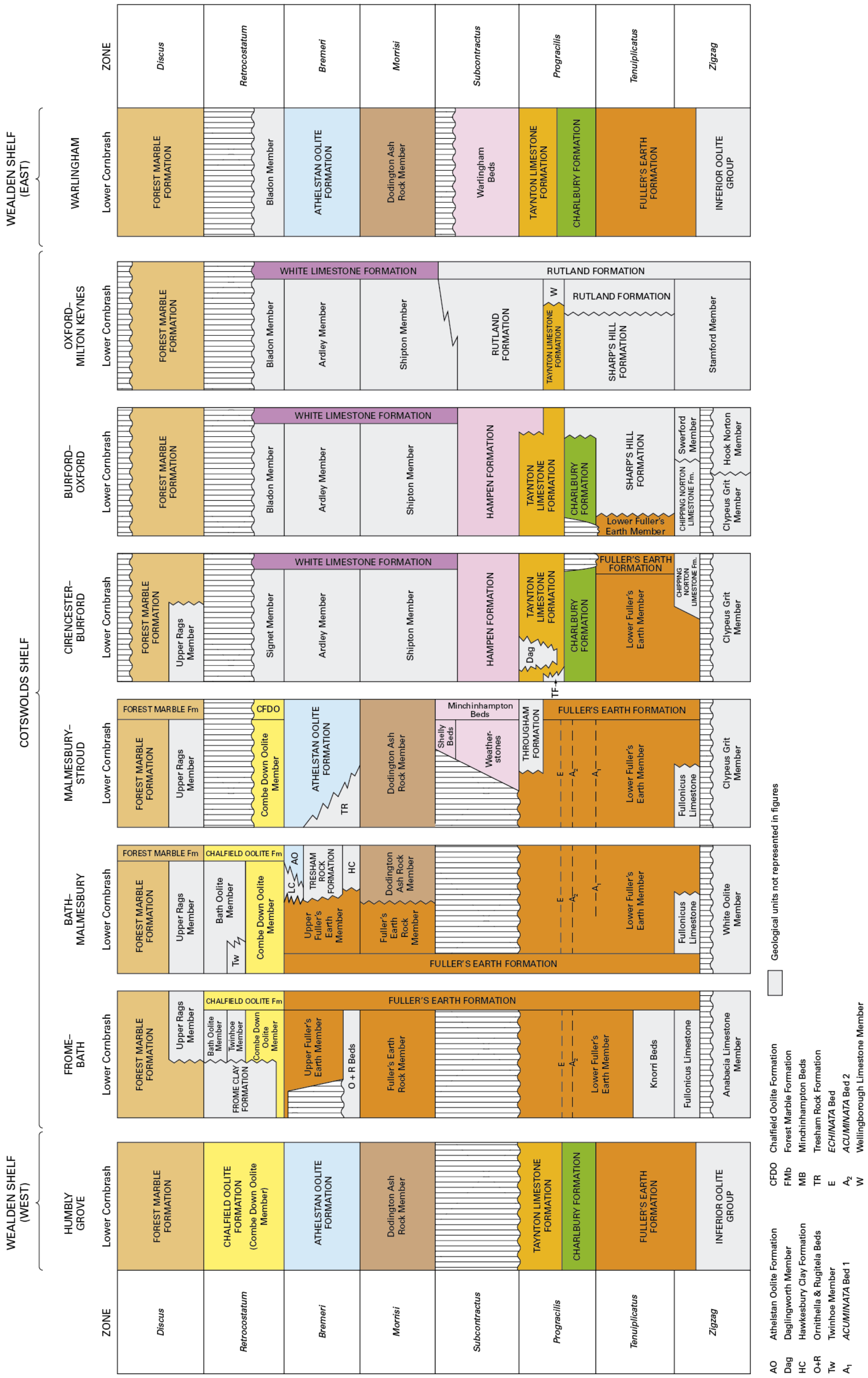
WYATT, R J, and CAVE, R. 2002. The Chalfield Oolite Formation (Bathonian, Middle Jurassic) and the Forest Marble overstep in the South Cotswolds, and the stratigraphical position of the Fairford Coral Bed. *Proceedings of the Geologists' Association,* **113**, 139-152.

Acknowledgements

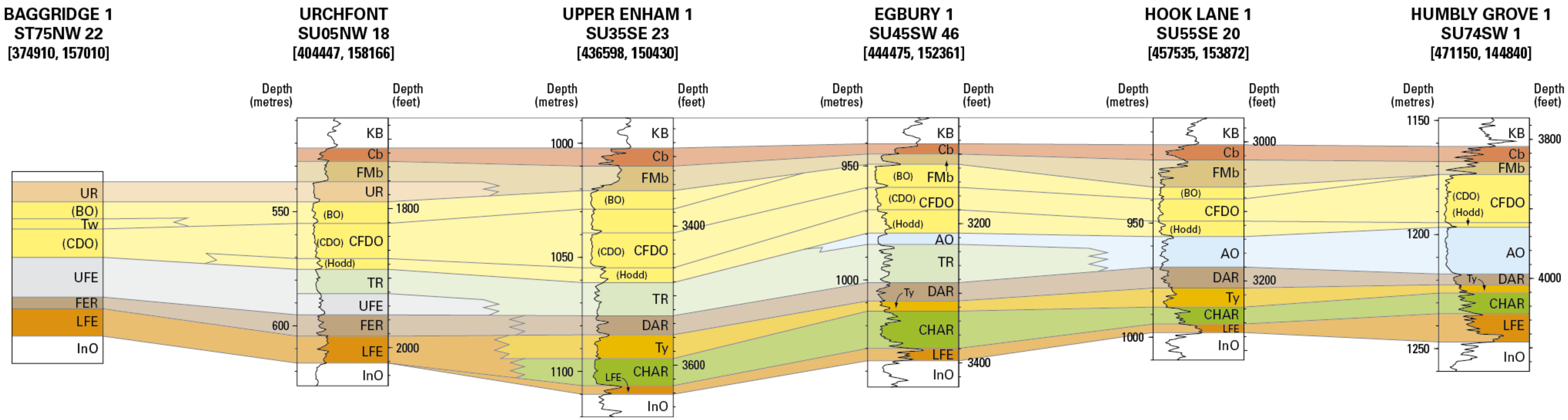
The author is grateful to Peter Hopson for his indispensible help in facilitating the preparation of this account and in seeing it through to publication. I am also grateful to Mark Barron who undertook a comprehensive and informative peer review of the draft.

Appendix

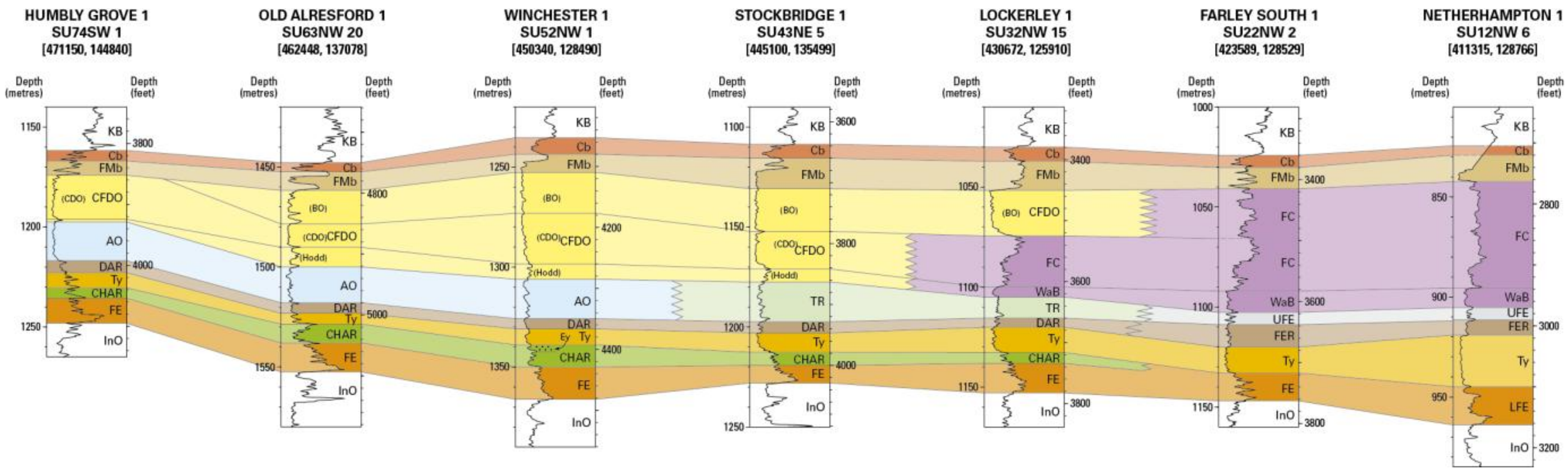
Lithostratigraphical classification of the Bathonian succession in the Cotswolds Shelf, extrapolated into the Wealden Shelf



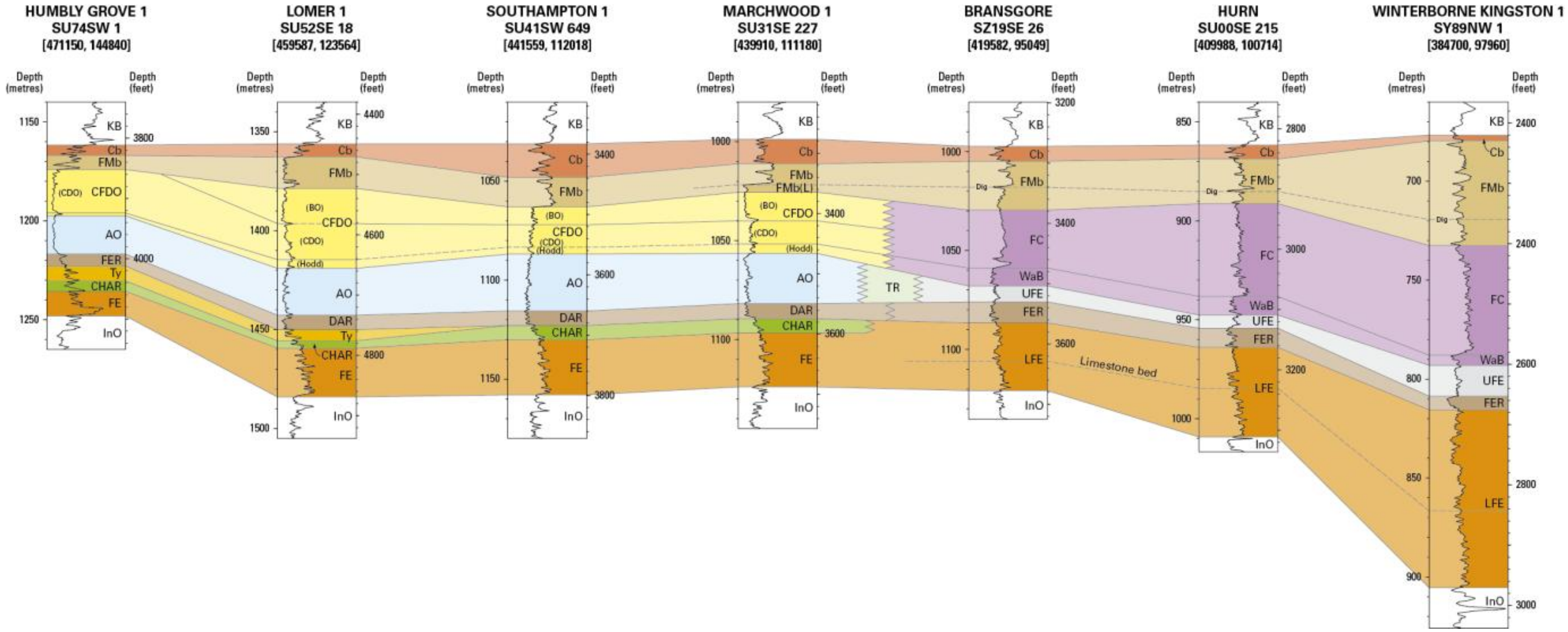
Traverse 1



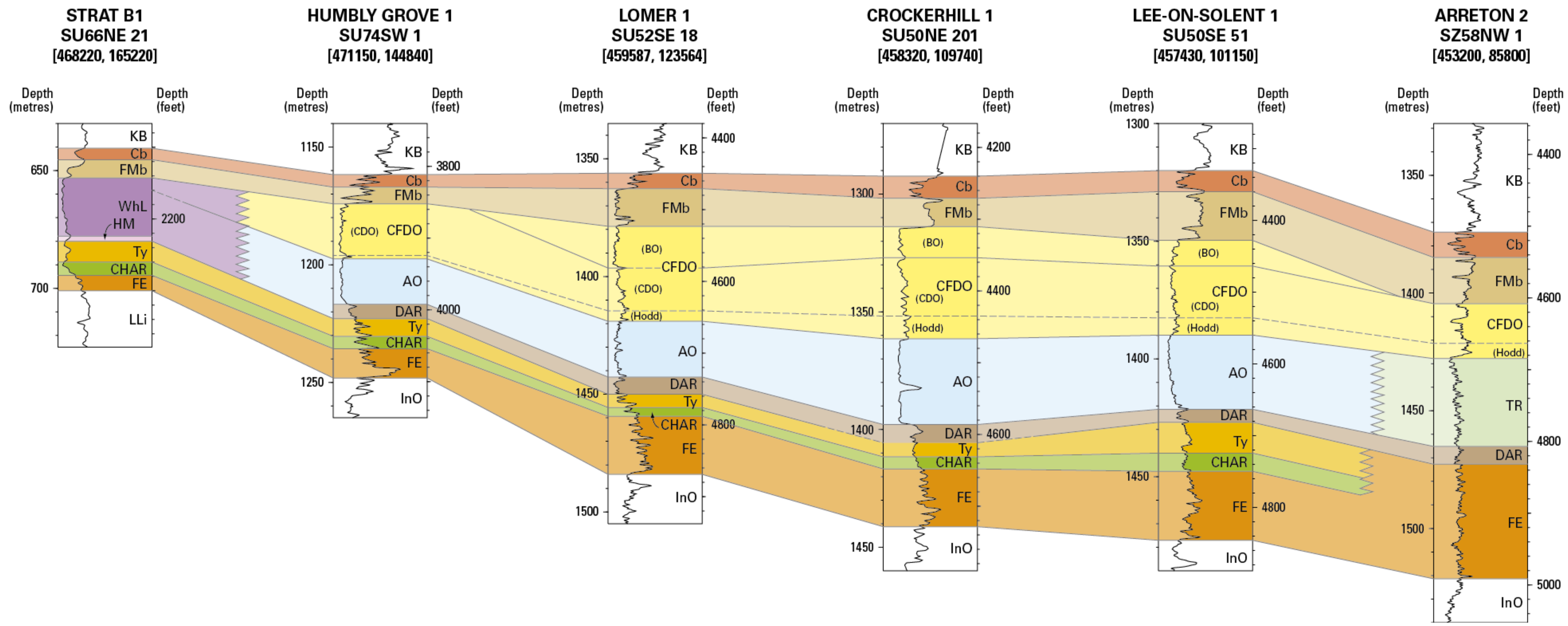
Traverse 2



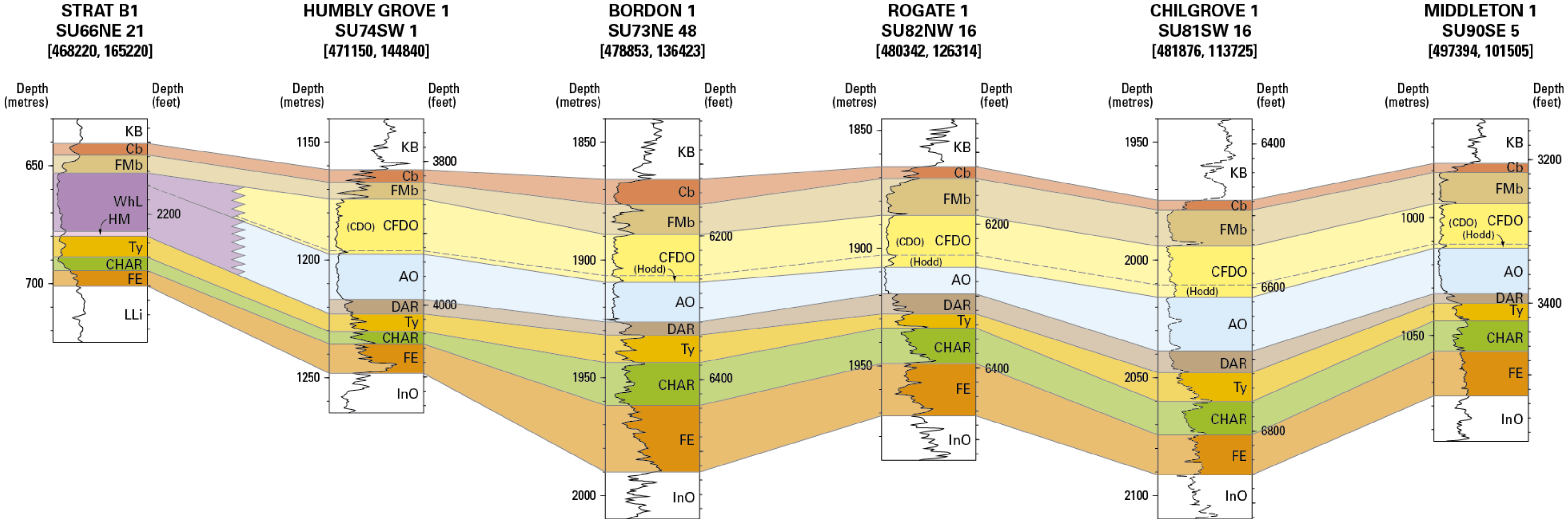
Traverse 3



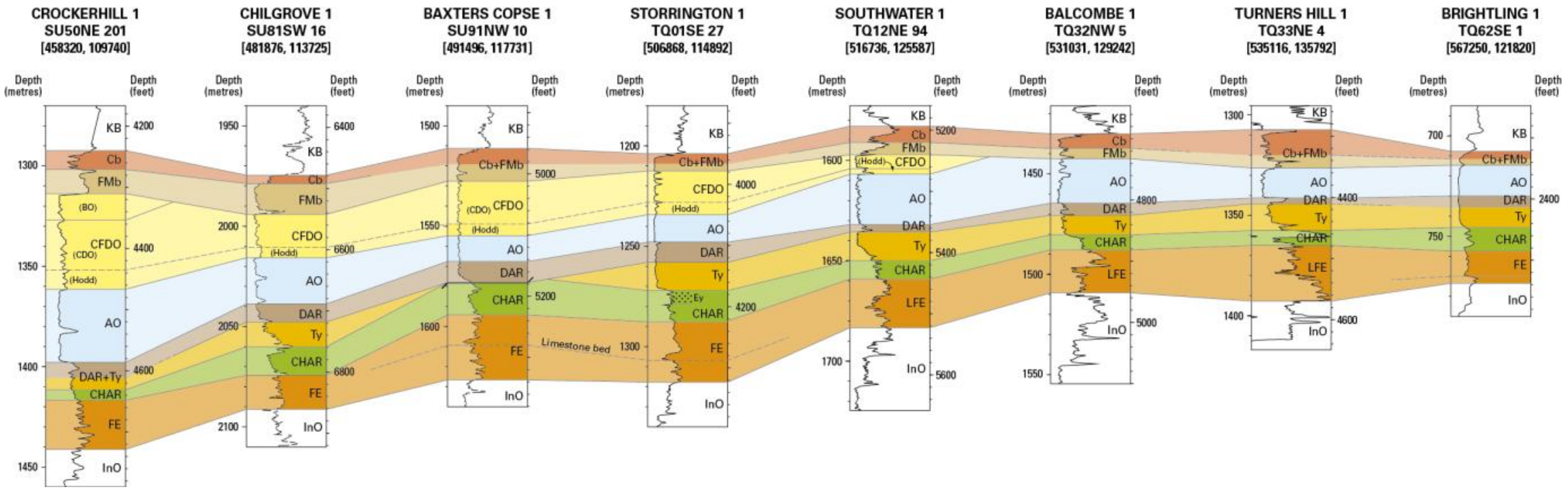
Traverse 4



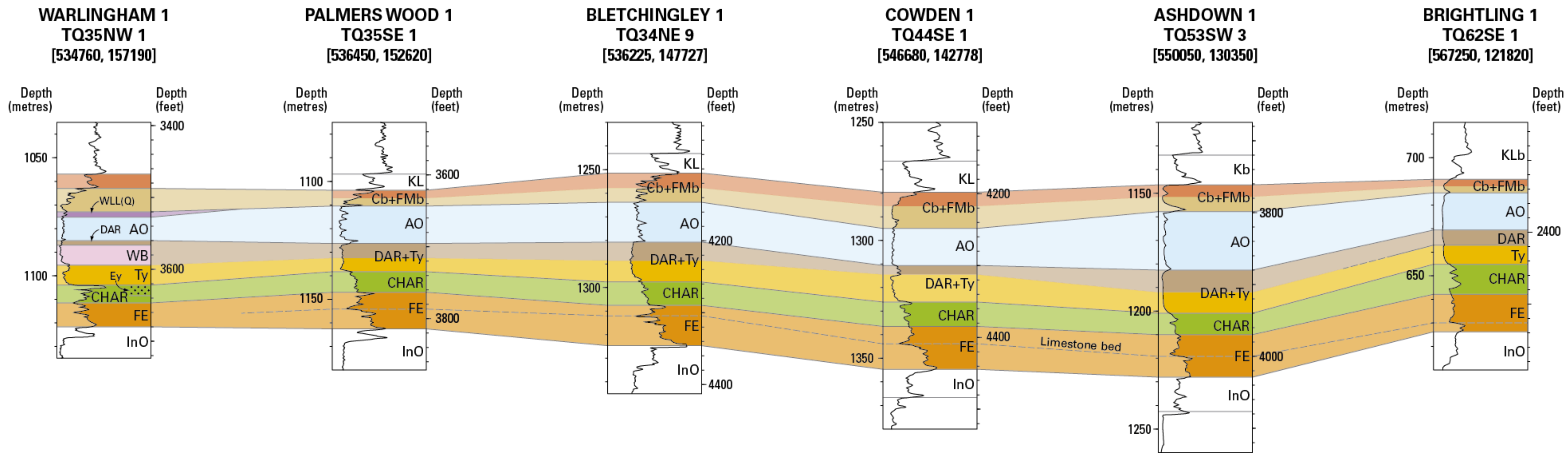
Traverse 5



Traverse 6



Traverse 7



Traverse 8