Chapter 1 General introduction to Oxfordian and Kimmeridgian stratigraphy

B.M. Cox

Introduction

The GCR sites described in this volume are representative of the British geological record of Earth history from about 157 to 145 million years ago (Harland *et al.,* 1990; Gradstein and Ogg, 1996). This interval, comprising the Oxfordian and Kimmeridgian ages, represents the greater part of the Late Jurassic Epoch (part of the Jurassic Period). The rocks that formed during that time — and bear witness to its events and environments — constitute part of the Upper Jurassic Series (part of the Jurassic System) (Figure 1.1). Although this volume is entitled 'British Upper Jurassic Stratigraphy', it does not cover the youngest subdivision of that Series (the Portlandian), which is described in the GCR volume dealing with the rocks either side of the Jurassic–Cretaceous boundary.

Palaeoenvironment and palaeogeography

In Callovian times, towards the end of the Mid Jurassic Epoch, a marine transgression spread across much of Britain drowning the varied shallow marine, fluvial, deltaic, saltmarsh and coastal lagoonal (brackish and freshwater) environments of the Bathonian. Thus, by the beginning of the Oxfordian Age, a shallow shelf sea was established over much of Britain. Sea levels rose throughout the Oxfordian Age and mud-rock deposition was widespread, although limestones and sandstones of the so-called Corallian facies, representing shallower water or nearer-shore deposits, had developed by the end of Early Oxfordian times. The Corallian facies is probably the best known because it forms hilly ground from Dorset to Oxford, and also in North Yorkshire (Tabular, Hambleton and Howardian hills), as well as having been extensively exposed in quarries for building materials. It was these rocks and the image of warm tropical seas that they engender, that first attracted the attentions of W.J. Arkell (1904–1958) who became such a prolific world authority on Jurassic stratigraphy. He was born at Highworth, Wiltshire and spent his family holidays at Swanage, Dorset, thereby gaining intimate knowledge of Upper Jurassic stratigraphy and palaeontology in these areas at an early age. His first important paper (Arkell, 1927) described the Corallian rocks of Oxfordshire, Berkshire and north Wiltshire, and his doctoral thesis formed the basis of a monograph on the Corallian bivalve fauna (Arkell, 1929–1937; Cox, 1958).

Mudrocks are also the predominant lithology of the Kimmeridgian Age, which represents a period of high, global sea level. These muds may have covered a more extensive area than any previous Mesozoic deposit, although the remaining extent of previously established landmasses, which almost certainly shrank during the Oxfordian and Kimmeridgian ages in response to rising sea levels, remains a matter of speculation (Figure 1.2). This scenario was terminated by a major fall in global sea level in Portlandian times, which led to the re-emergence of certain land areas such as the London Landmass, and the deposition of shallow-water arenaceous and carbonate sediments (Chadwick, 1985; Holloway, 1985; Cope and Rawson in Bradshaw *et al.,* 1992). The lateral extent of Oxfordian–Kimmeridgian deposits has been severely modified by later, particularly Early Cretaceous, erosion.

The Oxfordian–Kimmeridgian outcrop

On maps showing the solid geology of England, Oxfordian–Kimmeridgian rocks form an almost continuous strip from the Dorset coast to the North Yorkshire coast, broken only in the Market Weighton area, north of the Humber Estuary (Figure 1.3). They also occur beneath younger rocks in the whole of the land area to the east of the outcrop, with the exception of a large area beneath East Anglia and the Thames Valley (an area corresponding with the so-called London Landmass; see (Figure 1.2)). In Scotland, they crop out on the Hebridean islands of Skye, Scalpay, Eigg and Mull, and on the north-east coast between Brora and Helmsdale (in the former county of Sutherland) and near Port-an-Righ and Eathie (in the former county of Ross and Cromarty). These narrow Scottish outcrops lie at the margins of major offshore sedimentary basins.

Stratigraphical nomenclature

The Upper Jurassic Series comprises three stages, two of which (Oxfordian and Kimmeridgian) are the basis of the Geological Conservation Review (GCR) 'Blocks' (site selection categories employed in the course of the GCR) covered by this volume. The Oxfordian and Kimmeridgian stages, established by d'Orbigny (1850), take their names from English localities (the city of Oxford and the village of Kimmeridge in Dorset). For many years, British geologists also included the Callovian Stage in the Upper Jurassic Series because the base of the Callovian Stage in England (its type area; Callomon, 1964) approximately coincides with the end of the paralic and carbonate sedimentation that characterizes the bulk of the Middle Jurassic Series. The contentious subject of where the Middle–Upper Jurassic boundary should be drawn has been discussed by Melville (1956) and Torrens (1980), and at various international colloquia (Callomon, 1965; Maubeuge, 1970). However, following Arkell (1946, 1956), the original threefold gross lithological division proposed by von Buch (1839) for the Jurassic of Germany is now used as the basis of subdivision of the Jurassic System throughout the world, and current practice thereby takes the base of the Upper Jurassic Series as the base of the Oxfordian Stage.

Since d'Orbigny's (1850) definition of the term l'étage kimméridgien', there has been confusion regarding its scope, and the terms 'Kimmeridgian' and 'Portlandian', as understood by British geologists, have been used differently in continental Europe and elsewhere. The confusion arose from d'Orbigny's citation of the Kimmeridge Clay of Dorset and the Portland Beds of Dorset as typical strata of the Kimmeridgian and Portlandian stages respectively, but his inclusion of the ammonite *Gravesia,* which occurs in the middle part of the Kimmeridge Clay of Dorset, as a diagnostic fossil of the Portlandian Stage. The problems that this ambiguity has caused, with dual usage of the terms 'Kimmeridgian' and 'Portlandian' largely following nationalistic lines, have been aired most recently by Cope (1993, 1995a). He has proposed that the beds now referred to as 'Upper Kimmeridgian' by British workers and 'Lower Portlandian' by continental workers (Figure 1.4) should be assigned to the Bolonian Stage, originally proposed by Blake (1880, 1881) to resolve this same problem. Though less famous than W.J. Arkell, J.F. Blake (1839–1906), clergyman turned academic, is another important figure in British Upper Jurassic stratigraphy who published some key papers (Blake, 1875, 1880, 1881; Blake and Hudleston, 1877). Although the term 'Bolonian' (named after Boulogne-sur-Mer in France) has been available for over 100 years and the nomenclatural confusion between 'Kimmeridgian' and 'Portlandian' has been around for as long, Cope's recent campaign for its re-introduction will need to gain new ground if 'BoIonian' is to become one of the internationally accepted Jurassic stages. If it does, the term 'Kimmeridgian' will then become restricted to the 'Lower Kimmeridgian' of current British usage. The Kimmeridgian GCR 'Block' (site selection category) was conceived in 1977 at the start of the Geological Conservation Review project, and is based on the traditional British usage of the term 'Kimmeridgian'.

Oxfordian and Kimmeridgian zones and subzones

The traditional means of subdividing stages in the Jurassic System is by means of ammonite faunas that provide the basis of the standard stratal subdivisions (zones and subzones). Some problems exist in the Oxfordian and Kimmeridgian stages because of faunal provincialism such that there is no worldwide distribution of ammonite genera and species enabling straightforward international correlation. Even within the British succession, faunal provincialism causes problems for correlation in the Middle and Upper Oxfordian strata. A Boreal Province in which cardioceratid ammonites predominate covers much of northern Britain, whilst further south, perisphinctid ammonites, characterizing a Sub-Boreal Province, are more common. Separate zonal schemes have been developed for the two provinces as shown in (Figure 1.4).

In this account, and in line with current thinking, the Oxfordian and Kimmeridgian zones and subzones, into which the succession is divided without gaps or overlaps, are treated as chronostratigraphical subdivisions of the stages. They may be recognized by ammonite faunas but are not defined by them. They are labelled with the name of an ammonite species but these are written in Roman font with an initial capital; they are thereby differentiated from biozones/sub-biozones, which take the full italicized taxonomic name of their index species. The standard zonation used herein follows Arkell (1941a) for the Lower Oxfordian (see also Callomon, 1964), and Sykes and Callomon (1979, emend. Callomon in Wright, 1980 (Sub-Boreal); Birkelund and Callomon, 1985 (Boreal)) for the Middle–Upper Oxfordian. The Kimmeridgian zonation follows Salfeld (1913, emend. Ziegler, 1962) for the Lower Kimmeridgian (see also Birkelund *et al.,* 1978, 1983), and

Cope (1967, 1978) for the Upper Kimmeridgian.

In recent years, Jurassic ammonites have been used to develop ever more sophisticated schemes of stratal subdivision and correlation. So-called ammonite faunal horizons or biohorizons (Callomon, 1985a, b; Callomon and Chandler, 1990; Page, 1995; (Figure 1.4)) are perceived as a bed, or series of beds, characterized by a particular assemblage of ammonites and within which no further stratigraphical refinement, based on the contained ammonite fauna, can be made. They are usually named after a suitable index species, as well as being consecutively numbered or lettered. It is important to appreciate that, between biohorizons, there may be intervals of geological time (and rock) that are unrepresented in the ammonite record. Consequently, biohorizons do not form part of the chronostratigraphical hierarchy of terms (system, stage, series etc.) in which the rock succession is divided into sequential subdivisions without gaps or overlaps, and each unit of higher rank (e.g. a series) is a grouping of units of lower rank (in this example, stages). Recognition of ammonite biohorizons in the Oxfordian and Kimmeridgian stages has been largely driven by workers in continental Europe. As yet, there is incomplete coverage of these stages and only two biohorizons, relating to basal boundary specifications for the two stages, have been formally documented in Britain (Marchand, 1979; Callomon, 1990; Schweigert and Callomon, 1997), one of which (*paucicostatum*) has subsequently been removed from the Oxfordian and reassigned to the underlying Callovian (Fortwengler and Marchand, 1994) (Figure 1.4). Page (1995) indicated that there were potentially many more.

In the 1970s, a number of cored boreholes were drilled through the Oxfordian and Kimmeridgian succession in eastern England as part of a site investigation that required even minor lithological changes across the study area to be detected. The cores were classified on the basis of lithological and macrofaunal characters and the succession subdivided into over 100 small units (Figure 1.4), which proved to be recognizable extensively within the study area and beyond (Gallois and Cox, 1976; Cox and Gallois, 1979). Framed within the ammonite-based zonation, the units have proved to be a most useful and practical tool for the classification and correlation of Oxfordian and Kimmeridgian mudrock facies throughout much of eastern, central and southern England, and they are considered to be small-scale chronostratigraphical units. In many cases, particularly in the Lower Kimmeridgian, zonal boundaries, determined on the basis of the ammonite faunas, were found to coincide with widespread, minor erosion surfaces. On the whole, these 'event' horizons have remained valid as zonal boundaries even where further work on the ammonites has been undertaken. Minor adjustments to the position of zonal boundaries have been made in the Upper Kimmeridgian, where the Scitulus–Wheatleyensis zonal boundary has been raised to base KC40 (from base KC38) (Cox and Gallois, 1981), and in the Middle–Upper Oxfordian, where the Tenuiserratum–Glosense zonal boundary has been lowered to base AmC11 or 12 (from base AmC15) (Wright, 1996a). In addition, AmC37–42, originally tentatively assigned to the Regulare Zone (together with AmC26–36), are now regarded as more probably belonging to the Rosenkrantzi Zone. Birkelund *et al.* (1983) suggested that the Cymodoce–Mutabilis zonal boundary should be lowered to coincide with the marked incoming of finely ribbed raseniids rather than the first appearance of a ventral smooth band amongst them, but refinement and amendment of the present zonal–subzonal scheme, and formal definition of zonal boundaries, awaits further evaluation of the ammonites which remain the primary indicators for zonal recognition.

Upper Jurassic fauna

As well as an abundance of ammonites, there were many other animals and plants living in the Late Jurassic Epoch (Oakley and Muir-Wood, 1967; Gould, 1993; Benton and Spencer, 1995). Invertebrate faunas living on the muddy sea bed included abundant burrowing and surface-dwelling bivalve molluscs. Gastropods (snails), asteroids (starfish), ophiuroids (brittle stars), holothuroids (sea cucumbers) and echinoids (sea urchins) browsed on the sea floor. Sessile crinoids (sea lilies) also grew there and, in Kimmeridgian deposits, tiny remains of the free-swimming crinoid *Saccocoma* are found at several levels. Serpulids (calcareous tube-dwelling worms) were also common. Calcareous-shelled brachiopods (smooth terebratulids and ribbed rhynchonellids) were generally much rarer than in the Mid Jurassic Epoch but, as sessile gregarious creatures, their fossil remains tend to occur in clusters. The chitinophosphatic-shelled genus *Lingula,* which has survived relatively unchanged since the Early Palaeozoic, was relatively abundant in the sea bed muds of Kimmeridgian times. The climate was warm and equable and, in the Oxfordian Age, corals became a significant part of the marine fauna where there was carbonate sedimentation. Sponges, bryozoa, echinoids, gastropods and a prolific bivalve fauna also lived on or in these limey sediments. Lobster- and shrimp-like crustaceans dwelt in both muddy and carbonate sea bed environments, often leaving characteristic burrow networks within the sediments. Microscopic organisms included foraminifera, ostracods and phytoplankton such as dinoflagellates and coccolithophorid algae. Toxic blooms of the latter have been invoked as a possible cause of the anoxic conditions that led to the formation of oil shales, which are well developed in the Kimmeridge Clay (Gallois, 1976). Ammonites, their squid-like relatives the belemnites, and holostean and teleostean bony fishes, as well as sharks and rays, were probably the main food of the aquatic reptiles, which were the largest vertebrate animals in the sea. In the Oxfordian Age, these included plesiosaurs, pliosaurs and marine crocodiles. In the Kimmeridgian Age, there is fossil evidence additionally of pterosaurs, ichthyosaurs and turtles. The British Kimmeridge Clay has produced some of the best-preserved Late Jurassic marine reptile fossils ever found. Specimens representative of the rich vertebrate and invertebrate fauna of the Kimmeridge Clay are illustrated by Etches and Clarke (1999).

There is evidence of dinosaurs, such as ankylosaurs and stegosaurs, on land but, in general, relatively little is known of the Upper Jurassic terrestrial reptile fauna in Britain because only fully marine facies are preserved. Undoubtedly, vegetable-feeding and flesh-eating dinosaurs were present as well as meat- and fish-eating crocodiles, lizards, amphibians such as frogs and salamanders, and early mammals. The famous fossil *Archaeopteryx* comes from Kimmeridgian rocks in southern Germany. With strong clawed feet for climbing trees, its limbs show features of dinosaurian ancestry, but it also possessed feathers which, according to most palaeontologists, makes it the world's oldest bird. The feathers have narrow leading edges and broad trailing edges indicating that it could almost certainly fly. Land plants included gymnosperms, notably conifers, cycads and ginkgoes (the maidenhair tree). Ferns and horsetails were also abundant. As in the Mid Jurassic Epoch, insect life included forms such as dragonflies, crickets, cockroaches, bugs and beetles but not bees, wasps and butterflies, which did not appear until the flowering plants became established in the Early Cretaceous Epoch.

GCR site selection

The rationale behind the selection of sites described in this volume builds on the main premises of the Geological Conservation Review, i.e. the selected sites are (a) those of importance to the international community of Earth scientists because they represent type localities for time intervals or their boundaries, or for fossil species, or are of historical significance in the development of the science; (b) those that contain exceptional geological features; and (c) those that are nationally important because they are representative of a geological feature, event or process that is fundamental to Britain's Earth history (Ellis *et al.,* 1996). The philosophy behind site selection also states that there should be a minimum of duplication of the features of geological interest between sites and that it should be possible to conserve selected sites in a practical sense. Sites that are least vulnerable to potential threat, are more accessible, and do not duplicate features found at other sites are preferred (Ellis *et al.,* 1996). Category (a) is particularly relevant to the present volume in which type localities and areas of chronostratigraphical and lithostratigraphical units, and candidate GSSPs (Global Stratotype Section and Points) for the stage boundaries are conspicuous. Many Oxfordian–Kimmeridgian sites in Britain also belong to category (c), in that they are essential to the process of unravelling the geological history of Britain.

Oxfordian–Kimmeridgian GCR sites were originally selected, after extensive consultation with Earth scientists with relevant experience, in the early 1980s. The exercise built upon — and superseded — the inventory of geological Sites of Special Scientific Interest that had been compiled by the Nature Conservancy (predecessor of the Nature Conservancy Council). The results of this consultation exercise were consolidated by C. Makinson and J.K. Wright for the Oxfordian Stage, and C.P. van de Vyver and W.A. Wimbledon for the Kimmeridgian Stage. The documentation and justification for the site selection, presented in this volume, has thus been compiled retrospectively, which has inevitably led to some difficulties. Although most of the GCR sites originally selected continue to provide excellent representative exposures of Upper Jurassic stratigraphy, the physical appearance of sites inevitable changes through time. Pits that provided good sections 15 or 20 years ago may have become degraded, or the exposure changed in some other way as active working has proceeded. Inevitably, the amount of exposure of strata is subject to change. Moreover, some of the GCR sites initially selected are not recorded in the published literature but only in unpublished postgraduate theses or field guides. Nevertheless, the credentials of individual sites that originally justified their selection remain valid, as described in the site reports that follow. In addition, a number of sites have been subsequently proposed for the GCR as a result of work conducted after the main phase of site selection was completed, as the national and international importance of new potential GCR sites has begun to be recognized.

Invertebrate fossils in the GCR

N. V Ellis

Although the relatively common invertebrate fossils do not have a separate selection category in the GCR in their own right, the scientific importance of many stratigraphy sites lies in their fossil content. Invertebrate fossils are important in stratigraphy because they help to characterize stratal units. In practice, stratigraphy is at its most secure where adequate fossils are found. One of the main tasks of stratigraphers is to determine the relative ages of strata and to compare or correlate them with strata of the same age elsewhere. Fossils have long provided one of the most reliable and accurate means of approaching these problems.

Therefore, some 'stratigraphy' GCR sites are selected specifically for their faunal content, which facilitates stratal correlation and enables the interpretation of the environments in which the animals lived. Other 'stratigraphy' GCR sites are of crucial importance palaeontologically and palaeobiologically, because they yield significant assemblages of invertebrates that provide evidence for past ecosystems and the evolution of life. Moreover, some sites have international significance because they have yielded fossils that are the 'type' material for a species.

In contrast to the manner in which most invertebrate fossils are represented in the GCR, fossils of vertebrates, arthropods (except trilobites) and terrestrial plants do have their own dedicated selection categories, owing to the relative rarity of the fossil material.

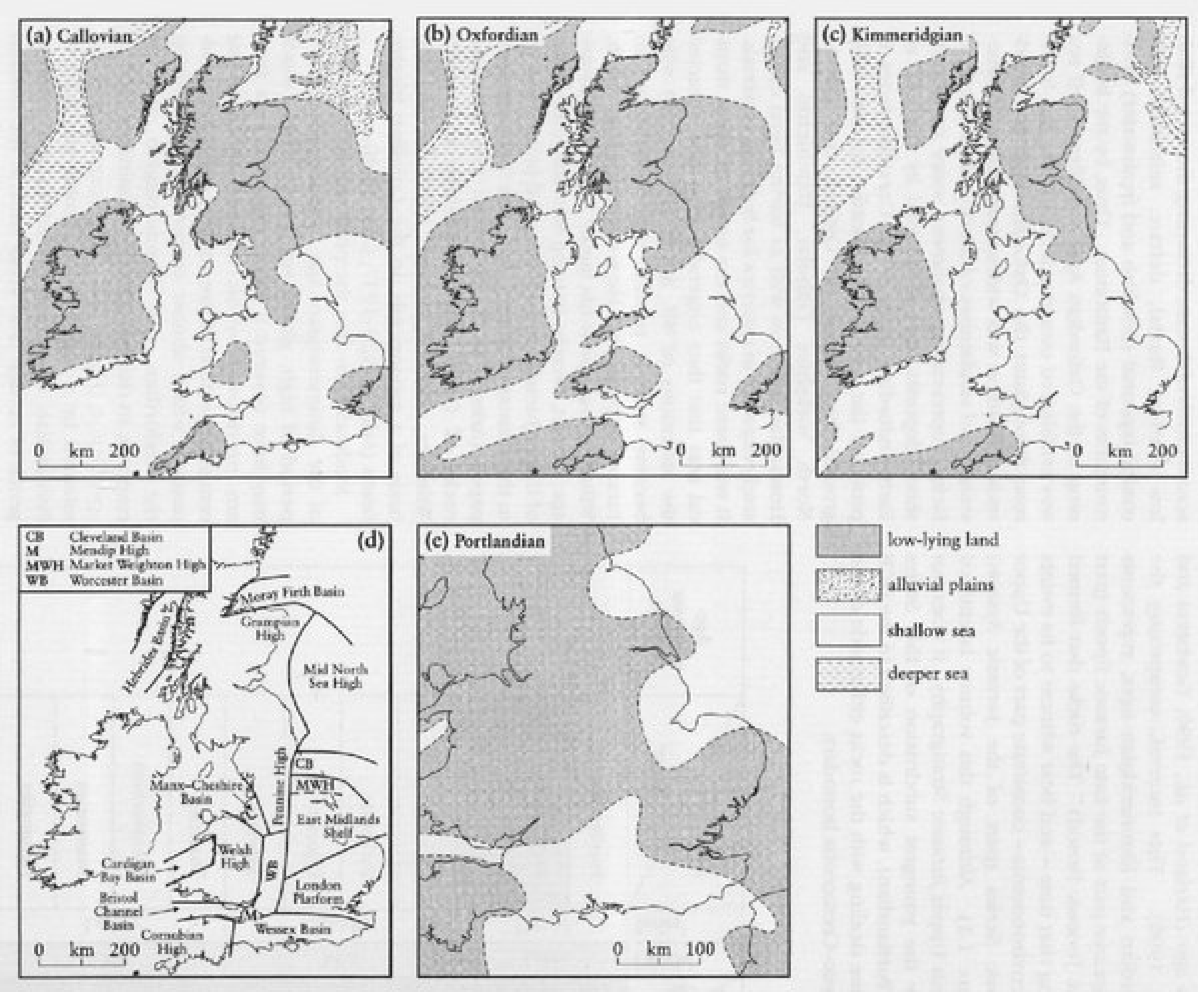
Volume structure

Within this volume, the sites are arranged geographically from south to north. The chapters into which the sites are divided (Dorset to Oxford, East Midlands, North Yorkshire and Scotland) reflect the Late Jurassic depositional setting, which was largely controlled by deep-seated structural features (see (Figure 1.2)d). The Dorset to Oxford chapter represents the Wessex Basin and western margins of the London Platform. The sites in the East Midlands chapter represent the East Midlands Shelf, those in the North Yorkshire chapter represent the Cleveland Basin, and those in the Scottish chapter represent the Moray Firth and Hebrides basins.

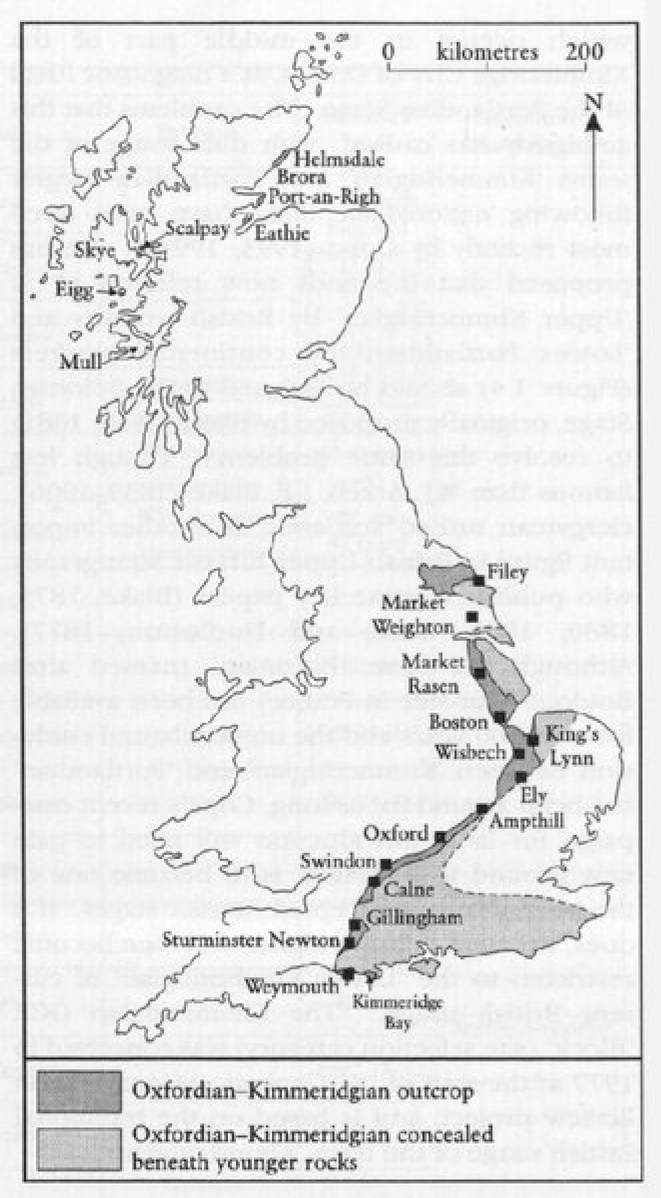
References

Period[1] / System[2]	Epoch[1]	Series[2]	Age[1] / Stage[2]	Age in millions of years
Jurassic	Late	Upper	Portlandian	
			Kimmeridgian	145.6*
			Oxfordian	154.7† 154.1*
	Mid	Middle	Callovian	157.1† 159.4*
			Bathonian	
			Bajocian	
			Aalenian	
	Early	Lower	Toarcian	
			Pliensbachian	
			Sinemurian	
			Hettangian	

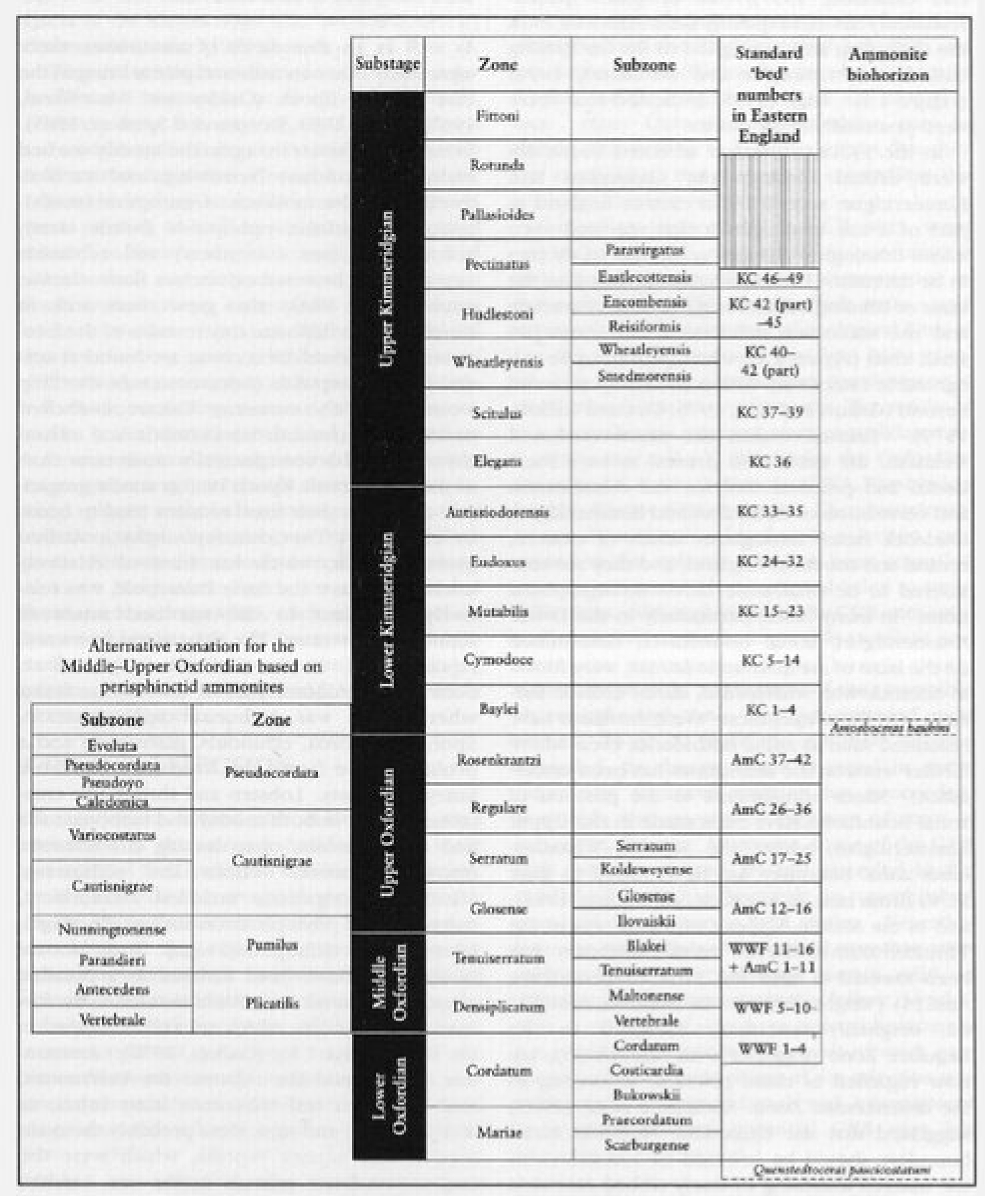
*(Figure 1.1) Major Jurassic subdivisions. [1] geological time terms [2] chronostratigraphical (time-rock) terms Harland et al. (1990) * Gradstein and Ogg (1996) (95% confidence level).*



(Figure 1.2) (a)–(c), (e) Palaeogeographical reconstructions for the British area during the late Mid and Late Jurassic (based on Cope and Rawson in Bradshaw et al., 1992; Cope, 1995b). In many cases, the extent of land areas is uncertain. (d) Main structural elements affecting sedimentation in the British area in the Mid-Late Jurassic (terminology as used in this volume). The 'London Platform' is a structural high, the limits of which remained generally constant. The emergent part of the Platform, the position and limits of which varied, is referred to as the 'London Landmass'. (Compiled from various sources.)



(Figure 1.3) Simplified sketch map showing occurrences of Oxfordian–Kimmeridgian rocks in Britain (onshore area only).



(Figure 1.4) Chronostratigraphical subdivisions and ammonite biohorizons recognized in the Oxfordian and Kimmeridgian stages in Britain (for sources, see text). AmC = Ampthill Clay Formation; KC = Kimmeridge Clay Formation; WWF = West Walton Formation. In Dorset, where the Kimmeridgian succession is more complete, additional 'beds' (KC50–63) up to the base of the overlying Portland Group (Portlandian) have been detailed by Gallois (2000). (See the Tyneham Gap–Hounstout GCR site report, this volume.)