# Chapter 4 Mesozoic fossil arthropods

E. A. Jarzembowski and D. Palmer

## Introduction

The chronological distribution of Arthropod GCR sites from Mesozoic strata ranges from Rhaetian (Aust Cliff, Triassic/Jurassic boundary, *c.* 200 Ma) up through Jurassic times represented by six sites (Charmouth, Dumbleton, Stonesfield, Poxwell, Dinton and Durlston Bay, see (Figure 4.1) and (Figure 4.2)) into early Cretaceous times, represented by a further four sites, Teffont Evias, Clockhouse Brickworks, Smokejacks Pit and Auclaye Brickworks (see (Figure 4.2)).

The vast majority of the arthropods fossilized within the strata of these sites are insects. Indeed, the primary selection of these sites within the context of this GCR volume is largely based on their insect faunas, although several of the sites have also been selected for the GCR for other palaeontological reasons, especially their fish and reptile faunas (see Dineley and Metcalf, 1999, and Benton and Spencer, 1995, respectively). The discovery of some of these insect sites dates back to the mid-19th century and they have the added value of historical interest associated with pioneers of the study of fossil insects such as the Reverend P.B. Brodie (1845).

Most of the fossil insects considered here are terrestrial, consequently their preservation requires particular enviroiunental conditions within which deposition occurs in freshwater environments. Charmouth is the exception; here the entomofauna has been recruited in a marginal but fully marine environment. Fortunately, the evolution of the British Isles during Mesozoic times saw the development of extensive shallow marine, marginal marine and fluviatile environments, especially in southern England.

## Regional setting

The regional setting for the late Triassic and Jurassic geological development of the British Isles was the progressive breakup of the supercontinent of Pangaea (Figure 4.3). The supercontinent straddled the Equator and there was no land at either pole. However, the supercontinent had no sooner formed than it began to break up. Of particular relevance here is the formation of ocean floor in the Central Atlantic area by early Jurassic times, which opened the way for the separation of Laurasia and Gondwana.

These regional changes in palaeogeography had profound long-term effects on the climates and environments of deposition in the British Isles throughout late Triassic and Jurassic times. Monsoonal climates were replaced by a more modern-type latitudinally zoned pattern of climate (Figure 4.3) and (Figure 4.4). However, this new climate pattern was perturbed by widescale volcanism from late Triassic times onwards. The rifting of the Central Atlantic at the end of the Triassic Period was marked by vast outpourings of basaltic igneous rocks. And, by mid Jurassic times, regional uplift and rift-associated volcanism had migrated to the North Sea area with considerable effect on the British Isles.

Sedimentary basins developed across northwest Europe with a pattern deeply influenced by previous geological structural events. Most important here are the east-west orientated and fault-bounded southern sedimentary basins that developed in the Wessex and Bristol Channel areas (Figure 4.5). They inherited their orientation from Variscan thrusts in the underlying Palaeozoic basement. However, there were also many newly formed fault systems in the Mesozoic Era that do not owe their patterning to older structures. There were important syn-sedimentary faults related to regional extension that originated in structural weaknesses associated with buried Triassic salt deposits while others were related to gravitational collapse of seafloor topography.

Sedimentologically, the late Triassic and Jurassic environments of deposition are dominated by fine-grained clastic deposits (clay and silt) and carbonates with relatively little sand (Figure 4.4). This suggests that despite some uplifted fault blocks, the general topography was subdued with no major local providers of sediment to the subsiding basins. The large volumes of clay-sized sediment may well have been ultimately derived from much farther away, for example, Laurentia. However, in mid-Jurassic times the mid-North Sea was one area of uplift that significantly influenced the pattern of sediment dispersal.

The break up of Pangaea continued into early Cretaceous times with the South Atlantic beginning to rift during the Valanginian–Aptian interval (Figure 4.6). North-west Europe continued to he directly influenced by the extension associated with the opening of the North Atlantic Ocean. Rifting along pre-existing basement structures produced a series of horst and graben structures that affected patterns of sedimentation. Volcanism had ceased in the North Sea by early Cretaceous times but the central graben continued to receive significant volumes of sediment. A marine connection between the North and South Atlantic was established by late Albian times at the end of the Early Cretaceous Epoch (Figure 4.7) and (Figure 4.11).

Since there are no fossil arthropod GCR sites subsequent to Barremian times in the British Early Cretaceous strata, geological developments within late Cretaceous times are of no particular importance here. However, the reason why there are no fossiliferous arthropod sites is of passing interest. A significant increase in the rate of production of ocean floor crust occurred between Aptian and early Campanian times (125–183 Ma ago, (Figure 4.6)) and has been interpreted as resulting from the rise of a mantle superplume in the Pacific Ocean. Associated increases in atmospheric carbon dioxide enhanced the Cretaceous greenhouse climate warming from the Barremian Stage onwards, reaching a maximum in the late Cenomanian times. In addition, there was an overall rise in sea-level that peaked in Turonian times. Consequently, there was a marine transgression and flooding of much of lowland Britain by shallow seas whose faunas were predominantly marine.

### Climate and sea level

From latest Triassic through Jurassic times, the British Isles lay between 30° and 40° North (comparable to the Mediterranean today). The region straddled the boundary between a continuously dry 'megamonsoonal' and a more northerly climate with wet winters. The mega-monsoonal climate was one of relatively dry high pressure influenced by powerful heating that was in turn induced by the large high latitude continental masses.

The late Triassic and Jurassic sedimentary sequences of the British Isles include excellent records of these changing climates from arid to humid and back to arid (see (Figure 4.4)). In particular, the return to arid conditions by latest Jurassic and earliest Cretaceous times is marked by the development of carbonates and evaporites (the Purbeck Group facies) in southern England.

Estimated palaeotemperatures for Jurassic times in the British Isles, based on oxygen-isotope studies of marine invertebrates, range between 12 and 29°C. The lack of high seasonal variation may be due to the ameliorating effect of shallow seaways in the region, although the persistence of mean annual tree-rings in Jurassic fossil wood suggests that, nevertheless, there were seasonal variations.

There is good evidence for a general increase in global sea levels throughout the Jurassic Period (Figure 4.8) with a long-term rise in the order of 100 m. However, in detail there is also evidence for a stillstand or even a slight fall in mid-Jurassic (Bajocian–Bathonian) times in north-west Europe. The lack of evidence for any significant volume of polar ice through the period suggests that the rise in sea level is due to increasing rates of production of oceanic crust during the break-up of Pangaea. There were also a number of short-term eustatic changes with rises during early Toarcian, Sinemurian, Pleinsbachian, Bajocian, Callovian and Tithonian times and marked falls in the late Rhaetian, late Sinemurian, Aalenian, early Oxfordian and mid Tithonian (Figure 4.8).

By Cretaceous times, the Earth was entering a 'greenhouse phase' of global warming. There were low thermal gradients between the equator and the poles and an absence of polar ice at sea level. The warming began. in Berriasian times and continued through the early Cretaceous (see (Figure 4.6)). There was a mid-Cretaceous (Cenomanian–Santonian) thermal high with the development of a mid-latitude arid zone across Europe. Sea levels also rose and reached a maximum in Cenomanian–Coniacian times. The contemporaneous widespread epeiric seas were marked by the deposition of a white carbonate coccolith ooze now referred to as 'chalk'.

### Sedimentation — Late Triassic (Rhaetian) to earliest Cretaceous (Berriasian) times

Study of sedimentary basins in the south and west of Britain shows that there was rapid subsidence in early Jurassic times, probably associated with rifting along the northern margin of the Tethys Ocean. Borehole records in southern Britain also demonstrate thickening of Jurassic strata across major fault zones such as the Isle of Wight–Purbeck system in the Wessex Basin.

Offshore in the North Sea and Cardigan Bay basins, seismic reflection data commonly show lateral changes in thickness that result from differential subsidence across faults in Jurassic times which are closely associated with crustal extension. The Lower Jurassic strata of Cardigan Bay alone accumulated a thickness of 2.5 km, the thickest yet discovered in the British Isles which suggests that there must have been significant seafloor topography.

Elevated land areas undoubtedly existed during late Triassic and early Jurassic times but their extent is unclear largely because of the lack of coarse clastic sediments which would have fringed their coasts. The best-established is the western end of the Anglo-Brabant landmass (also known as the 'London Platform', see (Figure 4.9)) across which there was a progressive onlap of Lower Jurassic strata. There is also evidence of an uplifted elongate island that marked the northern margin of the Bristol Channel Basin.

Initiation of the latest Triassic passage from non-marine to marine deposition is well preserved in strata exposed today in south-west England and southern Wales (see (Figure 4.10)). The uppermost strata of the Mercia Mudstone Group are argillaceous red beds with minor coarse-clastic deposits denoting the proximity of an uplifted shoreline. Sulphate evaporites that were deposited in coastal sabkhas bordering hypersaline marine waters are present. A northward expansion of the marine waters is marked by a thin black shale unit known as the 'Westbury Formation' (see GCR site report for Aust Cliff) which is a basal unit within the Penarth Group.

Deposition of the black shales is a precursor to the more-persistent, Jurassic age, organic shales. The formation contains reworked vertebrate and invertebrate fossils of both marine and non-marine origin. In the Bristol area marine deposition was initially in shallow lagoons in which a stromatolite horizon developed (the Cotham 'Marble'). Alternations from brackish through normal marine to hypersaline waters are marked by interbedded sequences of different faunas and floras. Occasional regression and exposure is marked by mudcracked bedding planes. There are also adjacent fissure deposits containing important late -Triassic vertebrate remains (reptiles and early mammals, mostly small teeth) which are preserved within Carboniferous limestones.

Mudstone deposition was widespread by early Jurassic (Hettangian–Sinemurian) times with interbedded marls, shales and carbonate muds forming the Blue Lias facies. The rhythmic alternation on a decimetre scale of dark shale and pale-coloured limestones produces strikingly banded rock formations, especially in coastal cliffs such as at Charmouth GCR site. The dark organic-rich shales were deposited in oxygen-poor bottom waters, which supported low diversity faunas but also accumulated remains of pelagic organisms from higher levels in the water column, such as fishes and marine reptiles. The alternating beds (limestone/shale) probably reflect seasonal density stratification of the water column which may in turn reflect changes in the volume of surface run-off on adjacent landmasses. Analysis of oxygen isotopes in carbonates (Jenkyns and Clayton, 1997) suggests that the highest early Jurassic water temperatures were achieved in early Toarcian times. This seems to be connected with enhanced productivity in the marine plankton and intense oxygen demand in bottom waters.

There were dramatic changes in regional patterns of sedimentation at the start of mid-Jurassic (Aalenian) times. Doming and volcanism in the North Sea region (the North Sea Dome) was co-incident with extension and rifting in the Central Atlantic. As a result, northwest Europe saw a rejuvenation of clastic source areas and widespread deposition of sandy clastic deposits. However, southern shallow water areas developed carbonate platform areas instead of siliciclastic shoreline deposits (especially during Aalenian through Bajocian to Bathonian times). They were marked by the deposition of oolitic and bioclastic limestones with intermittent quieter water lagoonal mud deposition. Cross-bedding, sometimes up to a metre or so in amplitude, indicates strong tidally swept seas and perhaps intermittent storm activity These strata probably reflect sediment-starved environments of deposition which lay beyond the reach of siliciclastic shoreline deposits derived from the North Sea Dome.

There were further significant changes in palaeogeography at the end of mid Jurassic times largely brought about by a steady rise in sea level that drowned paralic sedimentary environments. A major marine transgression, marking the Bathonian–Callovian boundary, swept across much of Britain and Ireland (see GCR site report for Stonesfield). Marine mudstones were deposited over a wide area with interbedded marine sands which were commonly glauconitic. The subsequent deepening of late Jurassic times meant that no significant arthropod related faunas were fossilized during this latter interval. However, a subsequent Volgian shallowing affected most of Europe with the result that a number of insect-bearing strata were laid down. The Poxwell, Dinton, Teffont and Durlston Bay GCR sites expose some of these strata.

Late Jurassic transgression and drowning produced the mud 'blanket' known as the Oxford Clay (Callovian–Oxfordian) over much of the southern region of the British Isles. This passes laterally into a coeval sandy facies in the North Sea region. Isotopic analysis suggests that water temperatures were still high (12–19°C) and perhaps as high as 29°C with significant differences between bottom and top waters. The subsequent Kimmeridge Clay (Kimmeridgian) has especial economic importance as a major source for North Sea oil. In southern basins, the clay facies passes up gradually into a shallow water facies which is of particular interest here, whereas in the North Sea region it passes abruptly into early Cretaceous calcareous mudstones deposited under oxygenated waters.

Towards the end of Jurassic times, there was a return to more arid climates. Within the deposition of the Kimmeridge Clay this acidification is marked by a change from kaolinite to illite as the dominant clay mineral within the clay-rich facies. In southern England the mudstones give way to the carbonates of the Portland Group strata of Tithonian age. They are oolitic and bioclastic carbonates along with finer-grained dolostones that famously have been used for high-quality monumental building material. Above lie interbedded limestones and shales of the Purbeck Group, which were deposited within lagoons that suffered phases of high evaporation. This environment led to the deposition of some evaporite horizons with minerals such as halite, gypsum, anhydrite and celestite. Significant volumes of salt-rich (haliferous) evaporites were laid down in the area, which now lie in the Porcupine Basin off south-west Ireland.

In southern England, the existence of silicified gymnospern trees within the Purbeck Beds (especially within the 'Dirt Beds', see Cleal and Thomas, 2001 p. 109 ft) of Portland has long been known. More recently, analysis of the growth rings has suggested that there were marginal and variable Mediterranean-type climates with warm wet winters and hot dry summers. It has also been suggested (Francis, 1984) that the growing season was sometimes interrupted by significant dry spells that produced false 'growth rings'. An analogous modern climate is found today in seasonal lagoons near Perth in Western Australia where natural conifer stands grow close to small ephemeral lakes.

## Sedimentation — Cretaceous times

The tectonically controlled rift blocks and basins developed in the Palaeozoic basement continued to influence sedimentation during early Cretaceous times. The uplifted blocks were sources of sediment for adjacent basins of deposition but many of them were inundated by rising sea-levels by the end of Albian times. However, the East Anglian part of the London–Brabant Massif persisted as land until the end of the Early Cretaceous Epoch (see (Figure 4.7)). The Cornubian Massif of south-west England and the East Midlands Shelf persisted as a landmass into late Cretaceous times.

Southern England's early Cretaceous structural history was marked by occasional movement along east-west orientated basement structures during a rift phase that lasted into late Aptian times. Uplift rejuvenated sediment source areas and may have affected local climate.

The transition from the carbonate and mud deposits of the Purbeck Limestone to the clastic sediments of the Wealden Group represented a dramatic change in facies. This reflected a marked change in climate from the hot-arid to semi-arid conditions that produced the Purbeck marginal marine lagoons, sabkhas and hyper-saline lakes to more-humid climates with reduced seasonality and sedimentary dominance of rivers. Coincidently, there was renewed uplift of the landmasses surrounding the Wealden basin that may also have produced orographic rain.

The Wealden Supergroup sediments of the Weald area in southern England are subdivided into a lower Hastings Group (*c.* 400 m thick, see (Figure 4.11)) and a finer-grained, mud-dominated, upper Weald Clay Group (*c.* 450 m thick). There are three major sedimentary cycles in the Hastings Group with alternations of sandy and muddy phases. The sandy formations (e.g. the Ashdown and Tunbridge Wells sands) record southward advances of outwash fans and braided river flood plains from the London–Brabant Massif into the Weald see (Figure 4.13) and (Figure 4.14). However, during the upper part of the Hastings Group and in Weald Clay times, detritus was carried into the Weald Basin regularly from Cornubia. The muddy formations were laid down on a mud plain covered with ephemeral lakes occupied by a variety of freshwater molluscs and whose marginal shallows supported a thriving vegetation of horsetails (equisitalean sphenopsids) and later the early angiosperm *Bevhalstia.* North-westwards there was a connection to the northern Boreal Sea and marine influences increased in that direction as shown by greater proportions of brackish water molluscs (see Allen, P, 1981 and references therein).

These cycles may be related to changes in eustatic sealevels with transgressive rising levels generating extensive lakes and lagoons but is unproven. It may be that the sandy phases developed during uplift of source areas and their degradation produced the muddy phases. If this latter interpretation is correct, it is likely that the mud-dominated Weald Clay Group developed when the London–Brabant massif was in its most eroded and degraded state. A number of near-marine horizons are present in the Weald Clay, representing incursions from the Boreal Sea (in the north) and Tethys (lying to the south-east) into the mud plains of the Weald basin of deposition.

The Wealden deposits of the Wessex Basin (Dorset and the Isle of Wight) record a slightly different history of sedimentation. The lower part of the succession is distinguished as the Wessex Formation (over 400 m thick) and is comprised of mottled silts and clays that represent floodplain deposits that have been altered by soil forming (pedogenic) processes. A major river flowed east–west through the basin close to its fault-bounded northern margin and deposited point bar sands (5–10 m thick), which are regularly interbedded within the mud-dominated succession. The regular frequency of the sands suggests a climatic control on the river's development. Rhythmic units of mud, sand and coarser detritus with plant debris and amberized insects record heavy seasonal rains. The Wessex Formation thins westwards from east Dorset with locally developed quartz gravels deposited from proximal braided fans. The dark silty clays of the overlying Vectis Formation contain occasional insect fossils and are interpreted as deposits of a large lagoonal Water body of varying salinity. The presence of Jurassic fossils and clasts derived from Jurassic deposits in Vectis Formation deposits in the east of the Isle of Wight suggests a source in Cornubia to the west and perhaps Armorica to the south. According to Radley (2005) these fossils are probably derived in the main from scarps along the Purbeck/Isle of Wight structure just to the north of the present Wealden outcrop.

### Correlation

Jurassic strata have had a basically stable system of subdivision into stages with groupings into Lower, Middle and Upper since the mid 19th century when it was first introduced by d'Orbigny (1850). Biostratigraphical zonation has been developed using changes in marine ammonite faunas which were first recognized around the same time in German Jurassic strata by Oppel (1857). Ammonite biostratigraphy was subsequently also successful in helping subdivide Cretaceous strata (see (Figure 4.11)). The relative abundance, wide distribution, rapid evolution, case of recognition and preservability of ammonite fossils has made them particularly useful as biozonal indicators. Subdivision is now so well developed that the average duration of an ammonite biozone is about one million years. In some instances, biostratigraphical resolution may be as fine as 70 ka.

However, ammonites are not always common in all parts of the Cretaceous succession and other biozonal indices have proved more useful. Recently, complementary biozonal schemes based on microfossils have been developed, especially calcareous nannofossils (coccoliths). The schemes are especially important for the correlation of borehole information where macrofossils such as ammonites are not always recognizable. Of importance here is the problem of correlation between marine and terrestrial facies and the potential difficulties introduced by diachroneity of marginal facies between marine and terrestrial deposits, especially when sea levels are changing. Plant spores and pollen, which can readily be transported from terrestrial to nearshore marine environments by rivers and wind, have proved useful in correlation (see (Figure 4.14)). Also, one group of arthropods, the ostracods, which can be abundant as fossils, relatively well preserved and with relatively rapid evolution, have proved useful in the correlation of marginal and diachronously transitional environments (Horne, 1995). Different ostracod taxa occupy fresh, brackish, normal marine and hypersaline waters.

Increasingly, isotope stratigraphy is being used to supplement more traditional fossil-based biostratigraphy and correlation. The ratio of strontium isotopes preserved in fossil carbonate shells varies over time and records the radiogenic strontium composition of the seawater the organisms lived in. The ratio of $^{87}Sr$ to $^{86}Sr$, is relatively high in strontium derived from the weathering of continental rocks, and relatively low in strontium derived from mantle sources such as mid-ocean ridge lavas. Strontium isotope composition curves have been developed from analysis of strontium ratios in biostratigraphically well-constrained Jurassic oyster and belemnite shells and show distinctive changes between early, mid and late Jurassic times. The early ratios reflect the dominance of rifting processes whereas the late ratios show increased rates of ocean-floor magmatism. Analysis of carbon isotopes is also proving useful, especially as there have been significant short term perturbations of $^{12}C$ to $^{13}C$ ratios in ocean waters (see (Figure 4.6)). These are due to rapid changes in the burial and release of light carbon derived from organic matter and are recorded as carbon isotope excursions in both carbonate fossil shells and organic fossil carbon.

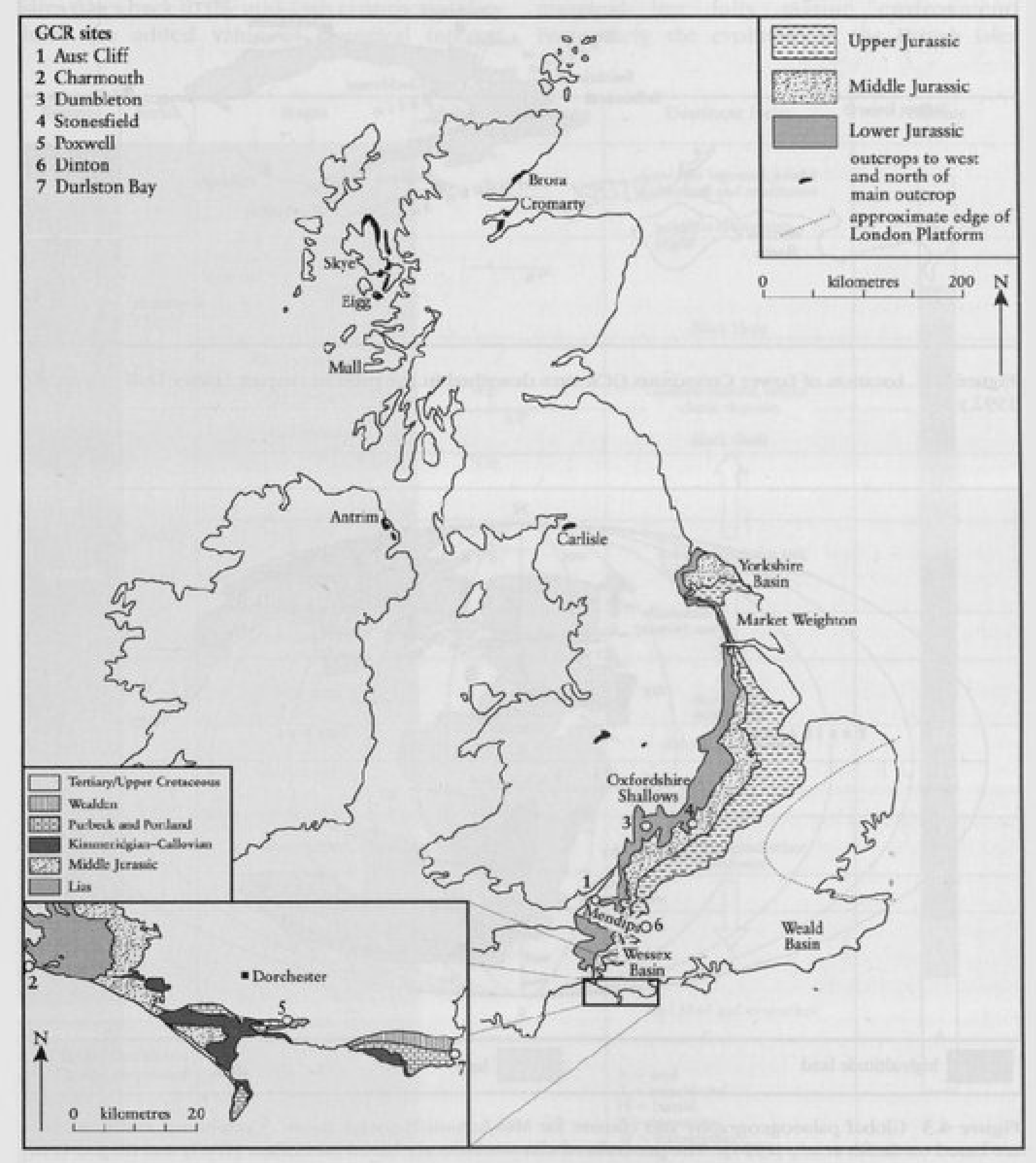
### Arthropods in Mesozoic times

The transition from the Permian to the Triassic periods is an important point in arthropod evoution, despite the lack of Permo-Triassic insects in Great Britain (Aust Cliff GCR site excepted), because the Permian/Triassic extinction is the most significant one in insct evolutionary history (Jarzembowski, 2005), Contrasting entomofaunas such as those from Writhlington Rock Store and Aust Cliff, however, show the significant changes. These changes include the disappearance of various palaeopterous insects such as Palaeodicytopteroidea Protodonata (giant dragonflies), and rise of hemipteroid and especially holometabolous insects, for example Coleoptera (beetles) and Diptera (true flies). Important changes during the Mesozoic Era included the rise of social insects, parasites and parasitoids (Jarzembowski, 1981) as well as the earliest occurrence of insects in amber, for example examples from the Wealden strata of the Isle of Wight (Jarzembowski *et al.,* 2008).

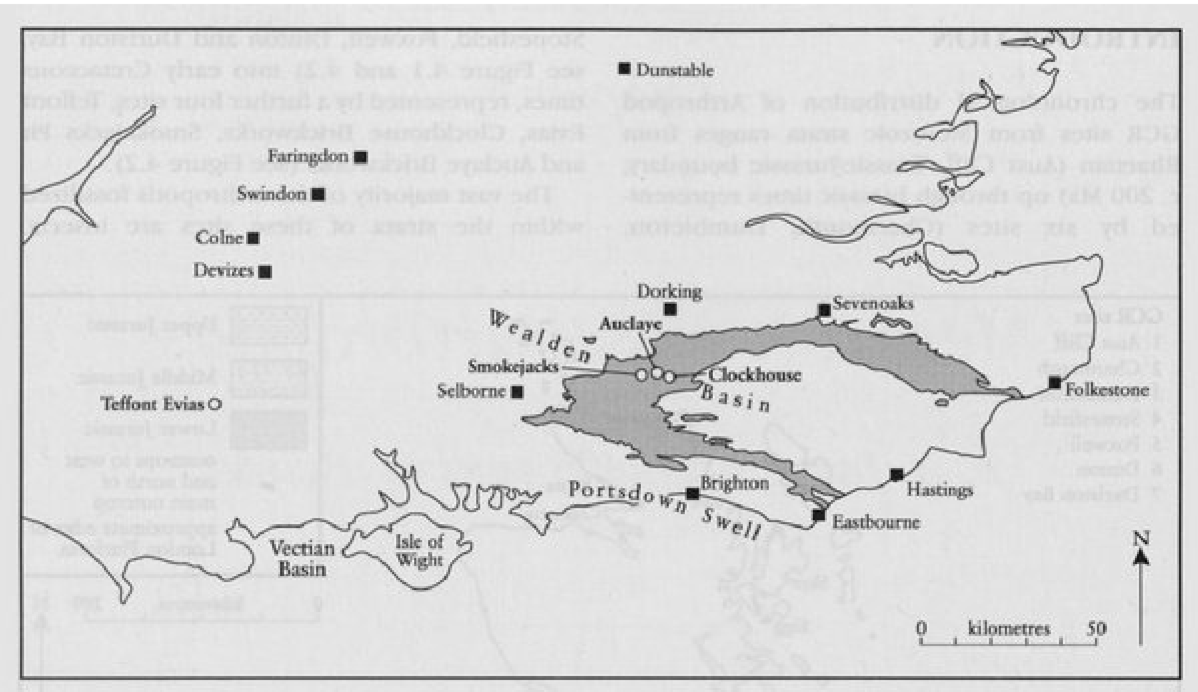
### Extinction events

There was a significant mass extinction at the end of the Triassic Period that affected both marine and terrestrial organisms, but there is little evidence that the insects were significantly reduced in abundance or diversity. Some Palaeozoic groups that had survived the Permo-Triassic boundary extinction finally became extinct (conodonts and strophomenid brachiopods). Although there is evidence that the extinction may have been rapid (i.e. within a stratigraphical resolution of *c.* 40 000 years) and catastrophic, there is, as yet, no evidence for any impact associated debris in Triassic–Jurassic boundary sediments. The Rhaetian sequence of the Bristol Channel Basin has been carefully searched for such evidence but to no avail so far. The outpouring of extensive flood basalts associated with the opening of the Central Atlantic Ocean is a more likely cause but the evidence for link is still largely circumstantial.

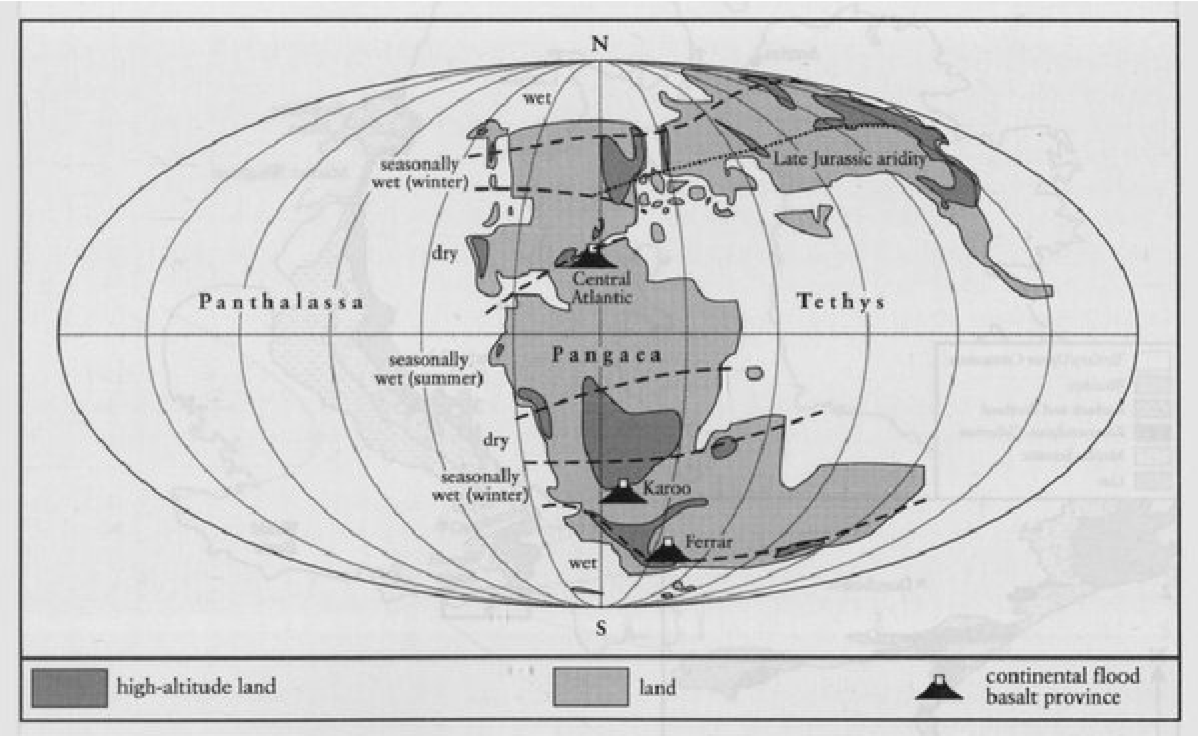
**References**



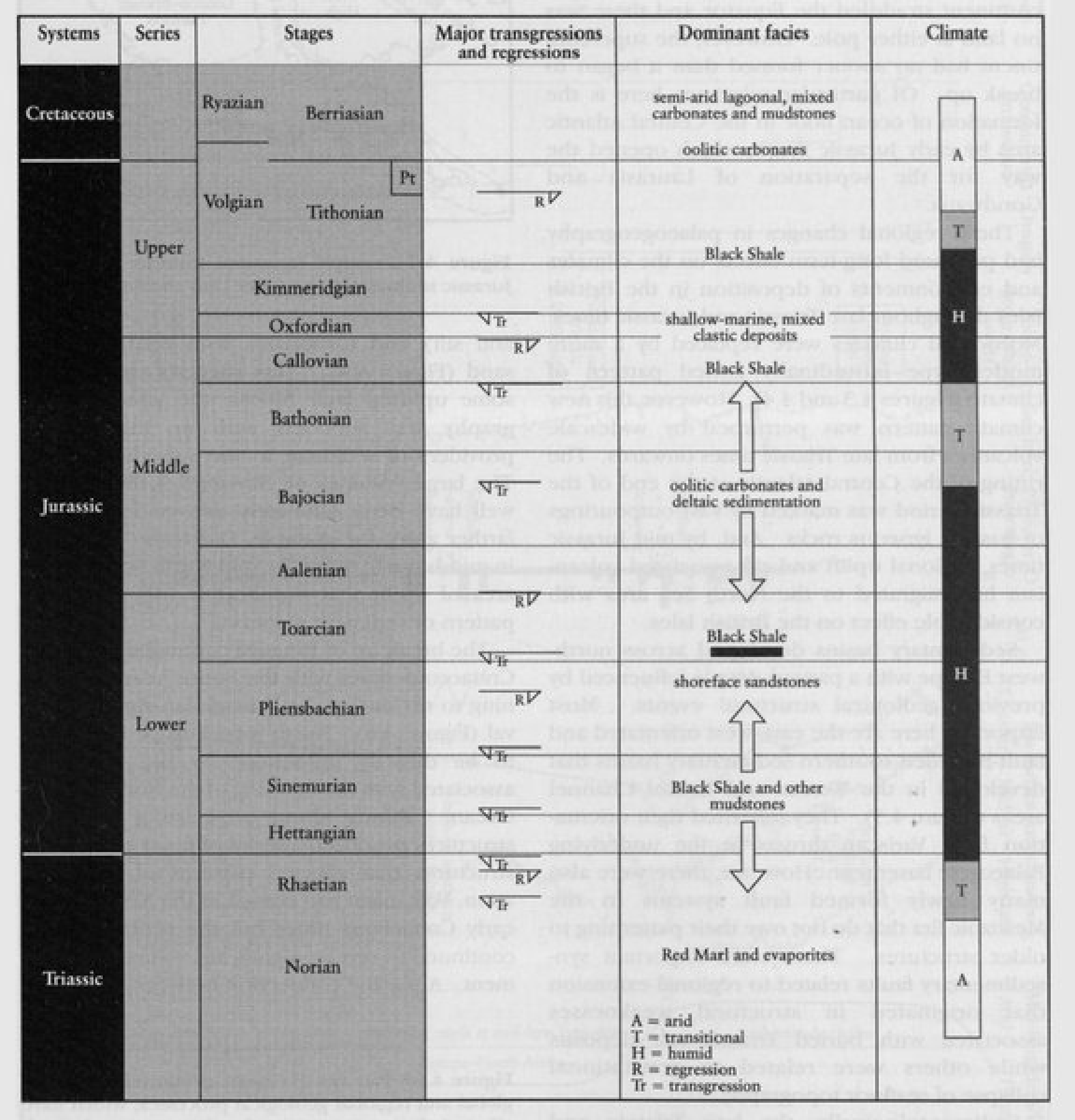

(Figure 4.1) Map showing the distribution of Jurassic rocks in Great Britan, showing the locations of GCR sites described in the present chapter. (After Dineley and Metcalf, 1999.)



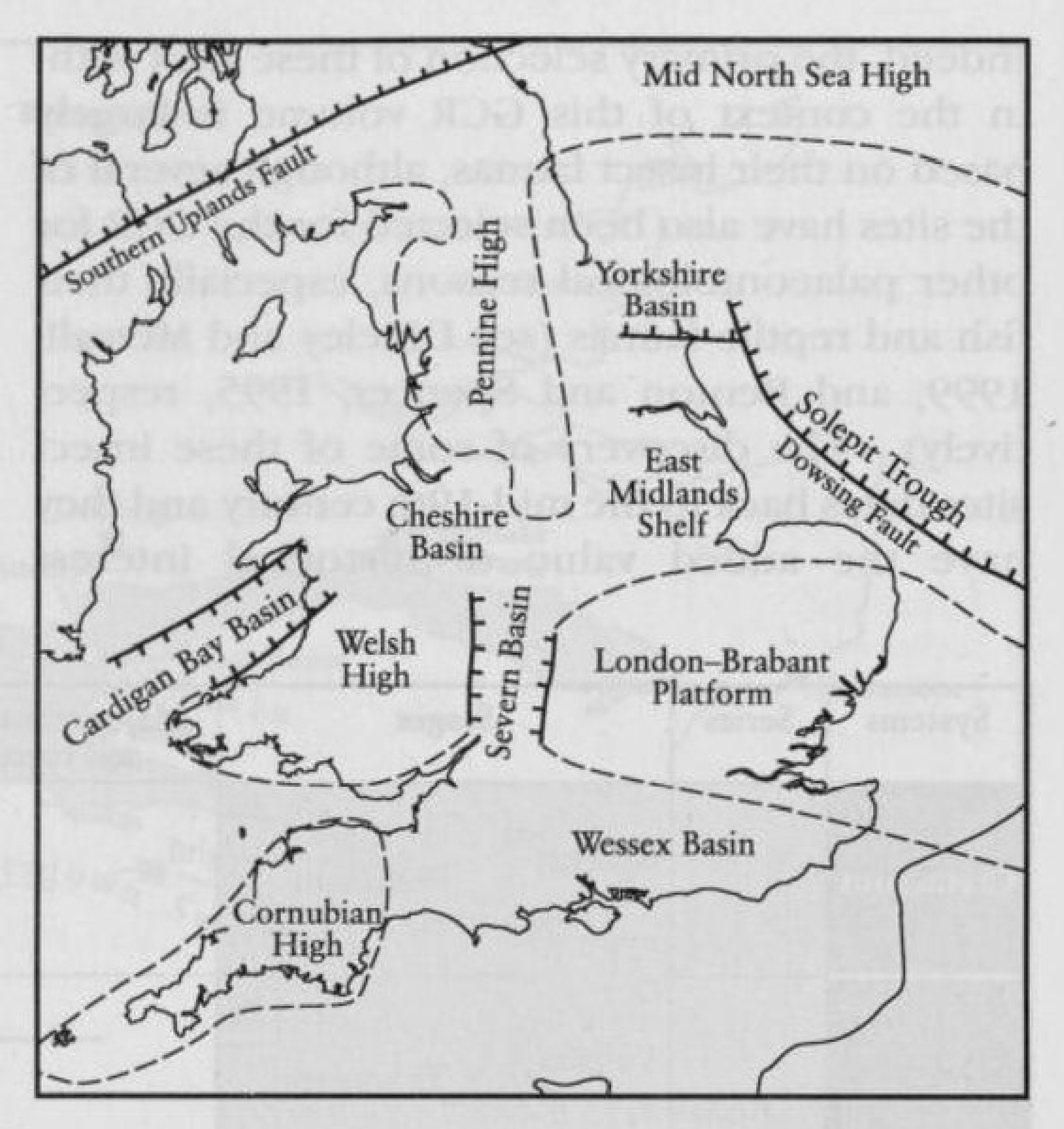
(Figure 4.2) Location of Lower Cretaceous GCR sites described in the present chapter. (After Duff and Smith, 1992.)



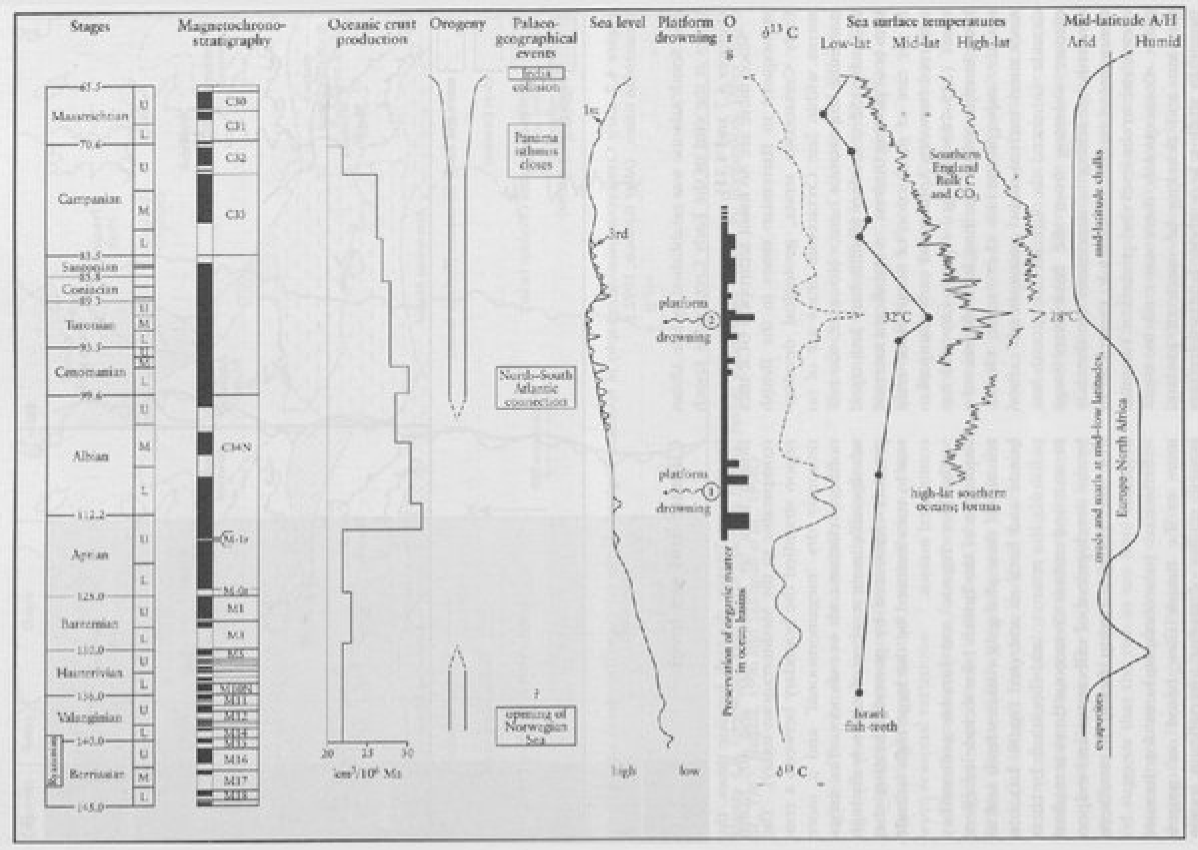

(Figure 4.3) Global palaeogeography and climate for Mid-Jurassic/Bajocian times. Continental configurations are based on Smith et at, (1994). The generalized climatic belts are based on Hallam (1985) and Ziegler et al. (1993).



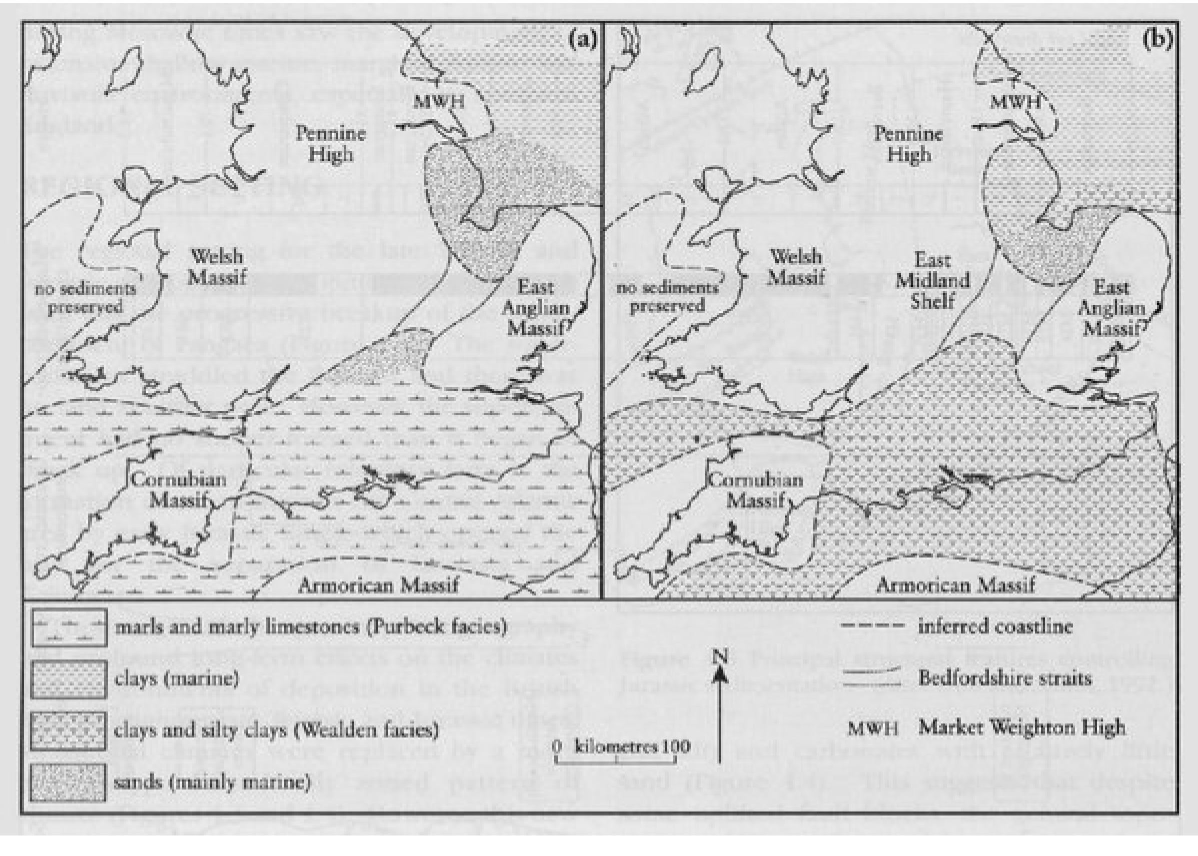

*(Figure 4.4) Summary of major features in the global stratigraphical record illustrating the connectedness between sedimentation, sea level, climate and the recognized stratigraphy in the British Isles. Pt = Portlandian. (After Woodcock and Strachan, 2000.)*



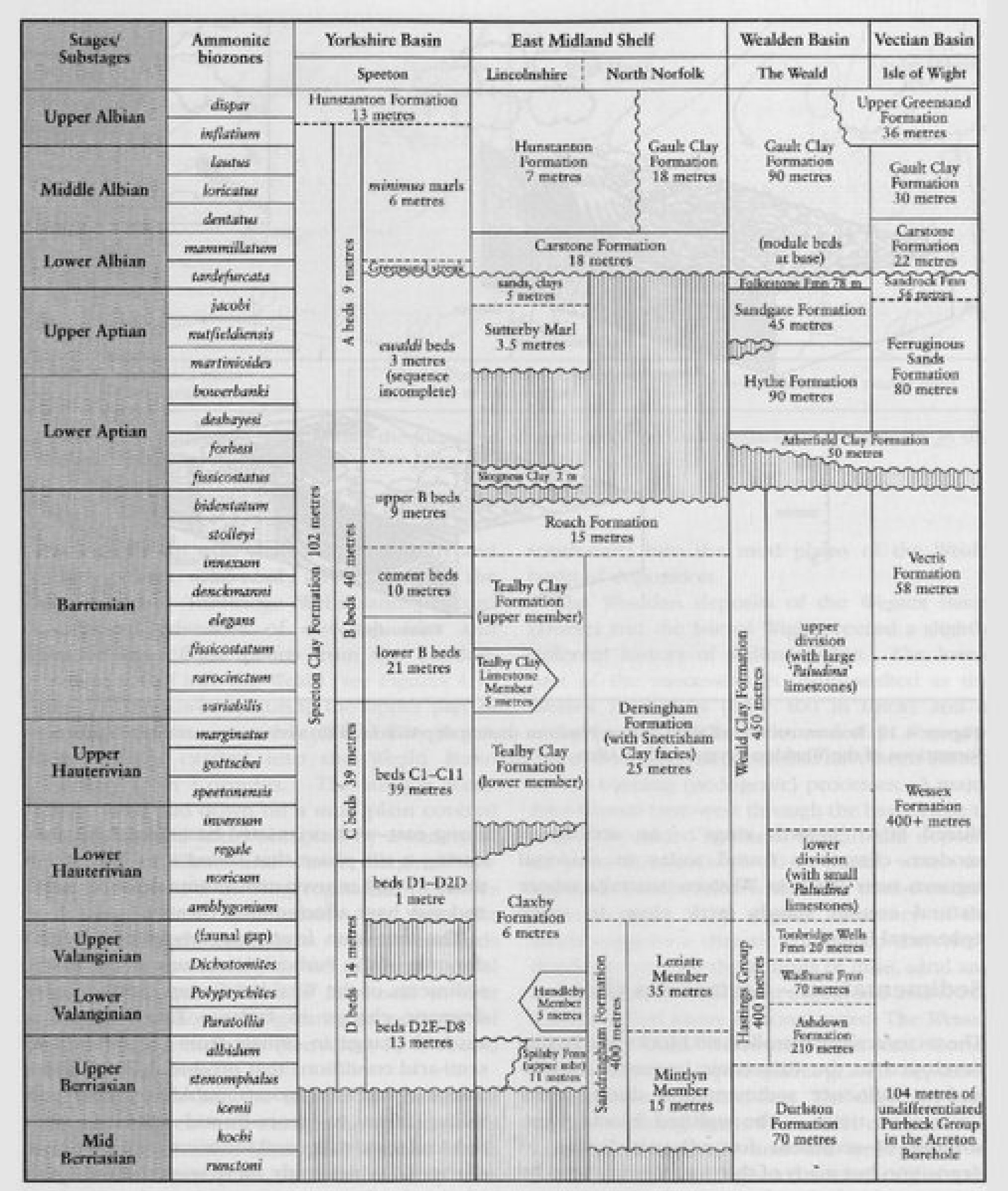

(Figure 4.5) Principal structural features controlling Jurassic sedimentation. (After Duff and Smith, 1992.)



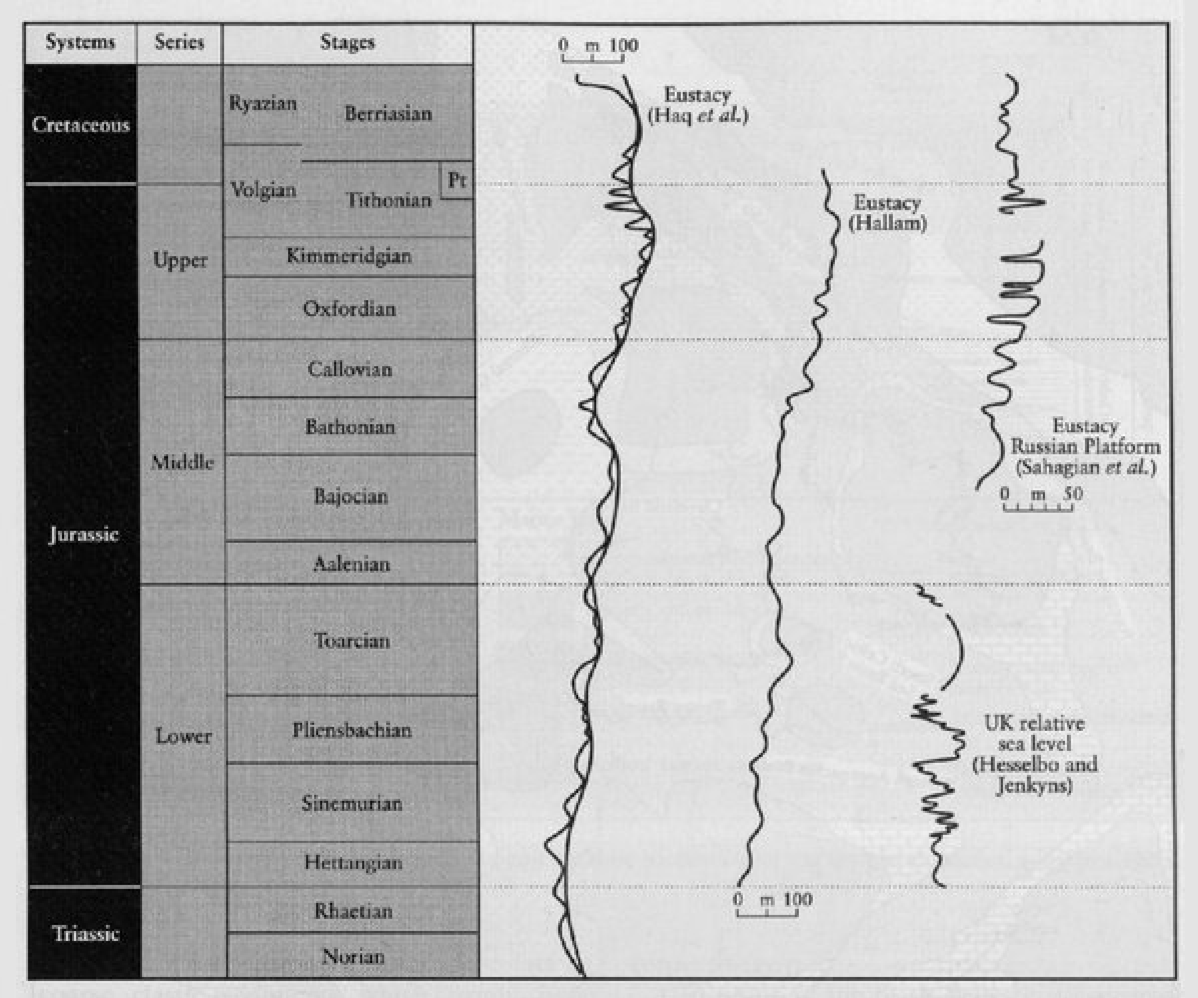

(Figure 4.6) Patterns of change produced by various global and regional geological processes, which have affected the environment of sedimentation through Cretaceous times. Indicators of global change through Cretaceous times. (Gale, 2000.)



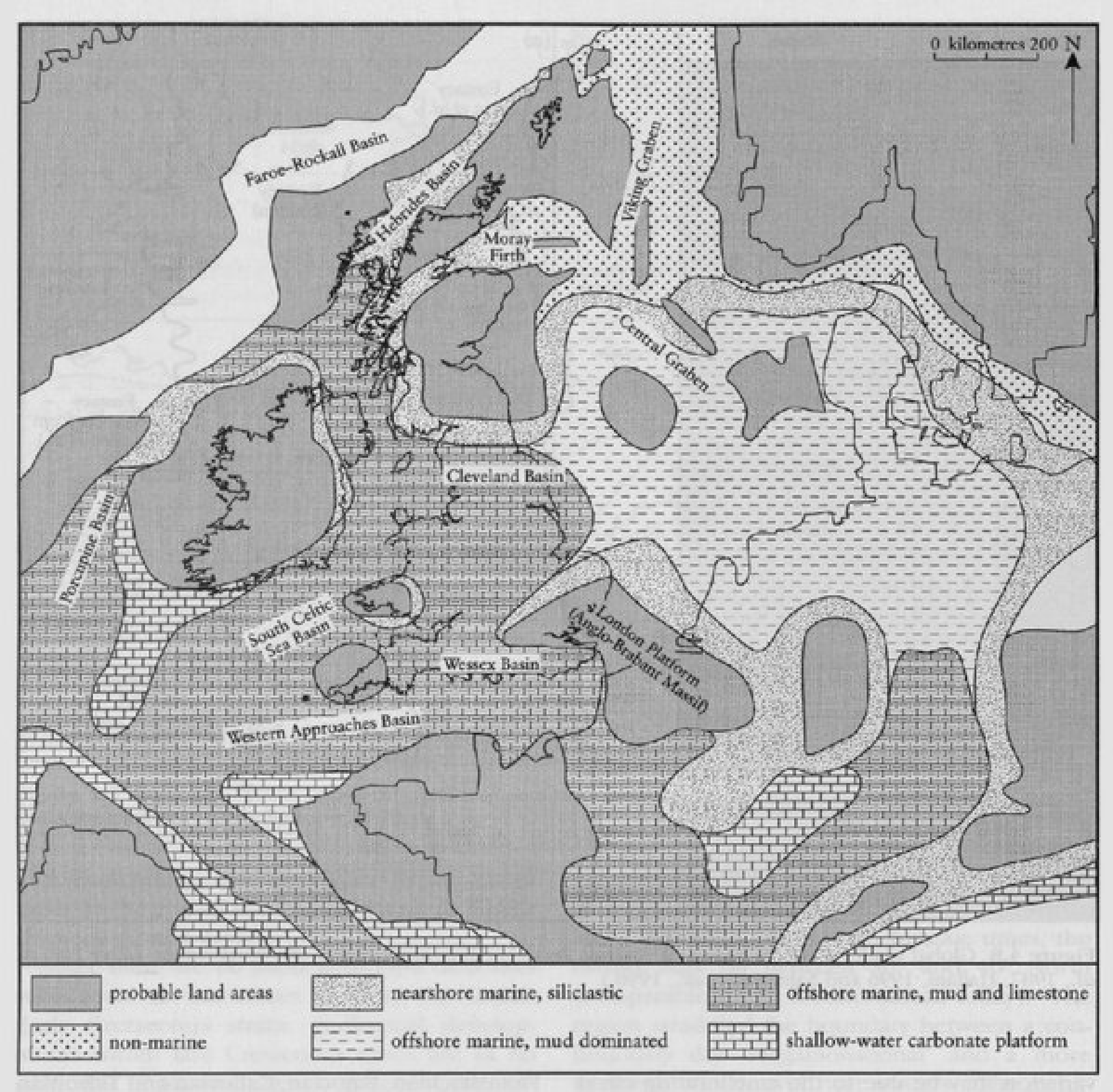

(Figure 4.7) Early Cretaceous palaeogeography of southern England during (a) Upper Berriasian and (b) mid-Hauterivian times. (After Rawson, 1992.)



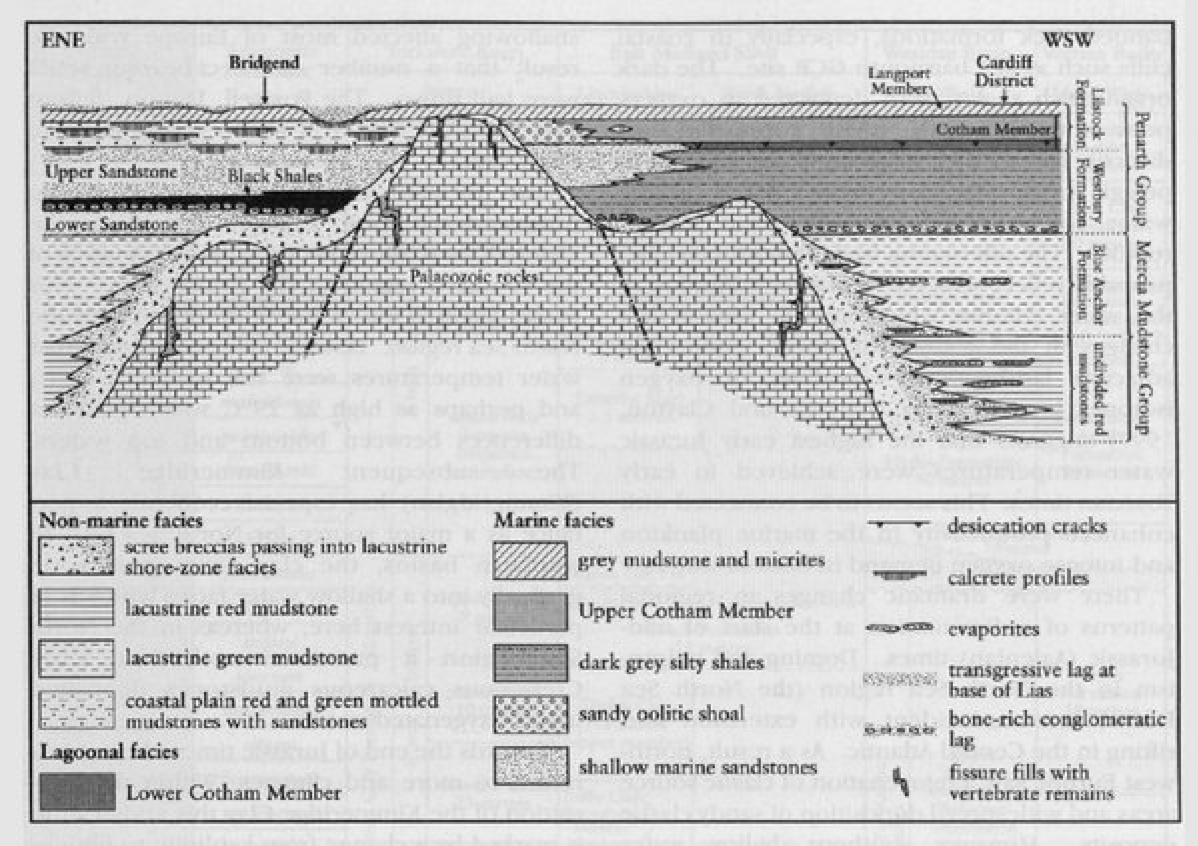

(Figure 4.11) Stratigraphical nomenclature of the Lower Cretaceous deposits of England. (After Rawson, 1992.)



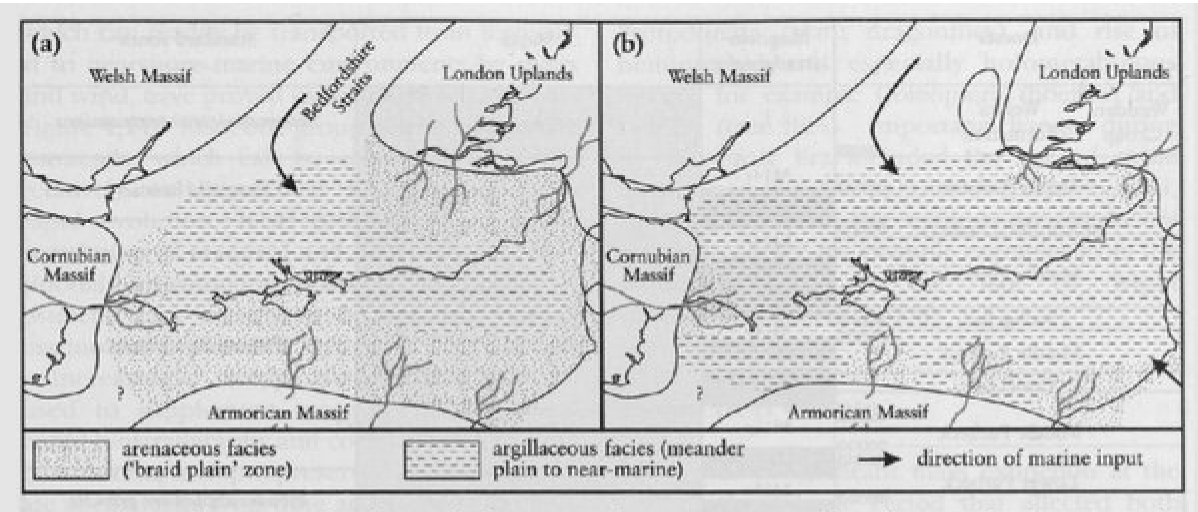

*(Figure 4.8) Global sea-level curves based on Jurassic Period sedimentary cycles. Pt: Portlandian. (After Haq et al., 1987; Hallam, 1996 and Sahagian et al., 1996.)*



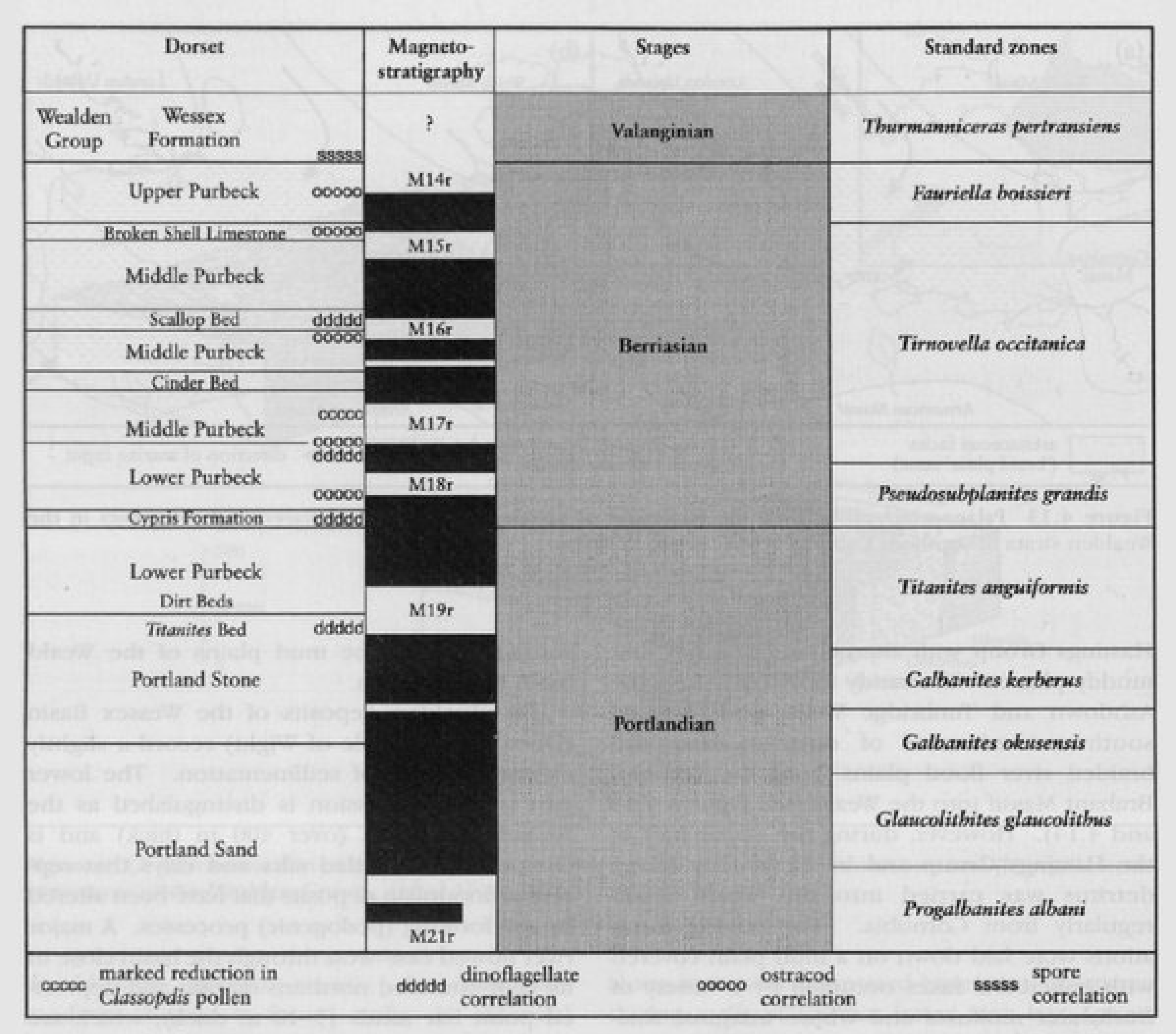

*(Figure 4.9) Palaeogeographical map of the' UK area, for early Hettangian times. (Based on Ziegler, 1990 and Bradshaw et al., 1992.)*




(Figure 4.10) Schematic section through the Late Triassic succession of the Bridgend district, southern Wales. (After Wilson et al., 1990.)




(Figure 4.13) Palaeogeography during the formation of arenaceous (a) and argillaceous (b) deposits in the Wealden strata of southern England. (After Allen, 1975.)




*(Figure 4.14) Summary of the Jurassic–Cretaceous boundary interval in Dorset. (After Ogg et al., 1995.)*