Chapter 5 The palaeoentomology of Tertiary (Cenozoic) strata in Great Britain

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Introduction

Of the fossil arthropods considered in this volume, the insects are by far the most important in the Tertiary part of the British stratigraphical record. Inevitably, given the biology of the group, most, but not all, of these fossil forms are continental (terrestrial and freshwater) in habit. As has already been mentioned, the preservation of such organisms depends either upon the formation of geological sediment traps within continental settings that are subsequently preserved as part of the stratigraphical rock record, or their transport into marginal marine and continental shelf settings where they are then recruited to the marine sedimentary rock record. Here the nature of the stratigraphical record of those deposits that host the insect faunas is briefly discussed.

Although the onshore British stratigraphical record of Tertiary deposits is limited to a certain few intervals in the period see (Figure 5.5), fossil insects are quite well represented in their deposits, because many of them were laid down in relatively quiet-water nearshore and transitional marine-freshwater environments with fine-grained deposits, into which insect remains could sometimes be recruited. In addition, early diagenetic rock formation of these sediments also played a major role in the preservation of fossil insects. Of particular importance was the formation of concretions, and also limestone layers within mudstone strata.

The six sites selected for the GCR as representatives of the Tertiary palaeoentomology of Great Britain (Figure 5.1) and (Figure 5.2) all lie within the British Palaeogene strata (Palaeogene time comprises the Palaeocene, Eocene and Oligocene epochs, from *c.* 65 to *c.* 23 Ma) and fall into two age groups. The older group ranges from latest Palaeocene in age (Ardtun) to slightly younger but still early Eocene in age (Bognor Regis). The younger group ranges in age from late Eocene (Gurnard) to early Oligocene (Bouldnor). As explained in the introduction to GCR site selection, no Quaternary sites have been selected especially for arthropods, although it is recognized that fossil and subfossil insects play an important role in the dating and palaeoenvironmental interpretation of many 'Ice Age' sites. Indeed, the role of beetles (coleopterans) in the interpretation of Quaternary environments in Wales is discussed by Campbell and Bowen (1989, p.158ff.).

The Palaeogene fossil insect assemblages of the six selected British sites tend to be intimately associated with ancient floras and are often but not always terrestrial elements introduced into otherwise brackish or marine environments of deposition, most of which are nearshore. The insect evidence tends to supplement that of the fossil plants especially in terms of palaeoenvironmental and palaeoclimatic interpretation.

Palaeoclimates and palaeoenvironments

Global climates changed significantly through Tertiary times (for a full discussion see the GCR volume on *British Tertiary Stratigraphy,* Daley and Balson, 1999).

Initially, temperatures rose to a peak in Eocene times and then progressively cooled with the first ice sheet appearing in Antarctica in early Oligocene times although permanent glaciation did not appear until mid-Miocene times when glaciers may have formed in Greenland. In addition there were shorter-term variations superimposed upon these overall trends.

The Palaeocene–Eocene transition in the early Palaeogene, around 56 Ma, was a phase of warm global climates and generally high sea-levels with polar broad-leaved deciduous forests extending high into the Arctic Circle (Basinger *et al.,* 1994). Nevertheless, the fossil plant records show variation in vegetation throughout the interval in response both to climate change and latitudinal position. During the latest Palaeocene times, around 55.1 Ma there was a very short-lived phase of warming followed by a marked cooling around 54.2 Ma.

There has been speculation (Dickens *et al.,* 2003) that the warm phase was a, consequence of the greenhouse effect caused by a catastrophic release of gas hydrates from within ocean-floor sediments, perhaps initiated by contemporary volcanism. Southern Britain supported freshwater mires and relatively low diversity, patchy forest-woodland populated with warmth-loving deciduous flowering plants. Farther north, at Ardtun, similar flowering plants were associated with more conifers and ferns. By contrast the floras of the earliest Eocene (as recorded by fossils from the Oldhaven beds and lowest strata of the London Clay) indicate the early development of a frost-free paratropical rain forest-type vegetation very similar in structure to that of the present day paratropical rain forest. Inevitably these climatic and vegetational developments impacted upon the entomofauna.

Palaeogeographical setting

There were significant differences between the palaeogeography of Tertiary times and those of today, including a northward plate-movement of Britain over some 8 degrees of latitude. Also important in the Northern Hemisphere context was the persistence of a land connection between Europe and North America that allowed continued biotic interchange (Figure 5.3). However, by late Palaeocene times increasing igneous activity related to the rise of the North Atlantic mantle-plume beneath the continental crust of East Greenland (Figure 5.4) led to the development of the Brito-Arctic Igneous Province (also known as the 'North Atlantic Tertiary Igneous Province') with extensive extrusive vulcanicity and associated intrusion of a variety of igneous bodies. Elevation of the continental crust in mid-late Palaeocene times led to the development of a landmass that encompassed much of present day Scotland and what is now the largely submerged Orkney–Shetland platform (Figure 5.5). The uplift and erosion of this landmass led to large-scale deposition of eroded sediment in the adjacent basins of the North Sea and Faroe–Shetland regions (Figure 5.5) where Tertiary sediment reached maximum thicknesses of 3 km and 4 km respectively.

There is no doubt that the Tertiary- and especially Palaeogene-age deposits were formerly more extensive over Britain. It is thought that the 'clay with flints' which blankets much of the Chalk is made up of the weathered residues of these deposits. However, it is also clear that there were phases during Tertiary times during which Britain was uplifted and eroded. During early- and the beginning of late-Palaeocene times (the first 7 Ma or so years of the Tertiary period) there appear to be no onshore sediments.

Study of borehole data and seismic profiles of this sediment infill has provided important information about the intimate relationship between igneous, tectonic and depositional activity and palaeogeographical evolution of the British Isles throughout much of Tertiary time. Most important from the depositional point of view has been the recognition of eight major depositional cycles within these offshore basins from the Palaeocene through to the Pliocene epochs.

Re-activation of Mesozoic structural, fault-bounded, basins (graben) in north-west Europe was associated with crustal attenuation and widespread volcanicity (seen in the Ardtun GCR site on the Inner Hebridean island of Mull). These processes eventually led to extensive rifting both to the north-west and north-east of the British Isles. And, in turn this led to progressive opening, beginning around 55 Ma, of the North Atlantic Ocean, as new ocean crust was formed. The new ocean extended northwards from the Central Atlantic area and finally severed the land connection between Europe and North America and isolated Greenland.

In the west of Scotland and north-east of Ireland, the magmatism associated with this phase of intense volcanic activity formed widespread flood basalt sequences associated with lava shields, shallow intrusive centres and spanned the interval from around 60.5–55 Ma. The igneous activity was intermittent with periods of rapid growth of the lava fields and intrusion of a variety of igneous bodies followed by significant hiatuses during which weathering and erosion allowed the development of relatively mature vegetated landscapes whose deposits and fossil remains are to be found within the plateau basalts (see (Figure 5.10)). Evidence of this Palaeogene volcanism is also present in the south of England where airborne pyroclastic material has been preserved as ash layers in the basal strata of the London Clay.

In comparison, southern Britain was less elevated and two structural basins, known as the 'London Basin' and 'Hampshire Basin', were formed from a single structural 'low' which originally covered much of today's North Sea region, the Low-countries of Belgium, north-east France and south-east England. The formation of the Weald–Artois 'high', which extended just into south-east England from Europe, split the original structural basin in two (Figure 5.6). Global high sea levels resulted in these structural lows also being sites of shallow water deposition with extensive alluvial plains and marshes and brackish to freshwaters dominated by fine-grained mud deposits. Open marine conditions lay to the north-east in the North Sea region and to the south-west in the Western Channel.

By latest Palaeocene to early Eocene times the shallow seas had extended over much of southern England interconnecting the London and Hampshire Basins (see Bognor Regis GCR site report) and flooding over the Low-countries.

Subsequently, in late Eocene-early Oligocene times, retreat of the shallow seas led to separation of the two basins and extension of the Weald–Artois 'high' as a land-bridge to Europe Nevertheless there is evidence for a continuing narrow extension of the Atlantic Ocean along the line of the present English Channel and into the Paris Basin, but this has left no marine deposits on the British mainland. However, there are deposits in the Hampshire Basin that record the retreat of the sea during middle Eocene times and a transition through marsh to fully terrestrial environments. Consequently, the remaining basin was infilled with fluviodeltaic sediments.

Stratigraphical background

All of these palaeogeographical changes have been reconstructed from relatively few outcrops in the south of England but these onshore outcrops have now been supplemented by a large volume of information from offshore boreholes.

The overall stratigraphy is described following the classification adopted in the *British Tertiary Stratigraphy* GCR volume (Daley and Balson, 1999).

Of the three early Palaeogene sites, the oldest — Ardtun, is unique in its Hebridean location within the Brito-Arctic Igneous Province. Consequently, it cannot be directly correlated on lithostratigraphical terms with any of the other British sites but can be compared with other similar sites on Mull (e.g. Bearraich, see Emeleus and Gyopari, 1992, p. 150) and other sites in the Brito-Arctic Igneous Province, such as those of County Antrim in the north of Ireland (e.g. Glenarm, see Watts, 1970) where interbasaltic sediments and plant material and occasional insects have also been found. The Ardtun sediments are essentially continental and were laid down on elevated landscapes developed during a pause in lava eruptions. The landscapes were originally covered either wholly or, in part, by late Cretaceous sediments, patches of which are preserved below the lavas and reworked elements such as flints are found within the lava sequence. The interbasaltic sediments include both terrestrial and waterlain deposits and it is within the latter that the plant and insect fossils, for which the site is internationally renowned, have been found.

Offshore, the 3–4 km of Tertiary sediments that accumulated in the Faeroe–Shetland Basin and North Sea Basin provide evidence that there were eight major depositional cycles between Palaeocene and Pliocene times (Figure 5.7), but only the first 6 cycles are relevant here. Cycle 1 in early Palaeocene times was relatively short. It mostly represents a continuation of the tectonic and depositional environments of the late Cretaceous with dean chalky limestones being deposited over much of mainland Britain with only a thin sequence of clastic materials following on top of Cretaceous sediments in the offshore basins.

Cycle 2 of the mid- to late-Palaeocene Epoch represents an abrupt increase in deposition brought about by the plume-induced uplift of the North Atlantic region and the onset of volcanism. As the rate of uplift slowed down, rising sea level brought further changes in the type of deposits with prograding shallow marine deposits on shelf edges. Away from the main focus of sedimentation, in the more distal parts of the North Sea Basin the deposits were mainly mudstones.

A second major phase of uplift in latest Palaeocene times marked the initiation of the short-lived Cycle 3, which continued through early Eocene times. This was related to the uplift of the north Atlantic rift margins leading to seafloor spreading between Scotland and Greenland. While in the north of Britain there was uplift this also produced a south-eastward tilting. An initial relative fall in regional sea level brought prograding sediments into the basins of deposition, and then rising sea level resulted in extensive shallow marine to terrestrial deposition. The North Sea Basin became more-or-less landlocked leading to a sharp change in facies from open marine to restricted marine conditions throughout north-west Europe.

The onset of Atlantic seafloor spreading in early Eocene times initiated the major and lengthy Cycle 4 that persisted for around 21 Ma until the end of Eocene times. The initial NW–SE extensional structural regime gave way to the SE-directed compressional one that still persists today. From Eocene times onwards north-west Europe became part of a thermally cooling and subsiding passive continental margin, which slowly but progressively moved away from the hotspot that continues today beneath Iceland. There was a rise in sea level and widespread flooding of the shelf areas. Offshore sedimentation was dominated by the deposition of muds, restricted circulation and stratified water columns.

Latest Eocene times were marked by another profound change in tectonic and sedimentary regimes and initiated Cycle 5 that lasted through early Oligocene times. Changes in plate motion in the northern Atlantic Ocean resulted in a shift in the direction of movement of north-west Europe from a south-easterly to a more ESE direction. The focus of uplift moved away from Scotland to Scandinavia produced more uniform patterns of sedimentation and rapid global cooling lowered sea level. The onset of renewed uplift in Scandinavia led to a more marked fall in sea level and initiated Cycle 6 throughout late Oligocene times with prograding sediments and in places freshwater mudstones and lignites.

Then, from the latest Palaeocene until the beginning of Oligocene times there was a long phase of sedimentation in the south-east of England. Apart from a few outliers of early Palaeogene age that give some information about the palaeogeography of south-western areas, there is little onshore data apart from in the south-east. Nevertheless, there is offshore evidence, for instance from the Western Approaches and the Mochras borehole near northern Wales that there were sediments accumulating in the westerns basins of Palaeogene Britain.

Sedimentation in these basins was also punctuated by several pulses of uplift but here in the south most of the pulses originated as distant ripples emanating from compressive events in the Alps. However, the mode of propagation of these compressive ripples is far from clear. Complexities in the inherited structural framework of the region are likely to have interfered with any simple translation of the stresses.

The region's most complete Tertiary sequences are preserved where marine deposition was most continuous such as the southern North Sea, which connected northwards with the main North Sea Basin, and in the southwest, where the Western Approaches opened westwards into the continuously widening North Atlantic Ocean. The pulses of uplift and sea-level change led to a series of transgressions and regressions into the intervening areas.

South-east England as a whole was gently uplifted during an early Tertiary phase of Alpine compression with the result that deposits of lowest Tertiary age are missing and it is late Palaeocene sediments that onlap onto eroded Chalk surfaces. The source for these sediments was the low-relief land surface of central England and parts of northern France, with the intervening depositional basins being infilled with shallow-water, marginal marine and fluviatile, fine-grained sediments. In detail, Palaeogene sequences were influenced by local tectonic movements and eustatic changes in sea level. The total thickness of Tertiary (Palaeogene and Neogene) deposits in southern Britain is much thinner than in the offshore basins to the north. Even so, some 2 km accumulated in the southern part of the North Sea Basin but farther south in the Hampshire–Dieppe Basin the total thickness is around 500 m.

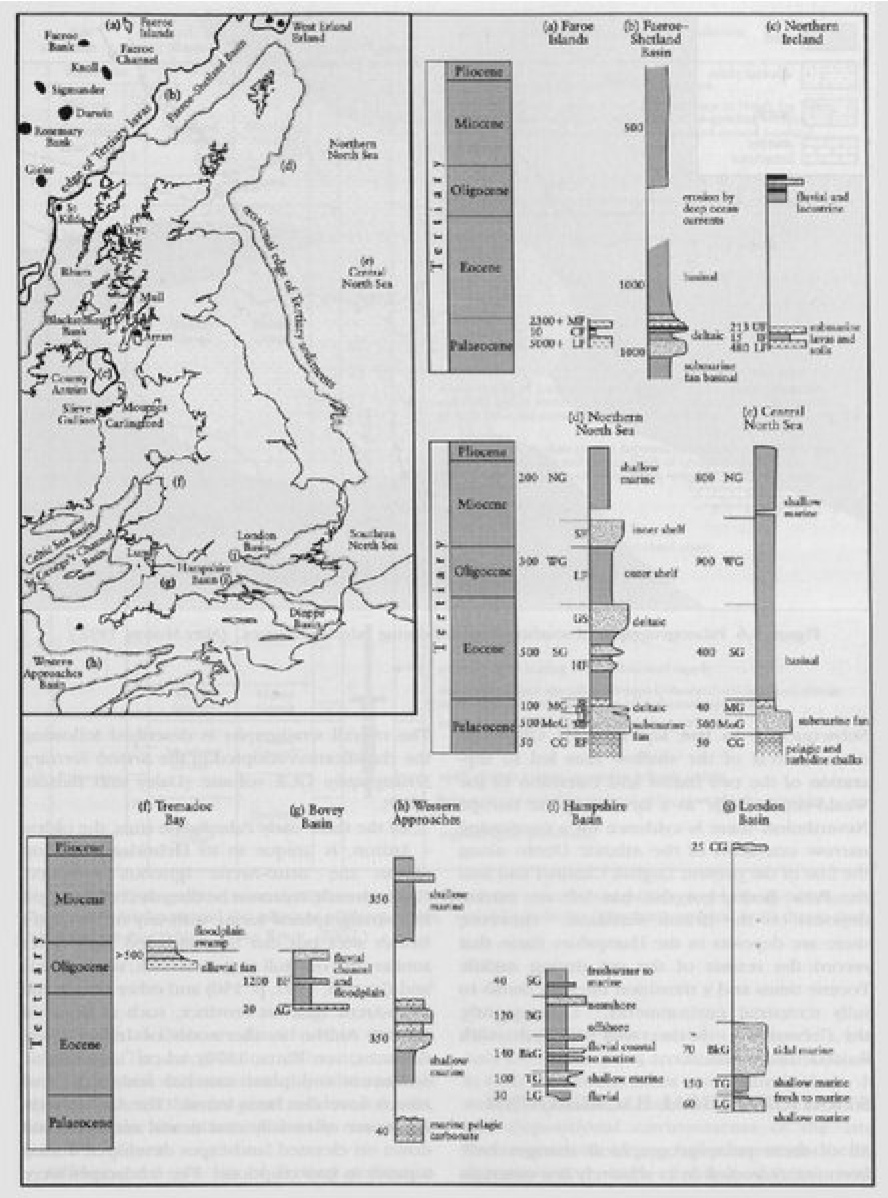
The lower part of the sequence in the south of Britain is divided into four major units: the basal Thanet Formation, the Upnor Formation, the Woolwich/Reading formations and the overlying London Clay Formation. The lowest members of the latter have also been referred to as the 'Harwich Formation' (Ellison *et al.,* 1994) and include King's Oldhaven Formation (King, 1981). The three lower formations are placed within the Lambeth Group of Palaeocene age whereas the London Clay Formation is within the Thames Group and is of Eocene age. The chronostratigraphy of lower Palaeogene times is still somewhat problematic, but the Palaeocene Epoch is currently divided into three stages — the Danian, Selandian and Thanetian. Above these, the Eocene stages are Ypresian, Lutetian, Bartonian and Priabonian. The London Clay Formation lies just above the Palaeocene (Thanetian) —Eocene (Ypresian) boundary and records the most far reaching of the transgressive phases of Tertiary times.

The occurrence of both marine and non-marine deposits of Eocene age in southern Britain has caused considerable problems of correlation and lithostratigraphical classification. The names of many of the deposits were long-ago established on the basis of their local occurrence and often were ill defined. The London Clay has been particularly notorious in this respect until King's (1981) detailed correlation of the outcrops across the south of England. He referred all of the London Clay to the Thames Group except for the lowest, more-sandy beds, which were placed in the Oldhaven Formation. Within the remaining bulk of the London Clay, King recognized five informal divisions (R to 'E') separated by discontinuities and perhaps representing cyclic depositional events. More recently, King's Oldhaven Formation and Al subdivision have been amalgamated by Ellison *et al.* (1994) to form the Harwich Formation.

The only younger strata of concern here are the post-Lutetian deposits of the Solent Group in the Hampshire Basin, especially those of late Priabonian–Rupelian age (late Eocene–Oligocene). Again, lateral variation in facies has resulted in considerable confusion with the lithostratigraphical nomenclature. Following the scheme of the Tertiary stratigraphy GCR volume (Daley and Balson, 1999), the post-Lutetian

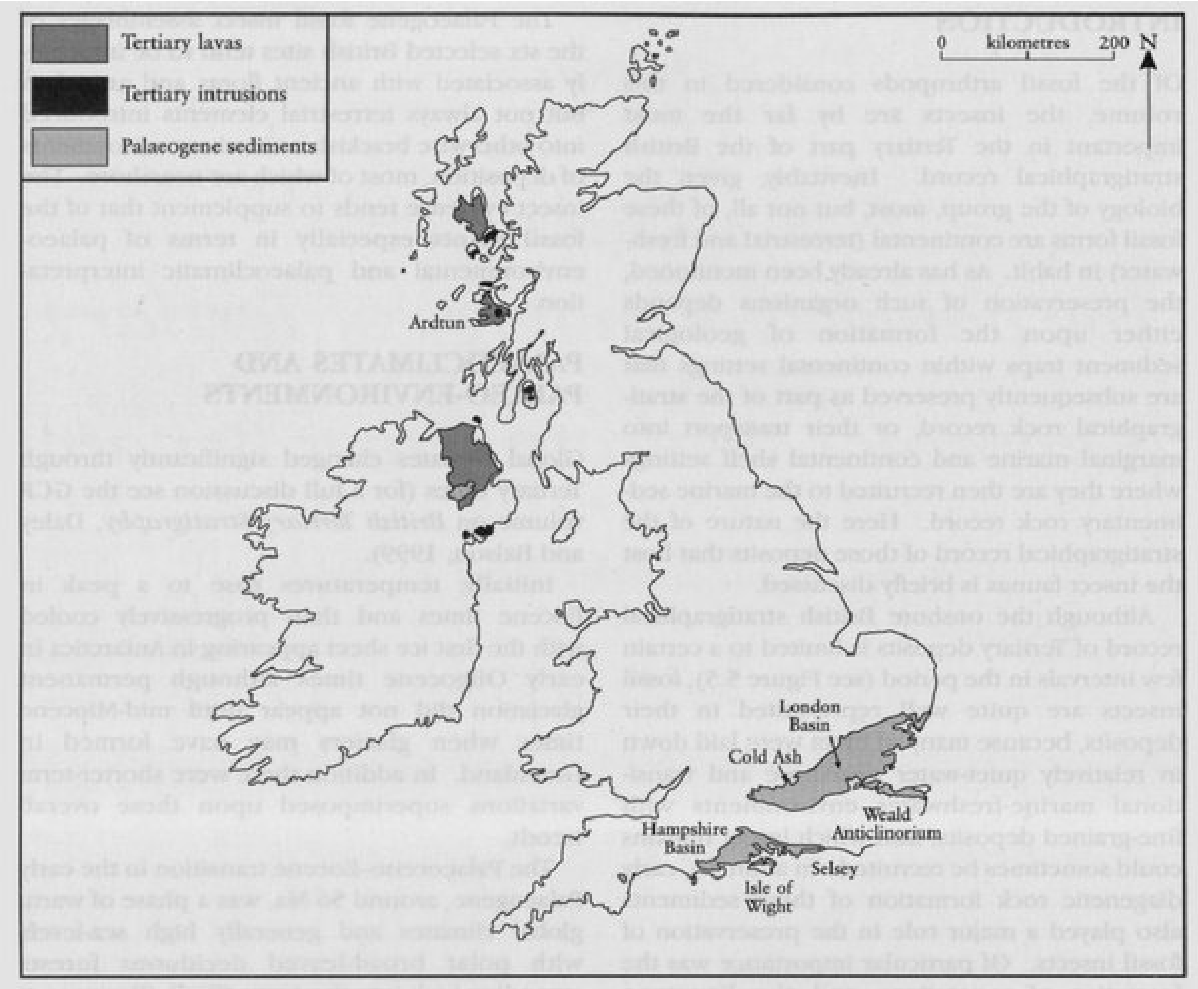
deposits are divided into a shallow to marginal marine Barton Group and a brackish to non-marine Solent Group, both of which are divided into a number of formations (Figure 5.8). The Barton Group is middle Eocene in age, and the younger Solent Group, which is of more concern here, is of late Eocene to early Oligocene age. Recognition of the Eocene–Oligocene boundary has been particularly difficult as it is defined by the extinction of certain marine foraminifera and the deposits of the Hampshire Basin had become non-marine by this time (for a detailed discussion see Collinson and Cleal, p. 231–2, in Cleal *et al.,* 2001).

References

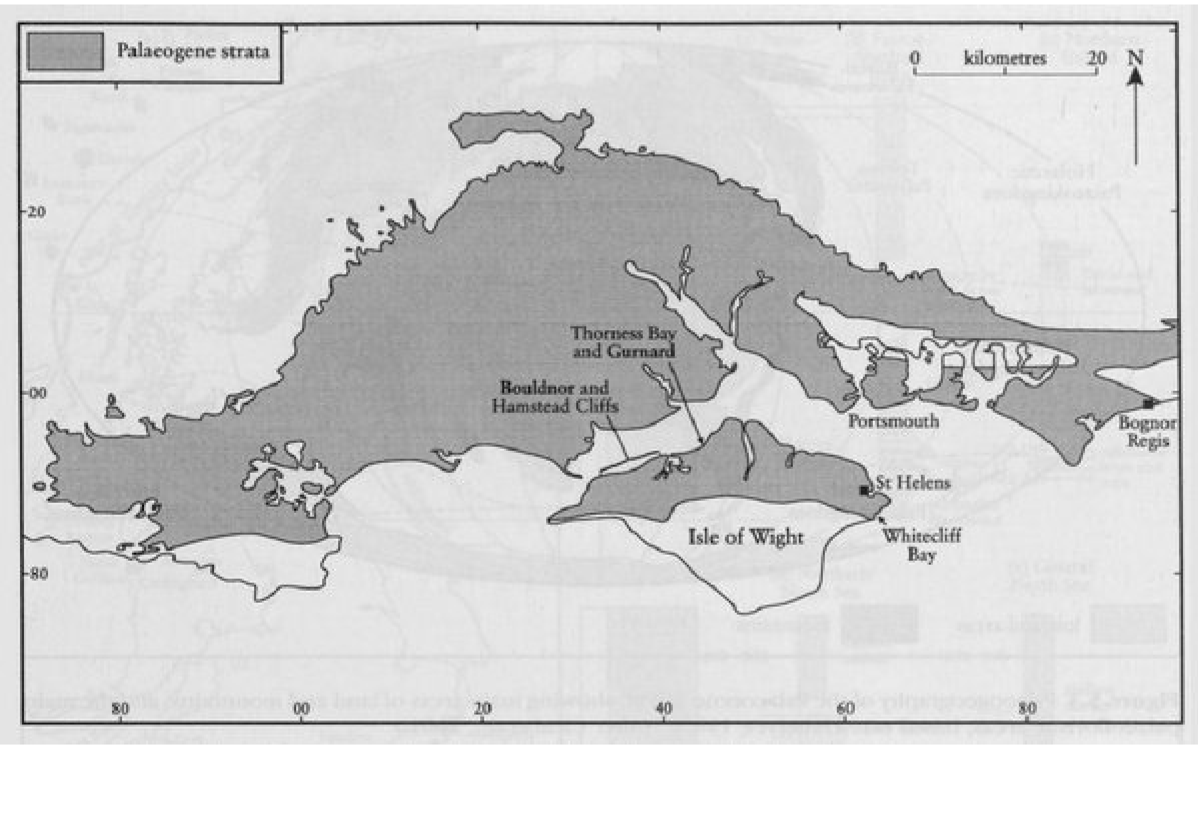


(Figure 5.5) Distribution of Tertiary sediments, lavas and igneous complexes around the British Isles. MF: Middle and Upper Formations; CF Coal-Bearing Formation; LF Lower Formation; LG Lough Neagh Group; UF: Upper Formation; IF: interbasaltic Formation; NG: Nordland Group; WG: Westray Group; SG: Stronsay Group; MG: Moray Group; MoG:

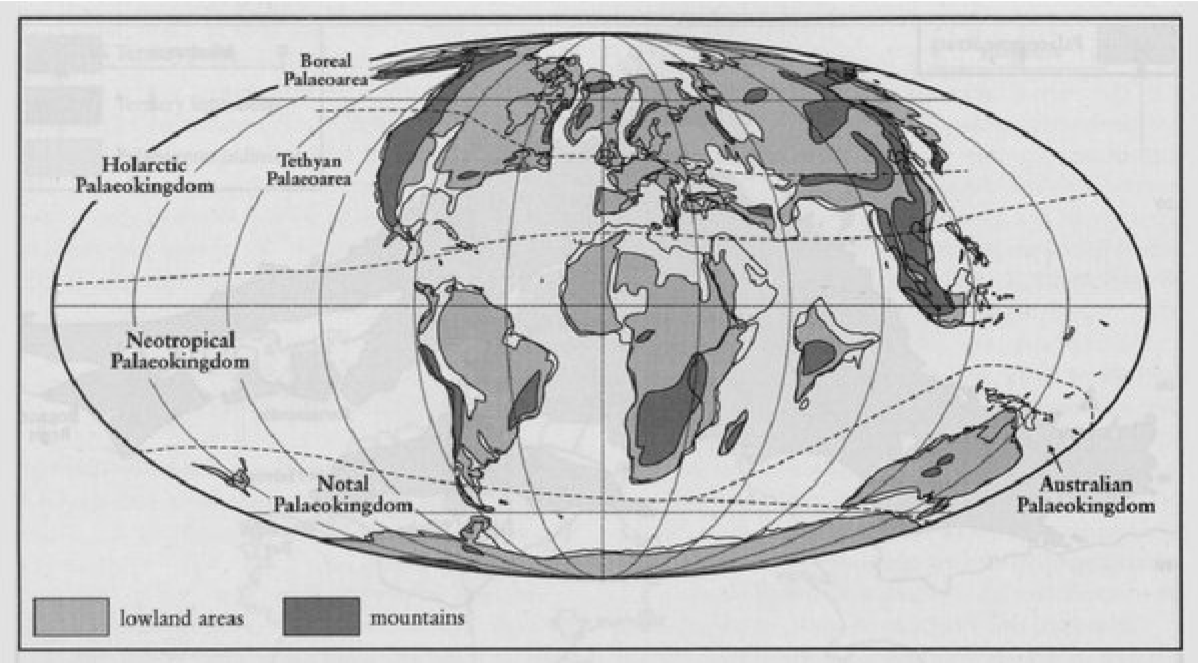
Montrose Group; CG Chalk Group; SF: Skade Formation; LF: Lark Formation; GS: Grit Sandstone Member; I IF: Horda Formation; BF Balder Formation; DF: Dornoch Formation; SF: Sele Formation; LF: Lista Formation; MF: Maureen Formation; EF: Ekofisk Formation; BF: Boyer Formation; AG: Mier Gravels; SG: Soloent Group; BG: Barton Group; BkG Bracklesham Group; TG: Thames Group; LG: Lambeth Group; CC Coralline Crag.



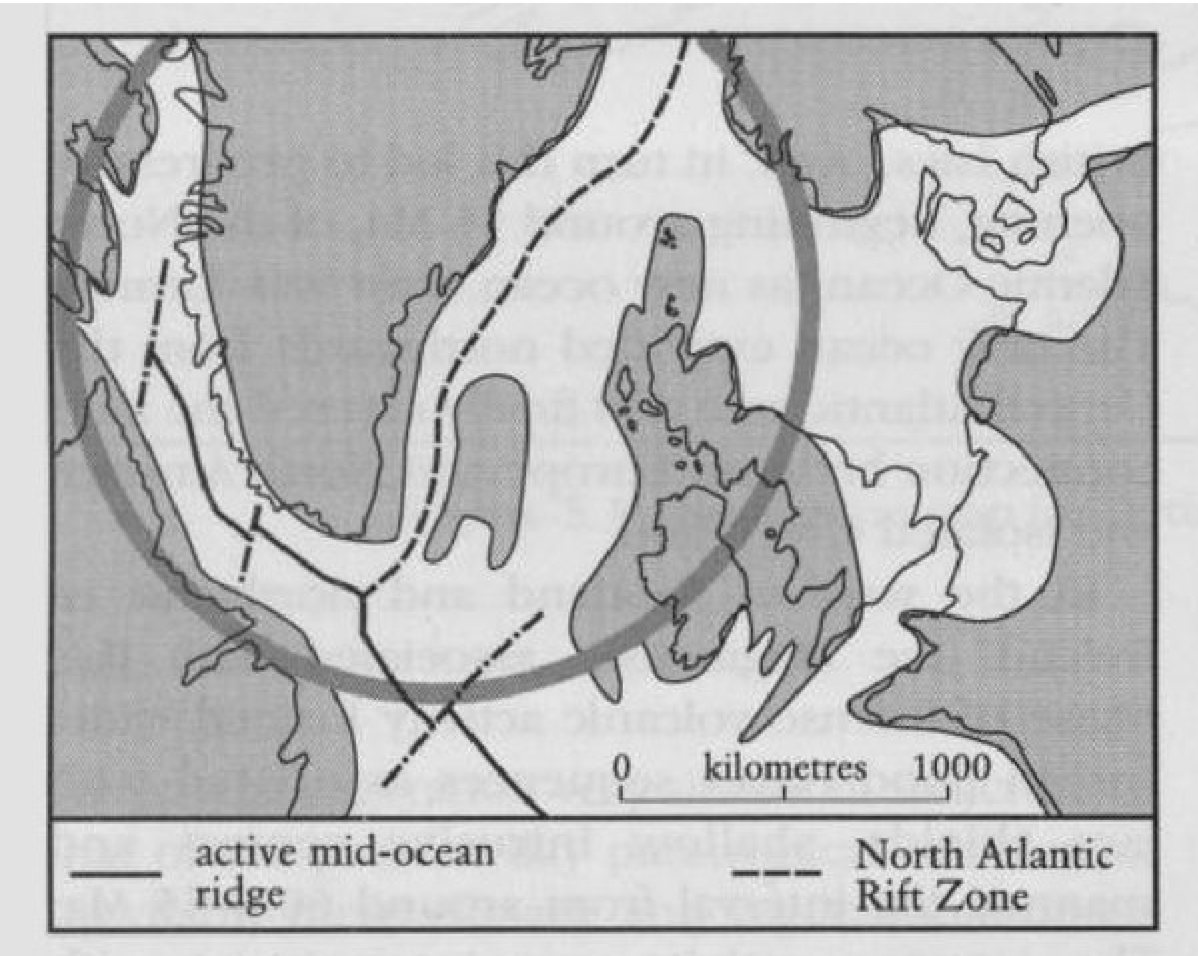
(Figure 5.1) Distribution map for Tertiary rocks. (After Benton et al., 2005.)



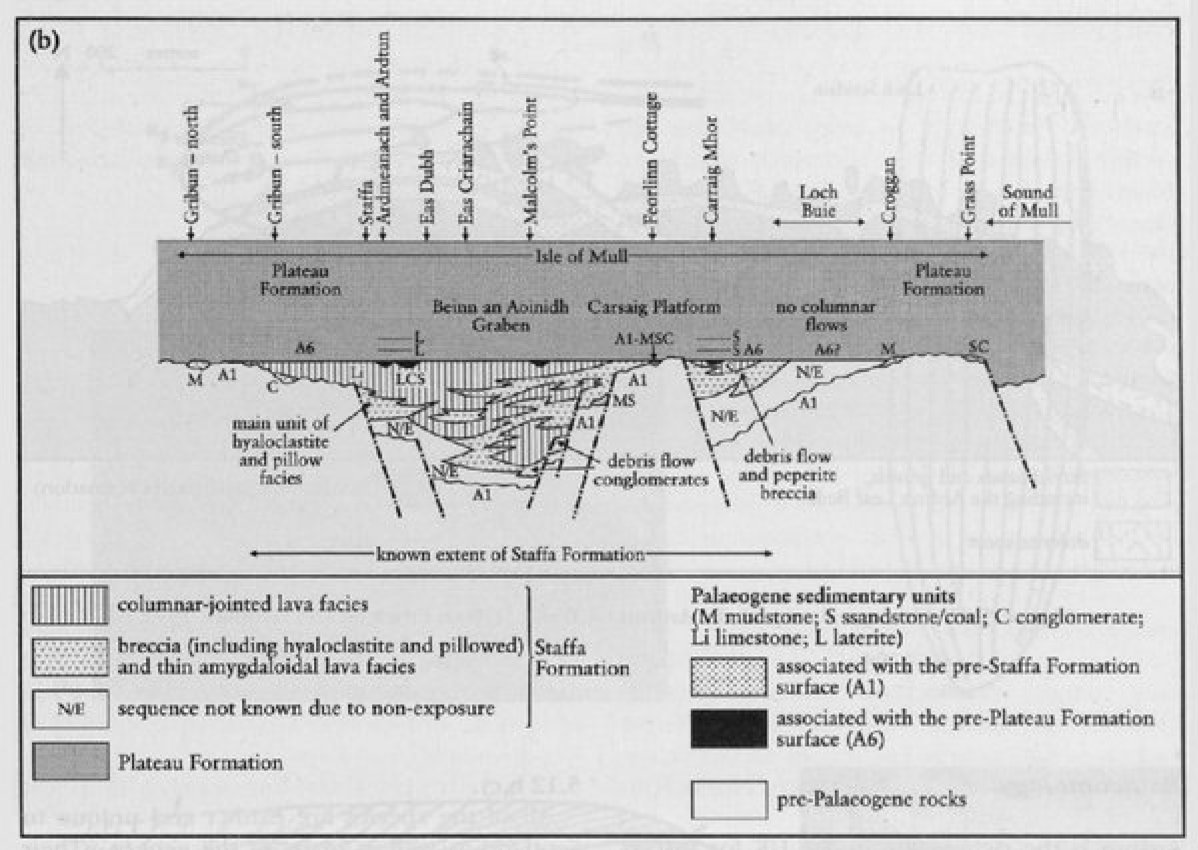
(Figure 5.2) Map showing the location of the arthropod GCR sites in the Hampshire Basin.



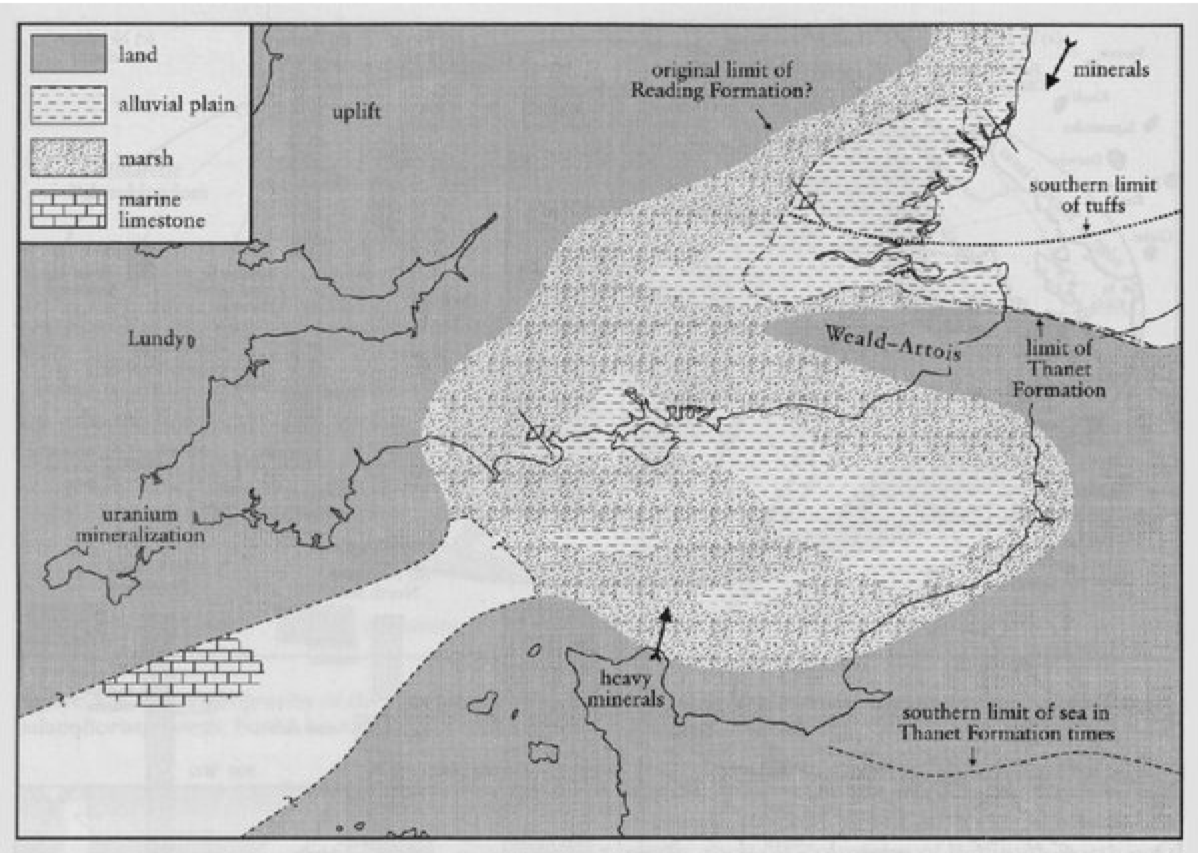
(Figure 5.3) Palaeogeography of the Palaeocene world, showing main areas of land and mountains, and the main palaeofloristic areas, based on Akhmetyev, 1987). (After Cleal et al., 2001.)



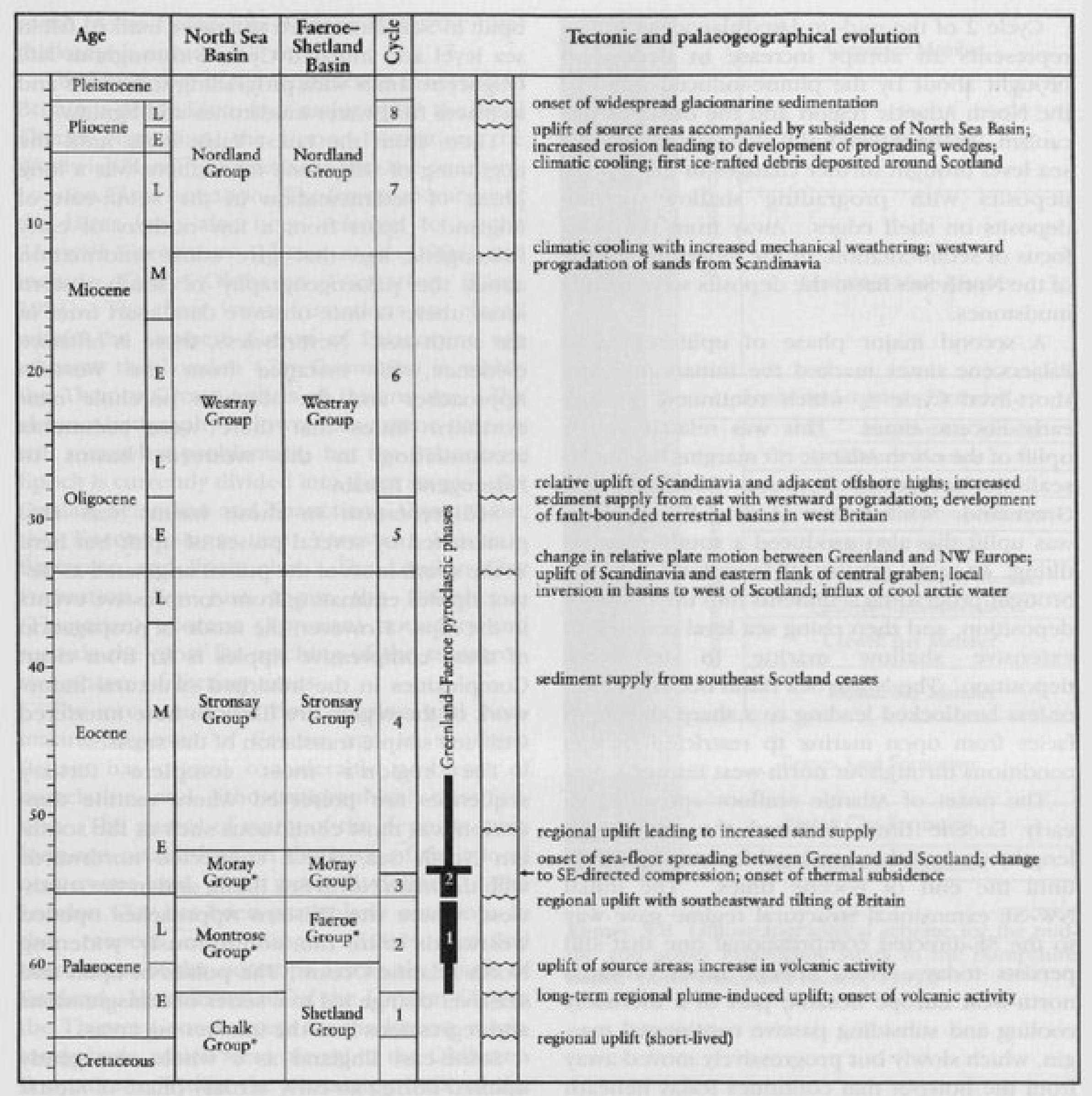
(Figure 5.4) Regional tectonic setting prior to the opening of the north-east Atlantic Ocean, between Greenland and Scotland. Inferred land areas are shaded in grey. The circle represents the approximate extent of the proto-Icelandic mantle plume. (After Knox, 2002.)



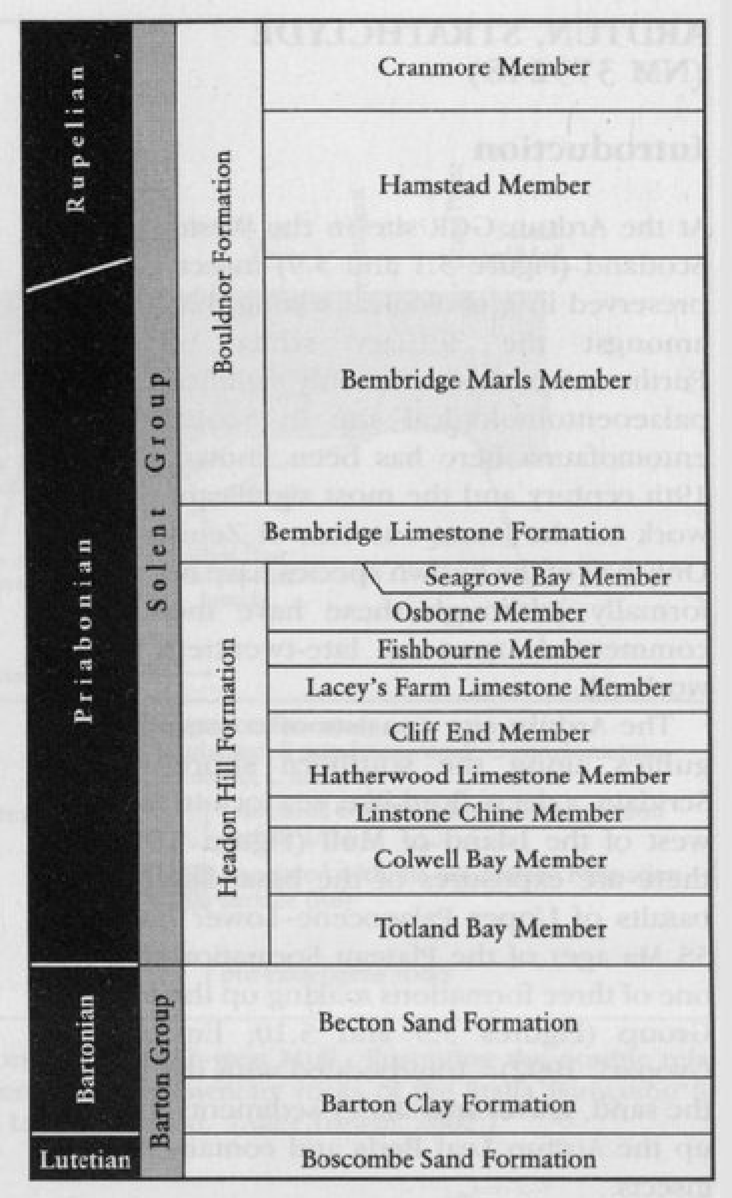
(Figure 5.10) Schematic cross section of the lava succession in south-west Mull, illustrating the possible relationships between the various volcanic facies and intercalated sedimentary rocks of the Staffa Formation to 'basement' structures and the succeeding Mull Plateau Lava Formation. (After Trewin, 2002.)



(Figure 5.6) Palaeogeography of southern England during Palaeocene times. (After Murray, 1992.)



(Figure 5.7) Timing of the most significant developments in the tectonic and palaeogeographical evolution of the Scottish landmass and the adjacent offshore basins. Asterisks indicate lithostratigraphical units that include hydrocarbon reservoirs. (After Knox, 2002.)



(Figure 5.8) Lithostratigraphical scheme for the middle and upper Palaeogene strata in the Hampshire Basin. (After Daley and Batson, 1999.)