Chapter 2 Introduction to the Palaeogene

B. Daley

Economic significance

Whilst the Palaeogene deposits of Britain are part of our geological heritage and of inherent scientific value, the importance of understanding their stratigraphy and palaeoenvironmental development has been emphasized by the discovery in the latter part of the 20th century of a number of offshore Tertiary basins adjacent to the British Isles (Figure 2.1) and an appreciation of the significance of this part of the geological succession for hydrocarbon exploration and exploitation. This is hardly surprising since the first oil field discovered in the North Sea in 1969 was in Palaeocene sandstones of the Montrose Field, to be followed less than a year later by the much larger Forties Field of similar age. Later, in 1971, the Frigg Field, one of the world's largest offshore gas fields, was found in Lower Tertiary sandstones (Lovell, 1983).

Palaeogene strata in the British area

Whilst there are small outliers of Palaeogene in Dorset and Devon, it is in south-eastern England that deposits of this age are at their most extensive both geographically and stratigraphically (Figure 1.3). The oldest rocks occur in the London Basin (and its northward extension into East Anglia) where late Palaeocene to mid Eocene strata are found. A thicker and stratigraphically more extensive succession occurs in the Hampshire Basin, and it is at its thickest in the Isle of Wight where a little in excess of 650 m of strata represent the late Palaeocene to early Oligocene.

The British onshore sites in these two tectonic basins provide a record for some 25 Ma; from the sediments of NP Zone 6 age exposed in Pegwell Bay (Figure 2.2) to the youngest surviving uneroded remnants of the Palaeogene on the Isle of Wight, where the uppermost part of the Bouldnor Formation may possibly be as young as NP Zone 23 in age (Figure 2.3).

History of research

The existence of some of the most magnificent Tertiary coastal sections in Europe, together with a wealth of small brickpits, sand-pits, quarries and railway cuttings close to major centres of population around London and the remainder of south-eastern England, led to an early interest in the Palaeogene strata and, in particular, the wealth and variety of well-preserved fossils that could readily be extracted from them. Indeed, the fossils were being collected and studied long before the stratigraphy was worked out. Amongst the earliest records of this is the description by Solander *in* Brander (1766; in Latin) of a collection of Hampshire fossils in the British Museum.

19th century studies

In the 19th century, a considerable interest in the Tertiary strata (as indeed in geology in general) came from amateurs, some of whom were professionals in other fields: Mantell was a surgeon; Forbes, whose early understanding of the Isle of Wight succession was to underpin much later stratigraphical work, was Professor of Natural History at the School of Mines; Webster (1814, 1816) trained as an architect (Edwards, 1971a), whilst Fisher, whose classification of the Bracklesham Beds (1862) is still valuable today, was, like a number of his geological contemporaries, in holy orders.

Those who were essentially 'collectors' also made important contributions. A'Court Smith's collection of plants and insects from Gurnard Ledge, Isle of Wight is but one example (see Jarzembowski, 1980). Amateur interest was encouraged by the Geologists' Association, founded in 1858, and records of its numerous visits to Tertiary sites have provided valuable geological data over the years.

From the middle of the 19th century, considerable interest in the stratigraphy and palaeontology of the Palaeogene led to the publication of numerous papers. To some extent these comprised local descriptions and reinterpretations whilst other studies were more thematic. Many different groups of Palaeogene fossils were written up, in particular in monographs of the Palaeontographical Society and later in the bulletins of the British Museum (Natural History). At the same time, as the Geological Survey systematically mapped the areas where Palaeogene deposits occurred, the accompanying sheet memoirs were to provide comprehensive descriptions of major Palaeogene sites. A number of such sheet memoirs were produced from the middle of the 19th century (e.g. Forbes, 1856; Bristow *et al.,* 1889).

Early and mid-20th century studies

The production of sheet memoirs by the Geological Survey continued into the 20th century and some, such as White's (1921) memoir on the Isle of Wight which was heavily dependent on the 19th century work, have yet to be replaced by modern revisions.

Apart from the work of the Geological Survey, and some other notable exceptions, the early part of the 20th century saw a lessening of research interest in the Tertiary. In his review of the Palaeogene strata in south-eastern England, Curry (1965a) suggested that this reflected the passing of the 'curio collectors' and, with them, books that would explain their treasures. Much of the 19th century interest had been by amateurs who, in the 1920s, had been replaced by professionals attracted by the more complicated geology of older rocks in western and northern Britain.

However, considerable palaeontological research continued. Chandler, working with Mrs Reid (Reid and Chandler, 1926, 1933) and alone (from 1921), described the palaeofloras of the major Palaeogene sites, whilst amateurs such as Wrigley and Davies researched their invertebrate faunas over a period of years (see Curry, 1965a for details). Curry himself began his major contribution to our understanding of the Palaeogene in the 1930s, whilst earlier, Wooldridge (1923, 1926) had begun a long interest in the London Basin and its development. Another important contribution was made by Stamp (for example, 1921), who recognized the cyclic nature of the Palaeogene in Britain.

Late 20th century studies

In the middle 1960s, Curry published two classic papers on the Palaeogene: one (Curry 1965a) a review of the succession in south-eastern England; the other (Curry, 1966) on the correlation of the latter with strata elsewhere in the Anglo–Paris–Belgian Basin. Just a little earlier, Ager (1963) had emphasized a new approach to palaeontology with his *Principles of Palaeoecology,* whilst the modern discipline of 'sedimentology' was developing fast. The study of micropalaeontology, seen as an important stratigraphical tool in the exploration for hydrocarbons, was also undergoing a period of growth at this time.

The Palaeogene, undeformed, with its profusion of well-preserved macrofossils, microfossils and sediments, proved irresistible to those researchers interested in palaeoenvironmental interpretation and a better understanding of the stratigraphy which, of necessity, underpinned it.

Ironically, this renewal of interest coincided with or postdated a marked diminution in the number and quality of Palaeogene exposures. Most of the small pits and quarries had disappeared, whilst even major sites such as 'Bournemouth Cliffs' had lost considerable exposures as a result of coastal protection measures. The extant sites were, however, to become and still are the subject of major research.

Many Palaeogene sections have attracted the interest of workers from a broad range of geological disciplines. One major and sustained interest had been in the micropalaeontology of the sites and the opportunities they have offered for both palaeoecological and chronostratigraphical research. Work was undertaken on the foraminiferids (by Curry, Bhatia, Haynes, Murray and Wright), the ostracods (Haskins and Keen) and pollen and spores (Ma Khin Sein and Machin (née Pallot)). Other microfloral research by a number of Charles Downie's students on the silicoplankton (Bujak, Costa, Eaton, Islam, Liengjaren and Williams) facilitated a much better understanding of lateral relationships through their work on zonation and correlation. Calcareous nannoplankton are rather less well represented, as might be expected in these essentially elastic sections, but work by Martini and, more recently, Aubry has facilitated the positioning of the English

Palaeogene in a broader international chronostratigraphical context.

The magnificent coastal sections of the Isle of Wight and adjacent mainland, with their almost unbroken stratigraphical continuity, provided opportunities for palaeoenvironmental researchers (e.g. Edwards, Daley and Plint) using a combined palaeoecological/sedimentological approach. King began his important comprehensive study of the London Clay at this time, whilst in Devon, Hamblin and others were taking a new look at the western Palaeogene outliers. Much of this work involved a reappraisal of the stratigraphy and the introduction of new lithostratigraphical nomenclature compatible with Hedbergian principles (Hedberg, 1976).

Over the same period of time, the Palaeogene sections provided research opportunities for a wide variety of palaeontological specialists. Many sites are characterized by prolific molluscan faunas which still attract considerable interest. Others provide opportunities to study assemblages indicative of particular environments, such as Prospect Quarry, Isle of Wight for terrestrial gastropods (Pain and Preece, 1968) and Headon Hill for freshwater molluscs (Paul, 1989). Gurnard Ledge is famous for its insect remains (Jarzembowski, 1976), whilst a number of sites have yielded mammalian assemblages to such workers as Cray, Insole and Hooker. That Crane and Collinson have undertaken considerable work on the macroflora despite Miss Chandler's extensive work over some 50 years, demonstrates that the research potential of the Palaeogene is far from exhausted.

Amateur involvement in research on the English Palaeogene sections has continued in recent decades. Bone, Kemp, Stinton and Ward are a few examples, and Dennis Curry's outstanding contribution over many years is acknowledged by all Tertiary workers. Amateur/professional co-operation both led and responded to the launching of the Tertiary Research Group in 1970, whose publications, initially *Tertiary Times* and later *Tertiary Research,* contain considerable site documentation undertaken by its members. The Palaeogene sections have also attracted foreign researchers, including Bosma (mammals), Buurman (palaeopedology), Castel (charophytes) and Gruas-Cavagnetto (palynology). Aubry sampled the major English sections in her research into the Palaeogene calcareous nannoplankton of north-western Europe, whilst more recently, Armenteros has undertaken work on the Isle of Wight as part of a wider study of freshwater limestones and their pedogenic modification.

Although much of the research on the sections used palaeontological and sedimentological data to determine depositional environments and the establishment of both chrono- and lithostratigraphical frameworks, other aspects of the sites have not been ignored. Mineralogical studies include research by Gilkes on the clay mineralogy and Morton on heavy minerals and their provenance. Other researchers (Catt, Weir and Knox) have investigated the contribution of contemporaneous volcanism to the mineralogy of sites such as Pegwell Bay and Herne Bay in the London Basin. Glauconite has been used for radiometric dating, and some of the larger, stratigraphically extensive sections have proved ideal for magnetostratigraphical work.

Despite the large volume of research undertaken on the major Palaeogene sections, it is only relatively recently that they are beginning to be comprehensively described and interpreted, in the light of modern findings. This partially reflects the fact that a number of the BGS sheet memoirs pre-date the modern phase of Palaeogene research. Some recent remapping by BGS has been undertaken, however, leading to such excellent new sheet memoirs as those for the Southampton (Edwards and Freshney, 1987a) and Bournemouth (Bristow *et al.,* 1991) areas.

In the late 1980s and extending to present times, increasing data from and understanding of the offshore Palaeogene sequences adjacent to Britain and particularly that of the North Sea has stimulated a continuing interest in the onshore Palaeogene sites. Much recent work has centred on refining the correlation of the Palaeogene strata in the British area (see particularly Knox *et al.,* 1996). Progress has been achieved through the palynological work of Aubry, Powell, Jolley and others, magnetostratigraphers such as Ali, and an increased emphasis on the application of sequence stratigraphy by such workers as Neal.

Age and correlation

As Curry *et al.* (1978) pointed out, the correlation of Tertiary strata had, until about half way through the 20th century, relied mostly on the comparison of fossil assemblages, particularly those of gastropods and bivalves. An early exception in the correlation of the Palaeogene was the use of different species of the foraminifer *Nummulites.* Since the 1950s, remarkable advances have been achieved, the early development of which is discussed in some detail in Curry *et al.* (1978, pp. 12–16). Whilst some radiometric dating of glauconites in the marine sequences has produced some approximate 'absolute' dates, the most stratigraphically significant progress has resulted from research into micropalaeontological biostratigraphy and magnetostratigraphy (Figure 2.2).

The former included the development of zonal schemes based on planktonic foraminifera (see, for example, Bolli, 1957; Banner and Blow, 1965) and calcareous nannoplankton (Martini, 1970a, 1971; Aubry, 1985, 1986). Later, and spurred on by the search for hydrocarbons in north-west Europe, zonal schemes based on non-calcareous microfossils, particularly dinoflagellates, were developed (e.g. Costa and Downie, 1976; Powell, 1988, 1992). More recently, a number of palynomorph association sequences have been recognized (Jolley, 1992, 1996).

Knox (1996) believes that it is now established that dinoflagellates provide the best means of correlating across a broad spectrum of facies in both the onshore and offshore basins of north-western Europe. In the correlation of the onshore Palaeogene deposits of south-eastern England dinoflagellates have been widely used, calcareous nannoplankton to a more limited extent and, with certain exceptions (the 'planktonic foraminiferid datum' of Wright, 1972), planktonic foraminiferids least of all (but see King, 1981, pp. 117–19) (Figure 2.3).

Correlation using magnetostratigraphical techniques (e.g. Townsend and Hailwood, 1985) has contributed significantly to a better understanding of the relationship of different Palaeogene outcrop and borehole sections in south-eastern England (Ali and Hailwood, 1995; (Figure 2.4)). Collaboration across the disciplines of nannofossil biostratigraphy and magnetostratigraphy (Aubry *et al.,* 1986) has further enhanced understanding by using the nannofossils to identify certain normal polarity magnetozones, whilst in more recent times, sequence stratigraphy techniques have become increasingly important for work on the Palaeogene (e.g. Neal, 1996).

In the predominantly brackish to freshwater deposits at the top of the Palaeogene succession (the Solent Group), there is only one horizon which is reliably dated by nannoplankton (the Colwell Bay Member of the Headon Hill Formation) and, as yet, there are no published magnetostratigraphical data. At this stratigraphical level, however, Hooker (1987) has been able to recognize a number of mammal zones. Whilst there is a restricted occurrence of dinoflagellates in the Solent Group, their study has contributed to attempts to determine the position of the Eocene–Oligocene boundary towards the top of the Isle of Wight succession.

Palaeogeography

At the beginning of the Palaeogene, Britain was at a latitude of 40° N, 12° S of its present position (Irving, 1967). During the early Tertiary, the Earth's climate was characterized by generally higher temperatures and higher equability of temperature than now (Wolfe, 1978). The British area was considerably warmer during the Palaeogene than at present, although from the latest early Eocene, floristic changes indicate that the climate was gradually becoming cooler (Collinson *et al.,* 1981).

Regional context

During the Upper Cretaceous, much of northwestern Europe was an area of marine carbonate deposition with a few areas emergent such as the Scandinavian massif and perhaps parts of Wales and Scotland. Signs of more general emergence appeared in the Maastrichtian and more widely in the Danian, at the end of which elastic sediments replaced the limestones which had dominated the area for the previous 40 Ma (Curry *et al.,* 1978). Such a change is thought to reflect increased erosion (both subaerial and submarine) resulting from uplift associated with ocean-floor spreading in the northern Atlantic region. The latter was associated with extensive igneous activity which reached its climax in Palaeocene times and which in the British area culminated in the early Eocene (see Knox, 1984).

At the beginning of Palaeogene times, Britain lay on the western margins of what has been called the Northwest European Tertiary Basin which extended eastwards at least as far as Poland (Sub-Group Lithostratigraphy and Maps, 1980; Vinken *et al.,* 1988). To the west of Britain lay the proto-Atlantic, with which the latter was sometimes connected via the so-called Central Channel and Western Approaches Basins (Kent, 1975, figs. IA and 1B; (Figure 2.1)). To the immediate east of Britain, lay the major North Sea Basin where a long period of Tertiary sedimentation, fed by rejuvenated source areas particularly to the north and west, ultimately gave rise to deposits in excess of 3000 m thick at their depocentre, and representing a wide variety of environments from non- or marginal marine to bathyal (Deegan and Skull, 1977).

The succession of sediments that accumulated in the Northwest European Palaeogene Basin is highly complex for, as Neal (1996) has reiterated, this basin comprises a series of sub-basins, each with its own stratigraphy. However, since they were essentially connected (Ziegler, 1990), some common factors are determinable. Neal (1996) has pointed out, for example, that all should show similar relative sea-level histories unless local tectonic uplift obscures the signal. He found that five major 'regressive/transgres-sive facies cycles' could be determined in the Palaeogene succession of the North Sea (Figure 2.5) ranging from 3 to *c.* 13 Ma in length. Of a different order, he also recognized 19 higher frequency 'sequence cycles' of 0.3 to 5 Ma duration, which control lithofacies distribution, and are correlative within biostratigraphical resolution as stratigraphical events throughout the basin and may represent a eustatic signal.

Palaeogene Britain

The contrast between the thick Palaeocene succession of the North Sea area and the relatively thin and younger strata of this age in southern England indicates that much of Britain was land during the early Palaeogene. Lovell (1977) has suggested that in this land mass, the shape of present-day Britain can be seen quite clearly. Its existence contrasts markedly with the situation in the Upper Cretaceous which was one of almost total submergence.

This land area was being actively eroded. In places, the Chalk cover had been reduced to a residuum of insoluble flints (as seen at the Tower Wood site), whilst elsewhere (e.g. the Bolter End site) evidence indicates the breaching of the Chalk and the erosion of older rocks. Provenance studies of heavy minerals indicate the active erosion of crystalline rocks, including suites from the South-West Peninsula, Scotland and Brittany. Little is known about the terrain or likely maximum altitude of such areas but considering the thick Palaeocene arenites of the North Sea succession, it seems likely that adjacent land was either of some height or being continually uplifted. However, as far as the south-west of the British area is concerned, this seems less likely. Whilst some topographical relief can be inferred from the rudaceous deposits of Blackdown and Bincombe Down, evidence from the 'continental' basins of sedimentation such of those of Bovey Tracey and Petrockstow, with their preponderance of argillaceous material, does not support the existence of a contemporaneous upland or mountain development.

What is clearly known is that in the late Palaeocene, south central and south-eastern Britain were low lying and readily inundated by transgressions from the east. Whilst the London Clay and older Palaeogene were laid down throughout this area, it is now believed that in early Eocene times, inversion of the Weald Basin (Ziegler, 1975) led to the development of a partial to complete barrier which persisted to the end of the Palaeogene (Murray *et al.,* 1989). Notwithstanding the latter, the thick development of mainly elastic Palaeogene sediments in south-eastern Britain must have been accompanied by considerable subsidence over a period of many millions of years.

These deposits are characterized by alternating transgressions and regressions, thought in the main to reflect global sea-level changes (Plint, 1983a, 1988a; Neal, 1996). The initial transgression for which evidence persists seems to have been limited to what is now the eastern end of the London Basin. Subsequent transgressions spread further westwards, some as far as the Dorset area. Some are readily proven by the presence of erosion surfaces, pebble beds and/or the occurrence of 'new' marine faunas, etc. Others may only be tentatively inferred from marginal-marine to freshwater sequences where the influence of variations in sea level produced a more ambiguous stratigraphical signature.

Those transgressions for which tangible evidence exists number in excess of 20 (Figure 2.6). The older Eocene strata (London Clay, Bracklesham Group, Barton Group) represent major transgressive periods of time involving a number of individual transgressive events. By contrast, relatively few are apparent from the younger, predominantly non-marine, Solent Group, where at only two horizons can the former presence of truly marine salinities be demonstrated.

The Palaeogene GCR sites

Altogether, 34 Palaeogene sites have been accorded GCR status as a result of their stratigraphical importance although many have also been selected independently for the GCR for other geological features.

The majority of the Palaeogene GCR Series (28) represent a variety of facies preserved in the paralic succession of the tectonic London and Hampshire Basins. Many of them are important both lithostratigaphically and chronostratigraphically and contain a variety of sediments and fossils which have facilitated palaeoenvironmental and palaeogeographical interpretation. Some, like Whitecliff Bay and Sheppey Cliffs, are of major international significance, whilst others, such as Bolter End and Wrabness, represent the best example of some special or even unique facet of the succession in some cases poorly preserved or absent elsewhere. The remaining six sites (in Dorset and Devon) represent continental developments to the west.

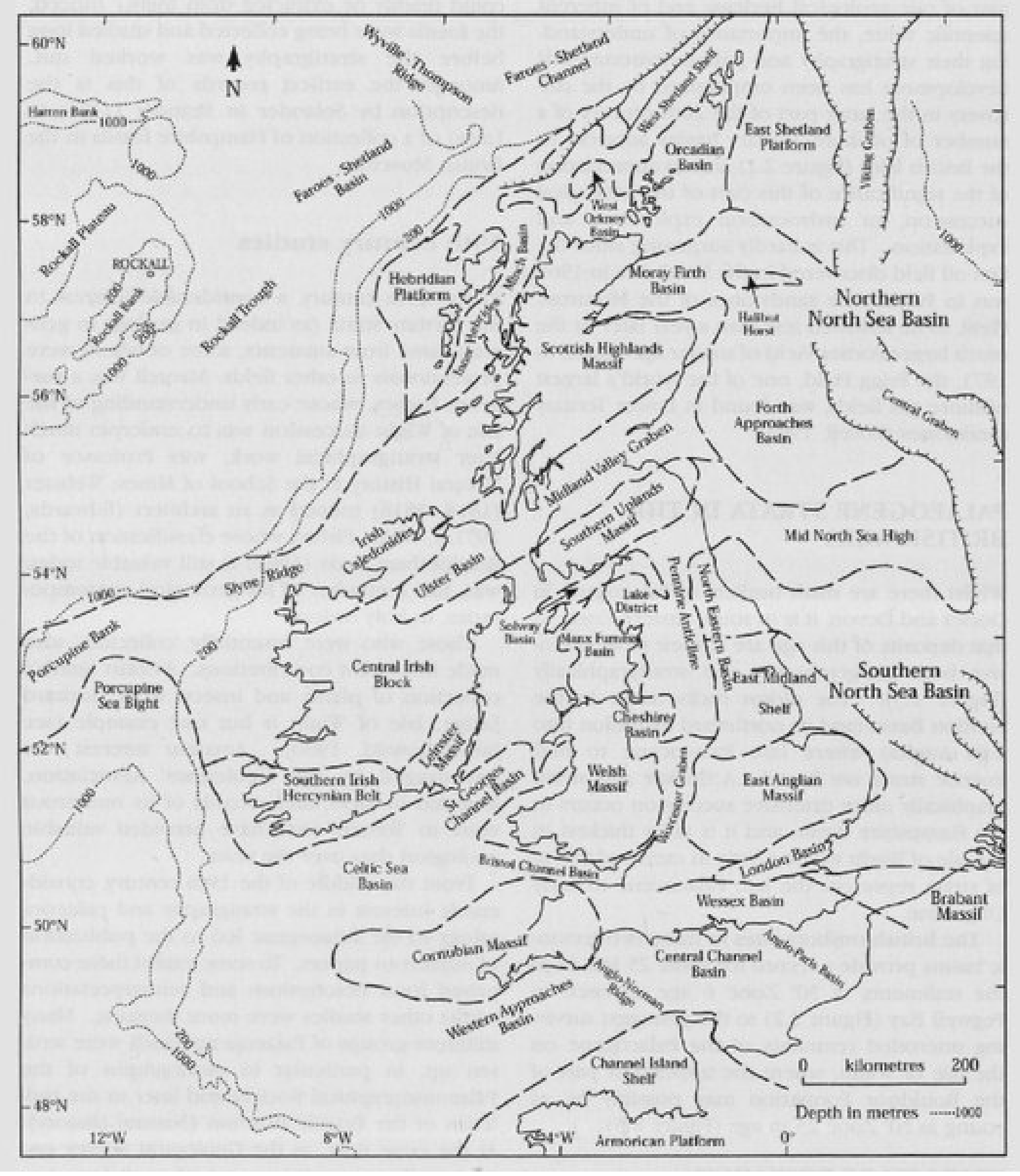
All the sites make their own particular contribution to our understanding of the Palaeogene. Early history of deposition is represented by such localities as Pegwell Bay and Herne Bay whilst Wrabness provides evidence for contemporary vulcanism, developed to a greater extent elsewhere in the North Sea Basin. Marine strata with rich and varied faunas are well seen in the sections at Whitecliff Bay and in 'Barton Cliffs', whilst Alum Bay and even more so, Bournemouth Cliffs, represent the increasing continen-tality apparent further to the west. The younger essentially regressive phase of the British Palaeogene is exemplified by the sections at Headon Hill and at Bouldnor and Hamstead on the Isle of Wight. Other localities, such as Prospect Quarry with its calcretes and terrestrial gastropod fauna, represent subaerial exposure and pedogenesis. Further west still, the outliers of Dorset and Devon give some insights into weathering, denudation, non-marine sedimentation and contemporaneous tectonism inland from the main area of sedimentation of the south-eastern British area.

Key to lithologies and structures within the graphic stratigraphical logs

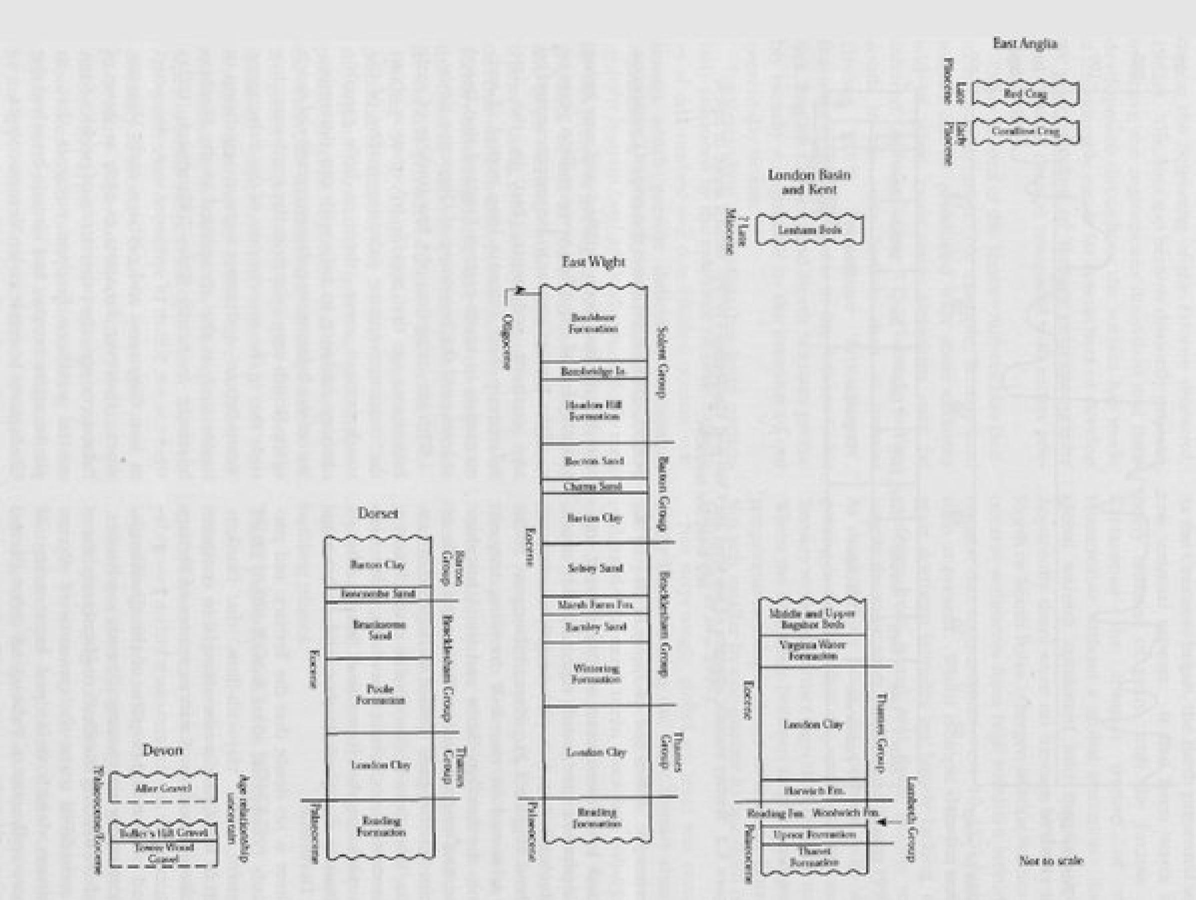
The Palaeogene chapters include stratigraphical logs compiled from the work of a number of authors. Such compilations mostly comprise three components: first, a generalized graphic lithological log, second, biostratigraphical and magnetostratigraphical information, and in some cases bed numbering/ lettering systems (to the left of the lithological log) and third lithostratigraphical information (to the right of the lithological log). The different lithologies represented graphically (Figure 2.7) are based upon a variety of data, sediment descriptions and termi nology used by different authors and are intended to convey the overall nature of each lithotype. Current lithostratigraphical terminology is given in the blocks to the right of the graphic logs, whilst earlier lithostratigraphical subdivisions/ terminology appear in the blocks to the extreme right.

It should be noted that since exposures of mainly unlithified Palaeogene rocks are subject to relatively fast rates of erosion, some variation in the character and the thickness of units exposed within a succession might be expected over time. Future examination of the sites may consequently reveal some differences from the stratigraphical successions described in this volume.

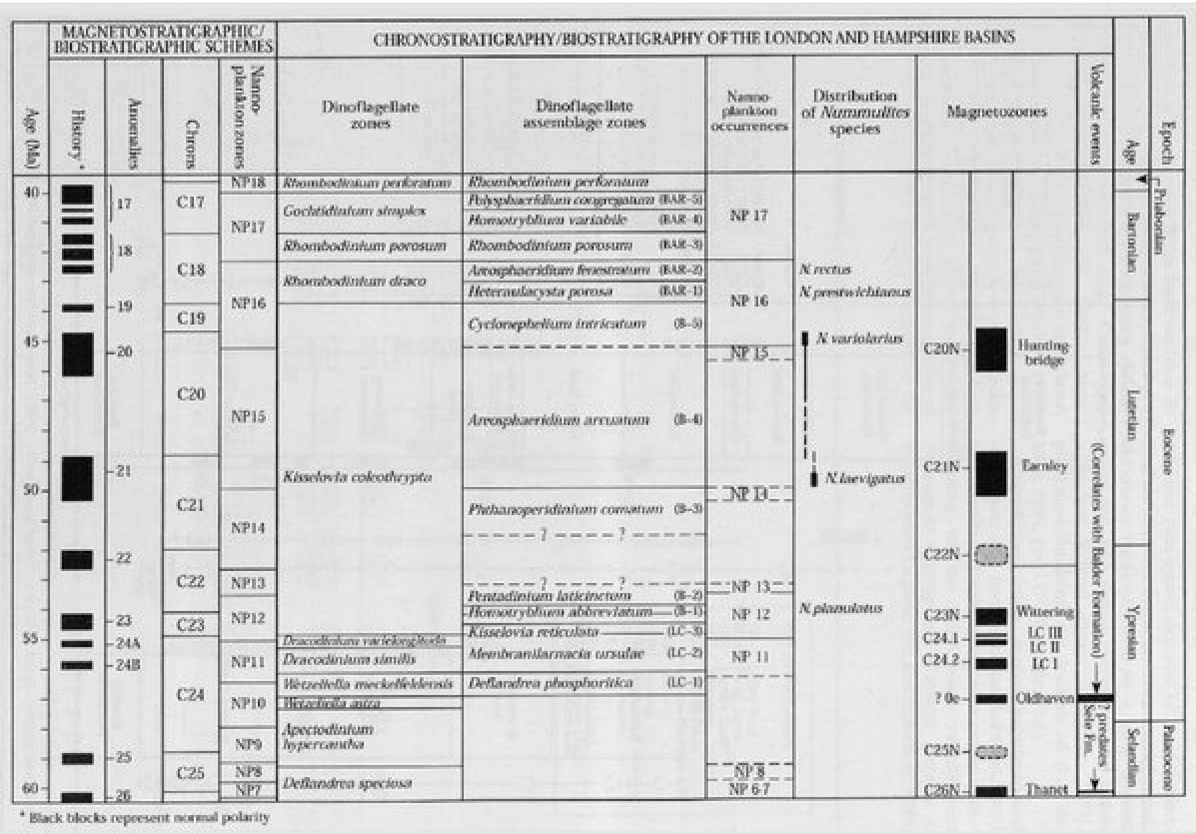
References



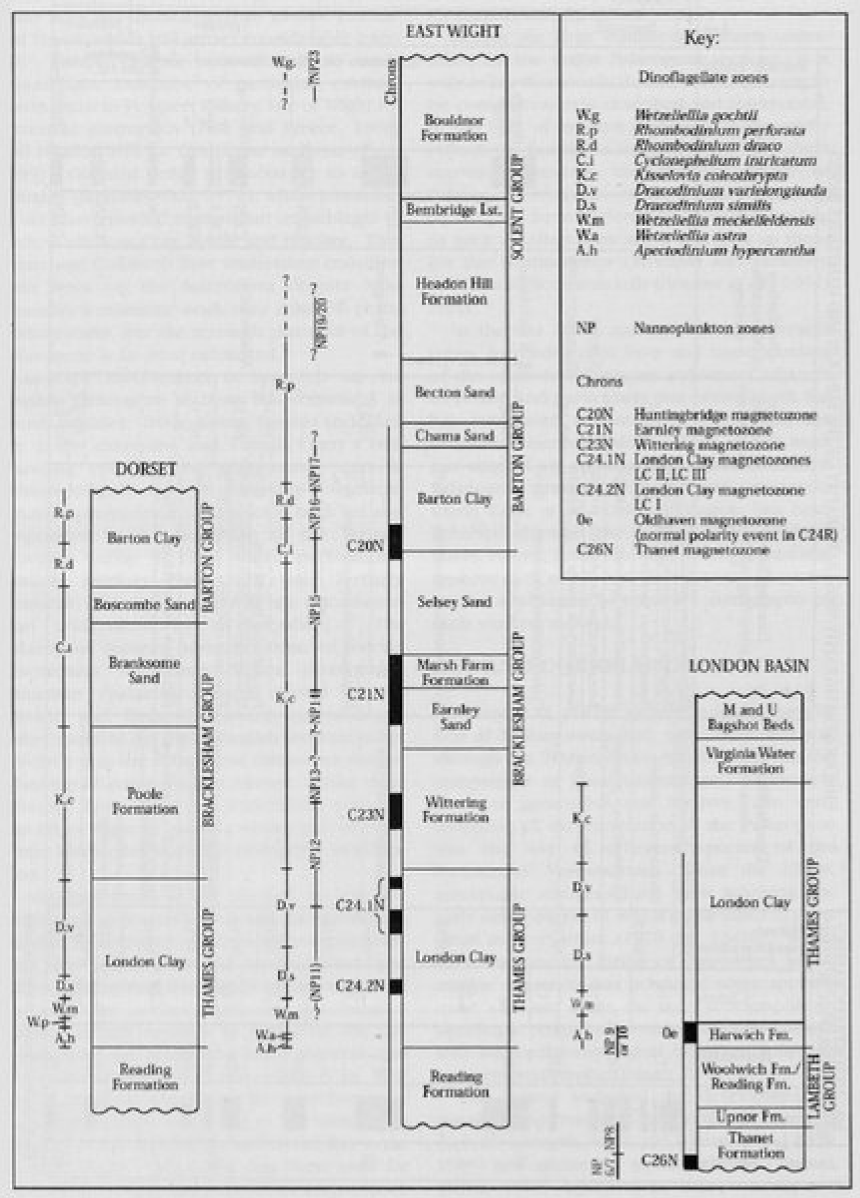
(Figure 2.1) Tertiary structural units in the British Isles region (adapted from Kent, 1975, figs 1A and 1B).



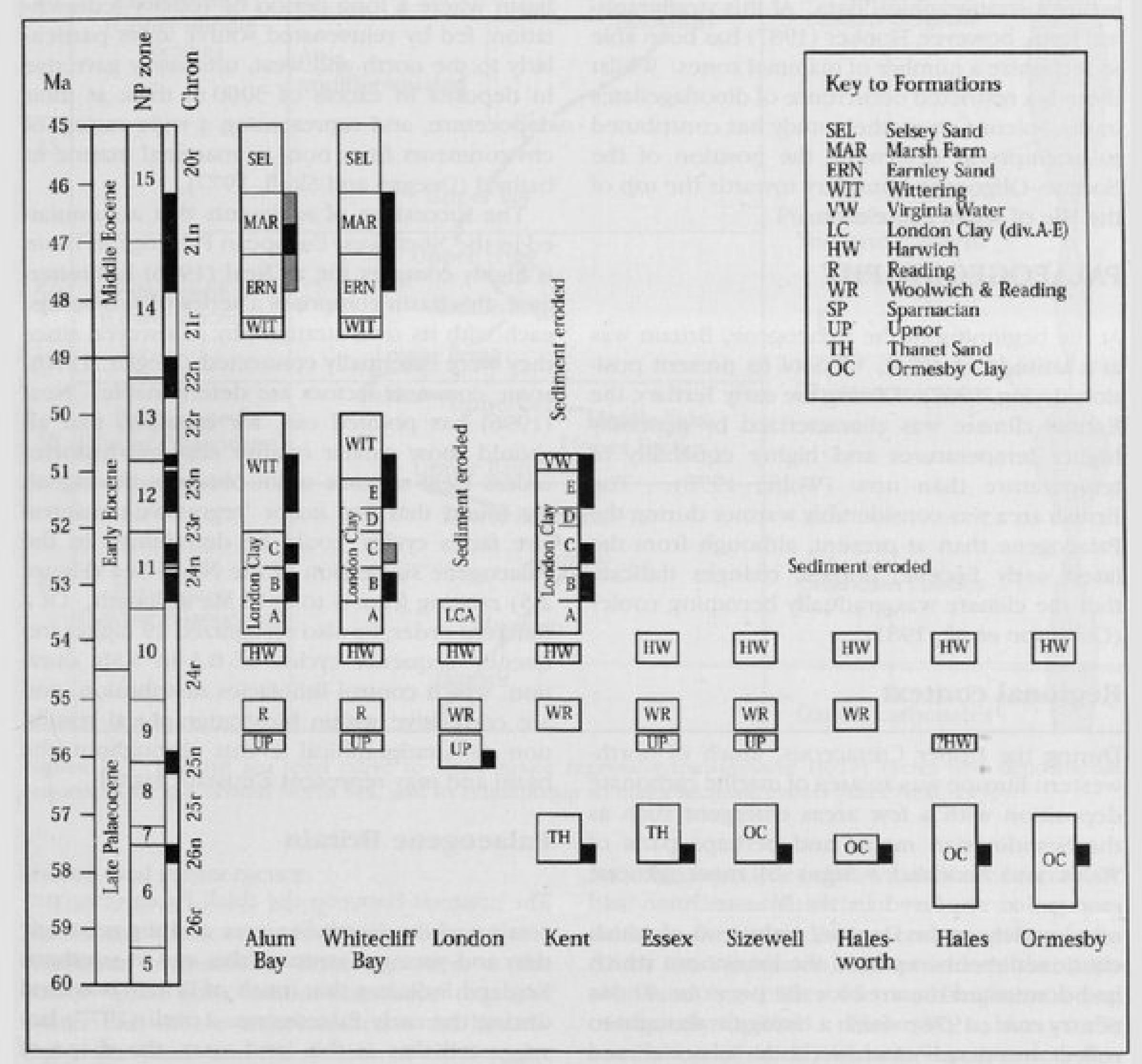
(Figure 1.3) Generalized Tertiary succession in southern and eastern England, to show major lithostratigraphical units.



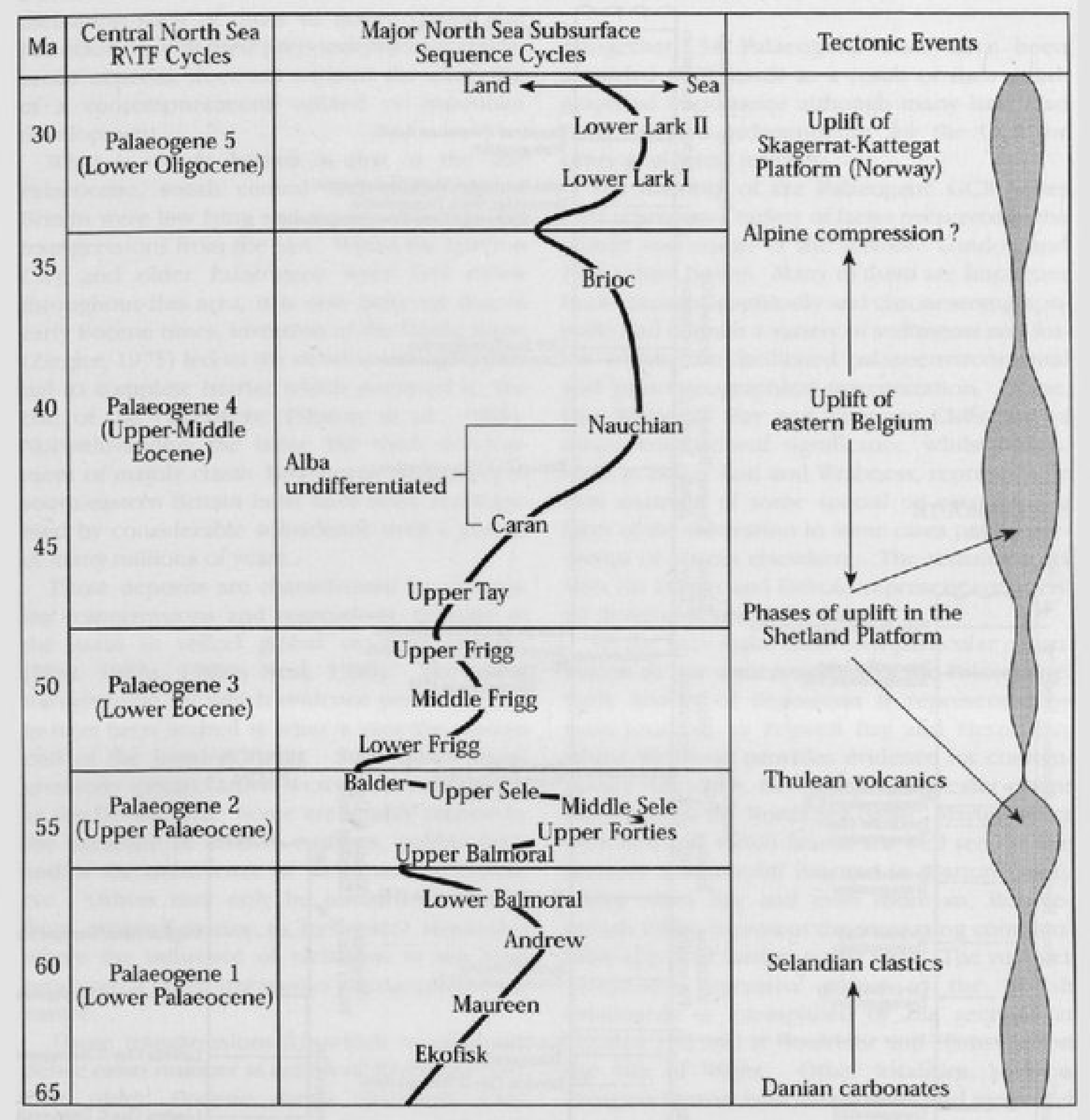
(Figure 2.2) Chronostratigraphical/biostratigraphical subdivision of the English Palaeogene succession (adapted from Aubry et al. (1986), with additional information from Bujak et al. (1980) and other authors).



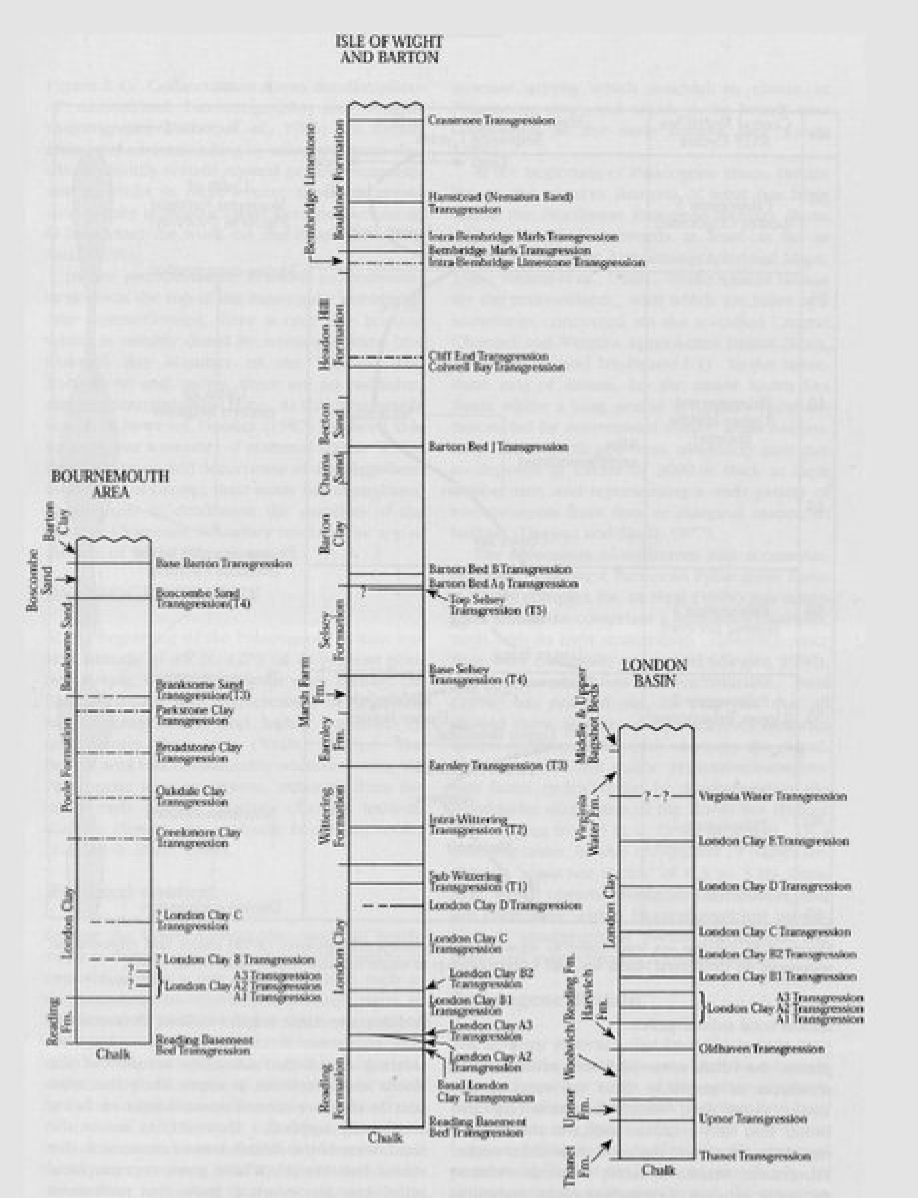
(Figure 2.3) Comparative succession of the Palaeogene strata in the Hampshire and London Basins, to show the relationship between the major lithostratigraphical units and magnetozones, nannoplankton zones and dinoflagellate zones (after various authors).



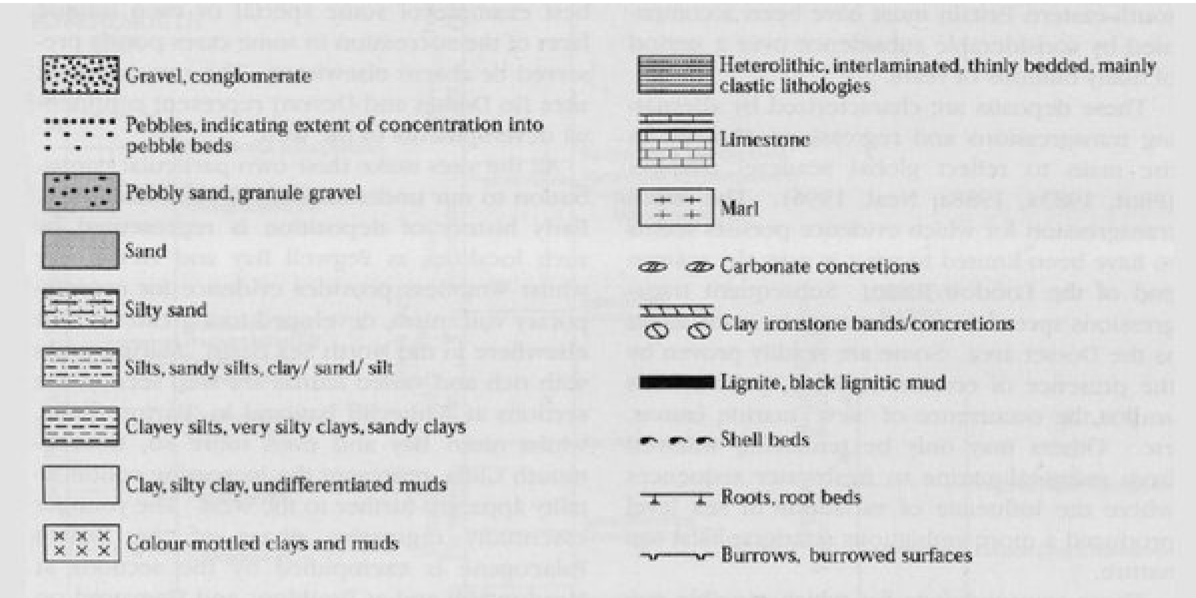
(Figure 2.4) Magnetostratigraphical correlation of Palaeocene to Middle Eocene outcrop and borehole sections in south-eastern England (after Ali and Hailwood, 1995). Black represents normal polarity. Where normal polarity zones are anticipated but have not yet been established, they are shown in grey.



(Figure 2.5) Relative sea level curve to show major regressive/transgressive (R/IT) cycles and depositional sequences for the central North Sea, and its relationship to major tectonic events (after Neal, 1996).



(Figure 2.6) Simplified representation of the relationship between transgressive events and the major Palaeogene lithostratigraphical units in southern England, based on a variety of sources. (T1) to (T5) numbering after Plint (1983a). Dot-dashed lines represent relatively minor events.



(Figure 2.7) Key to lithologies and structures within the graphic stratigraphical logs.