THE RELATIONSHIP BETWEEN SEA-LEVEL CHANGES, FACIES

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by

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ABSTRACT

New data on the Aptian and Albian sequences of the Anglo-Paris Basin has allowed a revision of their lithostratigraphy and ammonite biostratigraphy to a modern standardised format. The results are combined with a sequence stratigraphic analysis to correlate strata and determine the changes in relative sea-level. With this approach more detailed correlations are made possible than previously recognised.

As the sea-levels changed, so did the palaeogeography and lithofacies distributions. Ammonites were highly susceptible to such environmental changes and their distributions fluctuated accordingly, both vertically and laterally. Statistical methods have been utilised to examine the changes in both ammonite diversity and abundance through time. Generic/species diversity is based on all available material. Six diversity zones are recognised, three of high and three of low diversity. The boundary of each diversity zone coincides with a sea-level rise.

The abundance of families/genera is based solely on the author's collections. It was analyzed in relation to the biogeographic affinity of the taxa. This shows that there is a close link between diversity and abundance, both related to changes in sea-level. There were two main periods when endemic and heteromorph ammonites were abundant, the first corresponding to the Deshayesitid and lower part of the Cheloniceratinid diversity zones, the second peaked in the Hoplitid Diversity Zone.

The ammonite distributions are used as a tool for determining the relative importance of the various transgressions across the basin. Of the 23 transgressive surfaces recognised, 11 are marked by important faunal turnovers.

A combination of all the data is used to propose a revised sea-level curve for the Aptian-Albian in the Anglo-Paris Basin.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The Cretaceous period lasted for c.81 Ma, during which the climates were considered to be less extreme than at present. The pole to equator temperature gradient would have been less than it is today and the main barriers to faunal and floral migrations are more likely to have been physical and oceanographical than climatic.

On a global scale the Ammonoidea show a biogeographic division into two realms during the Early Cretaceous. The Boreal Realm occupied the northern part of the northern hemisphere, while the Tethyan Realm covered the rest of the World. This division was particularly marked in pre-Aptian times but became less sharp subsequently (Rawson 1981). During the Neocomian, an extensive continental region separated the shelf seas of north-west Europe from the deeper, warmer waters of Tethys. Links between the two areas were via narrow sea-ways. The strongest link with the Tethyan Realm was the Polish Furrow, which provided a migration pathway from the Carpathians, through the German Lower Saxony Basin, into the North Sea Basin. This closed in response to falling sea-levels early in the Barremian and probably only re-opened during the Albian.

This study considers the distribution of Aptian and Albian ammonites in the Anglo-Paris Basin in relation to facies and sea-level changes. It compliments work by Rawson (1981; 1993; *in press a*) on the distribution of Neocomian ammonites in north-western Europe, and aims to help complete the picture of Lower Cretaceous distribution patterns. The taxonomies of the Aptian and Albian ammonites are well-established, and this is why it is an ideal period for which to investigate their distribution. A necessary pre-requisite for this work is a critical re-evaluation of the lithostratigraphy, biostratigraphy and sequence stratigraphy of the basin (Table 1.1).

The Aptian and Albian was a period of generally rising sea-levels. The result was to introduce a thick succession of marine strata into the Anglo-Paris Basin (Lower Greensand Group, Gault and Upper Greensand Formations), these succeeding the predominantly non-marine beds of the Wealden Group of the earlier Cretaceous. The Aptian-Albian was essentially a period of transition towards the great Chalk seas of Late Cretaceous times, and a time in which endemicity in the ammonite faunas was progressively reduced with the destruction of physical and palaeoceanographical barriers.

SYSTEM	SERIES	STAGE		SUBSTAGE	ZONES	SUBZONES	LITHO- STRATIGRAPHY		
		MAASTRICH TIAN					GAULT FORMATION FORMATION		
		CAMPANIAN		UPPER	dispar	perinflata fallax			
					inflatum	inflatum varicosum			
		SANTONIAN CONIACIAN				orbignyi cristatum			
	ЬЪ			MIDDLE	lautus	daviesi nitidus			
\mathcal{O}	ſŊ				loricatus	subdelaruei niobe			
D					dentatus	intermedius dentatus			
Q		IURUMIAN				lyelli steinmanni			
H		CENOMANIAN		LOWER	mammillatum	puzosianus raulinianus			
TAC	LOWER	ALBIAN				floridum kitchini			
					tardefurcata	regularis farnhamensis			
Ê		APTIAN		UPPER	jacobi	anglicus nolani	que		
CR					nutfieldiensis	cunningtoni subarcticum	GR(
0		BARREMIAN			martinioides	gracile debile	AND		
					furcata	meyendorffi transitoria	ENS		
		HAUTERIVIAN			deshayesi	grandis deshayesi	GRI		
		VALANGINIAN				LOWER	forbesi	callidiscus kiliani fittoni	LOWER
					fissicostatus	obsoletus fissicostatus	Ι		
		BERRIASIAN							

Table 1.1. The Cretaceous System. The Aptian-Albian substages, zones, subzones and lithostratigraphy in the Anglo-Paris Basin are highlighted.

1.2 PREVIOUS WORK

The most important stages in the development of our understanding of the geology of the Anglo-Paris Basin are described in this section, whilst more detailed discussions are included where necessary in subsequent chapters.

Strata of Aptian-Albian age crop out in both SE England and northern France (see Figure 2.1). Initial investigations of the successions began in the early nineteenth century. The marine strata that were found between the non-marine Wealden beds and the geographically widespread Chalk were the cause of much controversy in these early studies, but by the end of the century detailed accounts of the lithostratigraphy and an early biostratigraphy had been published (Leymerie 1841-1842; Fitton 1847, Price 1874; 1875).

Work on the predominantly arenaceous Lower Greensand Group of southern England, immediately above the Wealden beds, concentrated mainly on the Isle of Wight (Fitton 1823; 1836; 1847). Here, the entire succession was accessible in cliff sections and ammonites were relatively abundant. However, in quarries in the Weald, ammonites were far more difficult to find, and a detailed zonation was long in the waiting. Because of the impoverished, poorly known ammonite fauna, descriptions of the stratigraphy in the Weald Basin appeared only spasmodically. The Weald Research Committee was formed to further the development of study, and produced numerous articles in the Proceedings of the Geologists Association, while British Geological Survey sheet memoirs were filled with detailed accounts. Slowly a biozonation of the Lower Greensand Group evolved, through the work of Spath and others. It was not, however, until the early 1960's that the synthesis of this research appeared, with the almost simultaneous publication of Casey's Stratigraphical Palaeontology of the Lower Greensand (1961) and the first part of his monograph (1960). The work of Casey (1961) was based upon twenty-five years of research, and the successive parts of his monograph (Parts II to IX) were published in the twenty years that followed; the final part is currently in progress, stimulated by the collection of Martin Simpson on the Isle of Wight made over the last ten years.

The equivalent stratigraphic levels in the Paris Basin are frequently more condensed and poorly exposed than their counterparts in southern England. Leymerie (1841-1842) described a succession of clays in the southern part of the Paris Basin that were equivalent to the lower part of the Lower Greensand Group, but higher beds are absent from this area. A discontinuous succession was also described from the Boulonnais, in the northern Paris Basin (Rigaux 1903; Briquet 1903; 1906; Dutertre 1923; 1925; 1936; 1938), and these beds were correlated with the formations of the Lower Greensand Group by Amedro & Mania (1976).

Studies in the argillaceous Gault Formation commenced at a similar time to those of the underlying Lower Greensand Group both in England and France. The type section of the Albian was described first by d'Orbigny (1842), although never formally defined by him. Most of the succeeding accounts have used the Aube as the type section (e.g. Sornay 1957; Larcher *et al.* 1965), and more recently Rat *et al.* (1979) suggested that the stratotype specifically lies at Saint-Florentin (Yonne). Spath worked predominantly on the ammonites of the Gault, and by 1923 work on his monograph had commenced. It was thanks to the finely preserved ammonite fauna that work could proceed so rapidly. Many of the findings in Spath's monograph still hold today because the endemic fauna was composed of a rapidly evolving lineage whose roots could be traced in the Anglo-Paris Basin. As more and more quarries were opened up within the Gault Formation, stratigraphical discussions were concerned with tightening up of the zonation and

finer subdivision of the beds.

The current biostratigraphical framework used by British stratigraphers is based primarily on the work of Casey (1961), Spath (1943) and Owen (1971; 1976; 1988a; 1988b), and is summarised in Hancock (1991). However, a different biostratigraphical scale has been adopted by French workers following work in the Paris Basin by Destombes (1970) and Amedro (1980). Not only are the latter scales used by the French biostratigraphers, but they have been used in the compilation of eustatic sea-level charts by researchers at Exxon (Haq *et al.* 1988).

A surge of interest regarding the changes of global sea-level resulted from the publication of the now famous *American Association of Petroleum Geologists Memoir 26*, **Seismic Stratigraphy** (Payton 1977). The origin of seismic stratigraphy was based upon the principles determined at outcrop by Sloss (1963). It was to be the start of a wave of research that swept through the 1980's and continues today. The concept of seismic stratigraphy was used to produce curves that supposedly predict global (eustatic) sea-level changes by changes in coastal onlap, and these are represented by chronostratigraphical surfaces on seismic profiles. The early papers on seismic stratigraphic analysis provoked numerous reviews and refinements of the technique.

After the large-scale seismic investigations, that only could be afforded by large industrial organisations, smaller-scale studies were engaged to test the principles over shorter distances. A return to the original methods of outcrop study provided a whole new terminology and a means by which the ideas could be tested by academic workers. A combination of the outcrop, seismic and well-log analyses was produced to give a detailed picture of sequence stratigraphy, with a revised sea-level curve, in *SEPM, Special Publication 42* (Wilgus *et al.* 1988).

The revolution in stratigraphical studies that came from sequence stratigraphy provided the impetus for renewed studies in the Anglo-Paris Basin. These investigations have extended from very limited areas of the Wessex Basin (e.g. Hesselbo *et al.* 1990b), through the entire basin (Ruffell and Wach 1990; Ruffell 1992a) to the whole of north-western Europe (Ruffell 1991).

The natural progression from the sedimentological studies was then to examine the effects of the proposed sea-level changes on the marine biota. Cooper (1977) reviewed the distribution of Cretaceous ammonites and found a broad link between these and sea-level changes. Owen (1973; 1979; 1988b) recognised various provinces in the Albian, and that at certain horizons mixing between the realms became apparent. Rawson (1973; 1981; 1993; *in press a*) has reviewed the distributions of pre-Aptian ammonites, and within these studies has found close correlation

between sea-level changes and ammonite distributions. Typically, endemism is considered to be greatest during the sea-level lowstands, whilst increased diversity and faunal mixing occur as the level of the seas are raised, although the inverse situation was given by Cooper (1977).

More recently, the magnitudes of faunal changes have been considered. House (1989; 1993) and Becker (1993) have plotted global ammonoid diversities, and revealed a link between the number of taxa and the Exxon sea-level curve (Haq. *et al.* 1987; 1988). Bulot (1993) discussed horizons at which faunal mixing occurred, which have been quantified and related to times of maximum flooding.

At a late stage in the writing of the thesis, I became aware of a newly published work that paralleled my own, this being L'Albien du Bassin Anglo-Parisien: Ammonites, zonation phylétique, séquences [The Albian in the Anglo-Paris Basin: Ammonites, phyletic zonation and sequences] (Amedro 1992). This work used many of the localities that I have done and some of the conclusions that I had arrived at are duplicated in the paper. However, this study examines ammonite distributions in far more detail than Amedro and different approaches are used. Despite the similarities of a few of the more interesting results, all the data referred to here is my own or that which has been acquired from the investigation of museum or private collections.

1.3 EXISTING PROBLEMS

The Lower Greensand Group comprises a very variable succession of strata, both vertically and laterally. The result of this variability has been the introduction of a very mixed and inconsistent terminology for the strata. The facies of the Gault Formation are more laterally continuous and fewer problems have been encountered in its nomenclature. However, difficulties have continually persisted regarding the definition of the base of the formation. The boundary between the Lower Greensand Group and Gault Formation has been shifted from bed to bed since the earliest description of the clays at Folkestone by De Rance (1868) until the most recent investigations by Owen (1992).

Casey's (1961) biostratigraphical framework for the Lower Greensand Group has seen no change in its lower part since its original publication, but numerous modifications to its upper part. Ammonites are relatively uncommon in the Lower Greensand Group, and Casey spent many years determining distributions in successions that are now obscured. However, the coastal succession on the Isle of Wight is still as clear as when Casey was collecting, and it is here that the strata are most fossiliferous. When the biostratigraphy is tested here, it becomes apparent that some of the zones and subzones defined by Casey are not firmly based. In parts of the succession, the framework is based upon a very small recovery from very limited geographical areas. The Gault Formation is far more fossiliferous than the Lower Greensand Group and much of the zonation proposed by Spath (1943) still stands. However, particularly in the condensed beds at the Lower Greensand Group to Gault Formation junction, some modifications are required.

The position of the Anglo-Paris Basin on the shelf means that the stratal expression of the sequence stratigraphy differs from that proposed in most sequence stratigraphic models, and high frequency sea-level events ("parasequences") are well-displayed. The sedimentological and facies analyses in the Anglo-Paris Basin have determined a large number of sea-level events, but the actual sea-level curve differs from author to author.

1.4 AIMS AND METHODOLOGY

1.4.1 AIMS

Taking into account the problems that exist in the stratigraphical interpretation of the Aptian and Albian, this thesis aims to:

(i) Review, and update into a modern framework, the lithostratigraphy of the Anglo-Paris Basin.

(ii) Define fully a biostratigraphic scale that is applicable throughout the Anglo-Paris Basin and, where possible, aids interprovincial links. It is desirable to retain traditional biostratigraphic divisions wherever these remain relevant.

(iii) Accurately correlate the strata and sea-level events across the basin.

(iv) Examine ammonite distributions, both vertically for individual sections and laterally across the basin to establish:

a) how these may change in relationship to the proposed sea-level events.

b) the extent to which facies controlled the distribution and evolution of ammonites.

(iv) Combine all the data to establish whether the faunal distributions are related to environmental changes that may have occurred as a result of fluctuating sea-levels. Varying ammonite distributions may reveal that different scales of sea-level change occurred, some of which may not be immediately apparent simply from the sedimentary record. This thesis aims to present an updated sea-level curve for the basin by synthesising lithostratigraphic, biostratigraphic, sequence stratigraphic and biogeographic principals.

1.4.2 METHODOLOGY

The primary data have been collected from the field examination of numerous localities. Different weight has been put upon the sections examined, depending most predominantly on the yield (or likely yield) of ammonites. The known fossiliferous localities have been logged and collected from. Compilation of the field data and examination of the literature has allowed a detailed stratigraphy of each locality to be built up. This has provided the basis for a basin-wide review of the lithostratigraphy.

The biostratigraphy is based primarily upon the observations of Casey and Spath, but some more recent developments are included. At localities where the range of ammonites has been established, either through field observation or from published accounts, some problems have been encountered with the present biozonation. A proposal for a workable biostratigraphy has been developed from the available data.

Sea-level changes are examined using the concept of sequence stratigraphy. For the purpose of this study, sedimentary cycles are assumed to be generated by changes in relative sea-level, although an alternative explanation may be given in terms of changes in sediment supply. It is also assumed that erosion surfaces are generated as a result of shallowing. Accurate chronostratigraphical dating of the "sequences" can be achieved from the biostratigraphy.

At all localities yielding ammonites **all** specimens were recorded, no matter how fragmentary or poorly preserved. A total of 5589 specimens have been recorded, of which 3292 were brought back to the laboratory. The remainder were identified in the field.

The ammonite data collected from the field, together with that from published accounts, were fed into a computer database (Ashton-Tate Dbase IV). The locality, region, subzone, member and the lithofacies was entered for each of the taxonomic ranks. For different parts of the study, different variables are required, and any combination is available.

The ammonite distributions are studied in a number of ways, and in each of these investigations, the database is manipulated accordingly (Fig. 1.1). Once the relevant information has been



Figure 1.1. Flow chart to show the use of the computer database to examine ammonite distributions.

gathered, it is transferred into a spreadsheet for calculations and plotting (Microsoft Excel 4.0). The distribution studies fall into two major areas; the first uses all known records, whilst the second uses data from the author's field collection alone.

(i) Diversity Analysis

To examine ammonite diversities all known records are used. The number of genera, the extinctions and radiations, and net diversity change are plotted for each subzone. Specific data concerning the distribution of individual genera are used to establish their range and determine biological events. Localised changes in diversity are examined by determining the number of species per genus at each individual locality, along with the facies and the biogeographical affinity of each of the genera.

(ii) Abundance spectra

Magnitudes of faunal changes are examined by plotting relative abundances of ammonite families and genera. Not all stratigraphic levels permit this form of analysis to be performed, for they have not yielded a sufficient quantity of ammonites.

The number of individuals within a family for a specified region are plotted for each subzone; this shows changes in the faunal spectra through individual vertical successions. Lateral changes of abundance spectra are shown by plotting the number of specimens for each genus at localities from which a statistically viable quantity of ammonites has been collected.

CHAPTER 2 THE GEOLOGICAL SETTING OF THE ANGLO-PARIS BASIN

The outcrop of the Aptian and Albian in the Anglo-Paris Basin is shown on Figure 2.1. Even if the effects of erosion are considered, it seems likely that this reflects approximately the extent of the basin, which was orientated along a NW-SE axis. Links with the North Sea Basin were achieved through the temporarily open Bedfordshire Straits, skirting the Anglo-Brabant Massif, whilst a southern connection to Tethys existed through the Bourgogne Straits.

2.1 TECTONIC SETTING

The structural development of the basin was along Variscan lines. Rift faulting in the North Sea area terminated in Early Aptian times and was followed by slow subsidence (Kent 1976; Chadwick 1986; 1989a; 1989b. Eyers 1991; Ruffell 1992a). The sediments that resulted from this phase of thermal relaxation show a gradual onlap against earlier Mesozoic and Palaeozoic structural highs. The structural features have a general east-west trend in southern England, but shift towards a north-south orientation through the Paris Basin, giving the impression of being concentrically arranged around the Cherburg Peninsula (Stoneley 1982). These features played a major role during the Aptian when the seas were shallow; small-scale fault action and low relief highs could profoundly influence the sedimentation. The downthrown sides of faults are characterised by thick sedimentation, whilst other areas are represented by a thin sedimentary layer, or underwent active erosion. The structural highs delineated the basin and caused different facies associations to be developed in various sub-basins (Fig. 2.1).

Southern England occupied a region known as the Wessex Basin, and this is further sub-divided into the Channel and Weald Basins. The Portsdown Swell, which at times was a positive feature, separated the Weald from the Channel Basin, across which the Lower Greensand Group sediments are strongly attenuated. Boundary faults surround the northern margin of the Weald Basin, and formed upstanding regions during the Early Cretaceous.

The Paris Basin was a large sedimentary basin that was bounded by the Brabant Landmass to the north-east and Amorican Platform to the west. It extended from the northern part of the Boulonnais, through a sweeping arc into the Aube, south of Paris, and back up into Normandy. Past investigations have proved a thick succession of clay at the base of the Aptian in central parts of the basin, the 'Argiles à Plicatules', which correlates in part with the clays of the





Wessex Basin. However, the present day outcrop of the Aptian in the Paris Basin is limited to a few temporary exposures in the Boulonnais (Amedro & Mania 1976). In the Aube, there is little known about the Aptian, which may be largely absent in this region to the south of the Bray-Vittel Fault. This fault also played a significant role in the Early Albian; the sediments that developed to the south of the fault are generally within a clay facies, whilst those to the north are considerably more arenaceous. Although the argillaceous Lower Albian facies has been proved from boreholes, and micropalaeontological studies, there is little remaining outcrop on which to base a macrofaunal investigation (Amedro 1992).

2.2 PALAEOGEOGRAPHY

During the Barremian, much of north-west Europe was occupied by land. A narrow deep marine connection between the Shetland Platform and Norway linked the north-west European seas with Svalbard and east Greenland, and at intervals with the Arctic Ocean. Another important deepwater connection linked the North Sea to the proto-Atlantic Ocean along the Rockall Trough-Faroe Rift (Ziegler 1982). In contrast, most of the Anglo-Paris Basin was characterised by non-marine deposition that occurred mainly within ephemeral lakes. The sediments are predominantly argillaceous. In southern England they show an increasing marine influence in their upper part, representing marine spillovers from the East Midlands Shelf, at the margin of the southern North Sea Basin. The topmost Vectis Formation (Isle of Wight) consists of quasi-marine shales in which periods of marine spillover are represented by bivalve shell plasters. Rare belemnites are also recorded in these beds at Redcliff (Rawson *in prep.*). The southern part of the Paris Basin is characterised by marine sediments in the early part of the Barremian, but these may be replaced by non-marine beds towards the top of the stage. This marine spillover came from the Jura.

The earliest part of the Aptian has no representation in the Anglo-Paris Basin, but occurs in the North Sea Basin. An important remanié fauna of earliest Aptian age also occurs in the Bedfordshire Straits. The first important Early Aptian transgression was in the *obsoletus* Subzone, one subzone above the base of the stage. This event saw the commencement of fully-marine deposition across large areas of the Anglo-Paris Basin for the first time since the Jurassic (Fig. 2.2A). A temporary link with the East Midlands Shelf was created via the Bedfordshire Straits. A shallow-water connection with the proto-Atlantic Ocean may also have opened along the line of the present day English Channel (Tyson & Funnell 1987; Evans 1990; Rawson 1992a). Transgressions through the Aptian and Albian increased the width of this sea-way as more and more of the Cornubian Platform was engulfed. This shallow connection is not shown

on any of Owen's (1979; 1988a) palaeogeographic reconstructions of the Albian.

The onset of the Austrian Tectonic phase closed the Bedfordshire Straits again (Fig. 2.2B), and the Anglo-Brabant Massif provided the northern limit of Lower Greensand Group deposition (Rawson 1992a). Movements along Austrian lines produced a fall in sea-level throughout Europe and the development of the widespread mid-Aptian unconformity across the Anglo-Paris Basin. In many areas this gap spans almost the entire *martinioides* Zone, which may be entirely missing or partially represented in remanié at the base of the *nutfieldiensis* Zone. Sediments spanning this gap are found only on the Isle of Wight and in western parts of Kent.

A renewed transgression, following the mid-Aptian break, saw a rapid increase in the depositional area (Fig. 2.2C). The Bedfordshire Straits now formed a permanent link with the East Midlands Shelf. This transgression also caused the overspill of waters westwards of the main Weald Basin. Several isolated outliers of *nutfieldiensis* Zone age rest unconformably on eroded Kimmeridgian, or older, strata and are believed to represent small embayments at the margins of the depositional area (Casey 1961; Hesselbo *et al.* 1990a; Ruffell & Wignall 1990). The *nutfieldiensis* Zone was a time of significant volcanic activity, demonstrated by the large thickness of smectite in the fuller's earths of Woburn and Surrey. These volcanics, and the intrusion of basalt to the west of Great Britain, are related to sea-floor spreading that commenced in the Bay of Biscay region (Rawson 1992a).

Tectonic activity in the middle part of the Early Albian led to development of a widespread unconformity in the *tardefurcata* Zone (Casey 1961). An eastward tilt of the Anglo-Paris Basin is indicated by the establishment of links between this area and northern Germany (Owen 1979). This rocking of the basin was then followed by the gradual westward retreat of the shorelines as the sea-level rose. A generally transgressive phase continued into the *mammillatum* Zone, although it is punctuated by several regressive episodes (Fig. 2.2D).

Continuation of the transgression through the Mid Albian led to the dramatic retreat of the landmasses through the later Albian (Fig. 2.2E & F). The Middle and Upper Albian Gault Formation clay facies extends across the Anglo-Paris Basin, northward into East Anglia. As the sea-levels increased, swell regions were overstepped and the northern margin of the basin became less clearly defined as a laterally continuous argillaceous facies developed through

Figure 2.2. Palaeogeography and lithofacies maps for selected intervals of the Aptian and Albian. All are modified from Tyson & Funnell (1987) and Rawson (1992a).



Cambridgeshire and East Anglia to link with the southern North Sea Basin. Thus a north-west European Mid and Late Albian epicontinental sea extended from south-east England across the North Sea, Denmark, northern Germany, Poland and into Russia. The Wessex Basin also extended its area westward to link up with the Western Approaches Trough (Tyson & Funnell 1987). The extent of sea varied with the occurrence of regional transgressions and regressions, which also affected the marine connections with other areas. Owen (1971; 1976) documented an expansion of the area of marine deposition at the start of the Mid Albian; the transgression reached its maximum extent in the *intermedius* Subzone. The end of the Mid Albian was marked by a short, but widespread, period of regression. The associated erosion led to the removal of the uppermost Middle Albian sediments from much of north-west Europe. The widespread regression has been linked with the onset of sea-floor spreading in the Rockall Trough (Roberts 1975). A further transgression in the *cristatum* Subzone re-established links with the Tethys - proto-Atlantic through the Polish Furrow, and the Bay of Biscay and Rockall Trough (Ziegler 1982).

2.3 FAUNAL PROVINCES

Pre-Aptian ammonites in north-western Europe were restricted in their distribution. The presence of physical barriers to their migration allowed a separate Boreal fauna to establish itself in northern parts of Europe, whilst different taxa evolved in Tethys to the south. The appearances of the latter forms in northern Europe were restricted mainly to periods of high sea-level. Barremian taxa appear to have been endemic until a very late Barremian rise in sea-level allowed some Tethyan immigrants to enter the North Sea Basin and evolve here (Rawson *in press b*). The early Aptian restoration of marine conditions in the Anglo-Paris Basin brought *Prodeshayesites* to the region from the North Sea area.

During Aptian-Albian times, the Anglo-Paris Basin lay within the shelf area of the North European Province (Fig. 2.3). This was at the northern margin of the European Region (Tethyan Realm), and it was characterised by ammonites of widespread geographical distribution (Rawson 1981). The centre of dispersal of many of the ammonite taxa seems to have lain in the South American area, and these were brought into the European Region with the prevailing west to east current systems (Casey 1961; Wiedmann 1988; Barron & Peterson 1989). At times the shelf area of NW Europe became isolated from the Mediterranean Province to the south, and it was characterised by endemic developments of taxa. A different ammonite fauna developed in the deeper waters of the Mediterranean Province which spread northward to the Anglo-Paris Basin at intervals of high sea-level.



Figure 2.3. Late Albian plate reconstruction, palaeogeography, faunal provinces and migration routes. (Modified from Wiedmann 1988).

Lower Aptian deposits are characterised by deshayesitid ammonite faunas, which extended across the north-west European area (Fig. 2.4A). These ammonites remained geographically restricted through the early part of their range, but gradually extended southwards in the Late Aptian. Late forms of the family persisted until the Early Albian further south. After the disappearance of the deshayesitids, the Anglo-Paris Basin was characterised by an impoverished ammonite fauna that

was of widespread geographic distribution.

In the early *tardefurcata* Zone, leymeriellinid ammonites developed in northern Germany and were restricted to this area during the earliest part of the Early Albian. A shallow-water region separated the North Sea from the Anglo-Paris Basin and prevented this group of ammonites spreading from the east into the basin, but did allow geographically widespread forms of *Hypacanthoplites* to intermingle (Owen 1988a). Species of *Leymeriella* did, however, spread into the Mediterranean regions. The 'mid-*tardefurcata* Zone tectonics' provided a stronger connection between the North Sea and Anglo-Paris Basin, and the eastward extension of the leymeriellinid ammonites. The transgression that saw the spread of *Leymeriella* also allowed the hoplitid ammonites to enter and develop in north-western Europe (Fig. 2.4B).

Regression at the top of the *regularis* Subzone led to the disappearance of *Leymeriella* before the start of the *mammillatum* Zone, but the hoplitids persisted, and were joined by a distinctive cosmopolitan element. The leymeriellinid stock may have remained in the Mediterranean region, and provided the root of the brancoceratids. By the Mid Albian, the hoplitinid ammonites characterised the whole of northern Europe, extending from the Anglo-Paris Basin across to Russia (Fig. 2.3C) (Owen 1971; 1973; 1976; 1979). The brancoceratids evolved separately in the southern European area during this time. Links with the Arctic north of Spitsbergen and east Greenland were only documented for the *dentatus* Zone (Owen 1979). Although marine connections with the Mediterranean Province are inferred, southern faunas tended only to migrate into the Anglo-Paris Basin at discrete intervals, whilst the hoplitinids were virtually restricted to the north European area.

Renewed transgression at the beginning of the Late Albian allowed the Arctic-North American genus *Gastroplites* to co-exist with the typical hoplitids in Spitsbergen, east Greenland, and very rarely in southern England. At the same time, in the *cristatum* Subzone, Tethyan ammonites entered the Anglo-Paris Basin from the south. These forms stayed in the north-west European region throughout the Late Albian. The hoplitinid ammonites still persisted in northern Europe, whilst these forms remained a great rarity in the Mediterranean Province.

The broader biogeographical affinities of these faunas are discussed in Chapter 7.



Figure 2.4. Palaeogeography and ammonite distributions in the North European and Mediterranean Provinces of the European Region.
CHAPTER 3 THE LOWER GREENSAND GROUP

3.1 INTRODUCTION

The Anglo-Paris Basin occupied a shallow-shelf area during the deposition of the Lower Greensand Group. The sedimentary records in the various sub-basins show rapid changes of facies and thickness. The different lithologies that developed in the sub-basins are discussed in this chapter, facies changes are recognised and the units are placed into a modern lithostratigraphical hierarchy.

3.1.1 Lithostratigraphical nomenclature

Modern lithostratigraphical practice includes a formalised procedure for naming and defining lithological units (e.g. Hedberg 1976; Holland *et al.* 1978; Whittaker *et al.* 1991). The guidelines suggest that each lithological unit should be given a geographical epithet. However, the British guides in particular recognise the need to retain as far as possible the old names for well-known units for the sake of continuity, recasting them as appropriate into a modern lithostratigraphical hierarchy. Often this involves discretely amending the name, clearly defining the base, while still giving credit to the original author. That is the procedure followed here.

3.2 CHANNEL BASIN

The Lower Greensand Group outcrops at a number of localities in the Channel Basin, both on the Isle of Wight and on the Dorset coast. The nomenclature of these beds was the source of much debate in the early Nineteenth Century. The term 'Greensand' is thought to have first been used by William Smith (Webster 1825), but with the realisation that two successions of sandy strata were separated by blue clay, confusion in the terminology appeared. Names such as Ferruginous Sand (Webster) and Carstone were applied to the lower sandy beds, whilst Firestone was used for the upper, but these were not adopted by all workers. Fitton (1824), aware of the misuse of the term 'Greensand', proposed the Shanklin Sands to describe the strata that lay between the Wealden and Gault. However, Greensand had by this time been used in numerous accounts of the geology, and Webster (1825) proposed that the terms Upper and Lower Greensand should be used for the beds above and below the Gault clays, but gave Woburn as the type section. This recommendation was grudgingly accepted by Fitton (1836) and has since been incorporated into all following accounts. The Lower Greensand Group varies from between 0 m to 90 m thick at the basin margins in Dorset, and is represented within a nearshore facies (Ruffell 1992b; Ruffell & Batten 1994). The group is very poorly exposed and not discussed further here. The sequence is much thicker (100-250 m) and more extensive in the Isle of Wight. Here, Fitton (1847) is accredited with making the first detailed account of the stratigraphy (e.g. Hancock 1972). His 1847 account is based upon earlier investigations by him (1824; 1836) and much of the nomenclature he used is based upon discussions with his field assistant, Charles Wheeler. However, working at a similar time to, but independently from, Fitton were Ibbetson and Forbes, whose publication of the Lower Greensand stratigraphy predates Fitton's by two years (Ibbetson & Forbes 1845). Fitton's observations were adopted by the Geological Survey (Bristow 1862; Reid & Strahan 1889; Osborne -White 1921), and later by Casey (1961), because the framework to which he worked was more appropriate for the subdivision of strata. Fitton recognised that the Lower Greensand succession could be divided into "Groups", each displaying similar lithological characteristics. However, Fitton's primary interest was with the ammonite fauna with which each of the "Groups" was associated, and the basis for his subdivision was influenced heavily by faunal content. Casey (1961) also was concerned with the ammonite distributions in Fitton's groups and he tended to accept that the faunal changes associated with his zonal and subzonal framework were coincident with lithological boundaries. Evidently many of the lithological boundaries are associated with changes in the faunal distribution because the boundaries between lithological units often represent breaks in deposition, with renewed deposition heralding a new ammonite fauna. However, this is not always the case, and unless the lithological changes and faunal changes are documented accurately, mistakes can occur and boundaries glossed over.

Renewed interest in the Lower Greensand Group of the Isle of Wight came with sequence stratigraphic and related studies (Ruffell 1989a; Ruffell & Wach 1991; Wach & Ruffell 1991). By the time these investigations materialised, it was clear that Fitton's (1847) and Casey's (1961) divisions could be used as formations and members. Simpson (1985) formally proposed the Atherfield Formation, comprising five members, each of these roughly equating to Fitton's groups or beds. Ruffell and Wach, with no such revisional work for the Ferruginous Sands Formation, encountered problems when trying to use Fitton's (1847) groups for the higher part of the succession. A result of this is that informal terminology has become confused with traditional and members have not been fully defined. This chapter, therefore, defines a workable stratigraphic framework to which all future investigations into the Lower Greensand Group can be referred (Table 3.1).

Fitton 1847		Geol. surv. 1889	Casey 1961		Present study			
Various Sands and Clays	F.	Carstone Car		Carstone	Carstone Formation			
				Five	Sandrock Member	farnhamensis anglicus		
Upper Clays and Sandrock	E .			Formation	Rocken-End Member	nolani		
Ferruginous Bands of Blackgang Chine					Blackgang Member	cunningtoni		
Sands of Walpen Undercliff					Walpen Undercliff Member	subarcticum		
Foliated Clay and Sand			ls	u	Cliff Farm Member			
Cliff-End Sands		ls	rruginous Sanc	àands Formatic	New Chine Member	gracile		
Upper Gryphaea Beds		Sano			Upper Gryphaea Member			
Walpen and Ladder Sands	D.	ns sn			Ladder Chine Member			
Upper Crioceras Beds		ouig			Upper Crioceras Member	debile		
Walpen Clay and Sand	l då		Fei	s sn	Whale Chine Member	meyendorffi		
Lower Crioceras Bed		Fe		Ferrugino	Lower Crioceras Member	– transitoria		
Scaphites Beds					Brown's Down Member			
					Small Ledge Member	grandis		
Lower Gryphaea Beds					Lower Gryphaea Member	deshayesi		
Upper Lobster Beds			lerfield iy Series	nerfield mation	Upper Lobster Member	callidiscus		
Crackers	C .				Crackers Member			
Lower Lobster Bed		ield			Lower Lobster Member	kiliani		
Atherfield Clay	B.	nerf iy	Ath Cla		Chale Member	fittoni		
Perna Beds	A.	Ath Cla			Perna Member	obsoletus		

Table 3.1. The stratigraphical nomenclature of the Lower Greensand Group at its type section (Chale Bay).

The thickest and most fossiliferous succession is displayed along a 5.5 km stretch of coast from Atherfield Point to Rocken-End, Chale Bay, Isle of Wight. It is this Atherfield succession that is now considered to be the type section of the Lower Greensand Group (e.g. Hancock 1972), and the section to which all of the thinner and more condensed successions are compared.

3.2.1 Atherfield Formation (Simpson 1985)

The term Atherfield Clay was first used by Fitton (1847) to describe the drab coloured clay that lies between the Perna and Lower Lobster Members. Later accounts extended the use of Atherfield Clay to include to a variable extent the argillaceous and arenaceous deposits at the base of the Lower Greensand Group and the blue clays above (Reid & Strahan 1889; Osborne - White 1921; Kirkaldy 1939; Arkell 1947; Casey 1961). This account follows Casey's usage, where it embraces units up to and including the Upper Lobster Member.

(i) Type section

The type section of the formation is found in Chale Bay, along the coastal cliff section between Shepherd's Chine (SZ 44667982) and Whale Chine (46847825).

Base: Base of the Perna Member.

Thickness: 52.10 m.

Lithological characteristics: The Atherfield Formation is a predominantly argillaceous succession of strata that sharply overlie the quasi-marine shales of the topmost Vectis Formation (Daley & Stewart 1979). The formation consists of silty clays, sandstones and sandy clays, and the definition given in Simpson (1985) encompasses five members.

Description of the members

a. Perna Member, Fitton (1847), modified Simpson (1985), Fig. 3.1.

The beds at the base of the Lower Greensand Group were first described by Fitton (1845) and Ibbetson & Forbes (1845), who both recognised the presence of a distinctive marine bivalve fauna. Fitton (1847) first named the 'Perna bed', based on the occurrence of his *Perna mulleti* (*Mulletia mulleti*). Simpson (1985) defined the Perna Member, and described three beds.



Figure 3.1. The lithology of the Perna Member (ammonite-bearing horizons indicated).

Type Section: Atherfield Point, Chale Bay (45327905).

Base: Atherfield Bone Bed (Simpson 1985). This bed of phosphatic nodules and grit with rolled Kimmeridgian ammonites (Casey 1961), set within a poorly sorted muddy sand, forms a distinctive bone bed at Atherfield Rocks (Simpson 1985), but is most frequently displayed in a slumped unit to the west of Atherfield Point, where only a thin bed (0.01-0.05 m) of gritty clay is seen.

Thickness: 1.50 m.

Lithological Characteristics: The Perna Member, forming a distinctive marker at the base of the Atherfield Formation, is divisible into five beds. The bone bed at the base records the influx of the sea at the base of the Aptian, and is followed upwards by grey-green silty clay. Three calcareous sandstone beds at the top of the member are typified by a shallow-water encrusting fauna (Wach & Ruffell 1991).

b. Chale Member, Simpson (1985), Fig. 3.2.

The member defined by Simpson (1985) refers to Fitton's (1847) Atherfield Clay, and the Atherfield Clay sensu stricto of Casey (1961).

Type Section: Atherfield Point, Chale Bay (45357905)





Base: The Chale Member commences at the base of a bed of silty, chocolate brown clay with a gritty base, resting sharply on the Perna Member.

Thickness: 17.50 m.

Lithological characteristics: The member comprises a succession of clays and silty clays that form the high cliffs of Atherfield Point, and comes to shore as a series of isolated outcrops between slumps. It shows a series of repetitive 'couplets' of blue and brown silty clays with clay-ironstone nodules at the top. The basal three beds of the Chale Member were described by Simpson (1985), whilst the upper part was lumped together in a single 16 m thick bed. Good exposure of this part of the succession has allowed a finer sub-division to be detailed.

c. Lower Lobster Member, Ibbetson & Forbes (1845), Fig. 3.3.

Fitton (1847) is widely quoted as defining the Lower Lobster Bed (e.g. Hancock 1972), however, its first published record is in Ibbetson & Forbes (1845):

"...clays which succeed [the Perna Member] are fossiliferous in their lower part, but very slightly so in the middle ... the uppermost of these clay strata [is] called the Lower Lobster Bed."

Type section: Cliffs in Fishing Cove, Chale Bay (457789).

Base: Simpson (1985) discussed the problems with identification of the base of the Lower Lobster Member. In a gradational succession a boundary must be arbitrarily fixed; the base of a distinctive laminated brown and blue clay, above which the beds are generally more silty, is the most logical point at which to draw the line between the Chale and Lower Lobster Members. *Thickness:* 12.80 m.

Lithological characteristics: The Lower Lobster Member comprises predominantly silty brown clays. Two bright blue beds (Beds 8 and 10) form a prominent marker in the cliff. Above these, the beds become progressively more sandy and grade into the Crackers Member.

d. Crackers Member, Fitton (1845), Fig. 3.4.

As with the Lower Lobster Member, the first recorded publication of the Crackers sand is earlier than given in Hancock (1972). Both Fitton (1845) and Ibbetson & Forbes (1845) describe the sandstone unit, with the more detailed account appearing in Fitton.

Type section: Coastal cliffs west of Whale Chine (46107875).

Base: With no obvious break in deposition, the base of the Crackers Member is arbitrarily defined at the point at which the sandy clays at the top of the Lower Lobster Member grade into argillaceous sands.

Thickness: 6.00 m.



Figure 3.3. The lithology of the Lower Lobster Member.

Lithological characteristics: The Crackers Member is a distinctive argillaceous sandstone body, occurring within the predominantly silty clay succession. Two beds of sandstone contain levels of large calcareous concretions, yielding a well-preserved fossil assemblage. The upper sandstone is clearly erosive into the lower, and at intervals has entirely removed the lower concretionary range.



Figure 3.4. The lithology of the Crackers Member.

e. Upper Lobster Member, Ibbetson & Forbes (1845), Fig. 3.5.

The Upper Lobster Bed was first described by Ibbetson & Forbes:

'A clay bed, 20' thick, having the properties of a fuller's earth, and of similar appearance to that preceding the Crackers, succeeds: it is very fossiliferous, and ... abounds in crustacea ... this is termed the Upper Lobster Bed.'

Type section: Cliffs west of Whale Chine (463785).

Base: The base of a bright blue bioturbated clay that rests sharply on silty sand at the top of the Crackers Member.

Thickness: 14.30 m.

Lithological characteristics: The member comprises an alternating succession of silty clays and sands, thought to represent a similar depositional environment to the Lower Lobster Member. Fitton (1847) described five equal beds, although new measurements suggest that the lowest clay bed is much thicker than given in earlier investigations (Casey 1961; Simpson 1985).

(ii) Other sections

The divisions of the Atherfield Formation at Redcliff (SZ 619853) were discussed by Simpson (1985). The Perna Member includes the Atherfield Bone Bed at its base, followed by 1.15 m of blue sandy clay, and capped by a 0.70 m thick calcareous sandstone, this yielding an identical fauna as the uppermost part of the member at Atherfield. The Chale Member is largely obscured, but its basal contact with the Perna Member is seen. The Lower Lobster Member is characterised



Figure 3.5. The lithology of the Upper Lobster Member.

by brown sandy clay and grades up into blue and brown argillaceous sands of the Crackers Member. The overlying grey-brown and gritty clays are the condensed equivalents of the Upper Lobster Member (Simpson 1985).

At Compton Bay (SZ 369853), a thickness of 9 m is estimated for the Atherfield Formation, but lithological details are lacking in beds that are covered by landslipped material. Simpson (1985) noted that the Perna Member was present, and indurated nodules of shelly limestone were correlated with the Crackers Member (Wach & Ruffell 1991; Ruffell & Batten 1994).

3.2.2 Ferruginous Sands Formation, Reid & Strahan (1889)

The term 'Ferruginous sand' was first used by Thomas Webster, in the early Nineteenth Century, to describe the whole of the Lower Greensand Group (Fitton 1824). This name was abandoned, but reintroduced in a new sense by Reid & Strahan (1889), to refer to the beds that lay between the base of the Crackers Member and the base of their Sandrock Formation, which commenced at the base of the present Sandrock Member.

(i) Type section

Atherfield Bay, along the coastal outcrop between Atherfield Point and Blackgang (478790-481772).

Base: The boundary between the Atherfield Clay and the Ferruginous Sands was originally considered to lie at the base of the Crackers Member (Reid & Strahan 1889). Later accounts included both the Crackers and Upper Lobster Members within the Atherfield Formation, and the base of the Ferruginous Sands Formation was redrawn at the Lower Gryphaea Member (Casey 1961; Rawson *et al.* 1978; Simpson 1985).

Thickness: 135.20 m.

Lithological characteristics: The formation is a predominantly arenaceous, marine succession with variable amounts of clay. The sediments typically display coarsening upwards cyclicity, with increasing bioturbation upwards. At some levels are concretionary horizons and firmgrounds, which have traditionally been used to subdivide the succession (Fitton 1847). However, it has been demonstrated that the levels of concretions are not always reliable as dividing lines between members, since many are discontinuous and, therefore, are not always seen. Other criteria have been used to subdivide the succession, and these are outlined below.

Description of the members

a. Lower Gryphaea Member, Fitton (1847), Fig. 3.6.

Type section: West of Whale Chine (463787).

Base: Base of an horizon of phosphatic nodules separating grey sandy clay of the Upper Lobster Member from the argillaceous sand of the Lower Gryphaea Member in the otherwise gradational succession.

Thickness: 9.30 m.



Figure 3.6. The lithology of the Lower Gryphaea Member.

Lithological characteristics: At its base, the Lower Gryphaea Member comprises a grey, argillaceous silt. The silts coarsen up to a firmly cemented bed, full of *Sellithyris* (Bed 4). This bed was documented by Fitton (1847) and termed the Terebratula Bed. The sands above Bed 4 take on a red-brown appearance and are much coarser grained, clay being largely restricted to the linings of burrows. The topmost bed of the member is clearly defined as the firmly cemented bed, full of *Aetostreon*, forming a distinctive marker, both within the cliff and the line that it

forms as it goes out to sea.

b. Small Ledge Member, New Name, Fig. 3.7.

Fitton (1847) named a unit the "Scaphites Beds" on account of the large heteromorph ammonites which were found in a firmly cemented bed toward the centre of this division. The beds above the concretionary level are normally poorly exposed and have previously been considered to



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Figure 3.7. The lithology of the Small Ledge Member.

form the top part of the Scaphites Beds (Casey 1961). However, recent exposure of this part of the succession has revealed that there is sufficient lithological difference from the beds below the concretions to separate Fitton's Scaphites Beds into two distinctive members, named here as the Small Ledge and Brown's Down Members. Fitton's old name is abandoned.

Type section: To the west of Whale Chine (466786).

Base: The base of the Small Ledge Member is clearly defined at a grey silty clay, sharply overlying the upper surface of Lower Gryphaea Member. Phosphatic nodules occur in this basal bed, but are commonly covered by slumped material.

Thickness: 5.40 m.

Lithological characteristics: The Small Ledge Member comprises nine beds, these being predominantly brown, argillaceous silts and sands. The top bed is highly distinctive, being full of phosphate and trace fossils. Concretions in the bed enclose very large ammonites, predominantly the heteromorph *Australiceras*, which co-exists with *Cheloniceras* and *Deshayesites*. The bed forms a very distinctive ledge on the beach when it is stripped of shingle, and described by Casey (1961) as:

"...the large concretions...may be seen to crop out in a band from the foot of the cliff to the water's edge, each balanced on a pedestal of the underlying sand like so many giant mushrooms."

c. Brown's Down Member, New name, Fig. 3.8.

This newly defined member corresponds to the upper part of Fitton's Scaphites Beds. *Type section:* In the coastal cliffs, beneath Brown's Down, west of Whale Chine (467785). *Base:* The basal bed of the member is a thin unit of clay that sharply overlies the burrowed upper surface of the Small Ledge Member.

Thickness: 6.00 m.

Lithological characteristics: Three thin beds of silty grey and blue clay are each separated by brown, clay streaked sand. Toward the top of the member discontinuous serpulid rich nodules occur, and these are very rarely exposed as ledges on the beach.

d. Lower Crioceras Member, Fitton (1847), Fig. 3.9.

Fitton identified the large heteromorph ammonites contained within these strata as *Crioceras* (now named *Tropaeum*) and hence named his Lower Crioceras Group.

Type section: Coastal section at Whale Chine (467784).

Base: The base of the member is drawn at the base of a silty clay band. Although lithologically



Figure 3.8. The lithology of the Brown's Down Member.

similar to the clay bands of the Brown's Down Member, this clay grades up into glauconitic green sands above.

Thickness: 4.50 m.

Lithological characteristics: The five cycles of the member are typified by green, glauconitic silts and sands, coarsening upwards and terminating at a concretionary level. The concretionary horizons represent periods of extremely inhibited deposition and current winnowing concentrated ammonites into these discrete levels. The top of the member is a distinctly cemented horizon that





forms a ledge across the mouth of Whale Chine. The amount of cementation is significantly less than seen at the top of the Lower Gryphaea and Small Ledge Members, but some pause in sedimentation prior to the deposition of the succeeding member is indicated.

e. Whale Chine Member, New name, Fig. 3.10.

Fitton (1847) caused a nomenclatorial confusion by naming three of his units the "Walpen Sand and Clay", the "Walpen and Ladder Sands", and the "Sands and Clays of Walpen Undercliff".



Figure 3.10. The lithology of the Whale Chine Member.

The first name is replaced here by the Whale Chine Member, which is best exposed at Whale Chine. Previous descriptions of this member are rather poor because the beds are frequently masked by downwash (Casey 1961).

Type section: Across the mouth of, and within, Whale Chine (468783).

Base: Glauconitic, silty grey clay overlies the bioturbated sand at the top of the Lower Crioceras Member.

Thickness: 20.00 m.

Lithological characteristics: Two distinctive units were recognised by Fitton (1847) and Casey (1961). Silty grey sands of the lower part of the member coarsen upwards to a distinctive marker of clean sand. Above a line of springs are smectitic clays and silts, characterised by sideritic nodule horizons.

f. Upper Crioceras Member, Fitton (1847), Fig. 3.11.

Fitton (1847) named the Upper Crioceras Beds after collecting numerous large heteromorph ammonites from the concretionary horizons that characterise these strata.

Type section: The beds of this member are best displayed in Whale Chine (468785).

Base: Problems have been encountered in the definition of the base of this member, which is often poorly exposed (Fitton 1847; Casey 1961; Wach & Ruffell 1991). Fitton (1847) took the lowest concretionary level to mark the base of the unit. This, however, is discontinuous and is set within a matrix that is similar above and below the concretions. The base of the member is lowered here, to the base of a silty clay band, which coarsens up into yellow sand. Above, a further coarsening upwards cycle has the first concretionary horizon at its top.

Thickness: 14.40 m.

Lithological characteristics: The Upper Crioceras Member is characterised by coarsening upward cycles of medium- to coarse-grained sand. The bases of the cycles are frequently marked by a thin bed of clay and may culminate in an horizon of large concretions. Five discernable lines of concretions occur, with irregularly disposed nodules between.

g. Ladder Chine Member, New name, Fig. 3.12.

The name is proposed as a modification of Fitton's (1847) term, the "Walpen and Ladder Sands" which he described as about 12 m of green and grey sands with fossiliferous concretions. As with so many of Fitton's "Groups", he based his measurements on the concretionary levels within the succession.

Type section: Ladder Chine (471781).

Base: The base of the member is a grey clay band with a weathered iron-pan at the top. The bed is clearly displayed in Whale Chine, and affords easy measurement in Ladder Chine. *Thickness:* 15.36 m.





Lithological characteristics: The member comprises glauconitic, silty and argillaceous beds deposited in a number of coarsening upwards cycles. Lines of siderite and calcite cemented concretions occur near the base and top. The argillaceous fraction decreases upwards, toward very coarse, clean sands in the upper part of the member.



Figure 3.12. The lithology of the Ladder Chine Member.

h. Upper Gryphaea Member, Fitton (1847), Fig. 3.13.

Fitton (1847) applied the name Upper Gryphaea Beds to 6 m of clayey sand with concretionary bands yielding bivalves.

Type section: Coast section between Walpen Chine and Blackgang (473778).

Base: The boundary between the Ladder Chine and Upper Gryphaea Members lies at the base of a red iron-stained sand, best seen at the western end of Ladder Chine.



Figure 3.13. The lithology of the Upper Gryphaea Member.

Thickness: 9.50 m.

Lithological characteristics: The member comprises predominantly glauconitic sands. Inhibited deposition is indicated by iron-cemented, highly bioturbated sands, that are encrusted with *Aetostreon*. Some of the iron-sands are very coarse-grained and reminiscent of the red sands toward the top of the Lower Gryphaea Member.

i. New Chine Member, New Name, Fig. 3.14.

Fitton (1847) named a unit of sands and pyritic clays the Cliff-End Sands. However, the Cliff-End Member has also been used for a unit in the Palaeogene of the Isle of Wight (Daley &



Figure 3.14. The lithology of the New Chine Member.

Insole 1984). To avoid further confusion, and as the unit is best exposed at New Chine, it is renamed after the latter locality.

Type section: New Chine, along the coast section between Walpen Chine and Blackgang, Chale Bay (475777).

Base: Gritty pebbles of the basal bed are set within an argillaceous matrix.

Thickness: 5.95 m.

Lithological characteristics: The basal bed coarsens upwards into a soft glauconitic sand. Two very prominent siderite cemented horizons are separated by the glauconitic sand. The sideritic horizons are full of trace fossils and may contain calcareous concretions. Bed 5, at the top of the

member, is terminated abruptly by clays.

j. Cliff Farm Member, New Name, Fig. 3.15.

Fitton (1847) named this unit the 'Foliated Sand and Clay', but with no geographical or palaeontological epithet, the name is no longer stratigraphically relevant.



Figure 3.15. The lithology of the Cliff Farm Member.

Type Section: Coastal section beneath Cliff Farm (478774).

Base: Large pyritic nodules are found within a laminated blue clay at the base of the member, this resting erosively on top of the New Chine Member.

Thickness: 12.00 m.

Lithological characteristics: Following the dark blue clays at the base of the member are a series of interlaminated pyritic clays and glauconitic sands. The interlaminated beds are punctuated by levels of cross-bedded, white friable sandstone and seen for a thickness of 9 m. The top 3 m of the member comprises a white cross-bedded sandstone, originally placed in the following Walpen Undercliff Member by Fitton (Kirkaldy 1939; Casey 1961).

k. Walpen Undercliff Member, Fitton (1847), Fig. 3.16.

Fitton (1847) was not consistent in his definition of this member. In the text of his paper he referred to the 'Sands and clays of Walpen Undercliff' (also having a 'group' called the Walpen sands and clays!), whilst in his figure he used the 'Sands of Walpen Undercliff'. The second name has been taken by succeeding authors (Osborne -White 1921; Casey 1961; Daley & Insole 1984), and so in the lithostratigraphical framework, the 'Walpen Undercliff Member' is used.

Type section: Along the undercliff between Walpen and Blackgang (482772).

Base: The base of the Walpen Chine Member is clearly defined at a pebble bed which cuts down into the clean washed sands at the top of the Cliff Farm Member below.

Thickness: 27.00 m.

Lithological characteristics: Glauconitic sands, often containing a high argillaceous fraction, are deposited in a number of coarsening upwards cycles. The tops of the cycles are marked by firm, clean sands that are often preferentially cemented.

I. Blackgang Member, Fitton (1847), Fig. 3.17.

This distinctive member at the top of the Ferruginous Sands Formation was named the 'Ferruginous Bands of Blackgang Chine' by Fitton (1847). Blackgang Chine does not exist as a geographical feature any longer, the cliffs having cut back and slipped, but the area around is named Blackgang, so the term 'Blackgang Member' is a suitable modification.

Type section: Blackgang Undercliff (485767).

Base: The basal bed of the member is a soft, fine-grained sand, resting sharply on the crossbedded, iron-cemented sand at the top of the Walpen Undercliff Member.

Thickness: 5.75 m.

Lithological characteristics: The Blackgang Member consists of fine-/medium-grained sands that



Figure 3.16. The lithology of the Walpen Undercliff Member.

alternate with iron-cemented concretionary bands. Five iron layers have been distinguished, and these have yielded a fauna comprising entirely of bivalves and gastropods.



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Figure 3.17. The lithology of the Blackgang Member.

(ii) Other Sections

The Ferruginous Sands Formation at Redcliff, eastern end of Sandown Bay, comprises glauconitic muddy sands at the base, and these pass up into cleaner white and iron-rich sands, similar to the type section, but the smaller subdivisions are not seen.

The southern end of Sandown Bay displays a further outcrop of the Ferruginous Sands Formation, that is exposed between Sandown and Shanklin (SZ 578779). The base of the formation is not exposed and correlations with the type section are only made available by the presence of widely spaced ammonite-bearing horizons (Osborne-White 1921; Casey 1961). Osborne-White (1921) divided the formation into five broad lithological divisions, and Casey (1961) proposed a finer division based upon the isolated ammonite records. Division 1 comprises greenish grey argillaceous sands with two distinctive iron-concretionary levels, seen for a maximum thickness of 9 m. This is succeeded by Division 2, consisting of 15 m of clean sands with discoidal concretions at the top. Casey (1961) correlated these concretions with the Upper Crioceras Member of Atherfield. 10 m of coarse, glauconitic sands were placed within Division 3, and the 7.50 m of argillaceous greensands that followed with Division 4. The bases of Division 5 is a prominent pebble bed, rich in Aetostreon and set within glauconitic sand. The fossils yielded from Casey's 'Urchin Bed' reveal an early nutfieldiensis Zone age. Brown argillaceous sands form the top part of the cliff at Shanklin. Ferruginous concretions that occur in the 6 m thick division have yielded specimens of *Parahoplites cunningtoni*, and are the equivalent of the iron-bands that characterise the Blackgang Member of the type section.

At Compton Bay, to the west of the Atherfield section, the Ferruginous Sands Formation is only about 50 m thick. The individual members are not recognised in the condensed succession here, but isolated fossil finds have allowed the correlation of parts of the succession with the type section. Wach & Ruffell (1991) noted that a *grandis* Subzone fauna was obtained from a clay band 8 m from the base of the formation, and a further band 18 m above yielded ammonites of the *bowerbanki* Zone (Casey 1961). Ruffell & Batten (1994) suggested that the upper divisions of the formation, from the Cliff Farm to Blackgang Members, were recognised here, but this is unlikely. The probable equivalent of the Cliff Farm Member is present at Compton, but the beds above have been eroded prior to the deposition of the Five Rocks Formation.

3.2.3 Five Rocks Formation, New name

Fitton (1847) originally described a lithological unit named the 'Upper Clays and Sandrock'. Reid & Strahan (1889) separated the Upper Clays from the Sandrock, and attached the former unit to the topmost part of the Ferruginous Sands Formation. This interpretation was followed by later authors, e.g. Osborne -White (1929), Kirkaldy (1939; 1963) and Casey (1961). Dike (1972) revived the idea that the Sandrock and Upper Clays should be grouped together rather than being split between two formations, and this proposal is followed here. Reid & Strahan's Sandrock is retained as a member of a new formation, named for the strata that are best displayed in the cliffs at Five Rocks.

(i) Type section

Chale Bay, from Blackgang to Rocken-End (482770-491750).

Base: The base of the Rocken-End Member.

Thickness: 82.80 m.

Lithological characteristics: The Five Rocks Formation comprises thick units of cross-bedded and massively bedded, white, quartzose sand, interlaminated, or interbedded with, black silty and glauconitic clay.

Description of the Members

a. Rocken-End Member, New name, Fig. 3.18.

In line with the revised definition, the Upper Clays of previous authors are now considered to be the lower member of the Five Rocks Formation, and these beds are assigned a new lithostratigraphical name, the Rocken-End Member.

Type section: Blackgang to Rocken-End (488756).

Base: Black, silty clays rest sharply on coarse-grained yellow sands at the top of the Ferruginous Sands Formation.

Thickness: 13 m.

Lithological characteristics: The characteristic black, laminated muds at the base of the member are punctuated by two glauconitic green stripes. The clays become silty upwards, and streaks of white sand occur in the topmost 2 m of the member.



Figure 3.18. The lithology of the Rocken-End Member.

b. Sandrock Member, Reid & Strahan (1889), Fig. 3.19.

The remainder of the Five Rocks Formation is placed within the Sandrock Member, this being equivalent to the whole of Reid & Strahan's "Sandrock".

Type section: Cliffs from Blackgang to Gore Cliff (485767-490763). Base: The Sandrock Member grades up from the Rocken-End Member below. The base is drawn at the first bed of white sandstone to occur within this gradational succession. Thickness: 69.80 m.



Figure 3.19. The lithology of the Sandrock Member.

Lithological Characteristics: The member comprises alternating units of black, laminated and glauconitic clay and thick white and yellow sandstones.

(ii) Other Sections

The formation reaches about 40 m at Luccomb Chine, near to Shanklin, and the Rocken-End Member is well-developed, but unfossiliferous, at its base. The overlying Sandrock Member has a glauconitic clay band containing phosphatic nodules 2.50 m from its base. This bed was described by Casey (1961) and it was from here that a sparse fauna, including specimens of *Hypacanthoplites*, was recovered. Unfossiliferous beds of the Five Rocks Formation are also recorded from Redcliff (Casey 1961; Wach & Ruffell 1991).

At Compton, the Rocken-End Member sharply overlies the topmost part of the Ferruginous Sands Formation, and contains a pebble bed at the base. It appears that a considerable period of erosion occurred prior to the deposition of this member. The succeeding 25 m of the Five Rocks Formation comprises white sands, separated by glauconitic sands, equivalent to the Sandrock Member of the type section.

3.2.4 Carstone Formation, Strahan (1886).

The formation was named by its lithological similarity with the Lincolnshire Carstone, and first defined by Strahan (1886), although it was as early as 1824 when this was noted by Fitton:

'The upper and more ferruginous beds correspond, I believe, with what is called the 'Carstone', at Hunstanton, in Norfolk.'

The likelihood is that the Lincolnshire, Norfolk and Isle of Wight 'Carstones' formed a continuous marginal deposit, for although the 'Carstones', along with the Iron-Grit facies of Sussex (Anderson 1986), are discontinuous at outcrop, they all occupy similar stratigraphic positions.

3.3 WEALD BASIN

The Lower Greensand Group is well-known from the Weald Basin, correlations having been made from the type section to here by Fitton (1824). Drew (1864) set about naming the formations of the Lower Greensand Group from the sections he measured along the coastal outcrop in the area around Folkestone. These formations were then traced around the Weald Basin by Topley (1875). Localised facies variations within the strata of the Lower Greensand Group has led to the introduction of a large number of names for these areally limited lithologies. The formations are divided into laterally restricted members (Table 3.2).

3.3.1 Atherfield Formation, Fig. 3.20.

The Atherfield Formation in the Weald Basin is the direct correlative of that seen at its type section on the Isle of Wight. At its thickest, in western parts of Sussex and the Surrey area, the Atherfield Formation reaches 18 m. Chocolate-brown and blue sandy clays overlie a green



Figure 3.20. A correlation of the Atherfield Formation through the Weald.

EAST KENT WEST KENT SURREY SUSSEX puzosianus raulinianus Basal Gault Formation Folkestone Formation floridum Basal Gault Formation Iron-Grit kitchini regularis Bat & Ball Mmb farnhamensis Folkestone Formation Folkestone Formation Wrotham Member anglicus Sevenoaks Member Marehill Member nolani Puttenham Mmb andgate Redhill dgate nation Pulborough Mmb Member cunningtoni

Table 3.2. The stratigraphical nomenclature of the Lower Greensand Group of the Weald.

	Pos	Form		Bargate Mmb	Puttenham Mmb
subarcticum			Nutfield Member		
gracile					
debile			Gods Men	stone nber	
meyendorffi	ų	mation	Dor Men	king nber	uc
transitoria	Formatio	the For	Rei	gate	Formatio
grandis	Hythe]	Hy	Men	nber	Hythe
deshayesi			Albury Member		
callidiscus	Atherfield Fm	p	pla	110	bla
kiliani		Atherfie Formati	Atherfie	rormau	Atherfic Formati
fittoni					
obsoletus		Perna Member	Perna M	lember	Perna Member
fissicostatus					

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calcareous sandstone, equivalent to the Perna Member, and represent a condensed version of the entire formation seen on the Isle of Wight (Simpson 1985; Ruffell 1989a).

Eastward, through Sussex, a progressive thinning of the Atherfield Formation occurs, initially so that only the upper part is present overlying the Weald Clay. There are records of a layer of phosphatic nodules containing rolled ammonites at the old Cuckmere Brickworks (Osborne - White 1926; Kirkaldy 1937). Casey (1961) and Gallois (1965) considered this horizon to represent a condensed remanié of the entire Atherfield Formation. Further to the east, the formation passes into the sandier facies of the Hythe Formation (Humphries 1964).

Thinning of the formation is also recognised as it is traced through Kent. In western parts of Kent, such as Sevenoaks, records of the Atherfield Formation give a thickness of about 9 m (Dines *et al.* 1969; Hart 1973; Simpson 1985). In the eastern part of Kent, there are very few records of Atherfield Formation outcrop, which is generally covered by younger strata. The best records of the formation in this part of the Weald were made available to Casey (1961) from borehole data in the Kent coalfield, near Dover. Here, 7 m of brown and blue silty clay have been found resting on the topmost Weald Clay across a distinctive erosion surface.

3.3.2 Hythe Formation, Drew (1864),

The Hythe Formation is of more limited areal extent than the Atherfield Formation. It does, however, outcrop over large areas of the Weald, and is well-exposed due to extensive quarrying for road stone. Unfortunately it is frequently barren of fossils. Facies change considerably across the outcrop, reflecting changes from shallower to deeper water towards the basin centre. Hence, several local members have been recognised in different areas.

(i) Type section, Figure 3.21.

The type section at Hythe consists only of isolated outcrops that can be seen along a coastal section (Ruffell 1992c). Inland, a sequence through the whole of the Hythe Formation was described by Casey (1961) from Otterpool Manor Quarry (TR 112 364). The pit has long been infilled, but the succession recorded by Casey appears representative for the Hythe Formation in eastern parts of Kent (Ruffell 1992c).

Base: At Otterpool Manor Quarry, Casey (1961) recorded the gradation of the Atherfield Formation into the Hythe Formation, from bluish silty clays to blue-green sandy clay.



Figure 3.21. The lithology of the Hythe Formation of Otterpool Manor (from Casey 1961).

Thickness: A thickness of 15 m is given for the Hythe Formation of eastern Kent (Casey 1961). *Lithological characteristics:* The typological expression of the Hythe Formation is a repetitive sequence of sandy limestone alternating with glauconitic muddy sands. At Otterpool, the formation is exceptionally fossiliferous and unusually rich in ammonites, particularly in the smectitic mudstone and phosphatic horizons that punctuate the rhythms (Ruffell & Wach 1991; Ruffell 1992c). The topmost Hythe Formation, and its junction with the Sandgate Formation, is still exposed on the foreshore at Mill Point, east of Folkestone Harbour. Here, the topmost calcareous beds are terminated abruptly by a phosphatic nodule bed (Casey 1961; Ruffell 1989a).

(ii) Maidstone, Fig. 3.22.



Figure 3.22. The Hythe Formation at Brishing Court (from Worssam 1963).

Westward from the type section, the typical Hythe Formation sandstone-mudstone alternations continue as it thickens from about 15 m to 20-30 m. Fine-grained sandy limestones dominate in the alternating succession, exposed in isolated areas around Charing (Ruffell 1992c).

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Thickening continues toward Maidstone, where up to 50 m of the Hythe Formation has been recorded (Casey 1961; Worssam 1963; Ruffell 1992c). Fitton (1845) divided the formation into two members. This subdivision was not accepted by later workers (Kirkaldy 1939), but revived by Casey (1961). The 'lower Hythe Formation' was believed to be overlain by the 'Boughton Member' that was only well-developed in the area surrounding Maidstone (Casey 1961; Ruffell 1992c). The Boughton Member was never fully defined, but its base was considered to lie at the 'Coalman Lane' of Coombe Quarry, or the 'Newington Lane' of Brishing Court (Casey 1961). However, the Boughton Member, as stated by Casey, is not distinguishable lithologically from the beds below, both successions comprising interbedded argillaceous sands and sandy limestones. Casey's (1961) Boughton Member was purely used to define a succession of strata that were stratigraphically younger than the Hythe Formation of eastern Kent. Although Ruffell (1993, in Worssam) argues for the status of the higher part of the Hythe Formation as a separate member, I am in agreement with Worssam (1963; 1993), and do not consider there to be any lithostratigraphical basis for the Boughton Member.

(iii) Surrey, Fig. 3.23.

Toward the centre of deposition, in the western Weald, a more arenaceous facies of the Hythe Formation is approached (Gossling 1929; Casey 1961; Humphries 1964; Ruffell 1989a; 1992c). Four divisions of the Hythe Formation can be recognised within the basinal facies of Surrey (Gossling 1921; Casey 1961). The terms applied by Gossling for the Hythe Formation of the western part of the Weald were only introduced as informal field terms, but have since been taken to define the lithostratigraphical units (Kirkaldy 1949; Casey 1961; Ruffell 1992c). The names of Gossling's units have no lithostratigraphical basis and are modified herein.

a. Albury Member, New Name

The new name corresponds to Gossling's (1929) Lower Hythe Sands.

Type section: Albury, near *Guildford* (TQ 048475). The fine-grained sands of this member are presently displayed in some outcrops in the Reigate region, and typified by the beds seen around Albury.

Base: The base of the formation is not seen in the district, but is believed to grade up from the Atherfield Formation with an increase of sand.

Thickness: 7.00 m.

Lithological characteristics: Fine-grained brown sands at the base of the Hythe Formation belong to this member. Increasing bioturbation and decreasing argillaceous matter define coarsening upwards cycles. The top of the member is characterised by a concentration of shells.



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Figure 3.23. The lithology of the Hythe Formation of Surrey.

b. Reigate Member, New Name

The beds of the member belong to Gossling's (1929) Lower Hythe Stone.

Type section: Scattered outcrops occur in the area around Albury.

Base: Above the shell bed at the top of the Albury Member is an argillaceous bed yielding scattered particles of phosphatic grit and pebbles.

Thickness: 9.00 m.

Lithological characteristics: The member comprises poorly cemented red and brown sands that alternate with beds of grey sandstone. The sandstone bands are coarser-grained than sands, and are frequently silica-cemented.

c. Dorking Member, New name.

Beds comprising unconsolidated cross-bedded sands were defined as the Mid Hythe Sands by Gossling (1929).

Type section: Area around Dorking (TQ 021483).

Base: The topmost silica cemented bed of the Reigate Member is sharply overlain by pebbly sands.

Thickness: 12.00 m.

Lithological characteristics: The member as a whole comprises medium- to coarse-grained sands that are strongly cross-bedded and show varying degrees of bioturbation.

d. Godstone Member, New name.

The topmost member of the Hythe Formation was divided into the Upper Hythe Pebble Bed and Top Hythe Chert by Gossling (1929). These two units are now considered to comprise a single member in the current lithostratigraphical framework.

Type section: Bletchingley Quarry (TQ 328502).

Base: A shelly, phosphatic pebble bed cuts down into the underlying member.

Thickness: Maximum of about 20 m, although frequently reduced to only 2-3 m.

Lithological characteristics: Sands with levels of chert are found at the top of the Hythe Formation in parts of Surrey. These beds are, however, absent from many localities, due to erosion prior to the deposition of the Sandgate Formation.



Figure 3.24. The lithology of the Hythe Formation of the Hoe's Farm Borehole and Bognor Common Quarry (Sussex). *=grandis Subzone.

(iv) Hampshire to Sussex, Fig. 3.24.

The Hythe Formation reaches a maximum thickness of 100 m in the Hampshire district of the South Downs where the arenaceous facies is still seen (Young and Lake 1988; Ruffell 1992c). Progressive thinning of the formation through Sussex is accompanied by a gradual return to the mudstone - limestone alternations that were so evident in Kent, on the opposite side of the basin.

The whole of the Hythe Formation was recorded from the Hoe's Farm Borehole, near Petworth (Bristow *et al.* 1987), and the upper beds of the formation are currently well-exposed in the Bognor Common Quarry (TQ 010215). Bristow *et al.* (1987) proposed that the argillaceous lower part of the Hythe Formation could be defined as a member (Hoe's Farm Member) separated from the more arenaceous beds above. Although there is a lithological distinction between the lowest 14 m and the remaining 27 m of the formation, it is only very minor, and never seen beyond the single borehole locality. It is not uncommon for the Hythe Formation to be more argillaceous at its base since it grades up from the clays of the underlying Atherfield Formation, and the same phenomenon is displayed in its type locality (Casey 1961). As a whole, the formation consists of coarsening upwards cycles, these commencing with argillaceous silts, through sandy and calcareous sandstones, and terminated by firmly cemented beds. Therefore the Hoe's Farm Member is not distinguished here.

As at the type section, argillaceous and smectitic mudstone horizons punctuate the Hythe Formation, and dark beds containing phosphatic nodules occur (Young & Morgan 1981; Bristow *et al.* 1987; Ruffell 1992c). The top of the formation is at a clearly defined erosion surface, upon which lies the Sandgate Formation.

Further outcrop records throughout the remainder of Sussex are given in Ruffell (1992c) who indicates the thinning of the formation as one proceeds eastward, until it passes into the very thin, undifferentiated Lower Greensand Group of east Sussex (Humphries 1964).

3.3.3 Sandgate Formation, Drew (1864), Fig. 3.25.

The Sandgate Formation was named from its exposures along the coast to the west of Folkestone in Kent, where a succession of glauconitic, sandy and clayey beds were seen lying between the

Figure 3.25. A correlation of the Sandgate Formation through the Weald. P.M.=Pulborough Member.



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Hythe and Folkestone Formations. Thickness variations are marked as it is traced into western parts of Kent, particularly in the Maidstone district, where tectonic disturbances may have removed most of the formation prior to the deposition of the succeeding Folkestone Formation. In the basinal parts of the Weald Basin, the thickest deposits are recorded, and facies changes are rapid. The basinal facies of the Sandgate Formation extends into western parts of Sussex, before it thins rapidly eastward towards Eastbourne at the margin of the Weald Basin

(i) Type section

Price (1875) recorded the presence of dark grey and yellow argillaceous sands near to Sandgate in Kent. These beds are believed to be from the upper part of the Sandgate Formation, but are unfortunately no longer exposed (Casey 1961). The base of the Sandgate Formation is exposed on the foreshore at Mill Point (TR 220352), where the section recorded by Casey (1961) can still be followed.

Base: At Mill Point, a complex nodule bed, containing a remanié fauna is found at the base of glauconitic and silty sands (Casey 1961; Ruffell 1989a; 1990).

Thickness: Worrall (1954) estimated a thickness of 35 m for the Sandgate Formation of east Kent, whilst Kirkaldy (1939) and Casey (1961) suggested a figure of 20 to 25 m is more likely. *Lithological characteristics:* Although no longer exposed at the type section, the Sandgate Formation in eastern parts of Kent is recorded as dark, argillaceous sand and clay containing variable amounts of glauconite (Drew 1864; Price 1875; Kirkaldy 1939; Casey 1961). The top beds of the formation, the dark silty clays of Price (1875), are important to note, because these may be correlated with organic-rich clays that formed over wide areas of the Wessex Basin toward the end of Sandgate Formation deposition.

(ii) Maidstone district, western Kent

As one proceeds north-eastward through Kent there are very few outcrops of the Sandgate Formation. Ruffell (1989a) recorded a thickness of about 30 m of glauconitic sands and clays at Millgate Park, to the south-east of Maidstone, but a sudden thinning at Maidstone itself, such that there may be only 0-4 m in total. However, included here on lithostratigraphical grounds are the smectitic fuller's earths that have previously been considered as the uppermost Hythe Formation (Ruffell 1992c). These beds, recorded from Allington Quarry, may be directly correlated with the Nutfield Member of Surrey.

(iii) Redhill-Reigate district, Surrey, Fig. 3.26.

In the eastern part of Surrey, good exposure of the Sandgate Formation is found in Patteson Court, near Redhill, where two members have been defined.

a. Nutfield Member, Ruffell (unpublished data)

Type section: Patteson Court, Redhill, Surrey (TQ 294507).

Base: The basal bed of the formation is a 2.50 m thick fuller's earth. At Bletchingley, this bed has been seen resting on the eroded upper surface of the Hythe Formation (Ruffell 1992c). *Thickness:* 10.00 m.

Lithological characteristics: Above the base, glauconitic, calcareous sandstone beds are seen to alternate with three thin beds of fuller's earth.

b. Redhill Member, Ruffell (unpublished data)

Type section: Patteson Court, Redhill, Surrey.

Base: A gritty and pebbly bed of argillaceous silt sharply overlies the Nutfield Member.

Thickness: 15.50 m.

Lithological characteristics: Above the basal pebble bed are glauconitic, argillaceous sands, interlayered with more calcareous beds. The sands become more pebbly upwards, with an accompanying loss of the clay fraction. The topmost 3.50 m of the member comprises a micaceous clay, similar in character to the Marehill Member of the Sussex area.

(iv) Godalming district, Surrey.

The facies of the Sandgate Formation changes rapidly west of Redhill, and the lithostratigraphical divisions are different in the Godalming district of Surrey (Wooldridge 1928; Kirkaldy 1933).

a. Bargate Member, Murchison (1826)

Calcareous sandstones at the base of the Sandgate Formation were first discussed by Murchison (1826) who named the 'Bargate Stone'. The name was resurrected by Kirkaldy (1933) who made the first detailed description of the 'Bargate Beds' of Surrey and western parts of Sussex.

Type section: Godalming, south of Guildford, Surrey (SU 876381).



Figure 3.26. The lithology of the Sandgate Formation at Patteson Court, Surrey.

Base: A pebble bed at the base of the Sandgate Formation rests on the eroded upper surface of the Hythe Formation (Kirkaldy 1933).

Thickness: Reaches a maximum of 25.00 m in the North Downs.

Lithological characteristics: The member is characterised by brown, poorly sorted, crossstratified sands. Variable degrees of calcareous cementation are found in these beds, and some distinctive layers of harder sandstone occur (Lake & Shephard-Thorn 1985). In the thick North Downs succession, chert layers are common toward the top of the member. The Bargate Member is laterally extensive, having been traced from Dorking, through to at least Petersfield in Sussex (Kirkaldy 1933; 1937).

b. Puttenham Member, Kirkaldy (1933)

The term 'Puttenham Beds' was first introduced to replace 'Loamy Folkestone Beds', which were seen to occur near the top of the Sandgate Formation.

Type section: Puttenham, west of Guildford, Surrey (SU 937477).

Base: The topmost chert bed of the Bargate Member is sharply overlain by an argillaceous sand. *Thickness:* The Puttenham Member may reach 30 m thick in the depocentre of the Sandgate Formation, in the area of Stock Farm, but thins to the north and south as the London Platform and Portsdown High are approached (Ruffell 1989a).

Lithological characteristics: Glauconitic and purple argillaceous sands are recorded through the thickness of the member. The sands are typically poorly sorted and pebbly in parts (Lake & Shephard-Thorn 1985).

(v) Pulborough district, West Sussex.

Recent accounts of the Sandgate Formation of the Pulborough district have introduced a lower unit called the Fittleworth Member (Bristow *et al.* 1983; 1987). This was seen to sharply overlie the Hythe Formation and have a distinctive pebble bed at its base. The yellow and purple, glauconitic and argillaceous sands were considered to be lithologically distinct from the Bargate Member of Surrey, which they are, hence the new name. However, these beds are identical to the Puttenham Member, and therefore assigned to this division in the present study. Bristow *et al.* (1983; 1987) appear to have been influenced by the fact that their Fittleworth Member yielded a "Bargate type" fauna and, therefore, they inferred it to be the lateral correlative of this member. Not only is this unacceptable lithostratigraphical practice, but the fauna was obtained from the basal pebble bed, suggesting that the true equivalent to the Bargate Member is either very thin here (reduced to a single bed) or that it has been removed prior to the deposition of the Puttenham Member. The Puttenham Member reaches a thickness of 50 m in the Pulborough district, and is overlain by two higher members of the Sandgate Formation.

a. Pulborough Member, Wooldridge (1928)

The Pulborough Sandrock was introduced to define the fine-grained soft sandstone underlying the Marehill Member in the upper part of the Sandgate Formation near Pulborough (Wooldridge 1928; Kirkaldy 1939).

Type section: Pulborough, West Sussex (TQ 052189).

Base: Yellow sands overlie the topmost pebbly beds of the Puttenham Member.

Thickness: 9.15 m.

Lithological characteristics: A succession of uniform, soft yellow sands, with variable ironcementation, are seen through the thickness of the member. The Pulborough Member has been correlated with the Blackgang Member on the Isle of Wight and, hence, the Puttenham Member of Surrey (Casey 1961; Ruffell 1989a). An iron-pan development at the top represents a significant hiatus before the deposition of the Marehill Member.

b. Marehill Member, Kirkaldy (1933)

The Marehill Clay was introduced to describe the 10 m of dark coloured, blocky weathering, silty clay at the top of the Sandgate Formation.

Type section: Marehill, east of Pulborough, West Sussex (TQ 064186).

Base: Black clays rest sharply on the Pulborough Member.

Thickness: 10.00 m.

Lithological characteristics: The topmost member of the Sandgate Formation consists of silty, organic rich clays (Kirkaldy 1939; Casey 1961; Bristow *et al.* 1983; Ruffell 1989a). The Marehill Member has been correlated with the Rocken-End Member on the Isle of Wight (Ruffell 1989a).

As one traces eastward through Sussex, the basal part of the Puttenham Member passes into a more calcareous deposit. Bristow *et al.* (1987) noted the similarity of this unit with the Bargate Member of Surrey, but renamed it the Rogate Member. Because there is no distinction between the Bargate Member and the so called Rogate Member, the latter name should be abandoned. The Sandgate Formation thins eastward, until finally, at Berwick, it is indistinguishable as a separate lithological unit (Kirkaldy 1937; Casey 1961).

3.3.4 Folkestone Formation Drew (1864)

The most abundant outcrops in the Lower Greensand Group of the Weald Basin are in the Folkestone Formation. There are numerous quarries scattered around the region, both active and disused; the type section is found along the coast between Folkestone Harbour and East Wear Bay. It is only in their type locality, and nearby, that the Folkestone Formation comprises glauconitic "greensands". Further into western parts of Kent and in Surrey, pebbly, clean white and silty sands of the formation reach a maximum thickness of 50 m. The unfossiliferous sands are terminated abruptly by a series of silty and sandy clays, with stratigraphic breaks represented by phosphatic nodules and glauconite. Although considered to represent the topmost part of the Folkestone Formation by Casey (1961) and Owen (1971; 1992), lithostratigraphically these beds are better considered to mark the base of the Gault Formation. In the basin centre, up to 60 m of white and yellow sands are recorded, but these thin to under 30 m at Washington, and finally merge into a condensed remanié at the base of the Gault Formation towards Eastbourne (Casey 1961).

(i) Type section, Fig. 3.27.

Since the publication of Casey's 1961 work on the type Folkestone Formation, a concrete promenade has been built from the harbour, to the west, and Baker's Gap, to the east, along the length of the Folkestone Formation outcrop. The result of this, and subsequent cliff stabilisation programmes, is that the section described by Casey has become highly weathered. The only remaining beds that can be accurately recorded in this area are those that outcrop in the cliffs toward Copt Point and on the foreshore as reefs at the western end of East Wear Bay (TR 243364).

Base: At Folkestone, Casey (1961) describes a basement bed of brown and black phosphatic nodules, set within an argillaceous sand.

Thickness: 17.30 m.

Lithological characteristics: The basal nodule bed is followed upwards by glauconitic and argillaceous sands. Above is a thick succession of alternating soft glauconitic sand and calcareous sand beds. The top of the formation consists of coarse yellow sands in which there are levels of phosphatic nodules.



Figure 3.27. The lithology of the Folkestone Formation at Folkestone. f & r = floridum and raulinianus Subzones.

(ii) Western Kent and Surrey, Fig. 3.28.

Four divisions of the Folkestone Formation in the northern part of the Weald Basin were described by Gossling (1929). He divided the succession up into the Basal Pebbly Sands, Silver Sands, Clay Band and Upper Pebbly Sands. Brown (1941) recognised that the three sandy divisions were widely developed in north-western parts of Kent, and that the Clay Band extended

as far east as Westerham. Many of the pits described by Gossling and Brown are no longer active, but there are many others in which the divisions can be recognised. The most complete succession through the Folkestone Formation in this part of Kent is presently exposed in the Sevenoaks Quarry.

a. Sevenoaks Member, New name.

This member corresponds to the Basal Pebbly Sands of Gossling (1929), and is modified to comply with modern lithostratigraphical practice.

Type section: Sevenoaks Quarry, Kent (TQ 537573).

Base: The junction with the Sandgate Formation is not seen in the Sevenoaks Quarry. It is believed the pebbly basal beds of the Folkestone Formation rest sharply on the bright green argillaceous sands of the Sandgate Formation.

Thickness: Brown (1941) suggested that the member reaches a maximum thickness of 12 m, 10 m of which are seen at Sevenoaks.

Lithological characteristics: The lowest member of the Folkestone Formation comprises pink and red, iron-rich sands. The sands are highly bioturbated and distinctly cross-bedded.

b. Wrotham Member, New name.

The Silver Sands of Gossling (1929) and Brown (1941) are now considered a member of the Folkestone Formation, and named from the area at which they are presently best exposed.

Type section: Wrotham, Kent (TQ 605597).

Base: The iron-rich sands of Sevenoaks Member are terminated sharply by clean white sands. *Thickness:* This member is 15 m thick in the area surrounding Wrotham and thickness rapidly westwards to over 35 m near Farnham in Surrey. It thins eastward towards Sevenoaks, where only 6 m are recorded.

Lithological characteristics: The member comprises fine-grained, clean white sands which are cross-bedded. Iron is absent from these beds, except for speckles of black limonite.

c. Bat and Ball Member, New name.

The Upper Pebbly Sands of Gossling (1929) are presently displayed at Sevenoaks Quarry, Sevenoaks. The station close to the quarry provides the name for the newly defined lithostratigraphic unit.





Base: Orange sands rest sharply on the Wrotham Member.

Thickness: 9.50 m at the type section. It thickens to over 18 m in Surrey.

Lithological characteristics: Brown and reddish, iron-rich and glauconitic sands are cross-bedded and bioturbated. Lenses and beds of more indurated sand occur throughout. The top of the member is marked by a rubbly line containing three or four beds of hard sandstone.

In the Farnham area, a 3 m thick silty clay band is developed at the base of the member, and this has yielded an important ammonite fauna including species of *Farnhamia* (Casey 1961). This is the 'Clay Band' that has been traced into Westerham, but apparently disappears to the east of this locality.

(iii) Sussex

The Folkestone Formation consists of white, yellow and red cross-bedded sands in the Sussex region. In a large part of Sussex, instead of argillaceous sediments above the sands of the Folkestone Formation, is an horizon, up to 1.00 m thick, of iron-cemented, coarse-grained sand. The "Iron-Grit" facies, well-displayed at Rock Common Quarry (TQ 128138), indicates the position of a structural high that caused the sediments, across a 20 mile stretch of outcrop, to become condensed into a single bed (Casey 1961; Anderson 1986).

Eastward, beyond Rock Common Quarry, the Folkestone Formation sediments thin rapidly as they become more argillaceous and glauconitic.

3.4 WESTERN MARGINS OF THE WESSEX BASIN

Areas such as Wiltshire and Devon lay outside the main Weald Basin, and were only subject to periodic overspills at times of high sea-level. The facies in these isolated areas are highly variable, shallow-water sediments, deposited at the margins of the seas, and rest unconformably on the eroded Upper Jurassic (Table 3.3).

Table 3.3. The stratigraphical nomenclature of the LowerGreensand Group in Wiltshire.



(i) Faringdon

3.4.1 Faringdon Formation, Austen (1850).

Type section: Faringdon, Wiltshire.

Base: Coarse, pebbly, yellow sands rest with marked discontinuity on the Kimmeridge Formation.

Thickness: The formation reaches a thickness of about 50 m.

Lithological characteristics: Yellow, coarse-grained sandstones at the base are separated from iron-cemented sands by a pebble bed. These coarse-grained deposits are then sharply overlain by argillaceous sands. Almost identical ferruginous deposits have been recorded from Seend in Wiltshire.

(ii) Calne

3.4.2 Calne Formation, Hesselbo et al. (1990a), Fig. 3.29.

Type section: Calne, Wiltshire (SU 016 710)

Base: A phosphatic pebble bed containing derived Jurassic fossils rests erosively on the Kimmeridge Formation below.

Thickness: 7.80 m.

Lithological characteristics: The Calne Formation comprises two main units. The lower is

characterised by soft, fine to medium grained cross-stratified sands. Above a scoured surface, the sands are generally coarser grained, but contain an abundance of argillaceous matter. The Calne Formation has been suggested to be stratigraphically younger than the Faringdon Formation, based upon palynological studies (Hesselbo *et al.* 1990a; Ruffell & Wignall 1990). However, in the absence of ammonites, this proposal must remain controversial.



Figure 3.29. The lithology of the Calne and Carstone Formations of Calne, Wiltshire (from Hesselbo *et al.* 1990a).

3.4.3 Carstone Formation

An orange-red, coarse-grained, iron-cemented sandstone occurs above the Calne Formation. This deposit is believed to occupy the same stratigraphical position as other Carstones in the marginal regions of the Anglo-Paris Basin.

3.5 BEDFORDSHIRE STRAITS

North of the London Platform, the lower part of the Lower Greensand Group is only represented in remanié. The upper, Albian part, is well represented, though generally unfossiliferous, in the Bedfordshire area (Table 3.4). The Woburn Formation is the lateral correlative of the Sandgate and Folkestone Formations of the Weald Basin. Strata were deposited in a narrow tidal channel that provided the connection between the Anglo-Paris and North Sea Basins.



Table 3.4. The stratigraphical nomenclature of the Woburn Formation,Bedfordshire Straits.

3.5.1 Woburn Formation, Cameron (1892), Fig. 3.30.

Type section: Woburn Sands, Buckinghamshire (SP 923356).

Base: The base of the formation occurs at a fuller's earth seam that overlies phosphatic nodule beds, and these in turn rest unconformably on eroded Jurassic strata.

Thickness: Up to about 60 m.

Lithological characteristics: It seems highly probable that the fuller's earths in this region are lateral correlatives of the basal Sandgate Formation fuller's earths. A thick succession of sand follows and, for the main part, this correlates with the Folkestone Formation of the Weald Basin. The Woburn Formation sands tend to be fairly pure, cross-bedded quartzites, with some ironstaining in their lower parts. Overlying the sands there are a complex series of nodule bands that form the basal part of the Gault Formation. The sandy beds of the Woburn Formation in the Leighton Buzzard area can be divided into five members. Some of these members were recognised in the lithostratigraphical subdivision of the strata by Buck (1987), but were not formally defined.

Figure 3.30. A correlation of the Woburn Formation in the Leighton Buzzard area. SM= Shenley Member. *= *regularis* Subzone.



Description of the members

a. Stone Lane Member, New Name

Type section: Stone Lane Quarry, Heath and Reach (SP 929290).

Base: The base of the member is not exposed in any of the quarries in the Leighton Buzzard area. It is found, however, in a railway cutting near the town centre (C. Bristow *pers. comm.*). The sands rest sharply on the fuller's earth beds that are found at the base of the Woburn Formation (Casey 1961).

Thickness: The upper part of the Stone Lane Member is exposed at a number of pits to the north of Leighton Buzzard. A maximum thickness of 15 m is exposed at Stone Lane, and a further 25 m of sand is believed to extend downwards beneath the base of the quarry (Eyers 1992).

Lithological characteristics: From the base of the quarry, a series of highly bioturbated, finegrained sandstones containing large quantities of goethite can be seen. Throughout, the sands are speckled with horizontal feeding burrows (*Planolites*) that follow the bedding. Iron-tubes that cut across and disrupt the bedding are *Ophiomorpha*, formed during breaks in sedimentation. Cemented horizons are rich in iron and reflect transgressive omission surfaces.

b. Heath and Reach Member, New Name.

The next member of the Woburn Formation is observed in a number of pits in the Leighton Buzzard area, and shows some lateral change in facies, particularly regarding the sedimentary structures.

Type section: Stone Lane Quarry, Heath and Reach.

Base: The member commences at a distinctive pebble bed.

Thickness: The thickest development of this part of the succession is developed in the northern part of the Leighton Buzzard district, where 10.90 m has been recorded. In the pits at the south of the district, only 2.90 m is recorded (Chamberlain's Barn).

Lithological characteristics: The member comprises cross-bedded, clean "silver" sands. The sands are largely unstained with iron, which may be due to subaerial exposure and leaching. In Stone Lane, the attenuation of the cross-bedding laminae reflect ebb tide bundles that are truncated by shallowly dipping surfaces. Packaging of the sand appears to show standstill with intense bioturbation, followed by bedform migration and then further standstill. This large-scale cross-bedded pattern is superimposed upon smaller scale ripple laminations. It seems likely that the sands only moved on a large scale under the influence of large tides or during storm events, whilst ripples were produced as an every day occurrence. In Nine Acres Pit, the sedimentary structures within the Heath and Reach Member change markedly. The sands are still wave-ripple

laminated, but with only isolated cross-bedded units. The predominance of the ripple-lamination suggests that the sands laid down in Nine Acres were in a protected embayment, away from the vast tidal currents of Stone Lane. The rare large-scale cross-bedded units probably reflect storm events, and are associated with erosional channels (C. Bristow *pers. comm.*). The sands coarsen upwards and are terminated abruptly by brown cross-stratified sand.

c. Munday's Hill Member, New name

This division did not appear in the lithostratigraphy of Buck (1987), but has been termed the 'Silty Beds' in previous studies (Owen 1972; Eyers 1992).

Type section: Munday's Hill Quarry (SP 940280).

Base: The argillaceous beds of this member rest sharply on the clean white sands below. *Thickness:* 4.50 m.

Lithological characteristics: Glauconitic argillaceous silts and sands contain a shallow-water ichnofauna. This member is only preserved in the quarries around Shenley Hill.

d. Chamberlain's Barn Member, New name

Type section: Chamberlains Barn Quarry (SP 930265).

Base: In the pits in the southern part of the Leighton Buzzard area, the Heath and Reach Member is overlain by coarse brown sands. The lithological change is abrupt in all the quarries in which it is observed, and always marked by an omission surface. The junction between the Heath and Reach Member and the Chamberlain's Barn Member is best observed in Chamberlain's Barn Pit, although has also been seen at Stone Lane.

Thickness: 6.35 m at Chamberlain's Barn, thickening to 13.60 m at Pratt's Quarry to the south. This member is absent from the quarries around Shenley Hill.

Lithological characteristics: At Chamberlain's Barn, the member can be seen as a large channel, with smaller parasitic channels, which cuts down into the Heath and Reach Member and pinches out at either end of the quarry. At the base of the member are very coarse deposits, including reworked burrows. The member can be seen in Pratt's Quarry, Billington Crossing, where the largest scale cross-bedding of the Woburn Formation is displayed. The coarse brown sands of this member are then terminated abruptly by silty, glauconitic clays that form the junction with the Gault Formation above.

e. Shenley Member

Type section: Shenley Hill (presently seen at Munday's Hill Quarry).

Base: Nodular fragments of limestone or iron-cemented sand rest sharply on silty clays below.

Thickness: The member reaches a maximum thickness of about 0.50 m.

Lithological characteristics: The typical nodule beds at the base of the Gault Formation in the Leighton Buzzard area are sometimes replaced by a patchily developed nodular limestone. The limestone itself occurs as lenses within a coarse, iron-cemented sand. The nature of the member, and its stratigraphic position, at the top of the Lower Greensand Group, suggests a correlation with the Carstone Formation of the Isle of Wight and Iron-Grit of Sussex.

3.6 PARIS BASIN

A thin and stratigraphically limited Lower Greensand Group succession has been described from the Boulonnais region of the Paris Basin. The clayey, glauconitic sandstones lying above the Wealden Group were divided into four formations by Amedro & Mania (1976) and Robaszynski & Amedro (1986). This study only recognises two formations, the upper one of which is divisible into two members (Table 3.5, Fig.3.31).

3.6.1 Sandgate Formation

Descriptions of the Sandgate Formation come from the numerous quarries that once scattered the Boulonnais, and part of the formation has been seen on the foreshore of Wissant (Rigaux 1903; Dutertre 1923; 1925; 1936; 1938; Destombes & Destombes 1938; Amedro & Mania 1976). The base of the formation commences at a phosphatic nodule bed, followed upwards by glauconitic sands, which progressively pass upwards into white sand. A thickness of 8 m of the Sandgate Formation has been recorded from the Boulonnais (Amedro & Mania 1976). The basal phosphatic nodule bed was considered to represent a separate formation by Amedro & Mania (1976). However, their Cat Cornu Formation is only represented in a remanié deposit in the Boulonnais, and is best considered to form the basal part of the Sandgate Formation. Ammonites contained within the basal nodule bed indicate that it correlates with part of the Hythe Formation of eastern Kent. The sands that follow were named the Verlincthun Formation from their exposure in the Sablonnière Quarry (Amedro & Mania 1976). However, since the beds are apparently the lateral continuation of the Sandgate Formation across the English Channel the French name is abandoned.

Table 3.5. The stratigraphical nomenclature of the Lower Greensand Group of the Boulonnais, and a correlation with that of Folkestone.





Figure 3.31. The lithology of the Sandgate and Folkestone Formations in the Boulonnais.

3.6.2 Folkestone Formation

Deposits that are laterally continuous with the Folkestone Formation of the type section were divided into two formations by Amedro & Mania (1976). These are now considered as members of the Folkestone Formation which is highly condensed in the Boulonnais.

Description of the members

a. Wissant Member, (Amedro & Mania 1976).

This member was introduced as the Wissant Formation by Amedro & Mania (1986), but reduced in status to a member in the present hierarchy.

Base: Glauconitic and argillaceous sands rest sharply on white sands below and scattered phosphatic nodules occur at the contact.

Thickness: 1.00 to 2.00 m.

Lithological characteristics: Clayey-glauconitic sands, rich in Hypacanthoplites, overlie the Sandgate Formation with marked discontinuity. The member is only seen at Wissant, elsewhere having been removed by regression at the top of the Upper Aptian.

b. Gardes Member, Robaszynski & Amedro (1986, as a formation).

Base: Phosphatic nodule bed (P1) that rests sharply on the Wissant Member.

Thickness: About 1.00 m.

Lithological characteristics: Coarse green glauconitic sands ('Sables Verts'), with variable cementation overlie the phosphatic nodule bed. The member is terminated abruptly at a phosphatic nodule bed (P2, Destombes & Destombes 1938).

Lower Greensand Group deposits are poorly known from the Aube. A thick succession of Aptian clay (Argiles à Plicatules) is believed to correlate with part of the Atherfield Formation and lower part of the Ferruginous Sands Formation, but has not been exposed for many years (Leymerie 1841-1842; Casey 1961). Following a considerable period of stratigraphic gap, coarse glauconitic sands, locally called the 'Sables Verts', were deposited. In the absence of fossils, these sands have been considered to be Lower Albian in age, although Amedro (1992) suggested that they may straddle the Aptian-Albian boundary. Consolidation is rare and localised within this unit, which is believed to be in the order of 15-25 m thick (Destombes 1979).

3.7 SUMMARY AND CONCLUSIONS

The Lower Greensand Group is a highly variable succession of shallow-marine, predominantly arenaceous deposits. In the Channel Basin, four laterally continuous formations have been recorded and these can be correlated with four formations in the Weald Basin. Marginal areas of the Weald Basin, the Paris Basin and Bedfordshire Straits contain rather thinner deposits, in which condensation or remanié beds are more frequent. The topmost part of the Lower Greensand Group is commonly condensed into a coarse sandy deposit in the marginal parts of the Anglo-Paris Basin, particularly in regions which are associated with major faults. Facies changes are rapid in these shallow-water sediments, and are related to a small-scale basin and swell topography on the palaeo-seafloor, the action of large scale faults and short-term sea-level changes. The variability of lithologies around the Anglo-Paris Basin has led to the evolution of regional lithostratigraphical nomenclature, often introduced in an informal sense. This chapter has reviewed the lithostratigraphical framework, and placed all the lithologies into a workable scheme.

CHAPTER 4 GAULT AND UPPER GREENSAND FORMATIONS

From the end of the Early to the start of the Mid Albian, the Lower Greensand Group was transgressed by a deeper shelf-sea, giving rise to widely distributed and uniform clays. The deposition of these clays reached its maximum extent in the Mid Albian, when the seas had transgressed the formerly upstanding massifs. The Albian clays extend north and east of the earlier Lower Greensand Group depositional area and in their extremities overlie earlier Mesozoic and Palaeozoic strata. In the Late Albian, uplift of the area to the west of the Anglo-Paris Basin provided an influx of glauconitic, sandy deposits, which extended gradually further eastward. The lithostratigraphy, thickness and facies changes of the argillaceous Gault Formation and the more arenaceous Upper Greensand Formation are discussed in this chapter.

4.1 GAULT FORMATION

The term Gault was first applied to the Albian clays by Hailstone (1816) in his description of the beds in the Cambridgeshire area. Since this earliest account, there have been numerous studies in the stratigraphy of the Gault clays, and most particularly those considering the beds at Folkestone, where the most continuous record through the strata exists at outcrop. More recent investigations have considered the Gault as a formation, although this definition was never formalised until Rawson (1992b). It has also long been recognised that the Gault Formation may be divided into laterally extensive lower and upper divisions. These have sometimes been considered as separate formations themselves (e.g. Amedro & Robaszynski 1986), but are best viewed as members of the single formation.

4.1.1 Weald Basin

(i) Type section

I.

Despite the original description from the Cambridgeshire region, the Gault has received most attention from the coastal cliffs at Folkestone, Kent. This locality has long been considered a suitable reference section, and regarded the type for the Gault Formation as defined herein (Hancock 1972).

The Gault Formation at Folkestone is best examined in the cliffs near the sewer outlet at Copt Point. Here, the lowest beds of the Gault can be seen clearly resting on the topmost levels of the Lower Greensand Group. The highest beds of the formation are rarely exposed in a section below the Martello Tower No. 1 and their junction with the Cenomanian seen on the foreshore in East Wear Bay, below the "Horse's Head". The cliffs are undergoing active erosion by the sea and show slumping to a variable extent. The amount of section exposed at any one time is dependent on the forces of nature. During the study, numerous visits were made to the cliffs at Folkestone and the Gault was in its best condition in the spring of 1993.

Thickness: 44.00 m.

Base: There is much controversy surrounding the definition of the base of the Gault Formation. Clay deposition commenced at different times in different parts of the basin and as a result lithostratigraphical and biostratigraphical concepts have become confused. At the type section, coarse-grained yellow and glauconitic sands, containing levels of phosphatic nodules, are sharply overlain by a silty clay, containing rolled and abraded phosphatic nodules (Ruffell 1990). In traditional stratigraphic studies, this last nodule bed, the "Sulphur Band", was taken as the commencement of Gault deposition (De Rance 1868; Price 1875). Elsewhere in the Weald, the deposition of silty clay commenced earlier than at Folkestone. This led Jukes-Browne (1900) to suggest that the lowest Gault Formation at Folkestone should then be positioned at a lower level, in coarse sands previously considered to lie near the top of the Folkestone Formation, thus proposing a synchronous base for the Gault Formation. Casey (1950) noted, however, that the Gault Formation was a lithostratigraphical unit, not defined by biostratigraphy, and returned the boundary to its original level of the Sulphur Band:

'In the Geological Survey memoir on the Gault and Upper Greensand, Jukes-Browne concluded that on account of its Albian fossils this bed [the Main mammillatum Bed] should be removed from the Folkestone Beds and attached to the Gault as "Bed 1a". Apart from the historical considerations, this decision disregarded the fact that the Gault and the Folkestone Beds are lithological units, not chronological concepts based upon palaeontology...the Sulphur Band...is the bed most readily taken as the commencing point of the Gault.'

Later investigators proposed that the base of the Gault Formation should be moved upwards, to commence at a phosphatic nodule horizon 0.50 m above the Sulphur Band (Casey 1961; Owen 1971; Ruffell 1990). The basis of this reasoning was that this higher nodule bed yielded a faunal assemblage of the *eodentatus* Subzone, then considered to be the basal Middle Albian subzone, which meant that the base of the Gault Formation coincided with the base of the substage. Because this modified base of the Gault Formation was again founded upon biostratigraphical criteria, the older argillaceous beds in the northern Weald were correlated with the upper part of the Folkestone Formation, despite their lithological similarity with the basal beds of the Gault

Formation at Folkestone (Casey 1961):

"No dividing line has been drawn between Folkestone Beds and Gault in this section [Squerryes, Westerham]. Above the clean white sands of typical Folkestone facies there is a thick series of clayey sands and sandy clays that grade upwards into the Gault. If this section were considered on its own merits, the base of the Gault would be drawn at the bottom of the *mammillatum* Zone (Bed 3). This, however, is the correlative of the *kitchini* Bed of East Cliff, Folkestone, unquestionably part of the Folkestone Beds."

Owen (1971) agreed with Casey's interpretation, but by 1984 had included the *eodentatus* Subzone (renamed the *steinmanni* Subzone) in the Lower Albian *mammillatum* Zone when he revised the zonal stratigraphy of the Albian. In line with the modified zonal stratigraphy, Owen (1992) proposed that the Gault Formation should commence in the overlying *lyelli* Subzone throughout sections in the Weald. Conversely, Rawson (1992b) indicated, in his correlation table of Cretaceous strata, that the silty nodule beds should be considered to mark the basal Gault Formation, which would then extend downward into the *regularis* Subzone of the *tardefurcata* Zone in inland exposures. Since the definition of the Gault differed between authors, Destombes (1979) decided that the term could not be reliably used in any discussion on the clays that are seen in the Paris Basin.

To resolve the differences in opinion regarding the base of the Gault Formation, the lithological expression of the strata must be considered alone, without being influenced by biostratigraphical matters. When viewed in this light, the base of the Gault Formation is diachronous: at its type section deposition commenced in the *puzosianus* Subzone (Sulphur Band), but often much earlier in other localities.

Lithological characteristics: The succession at Folkestone was divided into eleven units by De Rance (1868) and these redefined by Price (1874; 1875). Jukes-Brown (1900) provided a more detailed subdivision of the lowermost part of the cliff section, which resulted in the enumeration of units I to XIII, that have been the standard until today. Spath's detailed work on the ammonite stratigraphy of the Gault Clay, resulting in his 1923-43 monograph, suggested that many of the faunal changes coincided with the boundaries between beds, and from this a zonal and subzonal scheme within Price's (1875) framework was derived. Little changed with subsequent work, and Casey's (1966) revised list of ammonites from Folkestone treats bed boundaries as the limits of subzones in most instances.

Since the publication of the ammonite distribution by Casey (1966) there have been a number

of fine detail studies on the longevities of the Gault fauna on both a macro- and microfaunal scale (e.g. Owen 1971; Hart 1973). This fine-toothed examination of the Gault has proved that only one of Price's bed boundaries correspond to a subzonal boundary (Owen 1971; 1975; Gallois & Morter 1982). Owen has concentrated much of his research on to the lower part of the Gault, and it is from this that he has added new subdivisions, these still within the thirteen main divisions and given as lower case numerals within parentheses (Owen 1963a; 1963b; 1971).

Description of the members

a. Copt Point Member, New Name, Fig. 4.1.

This member corresponds to the 'Lower Gault' of earlier authors. In line with modern hith ostratigraphical practice the member is assigned a geographical epithet.

Type section: Copt Point, Folkestone, Kent.

Base: The base of the member is the Sulphur Band.

Thickness: 12.50 m.

Lithological characteristics: The member comprises dark and medium grey clays punctuated by levels of phosphatic nodules. The clays are often silty, gritty and glauconitic, particularly toward the base of the member and near the phosphatic horizons. The clays may lighten upwards from the phosphatic levels, through glauconitic and silty clays, to medium-grey mudstones below the next phosphatic nodule bed. The topmost part of the Copt Point Member is terminated abruptly by an erosion surface.

b. East Wear Bay Member, New name, Fig. 4.2.

The Upper Gault of earlier authors is now considered a member and, therefore, renamed with a geographical epithet.

Type section: Copt Point and East Wear Bay, Folkestone, Kent.

Base: Phosphatic nodule bed that overlies an erosion surface.

Thickness: 31.50 m.

Lithological characteristics: Above the base, clays of this member are distinctively lighter in colour than the Copt Point Member, with an overall higher carbonate content. Phosphatic nodule beds and shell beds punctuate the clays, but on the whole, there is less evidence for erosion and condensation within these strata.



Figure 4.1. The lithology of the Copt Point Member at its type section (Folkestone). Price's (1875) bed numbers are shown on the right-hand side.

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Figure 4.2. The lithology of the East Wear Bay Member at its type section (Folkestone).

(ii) Correlation across the Weald Basin

The Gault Formation is developed across the entire Weald Basin, and it displays marked thickness variations. Price's divisions of the formation are not seen beyond the type section, but the Copt Point and East Wear Bay Members are traced across its outcrop. Numerous sections were described by Owen (1971), but many of these have now disappeared.

The Greatness Lane Quarry in Sevenoaks was a working pit until 1991. The section was measured whilst quarrying was still active (Fig. 4.3). The adjacent Sevenoaks Quarry displayed the lowest beds of the Gault Formation, whilst Greatness Lane exposed the remainder of the Copt Point Member and lower part of the East Wear Bay Member (Owen 1963; 1971; 1976; Milbourne 1961). After cessation of operations, the section degraded rapidly and marker beds were soon lost.

Presently, a number of sandpits in western Kent and eastern Surrey display the basal beds of the Gault Formation. Clean white sands at the top of the Folkestone Formation are overlain abruptly by several metres of silty clays and argillaceous sands (Fig. 4.4). The beds are highly glauconitic and contain several levels of phosphatic nodules. They are best exposed at Squerryes Main Pit, Westerham. Here, they were considered to form a separate member at the junction between the Folkestone and Gault Formations, which Owen (1992) called the Junction Beds Member. The same unit was included by Rawson (1992b, table 12.2.) in the Gault Formation. The beds are similar in facies, although not in age, to the lowest part of the Copt Point Member at the type section and there is no basis for their lithostratigraphical separation from that member.

Through Surrey, into Sussex, there are no remaining sections through the Gault Formation until Rock Common Quarry, near Washington. The quarry was granted permission to extend its operations in 1991, and as a result stripped back the clays to reveal a clean section through the lowest parts of the Copt Point Member (Fig. 4.5). A clear dark-pale rhythmicity is observed in this part of the succession which is much expanded compared with its highly condensed equivalent at Folkestone.



Figure 4.3. The lithology of the Gault Formation (Copt Point and East Wear Bat Members) at Sevenoaks and Greatness Lane Quarries.

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Figure 4.4. The lithology and a correlation of the Gault Formation (Copt Point Member) exposed in Squerryes Main Pit (Westerham) and Pearson's Sandpit (Addington).


Figure 4.5. The lithology of the Gault Formation (Copt Point Member) exposed in Rock Common Quarry (Washington).

The most complete and expanded section of the Copt Point Member was described from the Horton Hall Clay Pit at Small Dole (Milbourne 1965; Owen 1971). The Blue Circle cement works was famous for its well preserved faunas, from strata that are often missing or highly condensed in other parts of the Weald. However, land fill operations commenced in 1991 and as a result little remains of the section. A portion of the pit was to be retained as an S.S.S.I., but was unavailable for measurement during the production of this thesis. Another relatively uncondensed section through both the Copt Point and East Wear Bay Members, was recorded in the Glyndebourne borehole, near to Lewes (Lake *et al.* 1988, Fig. 4.6. here).



Figure 4.6. A correlation of the Gault Formation between Horton Hall (Small Dole) and the Glyndebourne borehole.

4.1.2 Channel Basin

The Gault Formation of the Channel Basin is prone to being rather gritty and unfossiliferous. In this part of the Anglo-Paris Basin, the individual members of the Gault Formation cannot



Figure 4.7. The lithology of the Gault Formation at Blackgang (Chale Bay, Isle of Wight).

easily be traced, and on the whole the succession appears rather incomplete. The clays become progressively more silty upwards, and pass into the Upper Greensand Formation. The best exposure of the Gault Formation in the Channel Basin is found in the Isle of Wight, and the section at Blackgang is given in Figure 4.7. The clays have been estimated as reaching 30 m thick in the region between Sandown and Blackgang, but thin to only 20 m westward towards Compton (Owen 1971).

4.1.3 Bedfordshire Straits, Fig. 4.8.

The Gault Formation is well preserved in areas to the north of the London Platform, and useful stratigraphic information can be derived from the clays, particularly in the area surrounding Leighton Buzzard. Silty, argillaceous and glauconitic nodule beds rest sharply on the top Woburn Formation in many of the pits of the Leighton Buzzard area. This 'junction' facies with the Gault Formation is the lateral correlative of the basal part of the Copt Point Member of the northern Weald. Wright and Wright (1947) subdivided the phosphatic nodule beds of Pratt's Quarry into four bands, each containing a well-preserved ammonite fauna. Presently the best exposure of the lower part of the Copt Point Member is in Chamberlain's Barn Quarry, where a similar succession to that seen at Pratt's has been measured, although exact correlation of the "Bands" is difficult. Whilst deposition of the Gault Formation had commenced in the southern part of the Leighton Buzzard area, the pits around Shenley Hill (e.g. Munday's Hill) show that there, Lower Greensand Group deposition was still continuing. This area must have been lying on a swell region during the Early Albian, and the Shenley Member, with its typical 'carstone' facies, was developed. By the early Mid Albian, deeper shelf seas saw the commencement of Gault Formation deposition throughout the Bedfordshire area, and beds of the Copt Point Member extend eastward into Cambridgeshire and East Anglia.

The East Wear Bay Member commences at a phosphatic nodule horizon, as at the type locality, but only the lower part of this member is displayed in any of the quarries surrounding Leighton Buzzard. However, it has been demonstrated that the clay facies extends upward for the remainder of the Albian. These clays are laterally persistent through Bedfordshire, Cambridgeshire and East Anglia, although becoming rather silty in some areas (Bristow & Morter 1982). The topmost parts of the clay may have been removed by latest Albian regression, and the formation is sharply overlain by the Cambridge Greensand Formation. This latter formation yields a remanié fauna including ammonites of Late Albian age (Spath 1923-1943).



Figure 4.8. The lithology and a correlation of the Gault Formation (Copt Point Member) exposed at the Chamberlain's Barn and Munday's Hill quarries.

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4.1.4 Paris Basin



Figure 4.9. The lithology of the Gault Formation at Wissant (Boulonnais).,

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A succession of clays is present along the coastal section between Strouanne and Petit Blanc Nez, east of Wissant. French workers have also called the clays "Gault", and they are the correlatives of the Copt Point Member and part of the East Wear Bay Member as developed at the type section, but much thinner. Robaszynski & Amedro (1986) renamed the clays as the Saint Pô Formation. However, this name should be abandoned as it is synonymous with the Gault Formation.

In the more condensed Gault Formation at Wissant, the base is defined at a phosphatic nodule bed that overlies the Folkestone Formation. The nodules in this bed have yielded fossils of both the *mammillatum* Zone and *dentatus* Subzone, and are set within a matrix of the latter subzone age. Dark grey clays are glauconitic and gritty at the base, and become lighter upward. Levels of phosphatic nodules numbered P3 to P6 punctuate the succession, and show direct correlation with the Gault Formation clays of the type section (Destombes & Destombes 1938). Phosphatic bed P5 defines the base of the East Wear Bay Member of the Wissant succession.

(ii) The Aube, Fig. 4.10.

The type section for the Albian stage lies in the department of the Aube, on the south-eastern margin of the Paris Basin. Here, argillaceous deposits are seen, mostly being recorded from quarries that operated in the region. There was never a single representative section through the Gault Formation; the stratigraphy has been pieced together from isolated outcrops surrounding the River Aube. The decline of quarrying operations has seen the destruction of most Gault sections. The outcrops that do remain are largely degraded and have suffered from over-collection. The Lower and Middle Albian strata has been examined in detail by previous authors, but little is published on the very poorly exposed Upper Albian (Owen 1971; Destombes 1979). The Lower Albian strata of this region is represented within a clay facies. Lithostratigraphical subdivision of the strata into the 'Argiles tégulines de l'Aube' and 'Marnes de Brienne' was performed by Destombes (1979). These two members are again lateral continuations of the Copt Point and East Wear Bay Members of the Gault Formation, and the informal definition of Destombes should be abandoned.

Figure 4.10. The lithology of the Gault Formation, compiled from isolated outcrops and borehole data, in the Aube.



4.2 UPPER GREENSAND FORMATION, Webster (1825)

4.2.1 Weald Basin

In the western part of the Wessex Basin, the Copt Point Member becomes gradually more silty upwards. This coarsening upwards of the Gault Formation foreshadows the influx of sand that commenced near the start of Late Albian times, represented in the Upper Greensand Formation. As with the basal part of the Gault Formation, the base of the Upper Greensand is diachronous, becoming gradually younger eastward. At its greatest extent, the glauconitic sandy facies of the Upper Greensand Formation extended as far east as Sevenoaks along a line drawn from Dunstable to Eastbourne (Owen 1975; Rawson 1992b). The Upper Greensand Formation of the Weald is thickest near to Selbourne (reaching about 100 m). The most recent measurements of the Upper Greensand Formation of the western Weald, and the most fossiliferous deposits, were recorded by Owen (1975), and his section from Mertsham is re-drawn in Figure 4.11. Unfortunately little outcrop of the formation remains in the Weald Basin at present, except for a few unfossiliferous roadside cuttings. However, it is known to thin across the Mid Dorset Swell and then thicken again at its type section in the Channel Basin.

4.2.2 Channel Basin

A thick succession of the Upper Greensand Formation is displayed in the cliffs above Rocken-End, above the Gault Formation, on the Isle of Wight.

(i) Type section, Fig. 4.12.

The type section of the Upper Greensand Formation is in Chale Bay, Isle of Wight, where the name was first proposed by Webster (1825).

Base: The Upper Greensand Formation passes up from the Gault Formation through blue-grey silty clays. The junction between the two formations is at a line of calcareous concretions with a brown phosphatic core.

Thickness: A 30 m thick succession has been recorded at Chale Bay, and this is believed to thicken to a maximum of 40 m in the south-eastern part of the Isle of Wight.



Figure 4.11. The lithology of the Upper Greensand Formation at Mertsham, Surrey (Owen 1975).

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Figure 4.12. The lithology of the Upper Greensand Formation at Blackgang (Chale Bay, Isle of Wight).

Lithological characteristics: The lowest beds of the Upper Greensand Formation comprise sandy micaceous clays and argillaceous sands. The beds are argillaceous at their base, but become more arenaceous upwards. This lower unit passes into the calcite cemented, blue-grey glauconitic sand and siltstones forming the cliffs above Chale Bay. Phosphatic and calcareous concretions are common to many of the beds, as is bioturbation.

The Upper Greensand Formation of the Isle of Wight was divided into six lithostratigraphical units, lettered A to F, by Jukes-Brown (1900), and essentially encompasses two members. The members have never formally been named, but are referred to as the Passage Beds (Unit A) and Upper Greensand *sensu stricto* (Units B to F) in earlier accounts (e.g. Osborne -White 1929). The Upper Greensand Formation is best exposed in the vertical cliffs at the eastern end of Chale Bay, and forms the undercliff extending from Niton to Ventnor. The beds are prone to slipping, due to the Gault Formation clays that underlie the stronger, calcareous beds of the Upper Greensand Formation. As a result, there are few localities from which accurate measurements of the Upper Greensand Formation may be performed and repetitious successions are produced by landslides. A rich ammonite fauna has been recorded from the Upper Greensand Formation. However, because of the problems outlined above, it is often very difficult to accurately horizon material that is often found loose or within slumped and fallen blocks. Because of the time constraints imposed on the present study, only limited investigation has been made of the Upper Greensand Formation.

(ii) Dorset and Devon, Fig. 4.13.

The Upper Greensand Formation is well-known from south-western parts of England, particularly Dorset and Devon. In these areas it reaches a thickness approaching 100 m. On the Dorset coast three members have been defined. These beds are always poorly fossiliferous and the stratigraphic age is often controversial. Presently a review of the lithostratigraphy of the Upper Greensand Formation is being undertaken by a team of researchers from Plymouth (Simmons *et al.* 1991). Because of this, the members are only dealt with very briefly.

a. Foxmould Member, De La Bèche (1826).

Type section: Black Ven, Dorset.

Base: The base of the Foxmould Member is diachronous, and may either rest on micaceous clays, equivalent to the lower part of the East Wear Bay Formation, or directly on the Triassic. *Thickness:* Ranges from about 20 - 25 m.



Figure 4.13. The lithology of the Upper Greensand Formation in Dorset.

Lithological characteristics: Yellow, green or grey glauconitic sands which contain lenses of hard calcareous concretions, particularly in the lower part of the member. In more northern parts of Devon, the Foxmould Member passes laterally into the Blackdown beds of Fitton (1836).

b. Chert Beds, Meyer 1874

The beds described by Meyer obviously form a member, and the unit requires a definition and modification to fit with modern lithostratigraphical procedure. It is expected that this modification will appear with the revision of the lithostratigraphy of the Upper Greensand Formation.

Type section: Dorset Coast.

Base: Rests sharply on the topmost Foxmould Member. At the base is a distinctive shell bed, named the 'Exogyra Sandstone' by Wilson (1958).

Thickness: Up to about 30 m at the type section, but thins rapidly westwards.

Lithological characteristics: Fine-grained, calcareous and slightly glauconitic silty sands with lenses of chert.

c. Eggardon Member, Wilson 1958

Type section: Eggardon Hill, Bridport, Dorset.

Base: Rests sharply on the Chert Beds below.

Thickness: The member reaches 1-3 m thick.

Lithological characteristics: Soft, calcareous sandstones coarsen upwards, with increased cementation. The member is capped by an erosion surface, upon which rest the lowest beds of the Chalk Group.

4.3 SUMMARY AND CONCLUSIONS

The Lower Greensand Group was transgressed, and overstepped by the laterally widespread and relatively uniform Gault Formation. Deposition of these strata commenced towards the end of the Early Albian in the most basinal areas, but not until the mid part of the Mid Albian in the more marginal localities. Unlike in the Lower Greensand Group, lateral continuity of the beds has allowed a more stable lithostratigraphical nomenclature to develop. However, indecision and differences of opinion regarding the base of the formation have led to the abandonment of the term 'Gault' by French workers in the Paris Basin. Because the base is now defined clearly within a lithostratigraphical sense, the earlier problems should not persist and localised terms for the lateral continuations of the Gault Formation should be removed from use.

Most authors have recognised laterally extensive lower and upper divisions of the 'Gault Clay'; the present study views these as members of a single formation. Toward the top of the Albian, the calcareous sandy and glauconitic Upper Greensand Formation replaced the clays in western areas of the basin. The base of this formation is diachronous and it becomes younger to the east. A detailed subdivision of the Upper Greensand Formation has not been attempted and the old divisions have been retained.

CHAPTER 5 BIOSTRATIGRAPHY

5.1 INTRODUCTION

Much of what we understand of the standard zonation for the Aptian and Albian has been acquired from the many years of work carried out in southern England. Two monographic works form the basis of the ammonite zonation: Casey (1960-1980) monographed the Lower Greensand ammonites, and Spath (1923-1943) the Gault Formation.

Two major problems with the monographs are encountered when the ammonite distributions are examined. Firstly, both Spath and Casey tended to consider that biostratigraphical and lithostratigraphical boundaries were coincident with one another. It is, however, well known that the distribution of ammonites is restricted in the largely sandy Lower Greensand Group, and Casey's interpretations were based on the best fit to the available data. Since Casey proposed his zonation following many years' study on sections that are no longer in existence many of his recommendations have to be followed, with some reservations, because there is nothing better to replace them with. A second consideration lies in the concept of the species. Much of the material was split into a large number of 'species' that often differed only in trivial morphological detail. This has often obscured taxonomic relationships, though at times the 'splitting' into tightly defined morpho-species can be justified when it gives greater stratigraphic resolution.

Casey (1961) defined a zonal scheme for the Aptian and Lower Albian, much of it modified from earlier work in the Paris and Lower Saxony Basins (Jacob 1907; Brinkmann 1937; Breistroffer 1947; & references in Casey 1961). There are a number of problems with Casey's (1961) biozonation of the Lower Greensand Group, some of which cannot be fully resolved, largely due to the lack of datum points.

The first workable zonation of the Albian stage was proposed by Spath (1923); this was revised by him (1941) to something approaching the modern day framework. This scheme was based mainly upon the well-preserved ammonite fauna that was collected from the Gault Formation, particularly of Folkestone, East Kent. What made the scheme different from many of those proposed by Spath for other parts of the stratigraphic column was that much of the evidence acquired for the zonation was based upon his own field collection, and not examination of museum material and literature review. As more and more collections were made from the numerous sections that became available in the Gault Formation, modifications to the British zonal scheme gradually led to better resolution of the correlations; Casey (1961) and Owen (1984a; 1984b; 1988a) revised the Lower Albian, Owen (1958; 1960; 1971, 1984a), Milbourne (1955; 1963) and Hancock (1965) considered the Middle Albian, and Owen (1975) revised the zonation of the Upper Albian.

Work in northern France produced a different zonation for the Albian, based upon sometimes more complete sedimentary successions (Destombes & Destombes 1965; Destombes 1973; 1979; Amedro 1980; 1985; Amedro *et al.* 1981). The final synthesis of this French research was to provide a phyletic zonation based on the evolution of the principal families (Amedro 1980). The purpose of the phyletic zonation was to rid the schemes of superfluous zones and subzones, and to display the evolution of the dominant ammonite forms within the zonation itself (Robaszynski & Amedro 1986; Amedro 1992). However, despite these claims, the phyletic zonation reduces resolution in stratigraphical correlations and makes the tracing of inter-regional events all the more difficult, being based solely upon endemic species for the Middle Albian.

The recent zonal schemes are examined critically by the present author and the distributions of the index species are considered. In the light of these investigations, some proposed alterations are made to the biozonation in an attempt to aid correlation in often poorly fossiliferous strata. The results are shown alongside the most recently published ammonite time-scale (Hancock 1991) in Table 5.1.

	Hancock (1991)		Present Study	
UPPER ALBIAN	Stoliczkaia dispar	Mortoniceras (Durnovarites) perinflatum	Stoliczkaia dispar	Mortoniceras (Durnovarites) perinflatum
		Mortoniceras (M.) rostratum		Mortoniceras (M.) fallax
	Mortoniceras (M.) inflatum	Callihoplites auritus	Mortoniceras (M.) inflatum	Mortoniceras (M.) inflatum
		Hysteroceras varicosum		Hysteroceras varicosum
		Hysteroceras orbignyi		Hysteroceras orbignyi
		Dipoloceras cristatum		Dipoloceras cristatum
	Euhoplites lautus	Anahoplites daviesi	Euhoplites lautus	Anahoplites daviesi
		Euhoplites nitidus		Euhoplites nitidus
BIAN	Euhoplites loricatus	Euhoplites meandrinus	Euhoplites loricatus	Mojsisovicsia subdelaruei
LE AI		Mojsisovicsia subdelaruei		
IDD		Dimorphoplites niobe		Dimorphoplites niobe
M		Anahoplites intermedius		Anahoplites intermedius
	Hoplites (H.) dentatus	Hoplites (H.) spathi	Hoplites (H.) dentatus	Hoplites (H.) dentatus
		Lyelliceras lyelli		Lyelliceras lyelli
	Douvilleiceras mammillatum	Pseudosonneratia (I.) steinmanni		Hoplites (Isohoplites) steinmanni
N		Otohoplites bulliensis	Douvilleiceras mammillatum	Protohoplites puzosianus
ALBIA		Protohoplites puzosianus		
LOWER A		Otohoplites raulinianus		Otohoplites raulinianus
		Cleoniceras floridum		Cleoniceras floridum
		Sonneratia kitchini		Sonneratia kitchini
	Leymeriella tardefurcata	Leymeriella regularis	Leymeriella tardefurcata	Leymeriella regularis
		Leymeriella acuticostata		Farnhamia farnhamensis
		Leymeriella schrammeni		

Table 5.1. Zonation of the Aptian-Albian in the Anglo-Paris Basin.

UPPER APTIAN	Hypacanthoplites jacobi	Hypacanthoplites anglicus	Hypacanthoplites jacobi	Hypacanthoplites anglicus
		Hypacanthoplites rubricosus		Nolaniceras nolani
		Nolaniceras nolani		
	Parahoplites nutfieldiensis	Parahoplites cunningtoni	Parahoplites nutfieldiensis	Parahoplites cunningtoni
		Tropaeum (Epitropaeum) subarcticum		Tropaeum (Epitropaeum) subarcticum
	Cheloniceras (Epicheloniceras) martinioides	Ch. (Epicheloniceras) buxtorfi	Cheloniceras (Epicheloniceras)	Ch. (Epicheloniceras) gracile
		Ch. (Epicheloniceras) gracile	martinioides	
		Ch. (Epicheloniceras) debile		Ch. (Epicheloniceras) debile
	Tropaeum (Tropaeum) bowerbanki	Ch. (Cheloniceras) meyendorffi	Dufrenoyia furcata	Ch. (Cheloniceras) meyendorffi
		Dufrenoyia transitoria		Dufrenoyia transitoria
N	Deshayesites deshayesi	Deshayesites grandis	Deshayesites deshayesi	Deshayesites grandis
LOWER APTIA		Ch. (Cheloniceras) parinodum		Deshayesites deshayesi
	Deshayesites forbesi	Deshayesites callidiscus	Deshayesites forbesi	Deshayesites callidiscus
		Deshayesites kiliani		Deshayesites kiliani
		Deshayesites fittoni		Deshayesites fittoni
	Prodeshayesites fissicostatus	Prodeshayesites obsoletus	Prodeshayesites fissicostatus	Prodeshayesites obsoletus
		Prodeshayesites bodei		Prodeshayesites fissicostatus

5.1.1 The terms used and their definition

Each biozone and bio-subzone is defined by its relations to the biozones (or sub-biozones) that occur below and above. Depending upon the material available and the ranges of the ammonites, different criteria are used to define the zones. The terms used, and their definitions, were discussed by Whittaker *et al.* (1991) and are shown in Table 5.2.

Table 5.2. The definition of the biozones encountered in the Aptian and Albian of the Anglo-Paris Basin.



The ammonites occur sporadically in the strata, and very rarely can one record a continuous faunal succession, and therefore most of the biozones are 'interval biozones'. In condensed strata, the indices may appear to have a continuous range through the biozone, but interval

biozones are recommended, for the apparent range may be due to the condensation rather than representing the true range.

Assemblage biozones were discussed by Whittaker *et al.* (1991), where it was stated that an absolute definition of these types of zone was imprecise. In this study assemblage biozones are used in a definite way, in that the base of the zone is marked by the appearance of a taxon other than the index. The ranges of the taxa in the assemblage may or may not overlap.

5.2 ZONATION OF THE LOWER APTIAN (Table 5.3).

The Lower Aptian is characterised by the deshayesitid ammonites, which show an evolutionary lineage from *Prodeshayesites*, through *Deshayesites* to *Dufrenoyia*. This evolution of the closely knit subfamily of ammonites can be used to zone the entire substage and produce a phyletic framework along the lines of that proposed by Amedro (1980) for the Albian. In relatively expanded and complete sedimentary successions, the zonation is fully developed. In less complete successions stratigraphic gaps are then clearly highlighted.

5.2.1 Prodeshayesites fissicostatus Interval Biozone, Casey (1961).

Definition: The base of the zone is defined by the first appearance of *P. fissicostatus* and it ranges to immediately below the appearance of *Deshayesites forbesi*.

Type section: Speeton, Yorkshire.

Discussion: The zone essentially defines the period at the base of the Aptian stage in which species of *Prodeshayesites* were dominant over all other ammonites. *Deshayesites* appeared towards the top of the zone, but always as a minority of the overall assemblage. The definition of the *fissicostatus* Zone given by Casey (1961) encompassed two subzones, and these are emended herein.

Distribution: The only indigenous examples of the zonal species occur near the top of the Speeton Clay Formation of Yorkshire and in the Skegness Clay Formation of Lincolnshire (Casey 1963; Gallois 1965). However, the zone is widely represented in remanié beds on the East Midlands Shelf, extending towards the Bedfordshire Straits. Late *fissicostatus* Zone sediments are distributed widely in the Weald and Channel Basins.

Table 5.3. The zonation of the Lower Aptian.

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(1961)	This study, with range of index.	
Subzones	Zones	Subzones
Cheloniceras meyendorffi	Dufrenoyia furcata	Cheloniceras meyendorffi
Dufrenoyia transitoria		Dufrenoyia transitoria
Deshayesites grandis	Deshayesites deshayesi	Deshayesites grandis
Cheloniceras parinodum		Deshayesites deshayesi
Deshayesites callidiscus	Deshayesites forbesi	Deshayesites callidiscus
Deshayesites kiliani		Deshayesites kiliani
Deshayesites fittoni		Deshayesites fittoni
Prodeshayesites obsoletus	Prodeshayesites fissicostatus	Prodeshayesites obsoletus
Prodeshayesites bodei		Prodeshayesites fissicostatus
	(1901) Subzones Cheloniceras meyendorffi Dufrenoyia transitoria Deshayesites grandis Cheloniceras parinodum Deshayesites callidiscus Deshayesites kiliani Deshayesites fittoni Prodeshayesites obsoletus Prodeshayesites bodei	SubzonesZonesCheloniceras meyendorffiDufrenoyia furcataDufrenoyia transitoriaDufrenoyia furcataDeshayesites grandisDeshayesites deshayesiCheloniceras parinodumDeshayesites deshayesitDeshayesites callidiscusDeshayesites forbesiDeshayesites kilianiDeshayesites forbesiProdeshayesites obsoletusProdeshayesites fissicostatus

a. Prodeshayesites fissicostatus Sub-biozone, New name

Definition: The base is defined as for the zone. However, the top is not clearly established in the absence of succeeding fossiliferous deposits.

Type section: Speeton, Yorkshire.

Discussion: The basal subzone of the fissicostatus Zone was defined as the P. bodei Subzone (Casey 1961). In Casey's (1963, p.359) discussion, he states that the bodei type coiling and ribbing is assumed by adult specimens of P. fissicostatus. Inner whorls of both forms occur together at Speeton (e.g. Rawson collection) and the writer considers that, as hinted by Casey, these are variants of one species. Thus, the former bodei Subzone is here renamed to the fissicostatus Subzone. Forms of Prodeshayesites transitional to P. fissicostatus have been obtained from Speeton, Lincolnshire, Cambridgeshire and Bedfordshire. The fissicostatus Subzone has a wide distribution, and basal Aptian sediments have been proved from the clays of Germany (Kemper 1973; Casey 1980). Delanoy (1991) identified the subzone near the type section, in the Aptian, of the Vocontien Basin of south-east France, but the ammonites illustrated by him do not show any of the diagnostic features of Prodeshayesites.

b. Prodeshayesites obsoletus Sub-biozone, Casey (1961), emended herein, Fig. 5.1.

Definition: The base of this subzone has been defined using lithostratigraphical boundaries, rather than the appearance of diagnostic fossils. This rather unsatisfactory definition is used in the absence of ammonites in the basal Lower Greensand Group beds in southern England. *Type section:* Atherfield Point, Isle of Wight.

Discussion: Specimens of P. obsoletus are recorded from the upper part of the Perna Member of Atherfield Point and at Redcliff, Sandown Bay, and have been used to date the member as a whole (Casey 1961). P. obsoletus and its allies do not appear until the topmost calcareous and sandy beds of the Perna Member at Atherfield, and a single specimen has been collected from the topmost part of the clay below at Redcliff (Casey 1961; 1963). The Atherfield Bone Bed only contains derived Jurassic ammonites and the lower clay of the Perna Member contains no ammonites. No specimens of P. obsoletus have been recovered from Speeton nor the East Midland Shelf. The only evidence that the P. obsoletus Subzone is younger than the P. fissicostatus Zone is the co-occurrence in the former subzone of Prodeshayesites with the later deshayesitid genus Deshayesites.

Figure 5.1. The distribution of the index and characteristic species in the topmost *fissicostatus* Zone and *forbesi* Zone at their type section, Chale Bay (Isle of Wight).



Not only is the *obsoletus* Subzone fauna absent from the north of England, but it has not been categorically proven from the clays of the Lower Saxony Basin. Casey (1980) noted that Kemper identified a feebly ornamented *Prodeshayesites* from northern Germany as *P. obsoletus*. Casey suggested that the strength of the ribbing on the nucleus shows closer affinity to *P. lestrangei*, a species associated with typical *fissicostatus* Subzone ammonites in northern England. Casey (1964) recorded that *P. lestrangei* is restricted to his *bodei* Subzone on the East Midlands Shelf and Bedfordshire Straits, having been recovered from the remanié at the base of the Hunstanton Carstone Formation and Sutterby Marl Formation, and the base of the Lower Greensand Group at Upware. However, a possible record of the species occurs at the top of the Perna Member at Redcliff, Sandown, Isle of Wight. If the identification of the ammonite fauna is correct there are two possible alternatives. On the one hand it may by that *P. lestrangei* ranges through both the *fissicostatus* Subzone. Since nowhere is the *obsoletus* Subzone may overlap with the *fissicostatus*, this question cannot be answered at present.

Distribution: Represented at the base of the Atherfield Formation across the Channel and Weald Basins.

5.2.2 Deshayesites forbesi Interval Biozone, Casey (1961), Fig. 5.1.

Definition: Ranges from the appearance of Deshayesites forbesi to immediately beneath the appearance of D. deshayesites.

Type section: Chale Bay, Isle of Wight.

Discussion: The Zone of D. forbesi was introduced by Casey (1961) to highlight the errors that had persisted in earlier work concerning the identification of the deshayesitids. He noted that many specimens recorded by earlier workers as Deshayesites deshayesi in fact belong to D. forbesi. Casey showed that true D. deshayesi appear much higher in the succession than previously considered, an idea that is still accepted today.

Casey (1961) considered that the *forbesi* Zone commenced at the base of the Chale Member. However, the basal beds are barren of fossils. Following modern biostratigraphical practice, these beds are therefore included in the *fissicostatus* Zone. The Zone of *D. forbesi* begins with the first appearance of the index species 3 m above the base of the member.

D. forbesi occurs spasmodically through the remainder of the Atherfield Formation, and specimens are best known from the concretionary levels that characterise the Crackers Member. Early investigations into the stratigraphy of the Lower Greensand Group of the Isle of Wight

defined a 'Crackers Group', which embraced the Lower Lobster, Crackers and Upper Lobster Members of modern nomenclature. Numerous museum specimens are labelled 'Crackers', although some may have come from the members adjacent to the sand body itself. Also, some concretions in the Lower Lobster Member have an almost identical appearance to those of the Crackers Member concretions and if found loose on the beach they could be confused. With these problems, and the discontinuous nature of the ammonite distributions, it is difficult to fully resolve the ranges of particular species in the Atherfield Formation. Beyond the type section, into the Weald, *D. forbesi* is relatively common in the upper levels of the condensed Atherfield Formation where subzonal division is not possible.

Distribution: Rare occurrences of the index species in the Chale Member, common in the Lower Lobster, Crackers and Upper Lobster Members of Atherfield Bay; Punfield Bed of Dorset; Atherfield Formation of Dover and upper levels of the Atherfield Formation around the Weald.

a. Deshayesites fittoni Interval Sub-biozone, Casey (1961), emended herein

Definition: Ranges from the appearance of D. fittoni to below the appearance of the first Roloboceras sp.

Type section: Chale Bay, Isle of Wight.

Discussion: The base of the *D. fittoni* Subzone corresponds to the base of the *forbesi* Zone. The top part of the subzone is without ammonites.

Distribution: Apart from the type section, some rare examples of the index species have been recorded from Haslemere, Surrey by Casey (1963).

b. Deshayesites kiliani Assemblage Sub-biozone, Casey (1961) emended herein

Definition: The base is defined at the appearance of the first Roloboceras sp, the co-existence of Roloboceras spp. with Deshayesites kiliani and the zone ranges to below the appearance of D. callidiscus.

Type section: Chale Bay, Isle of Wight.

Discussion: The index species, D. kiliani, does not appear until Bed 12 of the Lower Lobster Member, leaving a gap of c.7 m between the last D. fittoni and first D. kiliani. However, species of Roloboceras occur in lower levels of the Lower Lobster Member, and are now used to indicate the lower part of the kiliani Subzone.

Distribution: This subzone has not been proved unequivocally in the more condensed successions beyond Atherfield Bay on the Isle of Wight.

c. Deshayesites callidiscus Interval Sub-biozone, Casey (1961)

Definition: Ranges from the appearance of D. callidiscus to immediately below the appearance of D. deshayesites.

Type section: Chale Bay, Isle of Wight.

Discussion: The base of the *callidiscus* Subzone is clearly defined at the appearance of the index species at the base of the Crackers Member. The index ranges up into the Upper Lobster Member, and is particularly common in Bed 3.

Distribution: Representatives of the D. callidiscus Subzone have been traced into the Dover Colliery shafts and found within the Punfield Bed of Dorset.

5.2.3 Deshayesites deshayesi Interval Biozone, Casey (1961), Fig. 5.2.

Definition: The base is defined by the first appearance of Deshayesites deshayesi. The zone ranges up until below the first appearance of Dufrenoyia sp.

Type section: Chale Bay, Isle of Wight.

Discussion: The *deshayesi* Zone was described long before Casey (1961), from both the Weald and Paris Basins. However, it was Casey who recognised that this zone occurs much higher in the succession than proposed by the earlier workers (e.g. Spath 1942). The *deshayesi* Zone is characterised by more complex forms of *Deshayesites* than in the preceding *forbesi* Zone, these essentially being the transitional forms to the late deshayesitid genus, *Dufrenoyia*. Casey (1961) proposed that the zone encompassed two subzones based upon the succession on the Isle of Wight, and these are modified in the present investigation.

Distribution: The *deshayesi* Zone is widely developed across the Channel and Weald Basins, in the Ferruginous Sands and Hythe Formations respectively. Important remanié faunas of this age have also been recovered from the northern part of the Paris Basin and the East Midlands Shelf.

a. Deshayesites deshayesi Interval Sub-biozone, New name.

Definition: Ranges from the first appearance of D. deshayesi to just beneath the first D. grandis. Type section: Lower Gryphaea Member, Chale Bay, Isle of Wight.

Discussion: The range of the deshayesi Subzone is almost equivalent to that of Casey's (1961) Cheloniceras parinodum Subzone. At its type section, the index species is found alongside other

Figure 5.2. The distribution of the index and characteristic species in the *deshayesi* Zone of the type section (Chale Bay, Isle of Wight).



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species of *Deshayesites* and early examples of *Cheloniceras* at the base of the Lower Gryphaea Member. *Cheloniceras parinodum* is found towards the top of the member, in the sands and concretions of Bed 10. If this were simply the case it could be argued that an assemblage subbiozone is recorded, in which the nominate species may be either of *D. deshayesi* or *Ch. parinodum*. However, also occurring within the nodules of Bed 10 are the first records of *Deshayesites grandis*. It was inferred by Casey (1961) that there are two ages of nodules represented at the top of the Lower Gryphaea Member; the older containing poorly preserved *Cheloniceras parinodum* and the younger specimens of *D. grandis*. There is, however, no evidence to suggest that these nodules are of different ages and apparently the ranges of *Ch. parinodum* and *D. grandis* overlap.

Distribution: Widely developed at the base of the Ferruginous Sands Formation of the Channel Basin and Hythe Formation of the Weald Basin.

b. Deshayesites grandis Interval Sub-biozone, Casey (1961).

Definition: Ranges from the first appearance of *D. grandis* to immediately below the appearance of *Dufrenoyia*.

Type section: Chale Bay, Isle of Wight.

Discussion: The D. grandis Subzone is problematic when correlating strata from the Isle of Wight to the Weald and beyond. The index species has been recorded from Atherfield Bay on the Isle of Wight, where it occurs in large numbers, and in a condensed bed in eastern Kent (Casey 1961). Elsewhere, grandis Subzone sediments may carry a restricted fauna, but this does not include the index. Casey (1961) used *Tropaeum hillsii* to established the presence of the grandis Subzone in sections around the Weald Basin. However, it was also noted by Casey that *T. hillsii* had not been proven in the grandis Subzone of Atherfield, and that species of *Tropaeum* did not appear until the following zone. Casey justified the correlation of the grandis Subzone using *Tropaeum hillsii* by the co-existence of D. grandis and T. hillsii at Mersham in Kent. However, here the two species may occur together within condensed strata, with a remanié grandis Subzone fauna preserved at the base of *transitoria* Subzone sediments. Without the benefit of sections to examine this proposal, subzonal correlations in the lower part of the Hythe Formation must remain tenuous. What does appear to follow is, however, that Australiceras gigas, so common in the Small Ledge Member of the Isle of Wight, can be traced into the Hythe Formation of eastern Kent.

Distribution: The distribution of the *D. grandis* Subzone is probably more restricted than Casey (1961), and then succeeding authors (e.g. Ruffell 1992a), thought. The subzone is limited to the newly defined Small Ledge Member on the Isle of Wight and as indicated by the associated

fauna, is almost always present only in condensed strata throughout the Weald, northern France and East Midlands Shelf.

5.2.4 Dufrenoyia furcata Assemblage Biozone, New name, Fig. 5.3.

Definition: From the appearance of the first species of Dufrenoyia, through the range of Dufrenoyia transitoria, which occurs alongside Tropaeum bowerbanki. The zone is equivalent to the total range of Dufrenoyia spp. in the Anglo-Paris Basin.

Type section: Chale Bay, Isle of Wight.

Discussion: The D. furcata Zone is proposed as a new name to embrace Casey's (1961) Tropaeum bowerbanki Zone. The base of the furcata Zone is drawn slightly lower than the original bowerbanki Zone, reflecting the first appearance of Dufrenoyia (which is earlier than recorded by Casey). Dufrenoyia is a more appropriate index for this interval as it is more widely distributed both laterally and vertically, and is a direct descendent of the previous zonal genus Deshayesites. Furthermore, the distribution of Tropaeum, and the other large heteromorphs, appears to be facies controlled. The Lower Crioceras Member at Atherfield contains an abundance of heteromorphs, but equivalent stratigraphic horizons elsewhere on the Isle of Wight are barren of such ammonites. The heteromorphs then re-appeared in the sections of the Hythe Formation at Otterpool and Maidstone, described by Casey (1961), but then disappear from the Hythe Formation throughout the rest of the Weald.

Distribution: The chosen index is of widespread distribution, having been found in other localities on the Isle of Wight, Hythe Formation of the Weald and in the remanié nodule beds of the East Midland shelf.

a. Dufrenoyia transitoria Assemblage Sub-biozone, Casey (1961).

Definition: From the first appearance of Dufrenoyia (see Plate IV) until immediately beneath the appearance of Cheloniceras cornuelianum-meyendorffi transitional species.

Type section: Chale Bay, Isle of Wight

Discussion: The base of this subzone is the same as for the zone, commencing at the base of the Brown's Down Member of the type section. Only occurring very sparingly at its first appearance, *Dufrenoyia* becomes abundant in the Lower Crioceras Member, in which it occurs with *Tropaeum* in the concretionary levels that characterise these strata.

Figure 5.3. The distribution of the index and characteristic species in the *furcata* Zone of the type section (Chale Bay).



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Distribution: D. transitoria is an index that can be traced from the type section, on the Isle of Wight, through the Hythe Formation of the Weald, and into the remanié at the base of the Hunstanton Carstone Formation on the East Midlands Shelf.

b. Cheloniceras (Cheloniceras) meyendorffi Interval Sub-biozone, Casey (1961)

Definition: From the appearance of Ch. meyendorffi, particularly early specimens transitional with Ch. cornuelianum, to below the first Cheloniceras (Epicheloniceras).

Type section: Chale Bay, Isle of Wight.

Discussion: The index species is closely linked with Cheloniceras (Cheloniceras) cornuelianum, which occurs in the Subzone below. Transitional forms between this and Ch. (Ch.) meyendorffi are common at the base of the subzone, and occur in the phosphatic nodules of the Whale Chine Member of the Isle of Wight.

Distribution: Species of Ch. (Ch.) meyendorffi are present in the Hythe Formation of Kent, particularly in the Maidstone district.

5.3 ZONATION OF THE UPPER APTIAN, Table 5.4.

5.3.1 Cheloniceras (Epicheloniceras) martinioides Assemblage Biozone, Casey (1961), emended herein, Fig. 5.4.

Definition: From the appearance of Ch. (E.) martinioides, through the range of the subgenus Epicheloniceras, until below the first appearance of Parahoplites.

Type section: The type section is proposed as Chale Bay, Isle of Wight, although an equally well-developed succession is found in the Hythe Formation of the Maidstone district.

Discussion: The appearance of *Epicheloniceras* at the commencement of the Upper Aptian is a geographically widespread event and the most obvious to define the base of the substage. The zone is characterised by the final forms of the Cheloniceratinae and Ancyloceratidae to occur in the Anglo-Paris Basin.

Distribution: The records of the index specimens are discontinuous, being largely restricted to concretionary horizons on the Isle of Wight, and limestone bands at Maidstone. Across much of the Anglo-Paris Basin, the zone is largely absent.

Table 5.4. The zonation of the Upper Aptian.

Casey (1961)		This study, with range of index species	
Zones	Subzones	Zones	Subzones
	Hypacanthoplites anglicus		Hypacanthoplites anglicus
Hypacanthoplites jacobi	Hypacanthoplites rubricosus	Hypacanthoplites jacobi	Nolaniceras nolani
	Nolaniceras nolani		
Parahoplites	Parahoplites cunningtoni	Parahoplites nutfieldiensis	Parahoplites cunningtoni
nutfieldiensis	Tropaeum subarcticum		Tropaeum subarcticum
	Cheloniceras buxtorfi		Cheloniceras gracile
Cheloniceras martinioides	Cheloniceras gracile	Cheloniceras martinioides	
	Cheloniceras debile		Cheloniceras debile

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a. Cheloniceras (Epicheloniceras) debile Assemblage Sub-biozone, Casey (1961).

Definition: The subzone ranges from the first appearance of the subgenus *Epicheloniceras*, through the apparent range of the index species.

Type section: Chale Bay, Isle of Wight.

Discussion: Ammonite distributions are always highly restricted in the levels represented by the Ch. (E.) debile Subzone. The sands between the characteristic concretionary horizons of the Upper Crioceras Member are generally barren of fossils, and the inferred ranges of the species have always been related to lithostratigraphical boundaries. The subzone ranges up to the sands beneath the concretionary level near the base of the Ladder Chine Member at Chale Bay.

Distribution: The *martinioides* Zone is poorly developed in most areas outside of the Channel Basin, and where sediments do exist subzonal correlations are not possible in the absence of diagnostic fossils.

b. *Cheloniceras (Epicheloniceras) gracile* **Interval Sub-biozone**, Casey (1961) emended herein.

Definition: Ranges from the first appearance of Ch. (E.) gracile to immediately below the appearance of Parahoplites spp.

Type section: Chale Bay, Isle of Wight.

Discussion: As with the preceding subzone, the scattered ammonite records only allow an approximation of the biostratigraphical scale based upon the lithostratigraphical units from which the characteristic species were collected.

This subzone must also be considered to incorporate Casey's (1961) *Ch. (E.) buxtorfi* Subzone. The basis for recognising a *buxtorfi* Subzone was the occurrence of two specimens from the remanié nodule bed at the base of the Sandgate Formation in East Kent (Casey 1961). The only other evidence for this subzone was from very poorly preserved ammonites that were found at the base of New Chine Member on the Isle of Wight. Casey (1961) inferred that this subzone was present since an association of *Ch. (E.) subnodosocostatum* and *Ch. (E.) buxtorfi* was used to define the Upper Gargasian in Switzerland, but on the scanty evidence provided the subzone should be abandoned.

Distribution: Strata containing Ch. (E.) gracile were formerly exposed in Offham Quarry, near Maidstone, where the index was found in the upper part of the Hythe Formation.



Figure 5.5. The distribution of the index and characteristic species in the *nutfieldiensis* Zone at its type section (Patteson Court, Surrey).

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5.3.2 Parahoplites nutfieldiensis Interval Biozone, Arkell (1947), Fig. 5.5.

Definition: From the first appearance of *Parahoplites* until immediately beneath the first appearance of *Nolaniceras nolani*. This definition encompasses the entire apparent range of *Parahoplites* in the Anglo-Paris Basin.

Type section: Nutfield, Surrey.

Discussion: Casey (1961) followed Arkell's (1947) proposal to promote the *P. nutfieldiensis* Subzone to a zone to replace the *Ch. (E.) subnodosocostatum* Zone of earlier authors (Spath 1923; Breistroffer 1947), and proposed the subzones of *Tropaeum subarcticum* and *Parahoplites* cunningtoni. The base of the zone is marked by a remarkable turnover of ammonites, most particularly the loss of *Epicheloniceras* from the Anglo-Paris Basin.

Distribution: Sandgate Formation (fuller's earths) of Nutfield-Redhill, Surrey, the Bargate Member of Surrey and Sussex, Seend and Faringdon Formations of Wiltshire, and Walpen Undercliff Member of Chale Bay and Shanklin. Poorly preserved examples of *Parahoplites* have been recovered from the base of Blackgang Member of Shanklin.

a. Tropaeum subarcticum Interval Sub-biozone, Casey (1961)

Definition: From the first appearance of T. subarcticum, until immediately below the first Parahoplites cunningtoni.

Type section: Nutfield Member, Patteson Court, Surrey.

Discussion: The index *Tropaeum subarcticum* has only been recorded from the Nutfield Member fuller's earths of Surrey and Shanklin on the Isle of Wight. Despite the probable facies control on the distribution of the index species, the *subarcticum* Subzone is retained, and recognised in other areas by the appearance of *Parahoplites maximus*.

Distribution: A remanié fauna of *subarcticum* Subzone age has been recovered from the basal Sandgate Formation pebble bed in Surrey and Sussex of the Weald, and from Shanklin on the Isle of Wight. Evidence for the subzone also exists on the East Midlands Shelf and in the marginal deposits at the western margin of the Weald Basin.

b. Parahoplites cunningtoni Interval Sub-biozone, Casey (1961)

Definition: Ranges from the first appearance of *P. cunningtoni* until just beneath the first appearance of *Nolaniceras nolani*.

Type section: Redhill, Surrey.

Discussion: The index P. cunningtoni is rather rare, largely restricted to the Bargate Member,

but there are records from the Puttenham Member of Surrey. Other ammonites are uncommon in this upper part of the *nutfieldiensis* Subzone, the start of which is characterised by the loss of the heteromorph ammonites from the Anglo-Paris Basin.

Distribution: The *cunningtoni* Subzone is of wide geographical distribution, but ammonites are always rare, and frequently absent from the Sandgate Formation. Beyond Surrey, its presence has been proved from the correlatives of the Sandgate Formation on the Isle of Wight and in the Faringdon Formation to the west of the main Weald Basin.

5.3.3 Hypacanthoplites jacobi Assemblage Biozone, Casey (1961), Fig.5.6.

Definition: Ranges from the first appearance of Nolaniceras nolani, through the acme of the genus Hypacanthoplites, to immediately beneath the first appearance of Farnhamia.

Type section: Folkestone, East Kent.

Discussion: Casey (1961) proposed a zone of Hypacanthoplites jacobi, that was divided into the Nolaniceras nolani, H. rubricosus and H. anglicus Subzones. The present definition encompasses the N. nolani and H. anglicus Subzones, in which Hypacanthoplites is present toward the top of the former and ranges through the latter subzone.

Distribution: The zonal index is quite rare in the Anglo-Paris Basin, and is always subordinate to *H. anglicus.* Only a few body chambers of *H. jacobi* are found at Folkestone and a single specimen from Chalvington in Sussex, and in its strict interpretation the species was rare outside of north-west Europe.

a. Nolaniceras nolani Interval Sub-biozone, Casey (1961), emended herein.

Definition: Ranges from the appearance of N. nolani, through the first Hypacanthoplites, until just before the appearance of H. anglicus.

Type section: Folkestone, East Kent.

Discussion: Until recently, the only locality in the Anglo-Paris Basin in which fossiliferous sediments of this age were recorded was at Folkestone. Here, Casey (1961) recorded two specimens of *Nolaniceras nolani* in the dark, glauconitic and micaceous clays at the top of the Sandgate Formation. Casey proposed that the *nolani* Subzone was followed by the *Hypacanthoplites rubricosus* Subzone, that marked the start of Folkestone Formation deposition

Figure 5.6. The distribution of the index and characteristic species in the *jacobi* Zone of Folkestone and Newington (Kent).



at its type locality. His argument was based on the presence of a remanié nodule bed at the base of the Folkestone Formation yielding a different fauna of *Hypacanthoplites* than that found in the overlying beds.

The species of *Hypacanthoplites* that were found in the basal Folkestone Formation remanié had never been found at any other locality beyond the type section. However, a temporary exposure at the top of the Sandgate Formation was opened during the excavations of the M20 Motorway widening programme. Here, black clays identical to those recorded by Price at the top of the Sandgate Formation near to Folkestone were discovered and yielded early species of *Hypacanthoplites* (Owen & Casey *pers. comm.*). There are two alternative explanations that can be given following this important discovery, these are:

i. The organic clays towards the top of the Sandgate Formation are of *nolani* Subzone age at their base, overlain by younger clays of the *rubricosus* Subzone.

ii. The base of the *nolani* Subzone may only contain *Nolaniceras*, but *Hypacanthoplites* had evolved by the topmost part of this subzone.

In the absence of evidence to prove the former statement, the second proposal is preferred. At Folkestone, therefore, erosion of the topmost part of the Sandgate Formation occurred, and its ammonites are represented in remanié at the base of the Folkestone Formation. Further west, the topmost part of the Sandgate Formation is preserved.

Distribution: Fossiliferous sediments of the *nolani* Subzone in the Anglo-Paris Basin have only been recorded from Kent. However, black unfossiliferous clays mark the topmost Sandgate Formation deposition throughout much of the Weald and the commencement of the Five Rocks Formation on the Isle of Wight.

b. Hypacanthoplites anglicus Interval Sub-biozone, Casey (1961).

Definition: Ranges from the first appearance of *H. anglicus* until immediately beneath the appearance of *Farnhamia farnhamensis*.

Type section: Folkestone, East Kent.

Discussion: Hypacanthoplites evolved rapidly from the base of the subzone, and the interval contains no other genus. Most specimens are recorded from a phosphatic nodule bed that occurs at the base of the subzone at most localities in which it is found.

Distribution: H. anglicus occurs at Wissant, in the same preservation as at Folkestone and in the

5.4 ZONATION OF THE LOWER ALBIAN, Table 5.5.

5.4.1 Leymeriella tardefurcata Assemblage Biozone, Breistroffer (1947), emended herein, Fig. 5.7.

Definition: The base of the subzone is defined by the first occurrence of Leymeriella schrammeni. Species of Leymeriella range throughout the zone at the type section. The base of the zone in the Anglo-Paris Basin is defined by the appearance of Farnhamia farnhamensis. Type section: Vörhum, Hanover-Braunschweig area, north Germany.

Discussion: The L. tardefurcata Zone was first proposed by Brinkmann (1937), and used by Breistroffer (1947) to define the base of the Albian. His recommendations were followed by Casey (1957; 1961), with the basal Albian subzone being marked by the appearance of Leymeriella schrammeni anterior in its type section (Breistroffer 1947; Owen 1979; 1984a; 1984b; 1988b; Birkelund et al. 1984). However, species of Leymeriella were restricted initially to the North Sea Basin alone, including its marginal German facies, gradually extending their range throughout the tardefurcata Zone, to become ubiquitous in Europe in the uppermost part of the zone (Owen 1973; 1984a; 1988b). In the Anglo-Paris Basin there are no records of any pre-regularis Subzone species of Leymeriella, and Casey (1961) proposed a subzonal division of the earlier part of the tardefurcata Zone in the British region based upon species of Farnhamia and Hypacanthoplites. The lower Farnhamia farnhamensis Zone was believed to be equivalent to the L. schrammeni Subzone and the Hypacanthoplites milletioides Subzone equivalent to the L. acuticostata Subzone of the type area. The correlation was made possible by species of Hypacanthoplites that were common to both Britain and Germany, although Farnhamia was only found in southern England (Owen 1984a).

Owen (1988a; 1988b) considered the evolutionary patterns of the Lower Albian ammonites, particularly noting the similarities between Casey's genus *Farnhamia* and *Arcthoplites*. *Arcthoplites* was restricted to the *acuticostata* Subzone of the Boreal-Arctic realm, proved by the interprovincial distribution of associate genera such as *Anadesmoceras* and *Cleoniceras* (Saveliev, in Owen 1988b). However, examination of museum specimens of both *Arcthoplites* and *Farnhamia* has shown that they are markedly different from one another, the former has an apparent root is *Freboldiceras*, as Owen suggests, whilst the origin of the latter is best placed within the desmoceratid genus *Uhligella*. Therefore, Owen's (1988b) proposal that the *farnhamensis* Subzone of the Anglo-Paris Basin correlates with the *acuticostata* Subzone of the

type area no longer holds. But, unfortunately, because the lowest subzone of the *tardefurcata* Zone was suggested to be absent in Owen's opinion, successive authors have indicated that a hiatus spans the whole of the *schrammeni* Subzone across the Anglo-Paris Basin (e.g. Amedro 1992). There is no sedimentary evidence for this gap, and species of *Hypacanthoplites* that are found at the top of the *jacobi* and base of the *tardefurcata* Zones appear to show an evolutionary line, which certainly gives little evidence for an extended break in the record.

Owen's (1988b) proposal that Casey's subzones should be abandoned in the Anglo-Paris Basin in favour of those of the North German area is not followed here. The index species of the *L*. *schrammeni* and *L. acuticostata* Subzones do not occur in the Anglo-Paris Basin. *Leymeriella* first appears in the *regularis* Subzone, and it is at this time that the zonal index, *L. tardefurcata*, is first found in sediments of this province.

a. Farnhamia farnhamensis Assemblage Sub-biozone, Casey (1961)

Definition: The interval corresponding to the total range of the index species, its association with, and the total range of *Hypacanthoplites milletioides*.

Type section: Farnham, Surrey.

Discussion: The base of the subzone is marked by the appearance of Farnhamia, which occurs alongside H. milletioides at Farnham. Elsewhere, the latter species has only been found alone, at the base of the Folkestone Formation in the area around Folkestone. Casey's (1961) reasoning for a separate Subzone of H. milletioides was based upon the tripartite division of the German succession, and this recommendation has been followed by recent authors in a revised sense; Amedro's (1980; 1992) partial range zone of H. milletioides is inferred to represent that part of the range of the index species not within the range of F. farnhamensis. However, with the limited evidence of time relations between the type German and Kent successions, it is not possible to separate subzonally those beds containing F. farnhamensis and H. milletioides in Surrey, and those simply with H. milletioides in Kent.

Distribution: Deposits of the *farnhamensis* Subzone are now thought to be geographically widespread, but are generally unfossiliferous.

Table 5.5. The zonation of the Lower Albian.

Casey	Casey (1961)		wen (198	88a; 1988b)	Amedro (1992)	This study					
Zones	Subzones		Zones	Subzones	Zones	Zones	Subzones				
	Hoplites (I.) eodentatus	2		Pseudosonneratia (I.) steinmanni	Hoplites (I.) steinmanni						
atum	Pseudosonneratia	llatum	plites formis	Otohoplites bulliensis	Otohoplites bulliensis	tum	Pseudosonneratia				
milla	puzosianus	mmi)tohc uritij	Pseudosonneratia	Otohoplites auritiformis	nilla	puzosiunus				
amı		maı	ai	puzostanus	Otohoplites larcheri	<i>imi</i>	Y				
s m	Otohoplites raulinianus	ras		Cleoniceras raulinianus	Pseudosonneratia puzosianus	s ma	Otohoplites raulinianus				
eicera	Cleoniceras floridum		ttia sis	Cleoniceras floridum	Cleoniceras floridum	sicera	Cleoniceras Aoridum				
ouvillei	Sonneratia	Dowvi	nnera halen:	Sonneratia kitchini	Sonneratia	ouville	Sonneratia				
Ď	RIICNINI		So	Sonneratia perinflata	kitchini	Ď	kitchini				
lla ita	Leymeriella regularis		lla ita	Leymeriella regularis	Leymeriella regularis	lla uta	Leymeriella regularis				
merie lefurco	Hypacanthoplites milletioides		merie. lefurcc	Leymeriella acuticostata	Hypacanthoplites milletioides	merie					
Leymeriella tardefurcata	Farnhamia farnhamensis		Ley tara	Leymeriella schrammeni	Farnhamia farnhamensis	Ley tara	Farnhamia farnhamensis				

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Figure 5.7. The distribution of the index and characteristic species in the *tardefurcata* Zone at Farnham (Surrey) and Folkestone (Kent).

b. Leymeriella regularis Total Range Sub-biozone, Breistroffer (1947, emended).

Definition: Interval between the first appearance of Leymeriella regularis and that of Sonneratia kitchini and Douvilleiceras mammillatum.

Type section: Hanover area of the Lower Saxony Basin, Germany

Discussion: The *regularis* subzone *sensu* Casey (1961) is widely recognisable, and used as the standard for all current biostratigraphical schemes (Owen 1988b). The *regularis* Subzone shows a variety of facies where it is preserved. It is only at Folkestone where a thick succession of sands has been recorded from this subzone, probably deposited in a sea-floor trough. Often the *regularis* Zone records the start of silty clay deposition, with phosphatic nodule horizons, of the basal part of the Gault Formation.

Distribution: The thickest development of the variable *regularis* Subzone deposits in England is at Folkestone, whilst the most diverse fauna has been collected from the condensed nodule beds at the base of the Gault Formation of Leighton Buzzard (Casey 1961). Elsewhere, this subzone has been recorded at Wrecclesham, Surrey; from the Horton Wood Member at Small Dole and Chalvington, Sussex, and from the Carstone of Norfolk. In the Paris Basin it has been proved from the Bec de Caux, Boulonnais, Porcien, Argonne, Perthois, Aube and Puisaye.

5.4.2 Douvilleiceras mammillatum Assemblage Biozone, Casey (1961), Fig. 5.8.

Definition: Ranges from the first occurrence of *Douvilleiceras mammillatum*, through its association with the Sonneratiinae, to immediately below the first appearance of *Hoplites* (*Hoplites*).

Type section: Folkestone, East Kent.

Discussion: The Douvilleiceras mammillatum Zone was proposed by Casey (1961) and has been the cause of much argument ever since. The problem in dating sediments of this age is that there is nowhere a complete succession and intervals may be poorly fossiliferous. Often the sediments have undergone more than one phase of erosion and faunas of differing ages have become mixed into single phosphatic nodule beds. More complete successions through the *mammillatum* Zone have been recorded in France than in southern England, and from here several proposed zonal schemes have arisen (Destombes 1973; 1979; Amedro 1980; 1985). The most detailed investigation into the sediments of this part of the Lower Albian was produced by Owen (1988a), who examined the zonal scheme for Europe, and then applied his revised scheme to the strata of the Weald (Owen 1992). Owen's (1988a) zonation of the *mammillatum* Zone is virtually a return to Casey's original scheme, with only minor amendments, the arguments for which all appear in his review of the current schemes. Owen's principal conclusion was to elevate the zone to superzone status. He recognised that early *mammillatum* times were represented by species of *Sonneratia*, whilst later in the 'superzone', *Otohoplites* was dominant. This is a useful rule of thumb when examining strata in which the subzonal correlations are difficult due to an impoverished ammonite fauna, but the zonal indices chosen only have very limited range.



Figure 5.8. The distribution of the index and characteristic species in the *mammillatum* Zone at Westerham and Folkestone (Kent).

The most recent investigation of the subzonal succession of the *mammillatum* Zone appeared in Amedro (1992). His revised scheme is an updated and modified version of his earlier work that is based upon Destombes (1973). The principal difference between the French and British workers is in the position of the *puzosianus* Subzone. The problems that have persisted are largely due to the misidentification of juvenile specimens and the incomplete picture that has been gained of the ammonite ranges. Destombes (1973) was prone to recognising new subzones of very short duration, more akin to bio-horizons, and it is very rarely possible to correlate these

beyond their type section. Table 5.6. shows that the species *P. puzosianus* makes its first appearance in the *raulinianus* Subzone, but the *puzosianus* Subzone commences in that part of its range after that of *O. raulinianus*. Likewise, *O. larcheri* first appears in the *raulinianus* Subzone, but continues through until the *puzosianus* Subzone. This is why the *larcheri* Subzone was believed to be equivalent to the *raulinianus* Subzone by Destombes, and the subzonal succession appeared to be inverted. Casey's subzones are preferred to the French, because these can be traced over greater distances than the very limited duration subzones used by the French workers.

Distribution: Preserved in a variety of facies throughout the Weald, Isle of Wight, Bedfordshire Straits and northern France.

Table 5.6. The distribution of index species in the *mammillatum* Zone, and a comparison of the zonation of Amedro (1992) and that proposed in the current investigation.

	Amedro (19	992).		Present study.								
bulliensis			0. bulliensis									
auritiformis			ohoplites auritiformis	puzosianus								
larcheri	a) puzosians	s larcheri	õ			r	swuzisosian w					
	misonnerati	Otohoplite				ulinianus	isonneratia)					
puzosianus	Ъ. (Но			raulinianus		Otohoplites ra	um P (Hem					
floridum			Cleoniceras florid	floridum			Cleoniceras forid					
kitchini	Sonneratia kitch			kitchini		Sonneratia kitch						

a. Sonneratia kitchini Interval Sub-biozone, Casey (1961)

Definition: Ranges from the appearance of S. kitchini to below that of Cleoniceras floridum. Type section: Folkestone, East Kent.

Discussion: Owen (1988a) suggested that two subzones can be recognised in the interval of time represented by Casey's S. kitchini Subzone, based upon the work of Saveliev in Russia. There is no evidence for Owen's earlier Sonneratia perinflata Subzone in any part of the Anglo-Paris Basin. The only occurrences of S. perinflata are in the Leighton Buzzard area, where in the condensed nodule beds at the base of the Gault Formation they occur with faunas indicative of the regularis, kitchini and even floridum Subzones (Owen 1988a). Elsewhere in the Anglo-Paris Basin, kitchini Subzone sediments rest directly on those of the regularis Subzone. In the current state of knowledge, the author recommends that the perinflata Subzone should be abandoned in favour of the kitchini Subzone as defined above.

Distribution: Isle of Wight, Weald, East Anglia. Porcien, Bec-de-Caux.

b. Cleoniceras floridum Interval Sub-biozone, Casey (1961)

Definition: Ranges from the appearance of Cl. floridum to below the first occurrence of Otohoplites raulinianus.

Type section: Squerryes Main Pit, Westerham, Kent.

Discussion: Sediments with an indigenous fauna occur in the type section and nearby (Casey 1961; Owen 1988a; 1992). In Chamberlain's Barn Pit, near Leighton Buzzard, a further example of an indigenous fauna is recorded, but here occurring with phosphatised debris representing the earlier *regularis* and *kitchini* Subzones. In many other localities, the *floridum* Subzone fauna is found remanié alongside that of the *raulinianus* Subzone, and incorporated into sediments yielding indigenous *puzosianus* Subzone fossils.

Distribution: Folkestone, through to the basal Gault Formation deposits of the northern part of the Weald. The subzone is preserved in a similar argillaceous facies in the Bedfordshire Straits, displayed at Leighton Buzzard. In France, representatives of the *floridum* Subzone have been collected from Wissant, in the Boulonnais, and Porcien (Amedro 1985).

c. Otohoplites raulinianus Total Range Sub-biozone, Casey (1961).

Definition: The total known range of O. raulinianus.

Type section: Ford Place, Wrotham, Kent.

Discussion: Sediments of this subzone are not well-represented, but beds containing a

raulinianus Subzone fauna were formerly seen overlying those with a *floridum* and underlying those with a *puzosianus* Subzone fauna at the type section. Elsewhere, they are often found incorporated with the *floridum* Subzone in phosphatic remanié beds (Owen 1992). The subzone is equivalent to Destombes' (1973) *puzosianus* and part of his *larcheri* Subzone.

Distribution: From Folkestone, through the northern part of the Weald, Leighton Buzzard and the Boulonnais within condensed deposits, and more completely in the Aube.

d. Protohoplites (Hemisonneratia) puzosianus Partial Range Sub-biozone, Casey (1961).

Definition: The subzone embraces that part of the range of P. (H.) puzosianus above the last appearance of O. raulinianus.

Type section: Folkestone, East Kent.

Discussion: As with the remainder of the *mammillatum* Zone, the *puzosianus* Subzone is often found as a remanié in phosphatic nodule beds. However, indigenous examples of a *puzosianus* Subzone fauna have been recorded in the 'Main mammillatum Bed' of Folkestone. Here, the subzone clearly overlies the *raulinianus* Subzone.

Owen (1992) suggested that the unfossiliferous sediments between those of known *puzosianus* and *steinmanni* Subzones age could represent the *bulliensis* Subzone of Destombes (1973) and that a fauna representative of this time span was collected from the equivalent of the 'Sulphur Band' at Newington and from Channel Tunnel excavations (Owen 1988a; 1992; *pers. comm.*). However, he based this argument on a specimen of *Otohoplites* collected from the Sulphur Band, which was identified as *O. crassus* (Owen 1992). Examination of this museum specimen has revealed the following:

i. The specimen is more evolute than typical O. crassus.

ii. The preservation is poor and a specific identification is not possible; the specimen should be recorded as *Otohoplites sp. indet*.

iii. If the specimen were *O. crassus*, this is not typical of the *bulliensis* Subzone, but is more characteristic of the *puzosianus* Subzone.

The *bulliensis* Subzone of Destombes (1973) is probably developed at the type section in the Prays de Bray, but as with other subzones defined in this area, is a limited duration bio-horizon,

which occurs at the top of the puzosianus Subzone as defined herein.

Distribution: Sediments of this subzone are widespread along the southern margin of the London Platform, particularly in Kent, but are unknown from outside of this region (Owen 1992).

5.5 ZONATION OF THE MIDDLE ALBIAN, Table 5.7.

5.5.1 Hoplites dentatus Assemblage Biozone, Spath (1923, emended), Fig. 5.9.

Definition: From the appearance of Hoplites (H.) to below the first occurrence of Anahoplites intermedius.

Type section: Folkestone, East Kent.

Discussion: The basal Middle Albian subzone was considered to be the Hoplites (Isohoplites) eodentatus Subzone by Casey (1961). Successive authors followed this interpretation until the Copenhagen proposals (Birkelund et al. 1984). A discussion was given by Owen (1984a), who suggested that the presence of typically Lower Albian ammonites within this subzone warranted its position at the top of the Lower Albian, and that the Middle Albian commenced with the Lyelliceras lyelli Subzone. The index species H. (I.) eodentatus was considered to be synonymous with H. (I.) steinmanni (Amedro 1980). However, the author is of the opinion that the substage boundary should be replaced to its original level, at the base of the steinmanni Subzone, because this is the time at which the first Hoplites and Lyelliceras appear. In this sense, the dentatus Zone ranges from the first appearance of Hoplites (H.) and through that part of its range below the first appearance of Anahoplites.

Distribution: Geographically widespread, extending throughout the Anglo-Paris Basin, in both condensed and uncondensed states.

a. Hoplites (Isohoplites) steinmanni Interval Sub-biozone, Amedro (1980, ex. eodentatus Subzone of Casey, 1961).

Definition: Ranges from the first H. (I.) steinmanni to the appearance of Lyelliceras pseudolyelli. Type section: Les Côtes-Noires, near to Moeslain.

Discussion: The subgenus Isohoplites has long been considered to represent the transitional species between the Lower Albian Sonneratiinae and the true Hoplitinae that characterise the Middle Albian. It was originally placed in the genus Hoplites, but always known to show characteristics that were intermediate between this genus and Pseudosonneratia (Casey 1961). Owen (1988a) proposed that it should be attached to the latter genus, considering it to have a closer affinity, and figured a phylogeny from which Hoplites s.s. evolved from Pseudosonneratia

Table 5.7. The zonation of the Middle Albian.

Owe	en (1971)	Amedro (1992)		This study						
Zones	Subzones	Zones	Zones	Subzones						
Euhoplites lautus	Anahoplites daviesi	Dimorphoplites	Euhoplites	Anahoplites daviesi						
	Euhoplites nitidus	biplicatus	lautus	Euhoplites nitidus						
	Euhoplites meandrinus			Moisisovicsia subdelaruei						
Euhoplites	Mojsisovicsia subdelaruei	Dimorphoplites niche	Euhoplites	25						
loricatus	Dimorphoplites niobe	111000	loricatus	Dimorphoplites niobe						
	Anahoplites intermedius	Anahoplites intermedius		Anahoplites intermedius						
Hoplites (H.)	Hoplites (H.) spathi	Hoplites (H.) dentatus	Hoplites (H.)	Hoplites (H.) dentatus						
dentatus	Lyelliceras lyelli	Hoplites (H.) benettianus	dentatus	Lyelliceras lyelli						
				Hoplites (I.) steinmanni						

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Figure 5.9. The distribution of the index and characteristic species in the *dentatus* Zone at Folkestone and the Aube.

through *Isohoplites*. However, the dominant evolutionary line appears to have been through *Otohoplites*, and this gave rise to *Hoplites* (H.) in the *steinmanni* Subzone. Occurring synchronously with this, was the evolution of *Lyelliceras* from *Tegoceras*. Therefore, if the base of the *steinmanni* Subzone is considered the substage boundary, a major faunal turnover is associated with the commencement of the Middle Albian, and this is widely demonstrated across

NW Europe and into the Mediterranean Province.

Distribution: Isle of Wight, East Anglia, Weald; Bec-de-Caux, Pays-de-Bray, Perthois and Aube.

b. Lyelliceras lyelli Assemblage Sub-biozone, Destombes & Destombes (1965).

Definition: Ranges from the appearance of Lyelliceras pseudolyelli and Hoplites (Hoplites) benettianus, then through the range of Lyelliceras lyelli.

Type section: Tuilerie Clerc, La Vendue-Mignot, Aube.

Discussion: The lowest part of the subzone does not include the index species, but does contain Lyelliceras pseudolyelli. In this sense, the subzone is an assemblage sub-biozone, still marked by the appearance of a widely distributed species. Amedro (1992) argued that since the *L. lyelli* Subzone is interpreted as the interval of time between the appearance of Lyelliceras pseudolyelli and the disappearance of Douvilleiceras mammillatum and Hoplites (Hoplites) benettianus, but not equivalent to the range of the index, the subzone is invalid. However, the assemblage of species is easily recognised and unique to this period, and the subzone should be retained.

Distribution: The most expanded succession through the *lyelli* Subzone in southern England was formerly seen in the Horton Hall clay pit, Small Dole, Sussex. In most other localities throughout the Weald, the subzone occurs in a condensed state. Similarly, uncondensed *lyelli* Subzone sediments are recorded in the Aube, but are condensed in, or missing from, the Boulonnais of France.

c. Subzone of Hoplites (H.) dentatus Partial Range Sub-biozone, Spath (1941, emended)

Definition: Ranges from above the disappearance of Lyelliceras lyelli until just below the appearance of Anahoplites intermedius, in which Hoplites (H.) dentatus is dominant.

Type section: Folkestone, East Kent.

Discussion: This subzone is equivalent to Spath's (1941) dentatus-spathi Subzone, which was subsequently abbreviated to the spathi Subzone (Owen 1971). According to Amedro (1992), H. (H.) spathi is a variant of H. (H.) dentatus. The Subzone of H. dentatus represents a period of time during which species of Hoplites were the dominant ammonites, following the rapid contraction of the cosmopolitan species at the end of the previous subzone.

Distribution: Weald, Isle of Wight and East Anglia; Bec-de-Caux, Pays-de-Bray, Boulonnais, Artois and Hainaut, Porcien, Argonne and Perthois, Aube and Puisaye.

5.5.2 Euhoplites loricatus Assemblage Biozone, Owen (1958), Fig. 5.10.

Definition: Ranges from the appearance of Anahoplites intermedius, through the range of Euhoplites loricatus, to below the appearance of Euhoplites lautus.

Type section: Folkestone, East Kent.

Discussion: The base of the zone sees the introduction of the first of the variable and long ranging genera Euhoplites and Anahoplites. Hoplites (H.) just extends into the base of the zone, but only as a rarity. The zone is characterised by rapidly evolving hoplitinid ammonites, and more cosmopolitan genera appear only at discrete intervals as minority elements.

Distribution: The basal part of the zone is of widespread occurrence, extending over a greater geographical area than the earlier *dentatus* Zone. However, upwards the zone becomes progressively less widespread in the European province. The topmost part of the zone is only recorded from the Weald and northern France.

a. Anahoplites intermedius Interval Sub-biozone, Spath (1923).

Definition: From the appearance of A. intermedius to below the appearance of Dimorphoplites niobe.

Type section: Folkestone, East Kent.

Discussion: The subzone is typified by species of *Anahoplites*, particularly *A. intermedius*, which ranges throughout. Other typical genera are *Hamites* and *Protanisoceras*, with *Falciferella milbournei* being present at certain horizons (Casey 1954; Owen 1971). A very rare cosmopolitan fauna has also been listed by Owen (1971) from some horizons in the *intermedius* Subzone.

Distribution: Deposits of the *intermedius* Subzone are developed across the entire Weald and Paris Basins, into the Bedfordshire Straits and extend further northwards and westwards than earlier Middle Albian sediments.

b. Dimorphoplites niobe Partial Range Sub-biozone, Spath (1941, emended)

Definition: From the appearance of D. niobe, through that part of its range before the appearance of Mojsisovicsia subdelaruei.

Type section: Folkestone, East Kent.

Discussion: The species D. niobe ranges from the base of the subzone through to the top of the loricatus Zone. Amedro (1980) suggested that this species should be used to define a total range biozone, and that the other subzones that occurred within the range of D. niobe should be



Figure 5.10. The distribution of the index and characteristic species in the *loricatus* Zone at its type section (Folkestone, Kent).

abandoned. However, this proposal disguises the fact that important changes within the ammonite assemblages occur during this interval. Milbourne (1963) proposed that evolution of *Dimorphoplites doris* from *D. niobe* could be used to index the topmost part of the *loricatus* Zone, but because Owen (1960) suggested that this evolution occurred at an even earlier stage, this has to be rejected. Owen (1960) proposed that the top of the partial range Sub-biozone could be fixed beneath the first appearance of Mojsisovicsia subdelaruei.

Distribution: The subzone shows its best development at Folkestone, whilst elsewhere in the Weald it appears in a generally condensed state. In northern France, the *niobe* Subzone has been proved at the Bec de Caux and Wissant (Owen 1971).

c. Mojsisovicsia subdelaruei Interval Sub-biozone, Spath (1941), emended herein.

Definition: From the first appearance of *M. subdelaruei* until immediately beneath the first Euhoplites lautus.

Type section: Folkestone, East Kent.

Discussion: Milbourne (1963) and Amedro (1992) had reservations in using an index species for which little is known about its evolution and range outside of the Anglo-Paris Basin. Because of this they abandoned the use of *M. subdelaruei* as an index species. However, with very little change in the composition of the assemblage of other ammonites, it is a useful marker that can aid detailed correlations over wide areas.

Owen (1960) proposed that strata yielding *M. subdelaruei* were succeeded by those containing a short ranging species, *Euhoplites meandrinus*, and that the latter were equivalent to Milbourne's (1963) *E. neglectus* and *D. doris* Subzone (Owen 1971). The *meandrinus* Subzone was represented by a single phosphatic nodule bed at Folkestone, and was succeeded immediately by the *lautus* Zone. Owen (1971) recorded a more expanded version of the *meandrinus* Subzone in northern parts of the Weald, but Milbourne's (1956; 1962) faunal lists reveal that an admixture of both late *loricatus* and early *lautus* Zone ammonites has been collected. In the present investigation, two specimens of *Mojsisovicsia spinulosa* (see Plate V) were collected from the phosphatic nodule bed at the base of Bed 11 at Folkestone (Owen's *meandrinus* Subzone); these occurred alongside other rolled and abraded ammonites of the *subdelaruei* Subzone and indigenous specimens of the *nitidus* Subzone. It is recommended, therefore, that Owen's *meandrinus* Subzone is abandoned.

Distribution: The subzone is represented at Folkestone and parts of the northern Weald of England, and at Wissant in France.

5.5.3 Euhoplites lautus Partial Range Biozone, Spath (1926, emended), Fig. 5.11.

Definition: From the appearance of *Euhoplites lautus*, through that part of its range until immediately beneath the first *Dipoloceras cristatum*.

Type section: Folkestone, East Kent.

Discussion: Owen (1971) believed that the *lautus* Zone was equivalent to the total range of the index species. However, this particular species of *Euhoplites* is now thought to range up into the base of the *orbignyi* Subzone, of Late Albian age. The zone should, nonetheless, be retained for it represents the period of time in which *Euhoplites* with channelled venter dominated, the characteristic species showing a total turnover from those of the zone below.

Distribution: As a result of erosion in early Late Albian times, few deposits of this zone remain beyond the Weald and northern France. Even in some of these areas, the topmost part of the zone has been removed by the *cristatum* Subzone erosion.

a. Euhoplites nitidus Partial Range Sub-biozone, Spath (1926, emended).

Definition: The range of Euhoplites nitidus before the appearance of Anahoplites daviesi. Type section: Folkestone, East Kent.

Discussion: This subzone was questioned by Amedro (1980; 1992) because the index species has the same range as the zonal index (*Euhoplites lautus*). Owen (1958; 1971) and Hancock (1965) justified the use of the subzone because of an ammonite assemblage that was subtly different from the succeeding assemblage containing *Anahoplites daviesi*.

Distribution: Although it is best known from Folkestone, Owen (1971) recorded the presence of the *nitidus* Subzone in localities in the northern Weald and Wissant.

b. Anahoplites daviesi Interval Sub-biozone, Spath (1926).

Definition: From the first appearance of Anahoplites daviesi until immediately beneath that of Dipoloceras cristatum.

Type section: Folkestone, East Kent.

Discussion: This subzone is based purely on the appearance of *Anahoplites daviesi* and its allies at its base, although there is only minor change in the accompanying ammonite fauna. As with the *M. subdelaruei* Subzone, the author believes that continued reference to the *daviesi* Subzone will aid stratigraphical correlations and help pin-point events more accurately than in the scheme proposed by Amedro (1980).

Distribution: Outside of its type locality, the *daviesi* Subzone is often missing. In the Weald, it is found in remanié at the base of the Upper Albian sequence.



Figure 5.11. The distribution of the index and characteristic species in the *lautus* Zone at its type section (Folkestone, Kent).

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5.6 ZONATION OF THE UPPER ALBIAN, Table. 5.8.

5.6.1 *Mortoniceras (M.) inflatum* Assemblage Biozone, Spath (1941, emended), Fig. 5.12.

Definition: The index only appears towards the top of the zone, which embraces strata from the first appearance of *Dipoloceras cristatum* until below the occurrence of *Mortoniceras (M.) fallax. Type section:* Folkestone, East Kent.

Discussion: The zone incorporates the period of time in which a major change of the ammonite fauna is seen from that of the Middle Albian. The brancoceratid ammonites that characterise this period were initially introduced as a minority element, but became the dominant form in the middle and upper parts of the zone. The zone defines a period in which the last species of the common Middle Albian hoplitinids occur. Extreme forms of genera such as *Euhoplites*, *Anahoplites* and *Dimorphoplites* have their final showing during this zone. They were replaced by the late hoplitinid genus *Callihoplites* at the top of the *inflatum* Zone, which then gave rise to end forms of the subfamily in the Upper Albian.

Distribution: Widely distributed throughout southern England, the Boulonnais, Pays-de-Bray and the Aube.

a. Dipoloceras cristatum Local Range Sub-biozone, Spath (1923, emended).

Definition: Embraces the total range of the species Dipoloceras cristatum.

Type section: Folkestone, East Kent.

Discussion: For many years arguments have raged when considering the position of the cristatum Subzone. The fauna contained in the cristatum Subzone sediments is predominantly characteristic of the Middle Albian, with the endemic hoplitid ammonites dominating. It is for this reason that the cristatum Subzone was considered to belong to the uppermost part of the Middle Albian (Spath 1923-1943; Amedro 1980; 1981; Amedro & Destombes 1978; Robaszynski & Amedro 1986). However, although in a minority, the cosmopolitan elements of the cristatum Subzone are the direct forerunners to the brancoceratids that dominated in the successive zones of the Upper Albian. Owen (1971) considered that the cristatum Subzone should mark the base of the Upper Albian, and this proposal has been followed in most of the succeeding works, particularly those concerning the positioning of stage and substage boundaries (Owen 1984a; Birkelund *et al.* 1984; Hancock 1991).

Distribution: Weald and Boulonnais. Only an isolated recovery from Porcien.

Table 5.8.	The	zonation	of the	Upper	Albian.	

	Owen	(1976)	Amedro (1992)		This study					
	Zones	Subzones	Zones	Zones	Subzones					
	Stoliczkaia	M. (Durnovarites) perinflatum	M. (Durnovites) perinflatum	Stoliczkaia	M. (Durnovarites) perinflatum					
	dispar	M. (Mortoniceras) rostratum	M. (Mortoniceras) fallax	dispar	M. (Mortoniceras) fallax					
		Callihopites auritus	M. (Mortoniceras) inflatum		M. (Mortoniceras) inflatum					
	Mortoniceras	Hysteroceras varicosum	M. (Mortoniceras)	Mortoniceras	Hysteroceras varicosum					
. .	inflatum	Hysteroceras orbignyi	pricei	inflatum	Hysteroceras orbignyi					
·		Dipoloceras cristatum	Dipoloceras cristatum		Dipoloceras cristatum					



Figure 5.12. The distribution of the index and characteristic species in the *inflatum* Zone at its type section (Folkestone, Kent).

b. Hysteroceras orbignyi Acme Sub-biozone, Spath (1941).

Definition: The base is defined by a swarm of Hysteroceras orbignyi, which becomes the dominant species over all others after the disappearance of D. cristatum.

Type section: Folkestone, East Kent.

Discussion: Hysteroceras orbignyi first appeared towards the top of the D. cristatum Subzone, where it is always subordinate to other species and genera. The base of the H. orbignyi Subzone is marked by a sudden swarm of brancoceratids, and the rapid increase in numbers of the index species is the most notable. Due to the fact that the subzone is not defined by the first or last occurrence of the index, Amedro (1980) suggested that a new index should be given for this time. He suggested a new zone of Mortoniceras (Mortoniceras) pricei, this being a total range Sub-biozone that incorporated the time period extending over the orbignyi and varicosum Subzones. However, there is no difficulty in recognising the acme subzone of H. orbignyi in the sections in which it is represented, and the author is of the opinion that it should be retained. Distribution: Weald and East Anglia; Boulonnais, Argonne and Perthois, Aube.

c. Hysteroceras varicosum Acme Sub-biozone, Spath (1941).

Definition: Hysteroceras varicosum first appears in the orbignyi Subzone, but always subordinate to the index. The reverse is seen in the varicosum Subzone, where *H. varicosum* is always dominant over *H. orbignyi*.

Type section: Folkestone, East Kent.

Discussion: This subzone forms the upper part of Amedro's (1980) *M. (Mortoniceras) pricei* Zone. Although not considered important by him, it is notable for the marked reduction in the diversity of the Hoplitinae, with only very few extreme or long ranging forms of *Euhoplites* and *Anahoplites* surviving until the end of it.

Distribution: Weald and East Anglia; Boulonnais, Argonne and Perthois, Aube.

d. Mortoniceras (M.) inflatum Interval Sub-biozone, Amedro (1980).

Definition: Ranges from the first appearance of Mortoniceras (M.) inflatum through until immediately before the appearance of M. (M.) fallax.

Type section: Folkestone, East Kent.

Discussion: The Mortoniceras (M.) inflatum Subzone was introduced by Amedro (1980) (as a zone) in the first of his proposed phyletic zonations. It replaced Spath's (1941) Callihoplites auritus Subzone, which was the only Upper Albian ammonite subzone to have a hoplitinid

index. The ranges of *C. auritus* and *M. inflatum* are identical, but Amedro's proposal is followed here because the latter species is more common and widely distributed than *C. auritus*. *Distribution:* South of England and East Anglia; Boulonnais, Argonne, Aube, Bec-de-Caux and Pays-de-Brays.

5.6.2 Stoliczkaia (Stoliczkaia) dispar Assemblage Biozone, Spath (1941), Fig.5.13.

Definition: The zone is characterised by the lyelliceratid ammonite Stoliczkaia, the lower part by Stoliczkaia (Faraudiella) and the upper by S. (Stoliczkaia).

Type section: Mertsham, Surrey.

Discussion: The dispar Zone as defined here comprises two subzones, those of Mortoniceras (M.) fallax and M. (Durnovarites) perinflatum. Although indexed by Stoliczkaia (S.), this subgenus only appears in the upper part of the zone. However, the importance of the Lyelliceratidae in the topmost part of the Upper Albian warrants the use of Stoliczkaia as a zonal fossil. Also characteristic of the zone are genera and species of the Hoplitinae that evolved from those of the *inflatum* Subzone below. These are well represented in the *fallax* Subzone, but the greatest diversity of the late hoplitinid species is found in the *perinflatum* Subzone.

Distribution: East Anglia, Cambridgeshire, Weald, Dorset and Devon; Boulonnais, Hainaut, Argonne, Bec-de-Caux and Pays-de-Bray.

a. Mortoniceras (M.) fallax Interval Sub-biozone, Amedro (1980).

Definition: From the first appearance of Mortoniceras (M.) fallax until below the appearance of M. (Durnovarites) perinflatum.

Type section: Mertsham, Surrey.

Discussion: This subzone is characterised by species of Mortoniceras (M.) with three tubercles per side (Amedro 1980; 1992). It replaces Owen's (1976) subzone of Mortoniceras (M.)rostratum, introduced to replace Stoliczkaia (Faraudiella) blancheti as the index of lower part of the dispar Zone. Amedro (1992) suggested that Owen's choice was not the best because the holotype of M. rostratum was from a condensed level in the Upper Greensand Formation and also that the species is poorly defined. Cooper & Kennedy (1979) considered it to belong to the subgenus Durnovarites, and this in turn is restricted to the topmost part of the Upper Albian. Distribution: As for the zone.

b. Mortoniceras (Durnovarites) perinflatum Interval Sub-biozone, Spath (1941).

Definition: From the appearance of the index until immediately beneath the first Cenomanian species, Mantelliceras mantelli.

Type section: Mertsham, Surrey.

Discussion: The topmost part of the Albian Stage is characterised by species of Mortoniceras with four tubercles per side, these belonging to the subgenus Durnovarites. Equally characteristic in this subzone are species of Stoliczkaia (S.) and a diverse assemblage of late hoplitid ammonites.

Distribution: As for the zone.

figure 5.13. The distribution of the index and characteristic species in the *dispar* Zone at its type section (Mertsham, Surrey).



CHAPTER 6 EVENT STRATIGRAPHY AND CORRELATION

6.1 INTRODUCTION

The lithostratigraphical and biostratigraphical frameworks established in the previous chapters are the primary tools in the correlation of strata around the Anglo-Paris Basin. However, in the palaeontologically impoverished or barren strata of the Lower Greensand Group, correlations are difficult, particularly because the shallow-water deposits are highly variable. The key for accurate correlation of these sediments is by way of genetically related sedimentary packages. Ammonites are more common in the Gault Formation, and correlations between areas are easier to make. However, sea-level events are again useful and help to divide what is at first sight a rather monotonous clay succession. Using a combination of lithostratigraphy, biostratigraphy and facies analysis, similar, geologically synchronous events can be traced across the basin.

6.2 SEQUENCE STRATIGRAPHY: MODELS AND APPLICATIONS

6.2.1 The development of sequence stratigraphy

Sequence stratigraphy is the study of rock relationships within a chronostratigraphical framework (Vail *et al.* 1977). Depositional sequences of relatively conformable strata have upper and lower boundaries defined by unconformities. The age of the bounding unconformities may be determined by tracing them into laterally conformable successions. It was considered that a relative rise in sea level was marked by the progressive landward shift of littoral or coastal non-marine deposits in a marine sequence, termed coastal onlap, and a relative fall by a downward shift in coastal onlap. On the basis of this analysis, regional sea level curves were drawn. If the cycles of regional relative sea level rise and fall could be correlated between widely separated regions the underlying control was held to be eustatic (Vail *et al.* 1977).

The publication of **AAPG Memoir 26** (Payton 1977) stimulated much discussion as regards the interpretation of stratigraphic data. The early work in this field came under much scrutiny, especially the "sawtooth" eustatic curve, with gradual sea level rises attenuating with almost instantaneous falls. The changes in coastal onlap are now considered to be related to sea-level change, but do not correspond exactly with the sea-level curve (Vail *et al.* 1981, 1984; Summerhayes 1986; Hallam 1988).

Criticisms of the work have been wide ranging, and a particular concern was with the lack of

published data from which Vail and his co-workers obtained their conclusions (Miall 1986). Pitman and Golovchenko (1983), Parkinson and Summerhayes (1985) and Summerhayes (1986) confronted the problem of subsidence at passive continental margins. The effect of eustatic sea level change will leave a variable expression in accordance with the specific subsidence rates. Superimposed on the long term subsidence in basins is that of regional tectonics, such as the tilt block taphrogenic tectonics and associated sedimentation of the Mesozoic North Sea. The division of sequences into systems tracts has revealed more clearly how onlap patterns reflect relative sea level changes and account for the effects of subsidence (Haq *et al.* 1988; Van Wagoner *et al.* 1988).

6.2.2 Relationship to sea-level

A sequence is interpreted to have formed during a complete sea level cycle, from fall to rise and then subsequent fall in sea level (Haq *et al.* 1987). It is composed of a linkage of contemporaneous depositional systems, defined by their position in the sequence and the stacking pattern of strata (Haq *et al.* 1988; Van Wagoner *et al.* 1988). Strata are bounded by marine-flooding surfaces, separating younger from older strata, across which there is evidence of an abrupt increase of water depth (Van Wagoner *et al.* 1988).

Sequence stratigraphical approaches were derived from the thick sedimentary successions that are found at passive margins, which were fed from the shelf and built up as submarine deltas. From these types of succession, now exposed on the continents, new terminology was applied to the different stacking patterns that could be seen in the strata. Depositional systems defined the lowstand, transgressive and highstand parts of the sequence, and these were separated by three types of depositional surface, marked by the most conspicuous lithological changes. The transgressive surface (TS) was used to define the commencement of strongly transgressive conditions, the first deposits to spread across the shelf, and this was said to lie at the top of the Lowstand Systems Tract (Van Wagoner et al. 1988). The maximum flooding surface (MFS) was associated with a period of depositional starvation on the outer parts of the shelf and slope. The depocentres moved landward, as a response to rapidly rising sea level, to produce a condensed section in which the relative duration of sediment starvation increased basinwards. Due to the lack of terrigenous input, the section may comprise a zone of high pelagic fossil concentration and be rich in glauconite or phosphate (Jenkyns 1971). The accompanying faunal and lithological changes at this surface often leads to confusion between the downlap surface (MFS) and sequence boundary (Haq et al. 1988; Hesselbo et al. 1990b). The final depositional surface, the sequence boundary (SB) may be an unconformity, or its correlative conformity in the basin

centre, and its magnitude is dependent upon the rate of relative sea-level fall.

The famous charts of sea-level change published by Exxon were the culmination of investigations by a team of experts in various fields of geology over large parts of the world (Haq *et al.* 1987; 1988). The aim was to produce a sea-level curve that would be valid to examine eustasy in all sedimentary basins for as much of Phanerozoic time as possible. However, none of the more recent Aptian-Albian data used by the Exxon team came from sedimentary basins on the British Isles, although sections in the northern part of the Paris Basin were used for their investigations. Earlier studies by Exxon had used seismic data from the North Sea Basin (Vail & Todd 1981). The relevant information from the Exxon chart (Haq *et al.* 1988, Fig. 15, Chart 3.1A) is shown in Table 6.1. Problems in its interpretation in the Anglo-Paris Basin are discussed below.

Correlations from the Mediterranean ('Tethyan' on the Exxon Chart) to North European ('Boreal') Provinces are often difficult, particularly where there are few biostratigraphical markers that can be traced from one basin to another (Hancock 1991; Owen in press). Despite their attempts to produce an integrated biostratigraphy that could be used globally, in fact Haq et al.'s (1988) scheme is unworkable for the Anglo-Paris Basin. The Exxon team used Busnardo's (1984) Aptian biochronozones, based upon the ammonite distributions in South-east France. Here, the succession is rather thin and poorly fossiliferous, and the ammonite distributions indicate the presence of considerable stratigraphical breaks. The Albian part of their 'Tethyan' zonation is not based upon Mediterranean areas at all, but uses Amedro's (1980) assemblage-zones, established in the northern part of the Paris Basin. Some problems are encountered when trying to use these zones in the Anglo-Paris Basin, and it is unlikely that they can be distinguished in the Mediterranean Province. Since the ammonite records of the Aptian and Albian of south-eastern France are poorly known, the most recent attempts to produce a Mediterranean biozonation have been from the ammonite records of Georgia, where the proposed zonal scheme is more readily correlatable with that of the British Isles (Hoedemaker, Company et al. 1993; Hoedemaker & Bulot 1990).

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Table 6.1. The Exxon Chart (part of Chart 3.1A Haq et al. 1988)

				A	PTI		I	T			ALBIAN										Stages												
1]	LOV	NE	R			U	PPI	ER					LO	WE	R					Μ	IDI	DLE	·			UP	PEF	2			
	fissicostatus			forbesi	deshayesi	bowerbanki		martinioides	nutfieldiensis	jacobi		dutempleana tardefurcata				raulinianus				dentatus			loricatus		inflatum		dispar			Ammonoid Biochrono-zones (Boreal) Great Britain			
prodeshayesites	coquandi	consobrinus	matheroni	hambrovi	grandis	bowerbanki	martinioides	subnodosocostatum	nutfieldiensis	jacobi	farnhamensis	milletioides	regularis	kitchini	floridum	puzosianus	larcheri	auritiformis	bulliensis	normannie	eodentatus	benettianus	dentatus	intermedius	niobe	biplicatus	silenus	pricei	inflata	fallax	perinflata	Ammonoid Biochrono-zones (Teth yan region)	
	1	L	J	U	JPP	ER	•	J			•	PHANEROZOIC												-	Megacycle set								
			LO	WEI	r zu	JNI	(LZ) (p	ars)			UPPER ZUNI (UZ) (pars)												Megacycles									
		I	ØW	E R	ZUI	NI I	3 (I	ZB)	(pa	rs)		UPPER ZUNI A (UZA) (pars)										Supercycle sets											
IBZ-3(pars) IBZ-4								UZA-1 UZA-2(pars											ars)	Supercycles													
			4.1 4.2								1.1				1.2		<u> </u>		t	1.3			1.4		1.5			2.1		Cycles			
		· · · ·	112					109.5		,		106							103				100.5			98		8		98		(96.5)	Sequence boundary age
		112.2	1133		111						108	1	107		1		104						101	.4		99.5	±		98.5	97		Downlap surface age	
		C-2-2	ວ ວ		11						.08		07				2						01			9.5			20 27	77		surface ag	

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The absolute dating of the event boundaries is based on the assumption that the average length of Aptian and Albian biochronozones is 500 000 years. It is most probable some subzones are of far greater duration than others, in these circumstances it is fair to suggest that Haq *et al.*'s (1988) curve would have to be stretched for some subzonal periods, and squashed down for others. The definition of, for example, the 100.5 Ma sequence boundary and the 99.5 Ma maximum flooding surface cannot be stated with any certainty. Because of these difficulties, authors have frequently encountered problems in matching sequence boundaries and related surfaces with the sequence chronostratigraphy of the Exxon chart. Combined with the tenuous correlations using the ammonite time-scales there is little wonder that considerable differences may exist between the position of a sequence boundary or downlap surface as shown on the sequence chart and what is seen in reality.

Despite the problems in its interpretation, the Exxon chart is a very useful starting point in sequence stratigraphical analysis. It shows very well the hierarchy of global sea-level events, from the first order, down to third order. Smaller scale events are frequently recognised, but not shown on the Exxon chart since they are unlikely to be recognised globally. These fourth and fifth, and even sixth and seventh, order cycles are defined by sedimentary cyclicity.

6.2.3 Applications in the Anglo-Paris Basin, Table 6.2.

There are many outcrops of Aptian and Albian strata in the Anglo-Paris Basin and these have been used to examine and correlate sea-level events (e.g. Ruffell & Wach 1991; Ruffell 1992a; 1992c Hesselbo *et al.* 1990a; 1990b; Amedro 1992). These strata are represented by almost wholly marine, shallow shelf facies. The general trend is that of a gradually deepening succession, from the non-marine and quasi-marine Wealden Group of pre-Aptian times, through the shelf sands of the Lower Greensand Group to the shelf muds of the Gault Formation. The overall deepening pattern is punctuated by periods of sea-level fall, and deposition is in a typically cyclic manner. The cycles are best developed in the most complete successions of strata, elsewhere they may be removed by erosive events and those that remain are thinner where the stratigraphic gaps are greater. In the Aptian, the most complete sedimentary successions are displayed on the Isle of Wight, particularly at the type Lower Greensand Group succession in Chale Bay. It is from here that the sedimentary cycles have been determined, and these correlated into the more incomplete successions of the Weald Basin, Bedfordshire Straits and

Table 6.2. The sequence stratigraphy proposed by workers in the Anglo-Paris Basin and that proposed in the present investigation. Arrows= transgressive surfaces, SB= sequence boundary.



northern France. Ruffell & Wach (1991) and Ruffell (1992a) attempted to correlate the cyclicity with the Exxon chart. The gaps in the sedimentary record at the eastern margin of the Wessex Basin were correlated with sequence boundaries in the same chart by Hesselbo *et al.* (1990b).

Sedimentary cyclicity was recognised in the Gault Formation of East Anglia (Gallois & Morter 1982). Phosphatic nodule beds were seen to rest upon eroded and bioturbated clays. Through a cycle, the clays appeared to become lighter and more calcareous, and terminated abruptly at the next phosphatic nodule bed. This cyclicity is not so obvious in the Gault Formation seen at outcrop, but many of the phosphatic nodule beds are laterally extensive. Hancock (1989) believed that all levels of phosphate recorded the peak of regression within a succession, and hence would represent the sequence boundary. This analysis stems from his work in the Upper Cretaceous Chalk Group, in which he defines all of the firmground horizons as the regressive troughs. Within these strata there is no lithological expression of the transgressive peak in a sea-level cycle, but this is positioned at the mid-point between two such firmgrounds. Hancock's methodology differs from that of standard sequence stratigraphical procedure, in which the condensed level can represent either maximum regression or transgression, but is logical in the respect that the same lithological expression is not believed to represent the two furthest extremes within a sea-level cycle.

The formation of phosphatic nodule beds in the Gault Formation have been related to two processes, i.e. erosion and then subsequent transgression. Alternatively, the development of these beds could be in response to sediment starvation. In this situation most of the erosion would have occurred in relatively deep-water and principally enabled by burrowing organisms resuspending sediment or increasing bed roughness so as to make erosion by weak currents a possibility (Hesselbo & Palmer 1992).

Other distinctive beds of phosphatic nodules are seen in the succession that do not appear to have any relationship with transgression. These concentrations of phosphate may be associated with periods of upwelling and heightened biological activity. The depletion of oxygen from lower levels of water column allows for the preservation of phosphate. In these instances, the phosphatic nodule beds could be related to changes in oceanographic structure without invoking any change in sea-level, and should not be confused with those of a transgressive nature.
6.3 SEDIMENTARY CYCLICITY AND TRANSGRESSIVE SURFACES

6.3.1 Lower Greensand Group

The main sedimentary cycles of the Lower Greensand Group are typically argillaceous at their bases and pass upwards into progressively more arenaceous deposits. The top of such a cycle is often firmly cemented and may be characterised by concretions and a firmground fauna. The boundaries between cycles lie at the base of finer grained sediments that directly overlie firmground horizons.

There are two main models that can be used for the sequence stratigraphy of the sedimentary cycles of the Lower Greensand Group. The first 'transgressive-regressive' model evisages an almost flat shelf. Because all the deposits are found landward of the shelf margin the Lowstand Systems Tract would not be expected to form; the first transgressive deposits would, by definition, be coincident with the sequence boundary (Rawson & Riley 1982; Haq *et al.* 1988; Hesselbo *et al.* 1990b). Very rarely would one expect the sediment supply to be cut off during the time of maximum flooding and the condensed section is unlikely to be a particular feature of shelf environments. Also, in extreme circumstances, the first transgressive deposits of a sequence may be found at the time of maximum flooding, and therefore the SB and MFS may be coincident with one another. Despite the frequency of events, rarely does one find evidence to show that the whole shelf was exposed during falls in sea-level as it is suggested to be the case from the Exxon models.

The second model has the presence of a clinoform break point on the shelf. Lowstand deposition of mass transported material at the toes of slopes of 'mid-shelf' clinoforms may occur. The sequence boundary may then lie at the base of the first sand within a sedimentary cycle, this marking the lowest point of the sea-level cycle when marginal deposits had been pushed seaward. The sequence boundary would be considered a correlative conformity. Topographically raised areas within the basin may have accumulated no sediment on account of regional, sea-level related starvation.

The second model allows for a more complete stratigraphic record than the first. However, the simple 'transgression-regression' model is used in the present study because the transgressive surfaces define the obvious stratigraphic breaks and mark the sharp changes in ammonite distributions.

The sedimentary cycles from the base of the Atherfield Formation to the top of the Ferruginous Sands Formation can be accurately tied to the biostratigraphy at the type section. The cycles found higher in the succession are almost wholly unfossiliferous and the type sections for the ammonite biozones lie outside of the stratotype during this time. In this instance the cycles are dated by correlation from the Weald to the Channel Basin. The ages must remain tenuous in the absence of fossils. Nonetheless, the remarkable correspondence of the transgressive surfaces from the Channel to the Weald Basin in the more fossiliferous part of the Lower Greensand Group succession provides some degree of confidence in these correlations.

a. LG1, Fig. 6.1.

Base: TS1, Bed 1 - Atherfield Bone Bed, Perna Member.

Cycle: The lowest cycle in the Lower Greensand Group is recorded entirely within the condensed deposits of the Perna Member. The Atherfield Bone Bed, consisting of phosphatic pebbles and grit with a derived fauna, rests erosively on the quasi-marine Vectis Formation below, and marks the transgression that restored fully marine conditions in southern England for the first time since the Jurassic. The following muddy sediments grade up into a burrowed glauconitic sandstone, which represents a period of sedimentary hiatus prior to the deposition of clay in the next cycle.



Figure 6.1. Cycle LG1 at Atherfield Point (Isle of Wight).

Age: The cycle lies entirely within the obsoletus Subzone.

Correlation: The Perna Member is present across much of the Weald Basin, having been recorded from West Sussex, Surrey and western parts of Kent. In all these areas, the transition from the non-marine Wealden to marine Lower Greensand Group is a sharply defined transgressive surface.

b. LG2, Fig. 6.2.

Base: TS2, Bed 1, Chale Member.

Cycle: The basal clays of the Chale Member rest sharply on the encrusted upper surface of the Perna Member. The beds coarsen up, through a series of clay - silty clay alternations, into the Lower Lobster Member and then the Crackers Member. The Crackers Member itself is complex, with two main beds, each with its own range of concretions. The lower, blue sand has its concretions along the top surface which may be removed by erosive events, with the upper bed clearly cutting down into the lower at some intervals in the section. The sands coarsen upwards and are overlain sharply by a blue grey clay, representing the transgressive surface of the following cycle.

Age: Deposition of this cycle commenced in the topmost part of the *obsoletus* Subzone, continued through the *fittoni* and *kiliani* Subzones, until the mid-part of the *callidiscus* Subzone.

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Figure 6.2. Cycle LG2 at Atherfield Point (Isle of Wight).

Correlation: The Perna Member of the Weald is succeeded by silty clays, thought to represent the condensed equivalents of the Chale and Lower Lobster Members, although precise correlations of these individual members is impossible. Borehole records at Hoe's Farm, Sussex, and Sevenoaks, Kent, have revealed that the silty clays pass upwards into silty sands towards the centre of the Atherfield Formation, and this may correlate with the Crackers Member of the type section (Bristow *et al.* 1987; Hart 1973).

c. LG3, Fig. 6.3.

Base: TS3, Bed 1, Upper Lobster Member.

Cycle: Cycle 3 begins with the deposition of the Upper Lobster Member. This comprises alternating silty clays and sands and grades into the Lower Gryphaea Member. Previous workers have placed a sequence boundary at the junction between the Atherfield and Ferruginous Sands Formations (Ruffell 1989a; Ruffell and Wach 1991; Wach and Ruffell 1991). From the





succession at Redcliff, Ruffell (1989a) stated that a break in deposition between the two formations exists. However, there is very little lithological change, simply a gradation from silty clay to silty sand, and certainly no evidence for an extended period of non-deposition. The sands of the Lower Gryphaea Member coarsen up into a firmly cemented bed, full of phosphate and encrusted by a bivalve fauna. It is this bed that represents a break in sedimentation and the eroded upper surface is overlain and infilled by silty clays of the next transgressive deposits.

Age: The cycle commences in the upper part of the *callidiscus* Subzone, continues through the *deshayesi* Subzone and includes the very lowest part of the *grandis* Subzone.

Correlation: Evidence for the *callidiscus* Subzone transgression in the Weald was provided by Casey (1961) from his account of the Dover Colliery shafts in Kent. Here, a phosphatic nodule bed, containing a derived fauna, sharply divides the Wealden Group from the Atherfield

Formation. Within the phosphatic nodules he recorded specimens of *Deshayesites callidiscus*. This evidence would suggest that the basal Aptian transgression in this part of the Weald may correlate with the basal Upper Lobster Member on the Isle of Wight, although it could also include the Crackers Member. In the western part of the Weald, the silty sands in the middle part of the Atherfield Formation are sharply overlain by silty brown clays; this return to typical Atherfield Formation deposition occurs as a result of TS3. The separation of the Atherfield Formation into an upper and lower division, between which there is clear evidence for deepening, has been proven from borehole records near Sevenoaks and Hoe's Farm, and at outcrop near Brook, in Surrey (Hart 1973; Bristow *et al.* 1987; Ruffell 1989b). The Hythe Formation succeeds the Atherfield Formation with no evidence for a stratigraphical break. The influx of sand is gradual, and the boundary between the two formations lies at the arbitrary point at which the sandy clays become argillaceous sands.

A break in deposition occurs above the base of the Hythe Formation at Folkestone, represented by an *Aetostreon* – rich limestone. In the Maidstone district the lower part of the Hythe Formation is condensed and poorly exposed, but a similar shell bed has been recorded and named the Exogyra Bed (Worssam 1963; Ruffell 1992c). A firmground horizon is also found at the top of the Albury Member in Surrey. In Sussex, the only recorded basal Hythe Formation is in the Hoe's Farm Borehole, and here no concentration of shells is obvious. However, near the base of the Hythe Formation is a sandstone bed with a burrewt upper surface. All of these firmgrounds at the top of the *deshayesi* Subzone are overlain by transgressive clays.

d. LG4, Fig. 6.4.

Base: TS4, Bed 1, Small Ledge Member

Cycle: The cycle commences with the first bed of the Small Ledge Member and coarsens, with the addition of more arenaceous material, over about 5.50 m of strata. The rhythm terminates with a firmly cemented bed, full of phosphate and trace fossils. The phosphatic concretions at the top of the bed nucleate around large ammonites, particularly *Australiceras*. The burgeousd upper surface is cich in *Aetostreon* and infilled by transgressive clays from the overlying cycle.

Age: The cycle spans the grandis Subzone.

Correlation: Correlations of strata of the grandis Subzone throughout the Weald have previously used the occurrence of Tropaeum hillsii, which was said to lie alongside Deshayesites grandis



Figure 6.4. A correlation of Cycle LG4. LCM= Lower Crioceras Member, BDM= Bown's Down Member.

in Kent. However, it now appears that *T. hillsii* appears only after the disappearance of *Deshayesites* from the Anglo-Paris Basin and that the *grandis* Subzone is generally in a condensed state. Often the topmost part of this Subzone is found within a bed of phosphatic nodules that is incorporated into the transgressive deposits of the *transitoria* Subzone.

e. LG5, Fig. 6.5.

Base: TS5, Bed 1, Brown's Down Member.

Cycle: A thin band of grey clay marks the transgression at the base of the Brown's Down Member, and this is followed upwards by silty clays and sands. Reduced deposition with periods of sedimentary hiatus are recorded in the following Lower Crioceras Member, through a succession of sands and silts that alternate with large glauconitic and calcareous concretions. A preferentially cemented bed at the top of the member contains pieces of wood, burrows and phosphatic concretions and pebbles. The bed is not remember to the extent of the firmground horizons seen lower in the sequence, but the concretionary level at the top of the member seems to represent the largest sedimentary break of all the levels within the Lower Crioceras Member.

Age: The basal transgression is dated as lowest *transitoria* Subzone age and the cycle lies entirely within this subzone.



Figure 6.5. A correlation of Cycle LG5. WCM= Whale Chine Member.

Correlation: The transitoria Subzone sediments of the Folkestone area show levels of condensation and shell accumulation, which is reminiscent of the glauconitic sands with concretions seen at Atherfield. As with the Isle of Wight, the topmost bed of the transitoria Subzone represents the greatest sedimentary break, here marked by a glauconitic limestone, rich in Aetostreon, and yielding phosphatised ammonites (Casey's 1961 'Green Bed').

Transgression TS5 is an obvious horizon throughout the Weald, being marked by remanié phosphatic deposits that overlie a shell bed in the Maidstone district. A similar shell bed is traced into the arenaceous Hythe Formation of Surrey, and this is sharply overlain by silty clays with phosphatic nodules. Ruffell (1992c) claimed that this transgression is recorded by a fuller's earth horizon in the Hoe's Farm borehole, but it is not apparent from the description of the beds by Bristow *et al.* (1987). There is, however, evidence for the transgressive clays of this age, which overlie the topmost *grandis* Sübzone sediments above an erosion surface.

f. LG6, Fig. 6.6.



Base: TS6, Bed 1, Whale Chine Member.

Figure 6.6. A correlation of Cycle LG6.

Cycle: This cycle lies completely within the lower part of the Whale Chine Member. Transgression TS6 is marked by clays, with scattered phosphatic nodules at the base of the member. The argillaceous fraction decreases upwards and it passes into medium-grained sands in which clay is restricted to the linings of burrows. The top sandstone is intensely bioturbated, with a bored upper surface, infilled by the succeeding transgressive clays.

Age: The cycle is represented in the lower part of the meyendorffi Subzone.

Correlation: The correlation of events in the Hythe Formation is made difficult by the lack of age diagnostic ammonites. TS6 is proved at Otterpool Manor, but the equivalent transgressive surface is hard to determine in the condensed and poorly exposed succession in the Maidstone area. Ruffell (1992c) attempted to divide the Maidstone Hythe Formation by the event boundaries that were previously displayed at Brishing Court Quarry, shown in his figure 6. The inconsistencies in the quarrymen's names for the beds caused problems when the Brishing Court succession was to be correlated with other successions in this area. Ruffell shows his proposed correlation on his figure 7, in which he shifted the positions of the event boundaries. The zonal boundaries are shown incorrectly on both his figures. This study proposes that Ruffell's Event

2 lies at the junction between the *transitoria* and *meyendorffi* Subzones, and correlates with TS6 (Figure 6.7. in this study). The same transgressive surface led to the influx of glauconitic sands of the Reigate Member in Surrey, and these rest abruptly on the bored upper surface of the Dorking Member. In the Hoe's Farm borehole, a bed of phosphatic nodules is succeeded by glauconitic sands and silts.



Figure 6.7. The events at Brishing Court Quarry (Maidstone, Kent). A comparison between the transgressive surfaces proposed by Ruffell (1992c) and those defined in the present study.



Figure 6.8. A correlation of Cycle LG7. LCM= Ladder Chine Member.

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g. LG7, Fig. 6.8.

Base: TS7, Bed 9, Whale Chine Member.

Cycle: Cycle 7 extends from the mid-part of the Whale Chine Member, continuing through the Upper Crioceras Member, and into the basal part of the Ladder Chine Member. Smectitic clays and silts of the Whale Chine Member are replaced by increasingly more arenaceous deposits of the Upper Crioceras Member (Ruffell 1989a). These sandy deposits alternate with concretionary levels similar to, although thicker and less glauconitic than, the Lower Crioceras Member. The top of the cycle lies above the base of the Ladder Chine Member, where a continuous line of concretions is found. These have a phosphatic core which is surrounded by calcareous sand and often followed by another phase of phosphatisation, and reflect periods of exhumation and erosion of the sea-floor (Ruffell 1989a; Wach and Ruffell 1991). The concretions are embedded in, and overlain by, firmly cemented iron sands.

Age: Ranges from the mid-part of the meyendorffi Subzone and through the debile Subzone.

Correlation: A transgressive surface towards the top of the meyendorffi Subzone at Otterpool Manor lies above a bed of calcareous sandstone, scattered with phosphatic nodules and carrying a rich ammonite fauna. The upper surface of this bed is rich in Aetostreon and is followed by a well-laminated grey argillaceous sand, with nodules of calcareous sandstone. The following deposits consist predominantly of argillaceous sands, with some thin levels of calcareous sandstone, and are terminated abruptly by a bed of phosphatic nodules. TS7 is also well-represented in the Hythe Formation of the Maidstone district, but has again been confused in the drafting of Ruffell's (1992c) figures 6 and 7 (see Figure 6.7. here). It is apparently younger than seen on the Isle of Wight and in other parts of the Weald, here being dated as the earliest martinioides Zone. It is likely that the erosion prior to the transgression was greater in the shallower water deposits of the Weald Basin, and deposition did not recommence until a later stage than in the Channel Basin.

Above a bed encrusted with *Aetostreon*, at the top of Reigate Member in Surrey, occur coarse sands and pebbles, with phosphatic nodules, representing TS7. The following sandy chert beds of the Godstone Member lack biostratigraphical control, but probably represent a condensed version of the entire upper part of the Hythe Formation of Maidstone (Casey 1961; Ruffell 1992c).

Both at outcrop, and in the Hoe's Farm borehole, a thin seam of fuller's earth lies in the lower part of the *meyendorffi* Subzone. Ruffell (1992c) discussed the fact that the Hythe Formation is on the whole rich in smectite, and that fuller's earth seams represent transgression, with the removal of terrigene input. This bed can, therefore, be correlated with TS7.



Figure 6.9. Cycle LG8 at Chale Bay (Isle of Wight).

h. LG8, Fig. 6.9.

Base: TS8, Bed 4, Ladder Chine Member.

Cycle: Sharply overlying the concretions at the top of LG7 are series of argillaceous and glauconitic silts, representing TS8. The fine grained sands of the lower part of the cycle are replaced by very coarse-grained deposits and then pyritic sands of the Upper Gryphaea Member. Gradually slowing rates of deposition and sedimentary breaks are recorded in the bivalve-rich horizons of the Upper Gryphaea member and in the glauconitic sands with siderite cemented horizons in the Cliff-End Member. The cycle terminates at a siderite cemented bed, full of *Thalassinoides*, containing large calcareous concretions, at the top of the Cliff-End Member. Following the break in deposition, transgressive sediments of glauconitic clay were deposited.

Age: The cycle commences at the start of, and lies entirely within, the gracile Subzone.

Correlation: No evidence has been found for TS8 in the Hythe Formation of the Weald. In many areas erosion has led to the removal of the upper part of the formation, although Ruffell (1992a) has suggested that transgressive deposits of the *martinioides* Zone are recorded in the upper part of the Hythe Formation in the area surrounding Petersfield, in the western Weald.

i. LG9, Fig. 6.10.

Base: TS9, Bed 1, Cliff Farm Member.

Cycle: Cycle 9 is recorded entirely within the Cliff Farm Member. A succession of interbedded glauconitic sands and dark blue pyritic clays are capped by thin units of cross-bedded, friable sandstone, which become more dominant up the cycle. The rhythm is capped by a thick unit of white cross-bedded sandstone with an erosion surface at the top.

Age: The cycle may lie in the lower part of the subarcticum Subzone.

Correlation: The transgression that heralded the *nutfieldiensis* Zone in the Weald is marked by the deposition of fuller's earths in Surrey and western parts of Kent. These beds may either rest on the eroded upper surface or, as seen in Kent, follow the Hythe Formation with little evidence for a stratigraphic break. At Folkestone, these earliest *nutfieldiensis* Zone deposits may be represented in the phosphatic nodule bed at the base of the Sandgate Formation, in which occurs an accumulation of several events. Elsewhere in the Weald, the beds are missing, probably having been removed by a limited tectonic event or a regression. Fuller's earths of equivalent age are also found at the base of the Woburn Formation in Bedfordshire, and these lie above phosphatic remanié beds of earlier Aptian times.



Figure 6.10. A correlation of Cycle LG9. WUM= Walpen Undercliff Member.

j. LG10, Fig. 6.11.

Base: TS10, Bed 1, Walpen Undercliff Member.

Cycle: The basal part of the cycle is marked by a transgressive lag deposit at the base of the Walpen Undercliff Member. Glauconitic and argillaceous sands of the member coarsen upwards

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into medium-grained sands, which are then followed by the yellow and brown sands, with intermittent iron-concretionary layers, of the Blackgang Member. The top bed of the cycle is a coarse brown sand that is then sharply overlain by laminated black muds of the Rocken-End Member.



Figure 6.11. A correlation of Cycle LG10.

Age: The cycle commences in the subarcticum and continues through the cunningtoni Subzone.

Correlation: A transgressive surface above the base of the *nutfieldiensis* Zone is widely developed throughout the Weald. Glauconitic clays of the lowest part of the Sandgate Formation at Folkestone may be of the *subarcticum* Subzone. In the western Weald a transgressive pebble bed formed in response to TS10. This may overlie the earlier *subarcticum* Subzone fuller's

earths, as in the case of the Nutfield Member, or rest directly in the eroded upper surface of the Hythe Formation, as does the Bargate Member. The same transgression led to the commencement of the Sandgate Formation (Puttenham Member) in Sussex, and also led to the overspill of waters from the main Weald Basin, with the deposition of the Faringdon and Seend Formations in Wiltshire.

k. LG11, Fig. 6.12.

Base: TS11, Bed 1, Rocken-End Member.



Figure 6.12. Cycle LG11 at Chale Bay (Isle of Wight).

Cycle: The laminated black muds that define the base of the cycle have a distinctly scoured base into the top bed of the Blackgang Member below. The clays pass up, through a number of glauconitic and more silty beds, into interlaminated black clays and white sands of the lower part of the Sandrock Member. Clay decreases rapidly upwards and passes into a coarse grit, with an eroded upper surface, at the top of the cycle. The top bed is overlain sharply by a bioturbated glauconitic clay.

Age: nolani Subzone?

Correlation: The topmost beds of the Sandgate Formation are poorly exposed in the Weald, and TS11 has only been recorded from the Pulborough district in Sussex, where the Marehill

Member sharply overlies the Pulborough Member above a firmly iron-cemented sand. Elsewhere, dark clays are present towards the top of the Sandgate Formation, e.g. at Folkestone and along the M20 Motorway near Ashford, but the transgressive base is not exposed.

I. LG12, Fig. 6.13.

Base: TS12, Bed 4, Sandrock Member.



Figure 6.13. A correlation of Cycle LG12.

Cycle: Bioturbated glauconitic clay at the base of the cycle coarsens upwards into glauconitic sands. The top of the cycles is marked by a line of large calcareous concretions, above which lie the laminated black clays of Cycle 13.

Age: anglicus Subzone?

Correlation: At Folkestone, the topmost Sandgate Formation is overlain by a phosphatic nodule bed, from which an important ammonite fauna has been collected and documented by Casey (1961; 1959-1980). Recent investigations by Owen (*in press*) have shown that some of the

phosphatised pebble fauna can be correlated with the *nolani* Subzone of the European Tethys. Also included in the pebble bed are ammonites of the succeeding *anglicus* Subzone. It appears that the topmost part of the Sandgate Formation was eroded prior to the commencement of the Folkestone Formation, that formed in response to TS12. In the northern Weald, the base of the Folkestone Formation has not yielded ammonites, but the pebbly sands (Sevenoaks Member) and the following pure white quartzites (Wrotham Member), were deposited in the *anglicus* Subzone (Casey 1961).

The sands of the Woburn Formation in the Bedfordshire Straits are generally unfossiliferous, but are believed to correlate with the Sandgate and Folkestone Formations of the Weald Basin. Brown sands of the Stone Lane Member are sharply overlain by a pebble bed at the base of the pure white sands of the Heath and Reach Member. Ruffell (1989a) correlated this pebble bed with the Sandgate - Folkestone Formation junction in the Weald Basin, hence indicating that it formed in response to TS12.

m. LG13, Fig. 6.14.

Base: TS13, Bed 6, Sandrock Member.

Cycle: Cycle 13 begins with the deposition of a series of laminated black clays; these coarsen upwards into more silty muds, with lenses of white sand increasing towards the top, and capped by a bed of bioturbated glauconitic sand. Following this there is a return to interlaminated white sand and clay, then black laminated clay. The pattern then appears to reflect shallowing followed by gradual deepening up the sequence, with no clear evidence for a break in deposition between. The black clays are then overlain by interlaminated white sands and clays, followed by coarsening upward white sands, reflecting a return to the gradually shallowing sequence recognised before. The topmost bed of the Sandrock Member is terminated abruptly by the Carstone Formation.

Age: farnhamensis Subzone?

Correlation: In the Folkestone region the *anglicus* Subzone nodule bed is followed immediately by an argillaceous greensand, full of abraded shells, and representing transgression in the *farnhamensis* Subzone. Although only 0.60 m thick at Folkestone, this bed thickens to reach 4.85 m west of the harbour and a similar thickness at Sandling Junction to the north (Casey 1961; Hesselbo *et al.* 1990b). In the northern part of the Weald the *anglicus* Subzone thickens

markedly, and is represented by the Sevenoaks and Wrotham Members. Subaerial leaching of the latter member was followed by the deposition of the Bat and Ball Member in the *farnhamensis* Subzone; transgressive clays and silts are recorded in Surrey. It has recently been suggested that the period of stratigraphic gap between the *anglicus* and *farnhamensis* Subzones is equivalent to an entire subzone of the *tardefurcata* \mathbf{z} one that is developed in northern Germany (Owen 1988b; Amedro 1992), but this is unlikely.

In the Bedfordshire Straits, clean white sands precede the glauconitic and silty beds of the Munday's Hill Member. As with the Weald, a period of subaerial leaching prior to TS13 may have occurred.



Figure 6.14. A correlation of Cycle LG13. CF= Carstone Formation.

6.3.2 The Lower Greensand - Gault junction, Fig. 6.15.

The events that occurred in the late *tardefurcata* Zone caused large-scale changes in the Wessex Basin, during which time the palaeogeography was significantly altered. The 'mid-*tardefurcata* Zone folding' event produced a distinctive sea-floor topography of swells and troughs onto which highly variable facies were deposited (Casey 1961; Owen 1992). The troughs saw the commencement of the Gault Formation, whilst Lower Greensand Group sedimentation, often with significant periods of non-deposition, continued on the swell areas. The basal Gault Formation of the northern Weald, Bedfordshire Straits and Paris Basin are correlated with the top part of the Folkestone Formation of Folkestone and the Carstone Formation of the Channel Basin. The Gault Formation did not form as the result of a single transgression, but in a number of phases, and the base varies in age depending upon the position in the basin. Successive transgressions in the *mammillatum* and *dentatus* Zones led to the gradual spread of the Gault Formation clay facies across the entire Anglo-Paris Basin which overstepped the formerly upstanding massifs.

Sedimentary cyclicity is not distinguished in the condensed deposits of the Lower Greensand Group to Gault Formation boundary, but transgressive surfaces can be used to correlate the events.

a. TS14, The regularis Subzone transgression.

At Folkestone, a thick succession of glauconitic sands, interbedded with calcareous sandstone, overlies a shell encrusted firmground. This entire succession is missing from the nearby Sandling Junction sandpit, where the *farnhamensis* Subzone is overlain by later *mammillatum* Zone transgressive deposits. Throughout much of the rest of the Weald, *regularis* Subzone deposits are absent, or preserved as a phosphatic nodule bed that rests abruptly on the top surface of the Folkestone Formation (Casey 1961; Owen 1992). In Sussex, *regularis* Subzone deposits are largely absent, except for a 4.50 m thick succession of clay seen in borehole records of the Horton Hall Quarry (Casey 1961).

Figure 6.15. A correlation of transgressive surfaces at the Lower Greensand Group to Gault Formation junction (TS14-TS18).



Rapid lateral facies changes occur in the Bedfordshire Straits, and the key to events at the Lower Greensand - Gault junction is given in the pits that occur to the north of Leighton Buzzard. In basinal regions (e.g. Chamberlain's Barn and Pratt's quarries) the *regularis* Subzone transgression led to the deposition of coarse brown sands of the Chamberlain's Barn Member. These sands rest with marked unconformity on the Heath and Reach Member below, and the erosion prior to their deposition led to the removal of the entire Munday's Hill Member from these areas. Shenley Hill appears to have occupied a swell region during the Early Albian, and as the basin was starved of clastic sediments, a thin veneer of limestone developed at the top of the Woburn Formation in this area.

b. TS15, the kitchini Subzone transgression.

Regression and erosion occurred prior to the commencement of the *kitchini* Subzone. At Folkestone, the succeeding transgression is represented by a phosphatic nodule bed which is followed upwards by coarse yellow sands. Throughout the remainder of the northern Weald, the *kitchini* Subzone commences at a phosphatic nodule bed either at the base of the Gault Formation or directly overlying the *regularis* Subzone transgressive nodule bed.

Coarse-grained glauconitic sands of the 'Sables Verts' in the Aube have been suggested as being of *regularis* Subzone age (Destombes 1979). These sands are followed sharply by clays, and a phosphatic nodule bed at the base has yielded ammonites of the *kitchini* Subzone. It is believed to have formed as a result of TS15.

Ammonites in the phosphatic nodules at the base of the Carstone Formation in the Atherfield succession of the Channel Basin reveal that TS15 led to the start of deposition of the coarse sands, and that the *regularis* Subzone is absent. This is believed to be the case for the other Carstones that developed in marginal localities of the Anglo-Paris Basin (e.g. Iron-Grit of Sussex and Carstone of Wiltshire), and confirmed by the succession seen in the Bedfordshire Straits. The limestone that developed in the *regularis* Subzone at Shenley Hill was eroded prior to the start of the *kitchini* Subzone. This erosion caused the break up of the limestone, which was then incorporated into the coarse iron sands (Shenley Member) that characterise the remainder of the Early Albian in this locality. Some of the blocks of limestone were washed down from the swell into deeper water localities and are found in the *kitchini* Subzone nodule bed found at the base of the Gault Formation in Chamberlain's Barn. This nodule bed has also yielded remanié ammonites of the *regularis* Subzone. A regressive phase in the *floridum* Subzone halted deposition in the Bedfordshire area, until at least the *steinmanni* Subzone.

c. TS16, the puzosianus Subzone transgression.

Minor transgressive events appear to have occurred in the *floridum* and *raulinianus* Subzones, and these are marked by phosphatic nodule beds throughout the Gault Formation of the northern Weald. However, a more significant transgression occurred at the start of the *puzosianus* Subzone, following a period of erosion that led to the destruction of these earlier deposits in all but the most central parts of the basin.

TS16 is represented at a phosphatic nodule bed which lies within the coarse yellow sands of the Folkestone Formation at the type section. This, the Main mammillatum Bed, yields remanié ammonites from the *floridum* and *raulinianus* Subzones, and these occur alongside indigenous species of the *puzosianus* Subzone (Casey 1961; Owen 1992). More expanded successions are represented in the northern part of the Weald, but frequently the *floridum* and *raulinianus* Subzone faunas occur mixed together below transgressive deposits of the *puzosianus* Subzone. Even in the least condensed sections, the *raulinianus* Subzone may be represented by a phosphatic nodule bed at the base of *puzosianus* Subzone sediments.

6.3.3 The Gault and Upper Greensand Formations. Fig. 6.16.

The first transgression of the Mid Albian led to the commencement of the Gault Formation at Folkestone. The effects of this transgression were not felt in all areas of the Anglo-Paris Basin, and in many areas a hiatus spans the earliest of the Mid Albian subzones. However, there is no locality in which Lower Greensand Group deposition continued beyond the *steinmanni* Subzone. Sedimentary cyclicity is not always obvious in the successions that are seen at outcrop, and so transgressive surfaces are again used to correlate between areas.

a. TS17, the steinmanni Subzone transgression

Regression and erosion during the upper part of the *puzosianus* Subzone was followed by transgression in the *steinmanni* Subzone (TS17). At Folkestone, the 'Sulphur Band' contains two layers of nodules set within glauconitic silt; the lower yields a *puzosianus* Subzone fauna and the upper, ammonites of the *steinmanni* Subzone. In the northern Weald, an unfossiliferous phosphatic nodule bed, assumed to be of late *puzosianus* Subzone age, is overlain by glauconitic sediments of the *steinmanni* Subzone. Transgressive *steinmanni* Subzone deposits are recorded from the Bedfordshire Straits, and in the phosphatic nodule bed at the top of the Carstone Formation at Atherfield.



In the Paris Basin, evidence for the transgression at the base of the *steinmanni* Subzone has only been proved from borehole records in the Aube. Here, a thin bed of argillaceous greensand is succeeded by grey clays.

b. TS18, the dentatus Subzone transgression.

The *dentatus* Subzone transgression is marked by a line of phosphatic nodules or sharp colour change throughout the Anglo-Paris Basin; the stratigraphic break beneath it represents a variable period of time. The shortest time gaps are apparently recorded at Small Dole, in Sussex, and in the Aube, where the *dentatus* Subzone succeeds the *lyelli* Subzone with marked colour change, from fawn grey clays, with marly concretions, to gritty, dark grey clay (Owen 1971). The clays above the transgressive surface lighten upwards and become less gritty. Throughout the northern part of the Weald, a bed of phosphatic nodules occurs at the base of *dentatus* Subzone clays, and this rests upon glauconitic and argillaceous silt of the *lyelli* Subzone. At Folkestone, the *lyelli* Subzone has been reduced to a thin bed of phosphatic nodules set within glauconitic silt. Above, the *dentatus* Subzone nodules are set within clays that are far less silty and in which the glauconite diminishes rapidly upwards.

Elsewhere in the Anglo-Paris Basin, the *dentatus* Subzone transgressive deposits rest unconformably on the beds below. At Wissant, the *dentatus* Subzone nodule bed rests on the Gardes Member at the top of the Folkestone Formation. Included in the nodules are ammonites of the *mammillatum* Zone and *dentatus* Subzone, set within a matrix yielding an indigenous *dentatus* Subzone fauna. This bed represents the accumulation of several events that occurred prior to TS18. The same phosphatic nodule bed at the base of the *dentatus* Subzone is seen in the Bedfordshire Straits, where it may rest either on the condensed *steinmanni* Subzone clays or directly upon the Shenley Member. The basal bed of the Gault Formation at Rock Common, in Sussex, rests sharply on the Iron-Grit. Clays are gritty at their base, but there is no sign of a phosphatic nodule bed. One of the most expanded successions through the subzone is seen here, and a distinctive dark-grey to fawn-grey cyclicity is recorded.

c. TS19, the niobe Subzone transgression.

Dark grey clay at the top of the *intermedius* Subzone is then overlain by a distinctive fawn clay of the *niobe* Subzone at Folkestone (Price's Bed III). Owen (1971) stated that the transition between the dark grey *intermedius* Subzone clays and the fawn clays was gradational and occurred through a series of lenses. However, this is not the case, and the colour change is sharp, as is the *appearance* of the new fauna. The boundary between the *intermedius* and *niobe* Subzones is a bioturbated erosion surface, at which the paler coloured clays from above penetrate downwards. An identical burrowed erosion surface between the sharp colour change is seen across the Channel at Wissant. The junction between the *intermedius* and *niobe* Subzones is marked by a line of phosphatic nodules in the northern part of the Weald and by a bed of glauconitic silt in the Bedfordshire Straits.

d. TS20, the nitidus Subzone transgression

Regression and erosion occurred at the top of the *subdelaruei* Subzone, and this was then followed by TS20 at the start of the *nitidus* Subzone. At Folkestone, the erosion removed the upper part of the *subdelaruei* Subzone. A phosphatic nodule bed at the base of the transgressive deposits contains abraded fossils of this subzone which have been incorporated with indigenous *nitidus* Subzone ammonites. In the thinner succession at Wissant, the erosion cut down lower and reduced the entire *subdelaruei* Subzone to a remanié at the base of TS20. The most expanded succession through the *subdelaruei* Subzone is found in the northern part of the Weald, but again abraded fossils of this subzone have been found at the base of TS20 at Sevenoaks.

e. TS21, the cristatum Subzone transgression.

A period of erosion and subsequent transgression provided a distinctive junction between the Middle and Upper Albian parts of the Gault Formation. At Folkestone, a very dense bed of phosphatic nodules rests upon the eroded upper surface of the *daviesi* Subzone clays. This transgressive surface is highly distinctive throughout the Weald, and forms the junction between the Copt Point and East Wear Bay Members. The erosion involved prior to the *cristatum* Subzone is greater in many areas outside Folkestone, where sediments of the entire *daviesi* and much of the *nitidus* Subzone have been removed. Above the basal nodule bed occur a number of step-like transgressions, represented in phosphatic nodule and shell beds. These continue through the remainder of the *cristatum* and through the *orbignyi* Subzones.

In western parts of the Channel Basin, deposition of the Upper Greensand Formation may have commenced as a result of the *cristatum* Subzone transgression. In some parts of Dorset and Devon, this transgression marks the start of Lower Cretaceous deposition and the basal Upper Greensand Formation rests directly on the Triassic.

f. TS22, basal inflatum Subzone transgression.

Transgression at the start of the *inflatum* Subzone was preceded by erosion in the late *varicosum* Subzone. Eroded remnants of the *varicosum* Subzone are found at the base of the transgressive deposits at Folkestone. The erosion cut down lower in the Boulonnais and the whole *varicosum* Subzone and part of the *orbignyi* Subzone have been reduced to a remanié at the base of the *inflatum* Subzone. A similar situation may exist in the Bedfordshire Straits, where a nodule bed of *varicosum* Subzone age lies beneath pale grey clays that have yielded abundant belemnites but no ammonites. Owen (1972) suggested that these clays were of the *varicosum* Subzone, but equally may be of the *inflatum* Subzone and therefore formed as a result of TS22.

g. TS23, top inflatum Subzone transgression

The top of the *inflatum* Subzone at Folkestone is represented within a silty grey clay, full of phosphatic nodules and glauconite. The clays of the succeeding *fallax* Subzone are glauconitic towards the base, but this diminishes rapidly upwards. This *inflatum* Subzone nodule bed forms the base of the Upper Greensand Formation in the western Weald, and it often cuts down into older strata, yielding a remanié of *inflatum*, *varicosum* and sometimes *orbignyi* Subzone age. The Glauconitic Marl, of the earliest Cenomanian, rests erosively on top of the topmost part of the Gault Formation.

This Late Albian event may be represented in the Upper Greensand Formation of the Dorset area, where transgressive deposits overlie a distinctive hardground at the top of the Foxmould Member (Simmonds *et al.* 1991). However, with the lack of biostratigraphic control, this is not possible to confirm.

6.4 THIRD ORDER SEA-LEVEL CHANGES

The cycles discussed above show some correspondence with those of the Exxon chart, but are of higher frequency. The parasequence sets, and their correlative transgressive surfaces, are undoubtedly short-term transgressive and regressive cycles. High frequency flooding is followed by longer-term regression, although often little change in relative sea-level is required to produce these cycles in the shelf environment. It appears that both third and higher order sea-level cycles are shown on the charts of Ruffell & Wach (1991) and Ruffell (1992c). It is very difficult to distinguish between events of different magnitude using the facies analysis approach. However, the more significant transgressions and regressions are bounded by unconformities in the

marginal localities of the Anglo-Paris Basin and typically defined by the more distinctive facies changes. The sediment distribution is plotted against relative time on Figure 6.17. In this figure, eleven unconformity bound packages of strata are recognised, which can then be correlated into the more complete succession of the Isle of Wight. These events are considered to represent third order sea-level change (see Table 6.2).

a. Sequence 1.

Restoration of marine conditions near the base of the Aptian in southern England is widely represented across the Channel and Weald Basins, where the Perna Member rests above an unconformity of unknown duration. Kerth & Hailwood (1988) suggested that the underlying Vectis Formation is of Aptian age and, therefore, the time-gap would be of very limited duration. However, the presence of Barremian belemnites in the same beds from Redcliff, Isle of Wight, suggests that at least the lowest part of the Aptian is missing from this area and presumably the entire Wessex Basin (Rawson *in prep.*). Above the Perna Member follows a succession of marine clays, found across most areas of the Wessex Basin, and a large part of the Paris Basin. These clays grade upwards into the silty and sandy Ferruginous Sands (Channel Basin) or Hythe Formations (Weald Basin), which were deposited as a result of gradually shallowing seas. Inhibited deposition persisted through the lower parts of these two formations, and the beds are thin and frequently encrusted by a shallow-water marine fauna.

b. Sequence 2.

A period of erosion occurred at the top of the *grandis* Subzone. This produced an unconformity of only limited duration, but led to condensation of strata, and the phosphatic remnants to be incorporated into the following transgressive deposits of the *transitoria* Subzone. The facies changes that occurred following the transgression are not significant. However, this event led to a rapid extension of the depositional area, and remanié nodule beds are found in the Bedfordshire Straits, East Midlands Shelf, and the northern part of the Paris Basin.

Figure 6.17. Sediment distribution plot from selected areas around the Anglo-Paris Basin. Transgressive surfaces overlying unconformities are shown in red, and 11 sequences are recorded.

	ISLE OF WIGHT	EAST KENT	WEST KENT	SURREY	WEST SUSSEX	EAST SUSSEX	WILTS.	SHENLEY HILL	CHAMBERLAINS BOULONNAIS AUBE BARN	
perinflatum	ж ж			II II						11
fallax	in in			in in						TS2
inflatum	ш									*
varicosum	ш ш.									10.
orbignyi										1
cristatum										TS2
daviesi									•••	9.4
nitidus										TS2
ubdelaruei										▲
niobe										8.
intermedius										1
dentatus										TSU
lyelli										7.1
teinmanni	· · · · ·									TCI
buzosianus	1.1.1.1.1.1.1					7.				▲ ¹³¹
aulinianus			· · · · ·	· · · · ·		/ \				6
Aoridum			· · · · ·							
kitchini			· · · · ·					12222		V TSI
regularis									••••	5.
rnhamensis										TS1
anglicus	7						·			4.
nolani										2 A 15L
unningtoni		1711		2-2-2	ing the second				-TTT_	3.
ubarcticum										TSI
gracile	1.1			_ <u> </u>				<u>[</u>]		Ť
dehile										2.
nevendorffi				· ÷ ·						
transitoria	1			· · ·				-		+
grandis	1.1.1		••••	· · · ·						TS5
dehavesi	1			÷ ÷ ÷						T
callidiscus										
hiliani		/	· · · · · ·		· · · · · ·					1.
fittani			· · · · ·	· · · ·						
sheeletus	111111				· · · · · ·					W
obsoletus	minini		V		1					TS1
issicostatus								•		

c. Sequence 3.

The *martinioides* Zone (*debile* and *gracile* Subzones) represents a generally regressive phase, and the change from a shelf to lagoonal environment in the Weald (Ruffell 1992a; 1993). The upper part of the Hythe Formation is developed in the Maidstone area of the Weald, but in many other localities has been removed as a result of the regression. Minor transgressive episodes have been recorded in the Ferruginous Sands Formation of the Channel Basin, and these may be represented by ammonite-bearing horizons in the Maidstone Hythe Formation. Nevertheless, the regressive phase is dominant, and a widespread unconformity developed across a large part of the basin.

d. Sequence 4.

Transgression occurred at the base of the *subarcticum* Subzone, and this marked the start of deposition of the Sandgate Formation in the Weald Basin. The first effects of the strongly transgressive phase were felt in the basinal parts of the Weald, and caused the Bedfordshire Straits to open. Smectitic clays and fuller's earths formed in response to this transgression in the *subarcticum* Subzone. A short tectonic disturbance folded the strata prior to a second transgressive phase that occurred later in the same subzone. A pebble bed rests sharply on the fuller's earths where they are preserved, or directly on the eroded upper surface of the Hythe Formation. This transgression saw a further enlargement of the depositional area. The Sandgate Formation extended across the English Channel into the northern part of the Paris Basin and waters overspilled from the main Weald Basin to give rise to shallow-water sands in Wiltshire.

Regression led to the removal of the top part of the Sandgate Formation at the margins of the Weald, and then the following transgression saw the start of Folkestone Formation deposition. A thick succession of sand developed in the northern part of the Weald, but this is condensed in the more marginal localities. Casey's (1961) 'mid-*tardefurcata* Zone' folding event, and its associated regression may have been the cause of the condensation, and it led to the development of a widespread unconformity across the Anglo-Paris Basin.

e. Sequence 5.

Transgression in the *regularis* Subzone saw the commencement of Gault Formation deposition in the inland sections of the Weald, whilst Folkestone Formation deposition continued at Folkestone. In the Bedfordshire Straits, coarse sands marked the start of the transgression, and these were later replaced by limestones in uplifted areas. Regression and erosion at the top of the *regularis* Subzone preceded the next phase of transgression at the start of the *mammillatum* Zone. The erosion led to the destruction of the earlier sediments, and these are often found in remanié at the base of the Gault Formation.

f. Sequence 6.

The depositional area increased markedly as a result of the *kitchini* Subzone transgression, and the basin margins are represented by the Carstone Formation, which rests unconformably on older formations of the Lower Greensand Group. Several transgressive pulses occur throughout the Early Albian. These are marked by phosphatic nodule beds, but it is difficult to separate individual episodes in the highly condensed strata.

g. Sequence 7.

A significant transgressive pulse occurred in the *steinmanni* Subzone. The event is represented by phosphatic nodule beds and glauconite which terminated Lower Greensand Group deposition in all areas. The argillaceous deposits that followed were best developed in basinal areas, but did not always extend to the more marginal localities.

h. Sequence 8.

Further transgression in the *dentatus* Subzone extended the area of the Gault Formation to the marginal parts of the basin and the areas associated with structural highs. Owen (1971) suggested that the clays in this sequence reached the greatest geographical extent of all of the Gault Formation.

i. Sequence 9.

An unconformity of limited duration occurs below transgressive *nitidus* Subzone sediments in the Weald and Boulonnais. The clays above the transgressive surface have been variably removed as a result of later Albian regression.

j. Sequence 10.

The *cristatum* Subzone transgression followed a significant period of erosion that led to the removal of several subzones outside of the basin centre. Clays above the unconformity are lighter in colour and thicker than previously seen, and appear to have been deposited in significantly deeper-water environments. Soon after this transgressive event, uplift of areas to the west of the Anglo-Paris Basin occurred, and this led to the gradual influx of glauconitic and arenaceous deposits into the basin. In Dorset and Devon this influx saw the commencement of the Upper Greensand Formation.

k. Sequence 11.

Regression at the end of the *inflatum* Subzone led to the development of a phosphatic nodule bed at Folkestone which is then followed upwards by glauconitic silt and clay. In western parts of the Weald, the same phosphatic nodule bed is followed by the Upper Greensand Formation that spread progressively eastward.

6.5 SUMMARY AND CONCLUSIONS

Sequence stratigraphy is a concept that has widely been used in the examination of stacking patterns in the Anglo-Paris Basin and other shelf sea environments. These studies have indicated that events are recorded that correlate with the global eustatic cycles of Haq *et al.* (1988). Many of the studies have defined sequence boundaries, transgressive surfaces and maximum flooding surfaces, and recognised the systems tracts that form the building blocks of depositional sequences.

This study has shown has the recognition of three distinctly different types of depositional surface is not possible within the epeiric seas of the Anglo-Paris Basin. Parasequence sets, and sometimes their constituent parasequences, are seen in the most basinal parts, and these are always bounded by strongly transgressive surfaces. Correlation of the transgressive surfaces is possible in the more marginal localities, and these are often characterised by phosphatic nodule beds. The parasequence sets are the smallest-scale, widely traceable events that can be seen across the basin. Shallow conditions prevailed, particularly during the Aptian, and only very minor fluctuations in the level of the seas could have led to significant changes of facies. The recognition of such small-scale sea-level changes is unlikely to be so obvious in the deeper-water areas of the outer shelf and continental margins.

Larger-scale changes of sea-level are defined by the more significant changes of facies. Again the predictable surface is the transgressive surface, but here will often coincide with widespread unconformities. The distinction between the different orders of sea-level change is important, yet almost impossible to prove - one man's sequence is another's parasequence. Very thick sedimentary successions may contain various scales of cyclicity, whereas more condensed deposits may be significantly less cyclic. It is highly likely that in other studies, several orders of sea-level change are displayed on the same chart. This study has suggested that some transgressive surfaces are more significant than others, and a general stacking pattern of the parasequence sets suggests that these are of longer duration, but on a purely lithological basis it cannot truly be established whether these really are all of third order duration. In the following two chapters the distributions of ammonites are considered. These show that sea-level events of apparently longer duration and higher intensity have a profound effect on the marine fauna. The changes in the ammonite distribution are shown to be a tool in the prediction of sea-level events, rather than a confirmation of what is already known from facies changes.

CHAPTER 7 AMMONITE BIOGEOGRAPHY, DIVERSITY ANALYSIS AND BIOLOGICAL EVENTS.

This chapter considers briefly the biogeographic affinities and occurrence of the Aptian-Albian ammonites. There is then a detailed examination of the correlation between diversity changes and the sea-level fluctuations which were commonplace during the Aptian and Albian. Ammonites were particularly sensitive to the global and regional palaeographic changes that were caused by both long and short-term sea-level events (Becker 1993; House 1985; 1989; 1993; Rawson 1993, *in press a*).

7.1 AMMONITE BIOGEOGRAPHY

The biogeographic grouping of ammonites was discussed by Kennedy & Cobban (1976) and more recently by Westermann (1993). These authors used a number of biogeographic terms which are used here when discussing the distribution of the ammonites of the North European Province. The terms are:

(i) Pandemic.

This refers to ammonites that attained an almost global distribution through both the Tethyan and Boreal Realms.

(ii) Tethyan\Cosmopolitan.

Tethyan ammonites evolved in the Tethyan Ocean and associated shelf seas. They may be distributed throughout the Tethyan Realm or restricted to only part of it. For those forms occurring throughout the realm Westermann (1993) used the term 'cosmopolitan'. Some of the Tethyan taxa may have entered the Anglo-Paris Basin at discrete intervals, but did not stay to evolve in this region.

(iii) Boreal.

The Arctic region is believed to have been occupied by land through most of the Aptian. However, in the Albian, a definite Boreal fauna developed there.

(iv) Endemic.

Endemic ammonites are those limited to a particular region, often a single basin.

The faunas of the North European Province are essentially of Tethyan affinity. The shallow waters of this province are characterised by an ammonite assemblage that is more restricted than

in areas further south. All four biogeographic groupings discussed above are represented in the area. Pandemic forms are represented by *Tropaeum* which reached as far north as Spitsbergen and Arctic Canada (Rawson 1981).

Several Tethyan taxa entered the Anglo-Paris Basin in large numbers. They often remained for considerable periods of time and evolved in this area. These forms are generally cosmopolitan in distribution and their final extinction often occurred at a later stage than that seen in north-western parts of Europe. Other Tethyan taxa entered the basin at discrete intervals but did not evolve in the region. In contrast, some Tethyan immigrants migrated into the basin to evolve into endemic forms. Evolution was generally rapid and well-defined roots are traced. Conditions favourable to the development of an endemic fauna allowed for allopatric speciation and, hence, the geographical restriction of the fauna. The endemic taxa rarely strayed into other regions, even when immigrations of southerly derived forms showed that biogeographical links were clearly established between realms.

7.2 THE AMMONITE FAUNA

There are 10 important ammonite superfamilies (18 families) recorded from the Aptian and Albian of the Anglo-Paris Basin. The origins and biogeographical affinities of each are discussed briefly below. Several other taxa did appear in the Anglo-Paris Basin, but only as extreme rarities and these are not discussed here. The biostratigraphical distribution for each of the taxonomic ranks in the Anglo-Paris Basin is given in tables 7.1 and 7.2.
Subzone	Superfamily	Family	Subfamily	Genus
perinflata	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Anisoceras, Idiohamites
		Baculitidae		Lechites
	Scaphitaceae	Scaphitidae	Scaphitinae	Mariella, Ostlingoceras
	Desmocerataceae	Desmoceratidae	Puzosiinae	Puzosia
	Hoplitaceae	Hoplitidae	Hoplitinae	Callihoplites, Lepthoplites, Pleurohoplites, Arrhaphoceras, Discohoplites
		Engonoceratidae		Engonoceras
	Acanthocerataceae	Lyelliceratidae	Stoliczkaiinae	Neophlycticeras, Stoliczkaia
		Brancoceratidae	Mortoniceratinae	Mortoniceras
fallax	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Anisoceras, Idiohamites, Pseudhelicoceras
		Turrilitidae		Turrilitoides
		Baculitidae		Lechites
	Scaphitaceae	Scaphitidae	Scaphitinae	Scaphites, Mariella, Ostlingoceras
	Desmocerataceae	Desmoceratidae	Puzosiinae	Puzosia
	Hoplitaceae	Hoplitidae	Hoplitinae	Lepthoplites, Pleurohoplites, Callihoplites, Arrhaphoceras, Discohoplites
		Engonoceratidae		Engonoceras
	Acanthocerataceae	Lyelliceratidae	Stoliczkaiinae	Neophlycticeras, Stoliczkaia
		Brancoceratidae	Mortoniceratinae	Mortoniceras
			Brancoceratinae	Prohysteroceras, Hysteroceras
inflatum	Turrilitaceae	Hamitidae		Hamites, Stomohamites
		Anisoceratidae		Pseudhelicoceras, Anisoceras, Idiohamites
		Baculitidae		Lechites
	Scaphitaceae	Scaphitidae	Scaphitinae	Scaphites
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Euhoplites, Epihoplites, Callihoplites, Lepthoplites,
	Acanthocerataceae	Brancoceratidae	Mortoniceratinae	Mortoniceras
			Brancoceratinae	Prohysteroceras, Hysteroceras
		Lyelliceratidae	Stoliczkaiinae	Neophlycticeras

Table 7.1. The biostratigraphical distribution of the Gault Formation and Upper Greensand Formation ammonites (Middle and Upper Albian).

			· · · · · · · · · · · · · · · · · · ·	
varicosum	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Pseudhelicoceras, Anisoceras, Idiohamites, Mastigoceras
		Baculitidae		Lechites
	Scaphitaceae	Scaphitidae	Scaphitinae	Eoscaphites
	Desmocerataceae	Desmoceratidae	Puzosiinae	Puzosia
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Euhoplites, Metaclavites, Epihoplites, Semenovites
	Acanthocerataceae	Brancoceratidae	Mortoniceratinae	Mortoniceras
			Brancoceratinae	Prohysteroceras, Hysteroceras
		Lyelliceratidae	Stoliczkaiinae	Neophlycticeras
orbignyi	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Pseudhelicoceras, Idiohamites
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras, Uhligella
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Euhoplites, Metaclavites, Epihoplites
	Acanthocerataceae	Brancoceratidae	Mojsisovicsiinae	Dipoloceras
			Mortoniceratinae	Mortoniceras
			Brancoceratinae	Prohysteroceras, Hysteroceras
		Lyelliceratidae	Stoliczkaiinae	Neophlycticeras
cristatum	Phyllocerataceae	Phylloceratidae		Phylloceras
	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Pseudhelicoceras
		Turrilitidae		Turrilitoides
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras, Uhligella
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Dimorphoplites, Euhoplites, Metaclavites
		Gastroplitidae	Gastroplitinae	Gastroplites
	Acanthocerataceae	Brancoceratidae	Mojsisovicsiinae	Oxytropidoceras, Dipoloceras
			Mortoniceratinae	Mortoniceras
			Brancoceratinae	Hysteroceras
		Lyelliceratidae	Stoliczkaiinae	Neophlycticeras
daviesi	Turrilitaceae	Hamitidae		Hamites
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Dimorphoplites, Euhoplites
	Acanthocerataceae	Brancoceratidae	Mojsisovicsiinae	Dipoloceras

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nitidus	Turrilitaceae	Hamitidae		Hamites
		Turrilitidae		Turrilitoides
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Dimorphoplites, Euhoplites
subdelaruei	Turrilitaceae	Hamitidae		Hamites
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Dimorphoplites, Euhoplites
	Acanthocerataceae	Brancoceratidae	Mojsisovicsiinae	Mojsisovicsia
			Brancoceratinae	Eubrancoceras
niobe	Turrilitaceae	Hamitidae		Hamites
	Hoplitaceae	Hoplitidae	Hoplitinae	Anahoplites, Dimorphoplites, Euhoplites
		Engonoceratidae		Engonoceras
	Acanthocerataceae	Brancoceratidae	Brancoceratinae	Eubrancoceras
intermedius	Tetragonitaceae	Tetragonitidae		Tetragonites
	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Pseudhelicoceras, Protanisoceras
	Haplocerataceae	Aconeceratidae		Falciferella
	Desmocerataceae	Desmoceratidae	Desmoceratinae	Desmoceras
			Puzosiinae	Puzosia
			Beudanticeratinae	Uhligella
	Hoplitaceae	Hoplitidae	Hoplitinae	Hoplites, Anahoplites, Dimorphoplites, Euhoplites
dentatus	Lytocerataceae	Lytoceratidae		Pictetia
	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Protanisoceras, Metahamites
	Desmocerataceae	Desmoceratidae	Desmoceratinae	Desmoceras
	Hoplitaceae	Hoplitidae	Hoplitinae	Hoplites
	Acanthocerataceae	Brancoceratidae	Brancoceratinae	Eubrancoceras
			Mojsisovicsiinae	Oxytropidoceras, Falloticeras
lyelli	Phyllocerataceae	Phylloceratidae		Phylloceras
	Turrilitaceae	Anisoceratidae		Pseudhelicoceras, Protanisoceras, Metahamites
	Desmocerataceae	Desmoceratidae	Desmoceratinae	Desmoceras
			Beudanticeratinae	Beudanticeras
	Hoplitaceae	Hoplitidae	Hoplitinae	Hoplites
	Acanthocerataceae	Lyelliceratidae	Lyelliceratinae	Lyelliceras
		Brancoceratidae	Brancoceratinae	Parabrancoceras
			Mojsisovicsiinae	Oxytropidoceras

eicerataceae E erataceae E xeae H	Douvilleiceratidae Desmoceratidae Hoplitidae	Douvilleiceratinae Beudanticeratinae Sonneratiinae	Douvilleiceras Beudanticeras Otohoplites
erataceae E xeae H	Desmoceratidae Hoplitidae	Beudanticeratinae Sonneratiinae	Beudanticeras Otohoplites
eae H	Hoplitidae	Sonneratiinae	Otohoplites
		Hoplitinae	Hoplites (Isohoplites), Hoplites (Hoplites)
C	Cleoniceratidae	Cleoniceratinae	Cleoniceras
cerataceae E	Brancoceratidae	Brancoceratinae	Parabrancoceras
Ţ	Lyelliceratidae	Lyelliceratinae	Tegoceras, Lyelliceras
,	cerataceae	Cleoniceratidae cerataceae Brancoceratidae Lyelliceratidae	Cleoniceratidae Cleoniceratinae cerataceae Brancoceratidae Brancoceratinae Lyelliceratidae Lyelliceratinae Lyelliceratinae

Table 7.2. The biostratigraphical distribution of the Lower Greensand Group ammonites (Aptian and Lower Albian

Subzone	Superfamily	Family	Subfamily	Genus
puzosianus	Turrilitaceae	Anisoceratidae		Protanisoceras
	Douvilleicerataceae	Douvilleiceratidae	Douvilleiceratinae	Douvilleiceras
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras
	Hoplitaceae	Cleoniceratidae	Cleoniceratinae	Cleoniceras
	Hoplitidae Sonneratiinae		Otohoplites, Sonneratia, Pseudosonneratia, Tetrahoplites, Protohoplites	
		Gastroplitidae	Gastroplitinae	Sokolovites
	Acanthocerataceae	Lyelliceratidae	Lyelliceratinae	Tegoceras
raulinianus	Turrilitaceae	Hamitidae		Hamites
		Anisoceratidae		Protanisoceras
	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites
	Douvilleicerataceae	Douvilleiceratidae	Douvilleiceratinae	Douvilleiceras
	DesmocerataceaeDesmoceratidaeBeudanticeratHoplitaceaeCleoniceratidaeCleoniceratinaLemuroceratinaLemuroceratina		Beudanticeratinae	Beudanticeras, Uhligella
			Cleoniceratinae	Cleoniceras
			Lemuroceratinae	Cymahoplites
		Hoplitidae	Sonneratiinae	Otohoplites, Sonneratia, Pseudosonneratia
	Acanthocerataceae	Brancoceratidae	Mojsisovicsiinae	Oxytropidoceras
		Lyelliceratidae	Lyelliceratinae	Tegoceras

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floridum	Furrilitaceae	Hamitidae		Hamites	
		Anisoceratidae	Protanisoceras, Rossalite		
	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	phoplitinae Hypacanthoplites	
	Douvilleicerataceae	Douvilleiceratidae	Douvilleiceratinae	Douvilleiceras	
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras	
	Hoplitaceae	Cleoniceratidae	Cleoniceratinae	Cleoniceras, Anadesmoceras	
		Hoplitidae	Sonneratiinae	Otohoplites, Sonneratia, Anahoplitoides	
		Engonoceratidae		Parengonoceras, Platyknemiceras	
	Acanthocerataceae	Lyelliceratidae	Lyelliceratinae	Tegoceras	
kitchini	Turrilitaceae	Hamitidae		Hamites	
	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites	
	Douvilleicerataceae	Douvilleiceratidae	Douvilleiceratinae	Douvilleiceras	
	Desmocerataceae	Desmoceratidae	Beudanticeratinae	Beudanticeras	
	Hoplitaceae	Hoplitidae	Sonneratiinae	Sonneratia	
		Cleoniceratidae	Cleoniceratinae	Cleoniceras, Anadesmoceras	
regularis	Lytocerataceae	Lytoceratidae		Pictetia	
	Tetragonitaceae	Gaudryceratidae		Eogaudryceras	
	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites	
	Douvilleicerataceae	Douvilleiceratidae	Douvilleiceratinae	Douvilleiceras	
	Haplocerataceae	Aconeceratidae		Aconeceras, Sanmartinoceras	
	Hoplitaceae	Cleoniceratidae	Cleoniceratinae	Cleoniceras, Anadesmoceras	
	Acanthocerataceae	Lyelliceratidae	Leymeriellinae	Leymeriella, Epileymeriella	
farnhamensis	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites	
	Hoplitaceae	Hoplitidae	Sonneratiinae	Farnhamia	
anglicus	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites	
nolani	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Hypacanthoplites, Nolaniceras	
cunningtoni	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Colombiceras	
			Parahoplitinae	Parahoplites	
subarcticum	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Tropaeum	
	Deshayesitaceae	Parahoplitidae	Acanthohoplitinae	Colombiceras	
			Parahoplitinae	Parahoplites	
gracile	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Australiceras, Ammonitoceras, Caspianites	
	Douvilleicerataceae	Douvilleiceratidae	Cheloniceratinae	Cheloniceras, Walpenites	
	Haplocerataceae	Aconeceratidae		Aconeceras, Doridiscus	

debile	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Tropaeum, Ammonitoceras, Caspianites
	Douvilleicerataceae	Douvilleiceratidae Cheloniceratinae		Cheloniceras, Vectisites
	Haplocerataceae	Aconeceratidae		Aconeceras
meyendorffi	Ancylocerataceae	Ancylocerataceae Ancyloceratidae		Tropaeum
			Helicancylinae	Tonohamites
	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Dufrenoyia
	Douvilleicerataceae	Douvilleiceratidae	Cheloniceratinae	Cheloniceras
	Haplocerataceae	Aconeceratidae		Aconeceras, Sanmartinoceras, Doridiscus
transitoria	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Australiceras, Tropaeum
			Helicancylinae	Tonohamites
	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Dufrenoyia
	Douvilleicerataceae	Douvilleiceratidae	Cheloniceratinae	Cheloniceras
	Haplocerataceae	Aconeceratidae		Aconeceras, Sanmartinoceras, Doridiscus
grandis	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Australiceras, Epancyloceras, Lithancylus
			Helicancylinae	Toxoceratoides, Tonohamites
	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Deshayesites
	Douvilleicerataceae	Douvilleiceratidae	Cheloniceratinae	Cheloniceras
	Haplocerataceae	Aconeceratidae		Aconeceras
deshayesi	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Ancyloceras, Lithancylus, Epancyloceras
			Helicancylinae	Toxoceratoides
	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Deshayesites
	Douvilleicerataceae	Douvilleiceratidae	Cheloniceratinae	Cheloniceras
callidiscus	Ancylocerataceae	Ancyloceratidae	Ancyloceratinae	Ancyloceras
			Helicancylinae	Toxoceratoides
	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Deshayesites
	Douvilleicerataceae	Douvilleiceratidae	Roloboceratinae	Roloboceras
	Haplocerataceae	Aconeceratidae		Aconeceras, Sanmartinoceras
	Desmocerataceae	Eodesmoceratidae	Pseudosaynellinae	Pseudosaynella
kiliani	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Deshayesites
	Douvilleicerataceae	Douvilleiceratidae	Roloboceratinae	Roloboceras
fittoni	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Prodeshayesites, Deshayesites
obsoletus	Deshayesitaceae	Deshayesitidae	Deshayesitinae	Prodeshayesites, Deshayesites

7.2.1 Suborder ANCYLOCERATINA a. Superfamily ANCYLOCERATACEAE (see Plates I & II)

Wiedmann (1969) proposed that the superfamily commenced with *Protancyloceras* in the Tithonian. Several families evolved through the early part of the Early Cretaceous, and these were commonly restricted to Tethyan areas. In the Aptian it was represented predominantly by the Ancyloceratidae, and this was the only family to be represented in the Anglo-Paris Basin. Here two subfamilies occur.

The Ancyloceratinae embraces the large heteromorph ammonites which show a definite coarsening of sculpture on the body chamber and display ancyloceratid and crioceratid coiling. Several parallel radiations occurred within this family during the Aptian, all apparently commencing from *Ancyloceras* (Casey 1960). The early genera are believed to have been openwater dwellers that are rare in the Anglo-Paris Basin (e.g. *Ancyloceras, Epancyloceras* and *Lithancylus*), whilst the later forms (*Australiceras, Tropaeum, Ammonitoceras*) are relatively common in transgressive beds in the Anglo-Paris Basin.

The Helicancylinae includes small heteromorph genera, in which the sculpture tended to simplify on the body chamber. The Helicancylinae evolved from the Ancyloceratinae at the top of the Barremian. There are no British records of *Toxoceratoides* in the Aptian of the Anglo-Paris Basin until the topmost part of the *forbesi* Zone. It is often found in association with *Deshayesites* at the base of the Ferruginous Sands Formation. *Toxoceratoides* gave way to *Tonohamites* in the *transitoria* Subzone, which then persisted in southern England until the top of the *meyendorffi* Subzone. Further records of the subfamily exist elsewhere in Tethyan regions, where it survived through most of the Aptian (Aguirre Urreta 1986).

b. Superfamily TURRILITACEAE (see Plate I)

The superfamily commenced with *Hamites*, which is believed to have formed the root for all the later genera. It may have first developed from *Leptoceras* in the latest Aptian, but first appeared in the *mammillatum* Zone of the Anglo-Paris Basin (Casey 1961; Wiedmann 1965). The Hamitidae and Anisoceratidae are the two most important families to be represented in the Anglo-Paris Basin.

The earliest hamitid ammonites were fairly restricted in their earliest occurrences, but *Hamites* became an abundant genus during Mid Albian times and at times was rivalled only by the

hoplitinid genera. Records exist for *Hamites* throughout the Mid- and Late Albian, into the Cenomanian. Late in the Albian, various end forms developed, which occur sparingly in the Gault and Upper Greensand facies of the Anglo-Paris Basin, but are best developed elsewhere.

Casey (1961) believed that the Hamitidae gave rise to the Anisoceratidae in the Early Albian. However, a record of the first anisoceratid genus was documented from the topmost part of the Aptian in Madagascar (Collignon, in Page 1993). Casey was aware of the African material, which he did not consider to be related to the Anisoceratidae that appeared in the Anglo-Paris Basin. Wiedmann (1969) also considered that *Hamites* gave rise to *Protanisoceras* early in the *mammillatum* Zone. The family continued only as a rarity at isolated intervals during the Mid Albian, but returned in the Late Albian, when several new genera appeared and then persisted into the Cenomanian.

The Turrilitidae evolved in Mid Albian times in Tethys (Page 1993). The family developed from the Hamitidae (Wright 1981), and the first representatives include *Turrilitoides* which first appeared in the *cristatum* Subzone of the Anglo-Paris Basin. These earliest forms gave way to *Mariella* and *Ostlingoceras*, which are characteristic genera of the Upper Greensand Formation. The early members of the family were the forerunners of large *Turrilites* that characterised Cenomanian strata (Spath 1923-1943).

Another typically Late Cretaceous family to first appear in the Albian was the Baculitidae. Wright (1981) suggested that the family evolved from the Anisoceratidae in the *inflatum* Zone of SE France. The only genus to be represented in the Anglo-Paris Basin is *Lechites*, which is found in the *dispar* Zone.

c. Superfamily SCAPHITACEAE

The Scaphitaceae comprises the single nominate family, which developed from *Hamites* in the Late Albian (Wiedmann 1965). The first scaphitids (*Eoscaphites*) appeared in the *varicosum* Subzone in the Anglo-Paris Basin. *Scaphites* developed in the latest part of the Albian, but became an important genus in the Cenomanian.

d. Superfamily DESHAYESITACEAE (see Plates III and IV)

Two families of the Deshayesitaceae, the Deshayesitidae and Parahoplitidae, appear in the Anglo-Paris Basin. Although the distribution of the early deshayesitids is predominantly Boreal,

the root is believed to be within the Tethyan heteromorph family Heteroceratidae (Tovbina 1963; 1965; Bogdanov 1979; Wiedmann *et al.* 1990). Although the actual genus from which the deshayesitids emerged remains controversial, the recent record of *Heteroceras* in the North Sea Basin suggest that this is a possible root stock (Rawson *in press b*). The appearance of *Prodeshayesites* defines the base of the Aptian. *Prodeshayesites* gave rise to *Deshayesites* in the *obsoletus* Subzone; this then evolved to *Dufrenoyia* in the *transitoria* Subzone. *Dufrenoyia* has been recorded in the Anglo-Paris Basin until the end of the Early Aptian, but may have persisted until the Early Albian in the Mediterranean region.

The Parahoplitidae is a family with its origins in western parts of Tethys, certain genera of which entered the Anglo-Paris Basin, and at times became dominant. Two subfamilies are represented in the Lower Greensand Group (the Acanthoplitinae and Parahoplitinae).

The Acanthoplitinae evolved from *Dufrenoyia* in South American during the *martinioides* Zone. Genera such as *Colombiceras* and *Gargasiceras* typify *martinioides* Zone deposits in Tethyan south-east France and South America, but are absent from the British records of this time. These early genera were joined by *Acanthoplites, Nolaniceras* and *Diadochoceras* in the *nutfieldiensis* Zone, and rare strays appeared on the East Midlands Shelf. However, it was not until the *jacobi* Zone that the Acanthoplitinae appeared in the Anglo-Paris Basin. *Nolaniceras* appeared first in the *nolani* Subzone, and then evolved into *Hypacanthoplites* before the top of the subzone. Casey (1960-1980) suggested that *Hypacanthoplites* had roots in both *Nolaniceras* and *Acanthoplites*. It persisted throughout the entire Lower Albian.

The Parahoplitinae, that first appeared at the start of the *nutfieldiensis* Zone in the form of *Parahoplites*, occurred to the exclusion of almost all other ammonite genera during this zone. *Parahoplites* may have evolved from *Colombiceras* in South America, and migrated to have a circum-global distribution. It did not persist above the *nutfieldiensis* Zone in the Anglo-Paris Basin.

e. Superfamily DOUVILLEICERATACEAE (see Plate V)

Casey's (1960-1980) definition of the Douvilleicerataceae included both the nominate family and the Deshayesitidae, which rendered the superfamily polyphyletic. However, it is more desirable to separate the Aptian derived deshayesitids from the douvilleiceratids, which have a continuous record from Middle Albian back to the Barremian. The current definition of the Douvilleicerataceae includes only the nominate family, with its three subfamilies, the Douvilleiceratinae, Roloboceratinae and Cheloniceratinae, and which evolved from the Lytoceratidae in the Barremian (Owen 1988a).

The first of the Roloboceratinae, *Paraspiticeras*, ranged from the Barremian to Lower Aptian, but has no record in the United Kingdom. However, it was this primitive form that gave rise to the Aptian genera, *Roloboceras* and *Megatyloceras* that characterised the upper part of *forbesi* Zone. No members of the Roloboceratinae survived beyond the *forbesi* Zone.

In north-west Europe, the Roloboceratinae were joined by *Procheloniceras* (Cheloniceratinae). This genus did not enter the Anglo-Paris Basin, but gave rise to *Cheloniceras* of almost world-wide distribution. *Cheloniceras* first appeared in the *deshayesi* Zone, and the subgenus *Epicheloniceras* evolved at the start of the Late Aptian. *Vectisites* and *Walpenites* appeared in the later part of the Aptian, but these two genera have only been recovered with any certainty from the Isle of Wight. The *nutfieldiensis* Zone saw the expulsion of *Cheloniceras* from southern England, although in southern Europe it persisted until the top of the Aptian.

Cheloniceras gave rise to the first Douvilleiceratinae (*Eodouvilleiceras*) in the topmost part of the Aptian. *Eodouvilleiceras* has no record in the Anglo-Paris Basin, but in the Early Albian the later genus, *Douvilleiceras*, marked the return of the Douvilleiceratidae into the Anglo-Paris Basin. The genus persisted into the Middle Albian and eventually disappeared in the *lyelli* Subzone.

7.2.2 Suborder AMMONITINA a. Superfamily HAPLOCERATACEAE

The superfamily ranges from the Jurassic to the top of the Cretaceous. The Anglo-Paris Basin only contains records of the Aconeceratidae (*sensu* Casey 1961; Riccardi *et al.* 1987).

British occurrences of the Aconeceratidae have been documented from the Hauterivian to Upper Aptian, although there is no continuous record of the family here. Casey (1954; 1961; 1960-1980) and Rawson (1981) discussed the distribution of this group of ammonites, and concluded that they were open-sea dwellers that only migrated into epicontinental areas at times when conditions were favourable. The small, smooth, thin-shelled ammonites tend to be restricted to argillaceous horizons, and are commonly associated with other genera of the Mediterranean Province, which supports their hypothesis. Three Aptian and Early Albian genera appeared in the Anglo-Paris Basin (*Aconeceras, Sanmartinoceras* and *Doridiscus*). The final genus of the Aconeceratidae was *Falciferella*, which appears to have evolved from *Doridiscus* and has only been found in the *intermedius* Subzone of the Anglo-Paris Basin (Casey 1954; Riccardi *et al.* 1987).

b. Superfamily DESMOCERATACEAE (see Plate V)

The Desmocerataceae is a superfamily of world-wide distribution, ranging through most of the Cretaceous, with its primary occurrences in the Tethyan area of southern Europe. The earliest genus is the late Valanginian *Jeanthieuloyites* (Holcodiscidae), which is probably derived from the Olcostephaninae (Thieuloy *et al.* 1990). The first Desmoceratidae appeared in the Hauterivian and an evolutionary lineage was established in the warm, deep-waters of the Tethyan Realm. Throughout the Aptian, the Desmoceratidae avoided the British area altogether, except for very rare examples of *Pseudosaynella* in the Atherfield Formation of the Isle of Wight. However, in the Paris Basin, numerous records of *Pseudosaynella* were reported to exist in the Lower Aptian 'Argiles à Plicatules' by Casey (1960-1980).

The Beudanticeratinae evolved from *Callizoniceras* (Puzosiinae) in the *jacobi* Zone, giving rise to *Uhligella* in the European Tethys. *Uhligella* occurred as a rarity in the British *mammillatum* Zone, but gave rise to *Beudanticeras* at the start of the Albian. It is this genus which is widely found in *mammillatum* Zone sediments across the globe. *Beudanticeras* disappeared from the Anglo-Paris Basin with the influx of the Gault sea at the start of the Mid Albian, but re-appeared at the start of the Late Albian. This final showing of the Desmoceratidae in the Anglo-Paris Basin lasted until the *varicosum* Subzone.

c. Superfamily HOPLITACEAE (see Plate V)

The Superfamily Hoplitaceae comprises the most important group of ammonites to have evolved in the Anglo-Paris Basin during the Mid and Late Albian. Three families are recognised, these being the Cleoniceratidae, Gastroplitidae and Hoplitidae. Although all the Hoplitaceae have their roots in the Desmoceratidae, the evolution of the individual families are from widely separated genera (Owen 1988a). The first known appearance of the Hoplitaceae is in a Boreal subfamily of the Cleoniceratidae, the Vnigriceratinae, which evolved from the Puzosiinae during lowest Albian times.

The Cleoniceratinae evolved from the Vnigriceratinae in the early *tardefurcata* Zone in Arctic regions and Russia (Owen 1988a). *Cleoniceras* and *Anadesmoceras* appeared in the Anglo-Paris

Basin in the *regularis* Subzone. The former showed a high degree of species diversity, whilst *Anadesmoceras* occurred only rarely in the Anglo-Paris Basin. *Cleoniceras* may have persisted into the *dentatus* Zone.

The Hoplitidae form a group of endemic ammonites that persisted through Albian times. The distinction between the Hoplitidae and Cleoniceratidae is that the evolutionary root of the former lay in the Beudanticeratinae rather than the Puzosiinae (Owen 1988a). The Hoplitidae comprised two subfamilies, the Sonneratiinae and Hoplitinae. The evolution of the family is well documented in the British region and the phylogeny well established (Owen 1988a).

The first Sonneratiinae (Farnhamia) evolved from Uhligella in the early tardefurcata Zone. The evolutionary line includes the genera Sonneratia, Pseudosonneratia, Protohoplites, Otohoplites, Tetrahoplites and Anahoplitoides. The Sonneratiinae persisted until the end of the steinmanni Subzone.

The Hoplitinae evolved from the Sonneratiinae in the *steinmanni* Subzone and the subfamily embraces genera and species that showed great intraspecific variability during the Middle and Upper Albian. The first genus to appear was *Hoplites*, from which a whole plethora of genera followed; all appear to have been almost totally restricted to the North European Province, although extending northwards to Greenland (Owen 1971).

d. Superfamily ACANTHOCERATACEAE (see Plate V)

At the start of the Albian, a development of generally keeled ammonites of primarily Tethyan affinity parallels the development of the Hoplitaceae. These ammonites are believed to have had their roots in the Desmoceratidae and two families (Lyelliceratidae and Brancoceratidae) appeared sporadically in the Anglo-Paris Basin.

The first Lyelliceratidae (Leymeriellinae) were derived from a root in the puzosiinid genus *Callizoniceras* in Upper Aptian times. The Leymeriellinae are a group of ammonites that are confined to the *tardefurcata* Zone. The subfamily spread into the British area from their early German habitat in the *regularis* Subzone. It did not stay in the Anglo-Paris Basin area for long, but provided the evolutionary stock for later Early Albian genera (Owen 1988a).

The Leymeriellinae are believed to have given rise to the Lyelliceratinae, the first genus of which (*Tegoceras*) first appeared in the British succession in the *floridum* Subzone. It persisted

until the end of the Early Albian. *Tegoceras* gave rise to *Lyelliceras* in the *steinmanni* Subzone, which then developed further in the *lyelli* Subzone. After this latter subzone, the Lyelliceratinae disappeared from the Anglo-Paris Basin and had no further records in this area.

The first genus of the Stoliczkaiinae (*Neophlycticeras*) evolved from the Lyelliceratinae and appeared as a rarity in the *cristatum* Subzone of the Anglo-Paris Basin. It continued through the *orbignyi* and *varicosum* Subzones and gave rise to *Stoliczkaia* in the later part of the Albian. It is this latter genus that characterises strata of the *dispar* Zone.

The earliest known genus of the Brancoceratidae (Mojsisovicsiinae) is *Oxytropidoceras*, which has been recorded from the condensed *mammillatum* Zone deposits of East Kent (Casey 1961). It seems likely that the subfamily evolved from *Leymeriella*, possibly reflecting a long-lived oxyconic development, principally occurring outside the British area and appearing during isolated periods of high sea-level in the Albian (Owen 1971; 1988a; Kennedy & Cooper 1977).

The Mortoniceratinae may have evolved from the Mojsisovicsiinae and is represented solely by *Mortoniceras* in the Anglo-Paris Basin. This genus first appeared in the *cristatum* Subzone of the Anglo-Paris Basin; it persisted through the *fallax* Subzone, before its final disappearance in the *perinflata* Subzone. The subfamily, however, persisted into the Cenomanian in Tethys (Kennedy & Wright 1981).

The early Brancoceratinae were always rare in the British sequence. The subfamily was apparently derived from the desmoceratid *Silesioides* in Tethys during the *mammillatum* Zone (Owen 1988a). The earliest genus is *Parabrancoceras*, which has been discovered along the south-eastern edge of the Anglo-Paris Basin, in the *steinmanni* Subzone deposits of Maurupt, Marne (Owen 1971; 1988a). Later records of the subfamily are of *Brancoceras* which has been found, along with *Eubrancoceras*, in the *lyelli* Subzone. A single specimen of *Brancoceras* has also been recorded from the *subdelaruei* Subzone of Wissant, northern France (Amedro & Destombes 1978). *Hysteroceras* first appeared in the *cristatum* Subzone of the Anglo-Paris Basin, and survived until the *varicosum* Subzone, when it was progressively overtaken by *Prohysteroceras*.

7.3 DIVERSITY ANALYSIS

Changes to the marine environment led to modifications of ammonite assemblages through radiation, extinction, immigration or emigration events. Diversity analysis examines changes in the number of taxa against a given time-scale. Investigations of the ammonite distributions as numerical data reveals several important intervals of evolutionary change, particularly extinction and radiation events. Previous detailed diversity analyses have been performed by House (1989; 1993) for the whole of the Ammonoidea, from the Devonian to end of the Cretaceous, and by Becker (1993) for the Devonian.

The distribution of the Aptian and Albian ammonites are plotted against the proposed biostratigraphic time-scale. Data regarding the ammonite distributions have been collected from a large number of sources; these include my own personal collection, published monographic works (Spath 1923-1943; Casey 1960-1980), many other published accounts, and museum and private collections. In the case of the published accounts, the exact stratigraphic horizon from which the material was collected is not always given. However, most records are listed to at least subzonal level. It is this division, therefore, that is considered as a single unit in the diversity studies despite the fact that in some cases appearances and disappearances can occur within a subzone itself.

In the present study, the genus is used for the diversity analysis. This ranking is fairly objectively defined, and represents phylogenetic lineages of species that share common qualitative characteristics. The species is often a more subjective concept, the definition of which varies from author to author. More recent workers have tried to group together several earlier defined species, which are considered to represent variation within a single form (e.g. Amedro 1992). However, there is still much to be done before definite bio-species can be separated from widely variable morpho-species. Three plots are used for the diversity analysis (Fig. 7.1), and these are discussed below.

(i) Chart A, Total Diversity. This graph plots the total number of taxa per subzone. It is from this chart that the main diversity changes are shown.

Figure 7.1. Ammonite diversity analysis and sequence boundaries.



(ii) Chart B, Changes in Diversity: the number of originations and extinctions per subzone. These terms are used loosely, for the apparent originations may often be a result of migration into the basin rather than the true evolution of a new form. Likewise, the 'extinction' events may show disappearance of taxa from the basin, but their true range may extend higher in regions elsewhere. This phenomenon is particularly common in the Aptian, and in some circumstances disjunct distributions are noted (e.g. *Aconeceras* makes several isolated appearances). Each pseudo-origination and pseudo-extinction is recorded on the chart.

(iii) Chart C, Net diversity change: the difference between the number of originations and extinctions for each subzone. The largest expansions and contractions in diversity are recorded and named on this chart.

The total number of genera collected in the current investigation is lower than that of the published accounts. Important deviations between total published diversity and that collected are illustrated in Fig. 7.2. This shows both inadequacies in my collection and the problems in the use of total diversity in some instances. The plot of family abundance shown in Fig. 7.2 is also based upon my own collection of ammonites and helps to distinguish the important changes in their distribution through time. The total number of ammonites collected throughout the basin are used for this plot. However, an exception to this is for the *mammillatum* Zone, in which the data collected from Folkestone are not included since subzonal division is impossible. Sections in the northern part of the Weald and Bedfordshire are used to compile this part of the chart.

Figure 7.2. Published and collected total diversity, diversity zones and abundance spectra, with their relationship to transgressive surfaces.



7.4 DIVERSITY ZONES

The total number of genera per subzone (Total Diversity) plotted on Fig. 7.1, Chart A shows that ammonite diversity can define six broad periods for the Aptian - Albian. Three of the periods are characterised by low diversities, and these are separated by high diversity assemblages. The boundaries to the individual periods are defined by significant net contraction or radiation events on Fig. 7.1, Chart C. The bases of periods 1, 3, 4 and 6 are defined by sequence boundaries proposed in Chapter 6. The bases of period 2 and 5 are not defined by sequence boundaries, but do correspond to transgressive surfaces. The relationship between the diversity and sea-level change is not immediately obvious, for a sequence boundary may either be followed by a rapid expansion or contraction in the number of ammonites. Other sequence boundaries have little effect on the overall diversity, but are typically associated with significant turnover events (Chart B), in which the net change remains largely unaltered (Chart C).

A similar pattern in the diversities is shown in the collected ammonite diversity (Fig. 7.2). However, low diversity period 5 commences at an earlier biostratigraphic level (*steinmanni* Subzone rather than *niobe* Subzone) than shown in the published data (Fig. 7.1). The important decrease in diversity is matched by a change in the abundance spectrum in the *steinmanni* Subzone, whilst abundances remain relatively unaltered between the *intermedius* and *niobe* Subzones. The periods of high and low diversity are here termed **Diversity Zones**.

Diversity zones provide a broad basis for the examination of the ammonite distributions and each is named according to the dominant ammonite family or subfamily. For each of the divisions, the stratigraphical ranges of the genera are plotted, which give the first appearance datums (FAD's) and last appearance datums (LAD's) of the ammonites (Figs. 7.3, 7.5, 7.7, 7.9, 7.11 & 7.13). This analysis indicates the total hospitality of the marine environment in the Anglo-Paris Basin. The ranges shown are those for the Anglo-Paris Basin (Tables 7.1 & 7.2), and do not necessarily equate to the total known range of a specific genus. In particular, the Aptian is represented by cosmopolitan taxa that migrated into the North European Province during times at which conditions were favourable. The disappearances of taxa from this province are often localised extinctions, whilst evolution continued in other areas. In effect, the Anglo-Paris Basin displays many pseudo-evolution and pseudo-extinction events, whilst true originations and extinctions occurred elsewhere.

Although the generalised distribution of the ammonites is established from the analysis of FAD's and LAD's, there are large-scale variations in facies which are accompanied by regional absences

of genera. The assemblages can vary significantly from one region to another. These variations can show the dependence upon lithofacies of certain ammonite genera and the differences in assemblages from the basin margins to the centre. To examine this phenomenon, the number of species per genus are plotted for selected intervals from around the basin to display semiquantitatively the relative importance of each genus within a particular subzone (Figs. 7.4, 7.6, 7.8, 7.10, 7.12 & 7.14). The plots are colour coded to indicate the distribution of the ammonites of different biogeographical affinity. Endemic ammonites are shown in cool colours, whilst warmer shades are given to the immigrant taxa.

Most of the data are obtained from the ammonite monographs, in which a large number of morpho-species described by Spath and Casey are recorded. It is preferable in this analysis to limit oneself to as few different authors as possible, for different authors split and lump the taxa to varying degrees. Obviously a large amount of data has been reviewed to include new records and localities, but an attempt has been made to remain consistent in the species definitions. In general terms, where a large number of species are recorded within a subzone, it indicates that a larger recovery of ammonites has been acquired than in those levels in which smaller numbers of species have been described. Clearly, this is not always the case and some care has to be taken not to overstate the method. Nonetheless, clues are revealed regarding the relative abundances of particular genera, confirmed by my own field collection, and discussed fully in the succeeding chapter.

7.4.1 Earliest Aptian events

The early deshayesitids evolved from the Tethyan heteromorph *Heteroceras*, which had entered the North Sea Basin, and its fringes, in the late Barremian. It occurred alongside another Tethyan genus (*Toxoceratoides*) and open-sea dwelling *Aconeceras* (Rawson *in press b*). The Tethyan genera entered the North Sea Basin as a result of a late Barremian sea-level rise.

The lowest part of the Aptian is not represented in the Anglo-Paris Basin, at least in a marine facies, but sediments of the *fissicostatus* Subzone are found at the margins of the North Sea Basin. *Prodeshayesites* is found within a clay facies towards the top of the Speeton Clay Formation in Yorkshire, and in the Skegness Clay Formation in Lincolnshire (Casey 1960-1980; Gallois 1975). Elsewhere, the records of *Prodeshayesites* occur within remanié phosphatic nodule beds on the East Midlands Shelf. Species of *Prodeshayesites* are also recorded from the *fissicostatus* Subzone of Northern Germany (Kemper 1973; Casey 1980), at the eastern margin of the North Sea Basin. Elsewhere, records of *Prodeshayesites* are unconfirmed, but it may have

extended into Tethyan areas of southern France and Spain (Delanoy 1991).

7.4.2 Deshayesitid Diversity Zone

The base of this diversity zone is defined by the *obsoletus* Subzone immigration event (Fig. 7.1, Chart C). This corresponds to the basal Aptian transgression (TS1) which marks the restoration of marine conditions to southern England. Low diversity assemblages persist through the period, and turnover events are few and small-scale.

Ammonite assemblage (Fig. 7.3): This early Aptian diversity zone is dominated by the endemic Deshayesitidae. Prodeshayesites entered the Anglo-Paris Basin as a result of TS1 and dominated in the obsoletus Subzone (comprising about 80% of the faunal spectrum). It gave rise to Deshayesites in the same subzone (20% of the spectrum). TS2 prompted the rapid evolution of Deshayesites, which proliferated in the argillaceous sediments that ensued. The newly established genus soon became dominant over Prodeshayesites, which had become extinct prior to the end of the fittoni Subzone.



Figure 7.3. The range of the ammonites in the Deshayesitid Diversity Zone (ranges shown in white are for inferred range, but with no appearance in the Anglo-Paris Basin).

Shelf mud deposition continued until the top of the Deshayesitid Diversity Zone. The Douvilleiceratidae made their entry into the Anglo-Paris Basin at the start of the *kiliani* Subzone.

The primitive Roloboceratinae, which had evolved near the base of the Aptian in northern Europe, are represented by *Roloboceras* and rare *Megatyloceras*. These two genera are more or less restricted to the northern part of Europe.

Geographic distribution (Fig. 7.4): The most diverse ammonite assemblage during this period is found in the Isle of Wight. More species of first *Prodeshayesites* and then *Deshayesites* have been recorded from this locality than any other in the Anglo-Paris Basin. *Deshayesites* continued to develop strongly throughout the *forbesi* Zone, and in the *kiliani* Subzone it was joined by the earliest forms of the Douvilleiceratidae. There is no better representation of *Roloboceras* than in the Atherfield Formation of the Isle of Wight. Elsewhere, very restricted faunal assemblages, containing only a few species of the Deshayesitidae, have been recovered from the western part of the Weald Basin.

Interpretation: It is almost certain that the Bedfordshire Straits provided an ephemeral link between the Anglo-Paris and North Sea Basins; it was through this temporary sea-way that the earliest deshayesitids migrated into southern England, and probably northern parts of France (Rawson *et al.* 1978). The north-to-south migration of *Prodeshayesites* was accompanied by the penecontemporaneous evolution of *Deshayesites*. A widely developed shelf clay facies provided ideal conditions for the rapid speciation of this early Aptian fauna, most particularly on the Isle of Wight, which lay far from the boundary landmasses. The douvilleiceratids entered this basinal area towards the end of the period, and these ammonites co-existed with the endemic fauna. Away from the Isle of Wight, thinner successions developed during the period, and these are presently poorly exposed. The lower diversities that are shown for Sussex and Surrey may in part be due to the lack of exposure and therefore suitable sections from which to collect ammonites. However, these sections are also considered to lie closer to the basin margins, and here only a low diversity assemblage would be expected. The immigrant fauna has not been recorded from these areas; it apparently preferred the deeper-water environs of the Isle of Wight.

Figure 7.4. The geographic distribution of genera in the Deshayesitid Diversity Zone (lithofacies symbols are as for Fig. 2.2).



7.4.3 Cheloniceratinid Diversity Zone

A relatively high diversity assemblage was created as a result of the *callidiscus* Subzone radiation event. The total diversity remained virtually unchanged through the remainder of the period, but turnover events were common. These main period of faunal change are associated with transgressive surfaces and sequence boundaries.

Ammonite assemblage (Fig. 7.5): The earlier part of the period is characterised by a mixed assemblage, which contains both endemic and cosmopolitan taxa. Despite the rapid diversification of ammonite genera in the *callidiscus* Subzone, most of the new taxa only appeared as a minority (Fig. 7.2). *Deshayesites* remained dominant and continued to co-exist with *Roloboceras*. These two genera were joined by ammonites of cosmopolitan distribution in the lower part of the *callidiscus* Subzone. Short-lived incursions of open-sea dwelling desmoceratids (*Pseudosaynella*) and aconeceratids (*Aconeceras* and *Sanmartinoceras*) are included as a rare component of the overall fauna, although none of these have any representatives in my collection.

Transgression TS3 occurred in the upper part of the *callidiscus* Subzone and resulted in the disappearance of the Desmoceratidae, and Douvilleiceratidae. The latter family did not stray far from the Anglo-Paris Basin, for early in the *deshayesi* Subzone, its later evolutionary forms, the Cheloniceratinae, returned to become a characteristic form for the remainder of the Aptian. Although these were stratigraphically isolated in the Anglo-Paris Basin, other areas of north-west Europe have a continuous record.

The first Aptian record of the Ancyloceratidae is found in the late part of the *callidiscus* Subzone, represented by *Ancyloceras*, which again is a genus that is more typically associated with deeper water deposits of the southern seas. It occurred alongside *Aconeceras*, and both genera were uncommon (Fig. 7.2). The ancyloceratid heteromorphs were then almost continuously represented throughout the Cheloniceratinid Diversity Zone. They still continued as a rarity in the *deshayesi* Subzone, when the open-sea dwellers, such as *Epancyloceras*, *Lithancylus* and *Toxoceratoides*, were recorded. It was not until after transgression TS4, however, that the family made a significant contribution to the overall ammonite assemblage. The very large, ancyloceratid-coiled genus *Australiceras* appeared in the *grandis* Subzone. This genus is particularly well-known in the southern hemisphere, but its geographic range extended through Asia, Africa and Europe, and it was strongly represented in the Anglo-Paris Basin. Only one species of *Australiceras* (*A. gigas*) has been recovered, yet this comprised around 40% of



Figure 7.5. The range of the ammonites in the Cheloniceratinid Diversity Zone.

the assemblage (Fig. 7.2). Along with the influx of *Australiceras* came the autochthonous evolution of *Tonohamites* from *Toxoceratoides*. The evolution of this later genus of the Helicancylinae occurred in or around the Anglo-Paris Basin, and both forms are found together in the *grandis* Subzone.

The heteromorphs continued to make a significant contribution to the assemblage, and transgression TS5 at the base of the *transitoria* Subzone saw the abundance of the Ancyloceratidae increase to around 50% of the assemblage. The transgression prompted the evolution of *Tropaeum* from *Australiceras*. Some of the earlier species of *Tropaeum* show similar ancyloceratid-coiling to *Australiceras*, but progressive in-coiling throughout the *transitoria* Subzone produced the crioceratid-coiling that is so typical of the genus. The Deshayesitidae declined markedly in relative abundance during the *transitoria* Subzone (Fig. 7.2). The transgression, however, prompted the evolution of *Dufrenoyia* from *Deshayesites*, although some ammonites approaching the later genus are recorded from the *deshayesi* Zone (e.g. Simpson collection). The new genus evolved rapidly, and increased rapidly in abundance in the silty clays in the lower part of the *meyendorffi* Subzone.

The heteromorphs declined rather suddenly as a result of the basal *meyendorffi* Subzone transgression, TS6. *Dufrenoyia* and *Cheloniceras* were the dominant genera through this early part of the subzone. Transgression TS7 introduced argillaceous sediments, from which only a single specimen of *Tropaeum hillsii* has been recovered. The deposits became rapidly sandy upwards and, although *Dufrenoyia* may have persisted, no further records exist in my collection. There are records of the genus surviving into the Late Aptian of Switzerland and possibly even later in South America (Casey 1980).

Figure 7.6. The geographic distribution of genera in the Cheloniceratinid Diversity Zone.



The *debile* Subzone commenced at a concretionary horizon above the base of the Upper Crioceras Member of Chale Bay; within this bed are found the earliest species of *Cheloniceras* (*Epicheloniceras*). Tropaeum persisted throughout the martinioides Zone (debile and gracile Subzones), where it was joined by the very large and almost normally coiled genus Ammonitoceras. Although they do not appear in my collection, Casey (1961; 1960-1980) recorded additional genera of the Cheloniceratinae (Walpenites and Vectisites). These two genera are homeomorphs of Roloboceras, and reflect the late evolutionary development of the family. The ammonites are restricted wholly to the concretionary horizons that separate the parasequences and parasequence sets.

Geographic distributions (Fig. 7.6): The Isle of Wight again contains the most diverse assemblage. *Deshayesites* was distributed basin-wide during the early part of the period, and then evolved into the equally widespread genus *Dufrenoyia* in the *transitoria* Subzone. Although *Roloboceras* appeared to be more or less restricted to the Isle of Wight in the Anglo-Paris Basin, the later Cheloniceratinae were distributed basin-wide. Several species of *Cheloniceras* evolved within the basin and the genus stayed to characterise the remainder of the period.

Heteromorph ammonites were introduced to the Isle of Wight at the beginning of the period. Initially restricted to this area, the heteromorphs spread basin-wide as a result of the *grandis* Subzone transgression. Although the figure indicates that *Australiceras* and particularly *Tropaeum* have seemingly widespread and continuous distributions, this is misleading. Most records of *Tropaeum* are from Chale Bay, where it is most commonly found in the concretionary levels that characterise the Lower and Upper Crioceras Members. In the intervening sandy deposits, crushed examples are extremely rare. When the interval is traced laterally, it is seen that *Tropaeum* is absent from equivalent stratigraphic horizons through much of the rest of the Isle of Wight, as it is from the western part of the Weald Basin. Rare occurrences have been recorded from the area around Folkestone, but it is only in Maidstone that an abundance to match that of Chale Bay has been recorded (Casey 1961). Rare open-sea dwellers have been recorded from the *callidiscus* Subzone of the Isle of Wight; some of these forms have also been recorded from similar stratigraphic levels in western Kent.

Interpretation: The top part of the Lower Aptian and then the lower part of the Upper Aptian are within a generally regressive phase. A change from shelf mud deposition to higher energy sands and sandy limestones is seen across the Anglo-Paris Basin. The higher energy conditions that resulted from the regression forced the evolution of more highly stressed forms of the Deshayesitidae. Eventually, the deshayesitids could no longer tolerate the prevailing

environmental conditions. They disappeared from the Anglo-Paris Basin, but similar genera persisted elsewhere, where deeper waters allowed for their continued development. The geographically widespread Douvilleiceratidae competed with the endemic ammonites through the early part of the period. They adapted to withstand the more extreme conditions and spread rapidly across the basin. Alongside the douvilleiceratids are the heteromorphs, which are notably absent from some regions for extended periods. The bulk of the fauna comprises very large adult specimens and no intervening growth stages are recovered. Most commonly these ammonites appear to have been brought into the basin as a result of the minor transgressions that separate parasequences and parasequence sets, and are rare in the intervening sediments. These heteromorphs reached an almost global distribution in the Aptian, and may have led a mode of life that was predominantly offshore from the shelf. Adult forms only occupied the shallower-water biotopes during periods of transgression. Juveniles appear to have totally avoided the shelf areas and may have led quite a different mode of life from their adult counterparts.

7.4.4 Parahoplitid Diversity Zone

A sharp reduction of diversity occurred with the *subarcticum* Subzone contraction event (Fig. 7.1, Chart C), which coincides with the transgressive surface (TS9) and sequence boundary (TS10) in the lower part of the *nutfieldiensis* Zone. Regression prior to TS9 led to the almost wholesale removal of ammonites from the Anglo-Paris Basin. Beds which had been poorly fossiliferous were replaced by those which were almost barren of ammonites. Evolution appears to have proceeded rather sluggishly, and this seems to have occurred outside of the basin. The total diversity remains very restricted throughout the period. The transgressive surfaces and sequence boundaries mark only very small-scale alterations in the ammonite distributions.

Ammonite assemblage (Fig. 7.7): Only Tropaeum persisted from the gracile subzone, and this genus disappeared prior to TS10. No heteromorphs are recorded from the Anglo-Paris Basin above the subarcticum Subzone until after the start of the Early Albian. The Douvilleiceratidae were banished from the basin before the start of the nutfieldiensis Zone, although Epicheloniceras is believed to have persisted in southern Europe and South America; in the latter region it gave rise to Eodouvilleiceras at the start of the Early Albian. Whilst the subarcticum Subzone saw the disappearance of the Douvilleiceratidae, it is also the time at which the Deshayesitaceae returned to northern Europe. In the meantime, this superfamily had continued to evolve in the Tethyan region, particularly South America, and given rise to the Parahoplitidae. The spread of the Parahoplitidae was facilitated by the first nutfieldiensis Zone transgression; first to appear was Colombiceras and later this was joined by Parahoplites. The latter genus had

an almost circumglobal distribution during the *nutfieldiensis* Zone and is the characteristic ammonite of the poorly fossiliferous sediments.

Parahoplites did not survive the *nutfieldiensis* Zone. In the early part of the *jacobi* Zone (*nolani* Subzone), the only ammonite genus recorded is *Nolaniceras*. It gave rise to *Hypacanthoplites* towards the top of the *nolani* Subzone, and then this cosmopolitan genus persisted through the uppermost part of the Aptian and the Early Albian.

The transgression in the earliest Albian *farnhamensis* Subzone (TS13) saw the introduction of the first Hoplitidae (*Farnhamia*) into the Anglo-Paris Basin.



Figure 7.7. The range of the ammonites in the Parahoplitid Diversity Zone.

Geographic distribution (Fig. 7.8): It is only in the basinal regions of the Isle of Wight and Surrey that Tropaeum persisted into the Parahoplitid Diversity Zone. Transgressions in the nutfieldiensis Zone led to the rapid extension in the depositional area of the Anglo-Paris Basin, and the distribution of ammonites over a wider geographic area than seen earlier in the Aptian. The first Parahoplitidae (Colombiceras and Parahoplites) first appeared on the East Midlands Shelf and in the Bedfordshire Straits. Transgression TS10 carried the fauna from the north of the London Platform and flooded areas to the west of the Weald Basin; the isolated outliers of the Lower Greensand Group may contain poorly preserved specimens of Parahoplites. *Nolaniceras* and then *Hypacanthoplites* characterised the later part of the diversity zone. Ammonites are commonly restricted to the more argillaceous and glauconitic beds which developed in the Weald during the interval. In the sandier facies, ammonites are largely restricted to the transgressive, phosphatic basement beds, and even then are very rare and poorly preserved. *Farnhamia* has only been recorded from the *farnhamensis* Subzone in Surrey.

Interpretation: The Parahoplitidae first appeared on the East Midlands Shelf in NW Europe. Transgression at the base of the *subarcticum* Subzone opened the Bedfordshire Straits and allowed the free movement of the ammonites from north of the Anglo-Brabant Massif. The appearance of the Hoplitidae at the end of the period is the first evidence of an endemic fauna which only survived for a limited duration. Transgression in the *farnhamensis* Subzone led to the deposition of silty clays in the centre of the Weald Basin, and the ideal conditions into which the endemic element could flourish. The return to sandy deposition later in the same subzone was unfavourable to the preservation of ammonites.

Figure 7.8. The geographic distribution of genera in the Parahoplitid Diversity Zone.



7.4.5 Douvilleiceratinid Diversity Zone

The *regularis* Subzone is marked by a very rapid extension of the ammonite fauna, which coincided with sequence boundary TS14. This was then followed by rapid contraction and then large-scale turnover events throughout the remainder of the period. The diversity zone ranges until the end of the Early Albian, during which time very important changes in palaeogeography and water-depth occurred; the high mobility of the ammonite fauna reflect these changes. Sequence boundaries and transgressive surfaces define the most significant changes in diversity (Fig. 7.1, Chart B), but these may have little effect on the net diversity change (Fig. 7.1, Chart C).

Ammonite assemblage (Fig. 7.9): Cosmopolitan genera are a common feature of the Douvilleiceratinid Diversity Zone, and these co-existed with endemic taxa. Although the transgression at the base of the *regularis* Subzone brought about a very rapid diversification of the ammonite fauna, the collected diversity is much less than that of the published accounts (Fig. 7.2). Well-developed species of *Leymeriella* and *Epileymeriella* (Leymeriellinae) spread westward from their early German habitats and dominated the assemblage. The Cleoniceratinae also spread from the north-east; both *Cleoniceras* and *Anadesmoceras* are represented in the *regularis* Subzone. The earliest species of *Douvilleiceras* appeared in this subzone, having evolved in other Tethyan regions. Although many of the earliest douvilleiceras exists in eastern European areas of Tethys (Ivanov 1991). Stray open-sea dwellers, such as the Phylloceratidae (*Pictetia*), Lytoceratidae (*Eogaudryceras*) and Aconeceratidae (*Aconeceras* and *Sanmartinoceras*), were swept into the Anglo-Paris Basin as a result of the transgression. Only *Hypacanthoplites* remained from the period below.

The start of the *kitchini* Subzone was marked by a further transgression, which saw the weakening of links with the east and a change in the biogeographic assemblage. The leymeriellinid ammonites disappeared from NW Europe, but probably persisted in the Mediterranean Province. The Hoplitidae re-entered and remained in the Anglo-Paris Basin; a closely knit evolutionary line was initiated in the *kitchini* Subzone. The Beudanticeratinae, which seem to have provided the root for the hoplitid ammonites, also appeared in the Anglo-Paris Basin, represented by *Beudanticeras*. It was this genus, along with *Douvilleiceras* that dominated in the assemblage. The transgression also led to the re-appearance of the heteromorphs. These ammonites persisted throughout the remainder of the Albian and into the Cenomanian, and have a cosmopolitan distribution.



Figure 7.9. The range of the ammonites in the Douvilleiceratinid Diversity Zone.

The Sonneratiinae evolved rapidly through the *floridum* and *raulinianus* Subzones, although there was little change in its abundance (Fig. 7.2). Links with the Tethyan Mediterranean were fully established in this part of the diversity zone, and the Tethyan Brancoceratidae made several penetrations northwards through the Paris Basin. The Lyelliceratinae (*Tegoceras*) and Mojsisovicsiinae (*Oxytropidoceras*) appear to have evolved from the Leymeriellinae in the Mediterranean Province, but transitional forms are unknown. Transgression TS16 in the *puzosianus* Subzone is characterised by the evolution of late forms of the Sonneratiinae and the

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southward incursion of the Gastroplitidae (*Sokolovites*) from the Arctic. The appearance of this genus was as an extreme rarity, and it has not been collected during the present study. The more significant effect of the transgression was to cause a sudden proliferation of the hoplitids, and the evolution of later forms of the Sonneratiinae was at the expense of *Douvilleiceras* and *Beudanticeras*. Lower diversity assemblages are represented in my collection than in the published accounts (Fig. 7.2).

Geographic distributions (Fig. 7.10): The ammonite diversities change rapidly from one part of the basin to another during this period. Initially the greatest diversity is recorded in the *regularis* Subzone of the Bedfordshire Straits (although only three genera have been recorded from the now poorly exposed *regularis* Subzone in this study), with the least diverse assemblages found in the eastern part of the Weald Basin. A transgression in the following *kitchini* Subzone allowed the fauna to spread more widely into the Weald Basin, whilst erosion led to the removal of most of the younger *mammillatum* Zone sediments from areas to the north of the London Platform. The Sonneratiinae are associated with the Douvilleiceratinae and Beudanticeratinae in the later part of the Douvilleiceratinid Diversity Zone of the Weald and Paris Basins.

Interpretation: Although shallow-water connections had existed previously, transgression TS14 in the *regularis* Subzone allowed the waters of the Anglo-Paris Basin to mingle with those of the North Sea and Lower Saxony Basins and the opening of a migrationary pathway for the leymeriellinid ammonites (Owen 1979). The simplest route from the North Sea was across the East Midlands Shelf and through the Bedfordshire Straits, hence the dominance of these forms in the Leighton Buzzard area.

Regression prior to the *kitchini* Subzone led to the loss of much of this *tardefurcata* Zone fauna from the Anglo-Paris Basin. Renewed transgression (TS15) allowed the immigration of later forms of the Sonneratiinae, which this time stayed to evolve as an endemic element in the basin. The presence of clays across wide areas of the Anglo-Paris Basin during the *mammillatum* Zone allowed this endemic element to develop by allopatric speciation. Although links with Tethys existed, the brancoceratids and lyelliceratids only appeared as rarities, whilst many of the biotopes were filled by cosmopolitan genera (Douvilleiceratidae and Desmoceratidae). Heteromorphs reappeared in the *kitchini* Subzone, and evolved rapidly in the Weald and Paris Basins, but did not penetrate into the shallower waters of the Bedfordshire Straits.

Figure 7.10. The geographic distribution of genera in the Douvilleiceratinid Diversity Zone.



7.4.6 Hoplitid Diversity Zone

The Hoplitid Diversity Zone commenced with transgression TS17 in the *steinmanni* Subzone. This is represented by a large-scale turnover event in the published ammonite distributions (Fig. 7.1) and a rapid contraction of the fauna in the collected data (Fig. 7.2). The early part of the diversity zone saw rapid changes in diversity and these coincide with transgressive surfaces. However, following the *niobe* Subzone contraction event (Fig. 7.1, Chart C), the total diversity stabilised, which may reflect the ammonite fauna reaching an equilibrium.

Ammonite assemblage (Fig. 7.11): The diversity zone as a whole is characterised by the endemic hoplitinid ammonites, and the widely distributed heteromorph *Hamites*. Other taxa include the Douvilleiceratidae and Beudanticeratinae, that only survived into the earlier part of the diversity zone, and the Brancoceratidae, which only appeared at discrete intervals.

Transgression (TS17) in the *steinmanni* Subzone led to important evolutionary changes, that were paralleled in the North European and Mediterranean provinces. Rapid developments occurred both within the Hoplitidae and Lyelliceratidae, although it is only the former family that is represented in my collection. Only late species of *Otohoplites* remained within the Sonneratiinae; this gave rise to true *Hoplites* (Hoplitinae) during the *steinmanni* Subzone, whilst *Pseudosonneratia* gave rise to the short-lived subgenus *Isohoplites*. *Hoplites* is the earliest genus in the rapidly evolving plexus of hoplitinid ammonites that characterised Middle and Upper Albian strata in NW Europe. Within the Mediterranean Province, this evolution is matched by the Lyelliceratinae. From *Tegoceras* sprang the Middle Albian genus *Lyelliceras*. Although the transitions are not recorded from the poorly represented lyelliceratinid ammonites of the Anglo-Paris Basin, both *Tegoceras* and the earliest species of *Lyelliceras* occur in the *steinmanni* Subzone. Conditions in the following *lyelli* Subzone allowed for the proliferation of *Lyelliceras*, which evolved *in-situ* alongside the rapidly evolving hoplitinid ammonites.

Further rapid turnover of the ammonite fauna occurred with the sequence boundary at the start of the *dentatus* Subzone (TS18). *Douvilleiceras* and *Beudanticeras*, that had been so typical of the earlier subzones in the Douvilleiceratinid Diversity Zone, disappeared from the Anglo-Paris Basin. *Lyelliceras* also disappeared, but continued to evolve further south. The hoplitinid ammonites were joined by occasional strays from Tethys. However, the diversity indicated during this subzone is somewhat misleading. It is likely that some of the ammonites that have been recorded from the *dentatus* Subzone are in fact a remanié of the eroded *lyelli* or earlier Subzones. In successions where the *lyelli* Subzone is absent, for example the Rock Common


Figure 7.11. The range of the ammonites in the Hoplitid Diversity Zone.

Quarry at Washington in Sussex, none of this accessory fauna has been collected during extensive fieldwork; the ammonite fauna comprises almost exclusively of species of *Hoplites*. Heteromorphs also occur, but are in a minority. Also, collections from beds above the basal *dentatus* Subzone nodule bed in the northern part of the Weald contain only the monospecific ammonite assemblage.

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The *intermedius* Subzone succeeds the *dentatus* Subzone with no evidence for a stratigraphic break. In this subzone, the endemic hoplitinids diversified. *Anahoplites* and *Dimorphoplites* evolved from one line of *Hoplites*, whilst *Euhoplites* was established from another line of the same genus. A brief incursion of the typically open-sea dwelling aconeceratid genus *Falciferella* occurred towards the top of the subzone, and it became locally abundant.

The *niobe* Subzone commenced with transgressive surface TS19. *Hoplites* had become extinct prior to this transgression, and the assemblage was dominated by *Anahoplites*, *Dimorphoplites* and *Euhoplites*. Cosmopolitan ammonites that have been recorded from the *niobe*, *nitidus* and *daviesi* Subzones probably represent chance migrations during a period in which north-west Europe appears to have been largely isolated from areas to the south. It was only in the *subdelaruei* Subzone that any real penetration of southern elements occurred basin-wide, and still this is only as a minority of the overall fauna. The incursion of the brancoceratid genus *Mojsisovicsia* in the *subdelaruei* Subzone was curtailed by transgression TS20.

The presence of *Beudanticeras* and *Dipoloceras* in the *daviesi* Subzone is questionable, and based upon Owen's (1971) faunal list. In his account of the stratigraphy, Owen recognised that *daviesi* Subzone sediments are restricted in their geographical distribution, having been largely removed by erosion prior to the *cristatum* Subzone transgression. The two genera have been listed from localities at which this erosion is evident, and late *lautus* Zone ammonites have been included into a basal remanié of the *cristatum* Subzone. It is, therefore, believed that these ammonites are quite possibly incorrectly assigned.

Geographic distribution (Fig. 7.12): The earliest Hoplitinae evolved in the *steinmanni* Subzone, and these were distributed basin-wide. However, it was only in the southern part of the Paris Basin that the Douvilleiceratinae and Beudanticeratinae continued, and here they were associated with the earliest species of *Lyelliceras*. A diverse assemblage has been collected from the succeeding *lyelli* Subzone in the north and western parts of the Weald Basin and southern Paris Basin. Condensed strata in other areas are generally poorly fossiliferous.

Figure 7.12. The geographic distribution of genera in the Hoplitid Diversity Zone.



From the start of the *dentatus* Subzone until the end of the diversity zone, the ammonite assemblages recorded from both southern England and France are very similar to one another. However, only a very limited fauna has been collected from the Bedfordshire Straits during this upper part of the diversity zone, the topmost part of which been removed by Late Albian erosion. However, it can be seen that in the *niobe* Subzone only species of *Euhoplites* and *Anahoplites* existed.

Interpretation: The regression prior to the steinmanni Subzone led to the removal of many of the cosmopolitan genera in all areas except for the Paris Basin, and here these forms were much less diverse than previously seen. The *lyelli* Subzone is poorly developed in many areas, but where it is best seen shows a return of the predominantly Tethyan forms. This spread was short-lived, and the events at start of the *dentatus* Subzone saw the removal of the more widespread genera from most areas. The Hoplitinae flourished in the argillaceous deposits, where there was little competition from other families. In the *intermedius* Subzone, later forms of the subfamily evolved.

As the facies remained relatively unchanged across much of the Anglo-Paris Basin in the later part of this period, so more homogeneous distributions of ammonites from one part of the basin to another developed. Several more species per genus are recorded from western parts of Kent, and it is from here that relatively uncondensed successions developed away from the supposed landmasses. Folkestone lay slightly closer to the Anglo-Brabant Landmass during the period, and therefore fewer species have been recorded. The assemblage recorded from Wissant shows fewer species still. The inferred palaeogeography places Wissant in an embayment in the Anglo-Paris Landmass. Effectively, this could have restricted the entry of ammonites into the shallower water area of the Boulonnais. However, an alternative explanation may lie in the fact that the data from which the Wissant assemblages were obtained were published by Amedro (1980; 1981), Amedro & Destombes (1978) and Amedro et al. (1981). Amedro has grouped many of Spath's morphospecies together, in an attempt to establish true bio-species. Therefore, the different authorship of the ammonite distributions is reflected in the number of recorded species between Folkestone and Wissant. However, the writer has visited the Wissant section several times, and made a sizeable collection from the coastal outcrop. These records are added to those of Amedro, and it does appear to follow that this region in the north of France is characterised by less diverse assemblages.

Heteromorphs and other immigrant fauna avoided the Bedfordshire Straits, which may have been narrower than shown in Rawson's (1992) palaeogeographic reconstruction. The presence of an

argillaceous facies, similar in character to that developed in the Weald, does not reveal that shallower-water conditions may have persisted in Bedfordshire during the Middle Albian, but the low diversity assemblage strongly suggests it. Furthermore, the strata are more condensed and stratigraphic gaps are of longer duration than seen further south.

7.4.7 Brancoceratid Diversity Zone

A sudden expansion in the number of ammonite genera occurred as a result of the *cristatum* Subzone sequence boundary (TS21). The diversity remained high for throughout the period, and transgressions influenced both the turnover events and net changes in diversity (Fig. 7.1). Previous workers have considered the *cristatum* Subzone to lie at either the top of the Middle Albian (Spath 1943, Amedro 1980; 1981) or the base of the Upper Albian (Owen 1971; 1975; Amedro 1992). Diversity analysis confirms its position at the base of the Upper Albian.

Ammonite assemblage (Fig. 7.13): The commencement of the period is characterised by both the endemic hoplitinids and the influx of cosmopolitan brancoceratids. The immigrant fauna remained throughout the whole of the diversity zone and showed an increasing dominance upwards. Geographically widespread heteromorphs also increased in importance and showed the greatest diversity in the topmost part of the interval.

The rapid change in generic diversity associated with the *cristatum* Subzone transgression (TS21) is not immediately apparent from the change in abundance spectra at this time (Fig. 7.2). All the typically Middle Albian genera of the Hoplitinae persisted into the *cristatum* Subzone, but here *Dimorphoplites* gave rise to *Metaclavites*. The Brancoceratidae, Lyelliceratidae and Desmoceratidae were only introduced as a minority element, but several genera appeared (*Dipoloceras*, *Hysteroceras*, *Neophlycticeras*, *Beudanticeras* and *Uhligella*).

The brancoceratids proliferated in the *orbignyi* Subzone and continued to develop through the *varicosum* Subzone. These taxa suddenly became important at a phosphatic nodule bed at which the sea-level may have stepped-up and links with the Mediterranean Province increased markedly. Several of the genera evolved *in-situ* whilst others migrated from the south. Many of the older hoplitid genera declined rapidly during the subzone, and were replaced by new taxa. Only *Euhoplites* remained in numbers from the subzone below.

Figure 7.13. The range of the ammonites in the Brancoceratid Diversity Zone.



Transgression TS22 at the base of the *inflatum* Subzone saw the Tethyan ammonites increase in abundance, to almost 70% of the total assemblage (Fig. 7.2). The stressed forms of the Hoplitidae declined in abundance but diversified; *Anahoplites* and *Euhoplites* were joined by *Callihoplites* and *Lepthoplites*. The late, highly ornate genera of the Hoplitinae evolved from these last two forms in the *dispar* Zone as a result of the latest Albian transgression (TS23).

Many of the diverse heteromorph genera were forerunners to those that became fully established in the Late Cretaceous. A large number of these eccentrically coiled ammonites were introduced as a result of the late *inflatum* Subzone transgression (TS23), and they persisted through the remainder of the Albian.

Geographic distribution (Fig. 7.14): The most diverse faunal assemblages at the start of the diversity zone are recorded from the eastern part of the Weald, particularly from Folkestone, where multitudinous collections have been made. Many of the same genera have been recorded across the English Channel at Wissant, but here the diversity of species is lower. The hoplitinid ammonites showed the greatest diversities at the base of the period, but these were progressively replaced by more and more diverse assemblages of both the brancoceratid and heteromorph ammonites. The heteromorphs did not reach the Bedfordshire Straits until the *orbignyi* Subzone, and the diversity of brancoceratid ammonites also appears to have increased one subzone later than seen throughout the rest of southern England.

An assemblage of the Hoplitidae, Brancoceratidae and the heteromorphs has been recorded from the *fallax* Subzone at Folkestone. Despite their rapid diversification, the heteromorphs never comprised more than 20% of the total assemblage at Folkestone, where my collection has been made (Fig. 7.2). However, these forms may have been locally more abundant in marginal localities of Dorset, Bedfordshire, Cambridgeshire and East Anglia. It is in these areas that a rapid diversification of heteromorphs occurred and many of these were precursors to forms that characterised the Cenomanian.

Figure 7.14. The geographic distribution of genera in the Brancoceratid Diversity Zone.



Interpretation: The transgression at the base of the *cristatum* Subzone opened strong links with the Mediterranean Province, and allowed the penetration of a southern derived fauna into the Anglo-Paris Basin. Conditions allowed the rapid evolution of this fauna within the North European Province, which competed for ecological niches with the endemic fauna. This competition prompted the development of a large variety of new species and genera in both the endemic and cosmopolitan families. The conditions also favoured the heteromorphs, which also evolved rapidly. The uplift of areas to the west of the Weald Basin, and the progressive eastward spread of the Upper Greensand Formation led to the retreat of the endemic ammonites from these regions, but the heteromorphs produced a number of very ornate and curiously coiled forms that proliferated in the shallow seas. Similar assemblages also established themselves in the shallow-water environments of the Bedfordshire, Cambridgeshire and East Anglian areas.

The low diversity assemblage that is recorded in the Boulonnais may again be the result of its proximity to the Brabant Landmass. The upper part of the Gault Formation has never been well-exposed in Surrey, and few ammonites are recorded. It is quite probable that a similar diversity of the genera may exist in this area.

7.5 THE RELATIONSHIP BETWEEN AMMONITE DIVERSITIES AND SEA-LEVEL CHANGE

The general trend of increasing sea-level throughout the Aptian and Albian stages is reflected in the ammonite diversities. Very low diversity assemblages occur in the lower part of the Aptian, following the first transgressions, whilst a large number of genera characterise the Albian. Smaller-scale fluctuations in sea-level are represented by changes in diversity, of which six broad diversity zones are described.

The sequence boundaries and intervening transgressive surfaces all affect, to varying degrees, the composition of the ammonite fauna. Numerical analysis combined with the examination of the geographical distribution allows several important events to be established which can be tied to the sequence stratigraphic framework.

When the lithological record is viewed in isolation from the ammonite data a large number of transgressive surfaces can be recognised. If a significant period of unconformity is recognised at the basin margin prior to the transgression, it is inferred that a sequence boundary is recorded. It was stated in Chapter 6 that differences between transgressive surfaces, maximum flooding surfaces and sequence boundaries could not be distinguished by the stratal expressions in the

shelf environment, although is was not ruled out that they may occur. When the total diversity charts are examined, it is certainly tempting to apply some of the sequence stratigraphical nomenclature. Here, the lowstand deposits that would overlie the sequence boundary may carry a low diversity assemblage, whilst the periods of maximum flooding could be represented by diverse assemblages with influxes of fauna from outside of the basin. In effect, three sequence boundaries, at the base of the *obsoletus*, *nutfieldiensis* and *steinmanni* Subzones may exist. Maximum flooding surfaces, or horizons of faunal uniformity (Bulot 1993), appear to be represented in the *callidiscus*, *regularis* and *cristatum* Subzones, and are characterised by rapid extensions of the ammonite fauna. Above the maximum flooding surface, diversity shows a gradual decline, in what may be considered the highstand systems tract.

This interpretation seems to be an over-simplification when considering the facies at these event horizons. It is not difficult to consider that the *obsoletus* and *nutfieldiensis* Subzones are characterised by sequence boundaries at their bases, for distinctive pebble beds cut down into older strata and definite unconformities are present in the marginal parts of the basin. The base of the *steinmanni* Subzone is also characterised by lithofacies changes, and below it are varying periods of unconformity. The concretions that have been found in the Crackers Member of the *callidiscus* Subzone have been suggested to represent maximum flooding by earlier authors (e.g. Ruffell 1992c). Both the *regularis* and *cristatum* Subzone sediments overlie distinctive erosion surfaces, and appear as sequence boundaries in most studies.

So, despite the definite differences between high and low diversity assemblages, they at first sight appear to be represented by similar stratal packaging. Sequence boundaries form the bases of both the high diversity and low diversity zones. In both cases the boundaries between diversity zones are associated with the rapid geographical extension of the ammonite fauna. Other sequence boundaries are marked by turnovers in the ammonite fauna which are not obvious from the total diversity chart.

The mobilisation of ammonites as a result of the sea-level changes are represented by the different assemblage characteristics. The distribution of the biogeographic elements may either remain the same throughout the period or, especially in the high diversity zones, change significantly through the time-span. The presence of an argillaceous facies at the base of the Aptian and through the most part of the Albian allowed a geographically restricted fauna to establish itself in the Anglo-Paris Basin and its surrounding areas. Transgression facilitated the development and the prevailing environmental conditions favoured the continued radiation of endemic taxa. Because speciation occurred within the basin, along closely knit lines, the endemic

genera did not generally extend into southern areas, except for occasional strays, despite the fact that connections with other regions are believed to have existed.

Most north-west European Aptian genera are regarded as immigrants from Tethyan regions, and conditions were such that an endemic fauna was unable to establish itself. In the shallow-shelf environments, only the most hardy of the immigrant taxa stayed to evolve in the Anglo-Paris Basin, and this was apparently at a considerably slower rate than seen in the more geographically restricted forms.

A combination of diversity analysis and examination of biogeographic distributions of the constituent genera allows the definition of several types of event. These are summarised in figure 7.15 and discussed below.



Figure 7.15. Diversity zones, biogeographic distributions and the relationship with sequence stratigraphy.

(i) Low diversity sequence boundaries: these sequence boundaries represent a period of transgression that follows a generally regressive phase. The best examples are found at the base of the Aptian and the middle part of the Upper Aptian. In both these instances, a very restricted fauna developed as the seas became shallower. Renewed transgression led to the installation of a new fauna, which then showed a gradual evolution upwards through the sequence.

The Deshayesitid, Parahoplitid and Hoplitid Diversity Zones are all represented by low diversity assemblages. The Deshayesitid and Hoplitid Diversity Zones are characterised by assemblages that predominantly consist of endemic ammonites. These typically are represented by times of rapid speciation in which the species are diverse, but number of genera are low. Both of the time-spans are developed in a predominantly argillaceous facies, and it is not surprising that the later endemic hoplitinids are homeomorphs of the earlier deshayesitids.

The base of the Hoplitid Diversity Zone has been placed at the base of the *steinmanni* Subzone, although the published data suggest that it should lie at *niobe* Subzone contraction event. However, the reduction in diversity associated with this later transgression may not in fact be as pronounced as that shown in Fig. 7.1, Charts A and C. In the earlier subzones of the Mid Albian, diverse assemblages are commonly found in the southern part of the Paris Basin, where connections with Tethys would have been stronger purely by the proximity of this area to the Bourgogne Straits. Rarely did the immigrant fauna make a significant contribution in the northern localities of the Anglo-Paris Basin, and particularly in the *dentatus* Subzone, some records may indeed be erroneous. Sections in the higher part of the Mid Albian of the Aube are poorly exposed and faunal distributions are imperfectly known. Therefore, the decrease in diversity at the start of the *niobe* Subzone may be as much due to the lack of data from the southern Paris Basin as it is to do with changing palaeoceanographical conditions. The most important changes in distribution of the biogeographic components appear to result from sequence boundaries in the *steinmanni* and *dentatus* Subzones.

The Parahoplitid Diversity Zone is dominated by ammonites with an a very widespread geographical distribution. This period commences with a rapid contraction of the ammonite diversity, caused by the retraction of the Douvilleiceratidae and large heteromorphs from the Anglo-Paris Basin. Transgression at the base of the *nutfieldiensis* Zone allowed the spread of the Deshayesitaceae from their main evolutionary area of the western Tethys. An endemic fauna could not persist in the extreme conditions on the shelf at this time, but the low diversity fauna is related to that of the Deshayesitid Diversity Zone, albeit significantly altered and at a distant hierarchical level.

(ii) High diversity sequence boundaries: In these cases much of the regressive part of the sequence has been removed prior to the deposition of sediments above the sequence boundary. More extended periods of erosion are then followed by very rapid transgression. These sequence boundaries are often marked by the most significant facies changes, for example the initiation of clay deposition at the start of the *regularis* Subzone in western parts of the Weald. The first transgression may equate with the maximum flooding, and the increased links with other faunal provinces. Therefore, in these sequence boundaries the faunal turnover appears to coincide with the times of strongest interprovincial links.

The high diversity unconformity at the base of the *cristatum* Subzone allowed for the immigration of the Tethyan fauna into the Anglo-Paris Basin, and the development of a mixed endemic and cosmopolitan assemblage. Strong links between northern and southern Europe allowed the brancoceratid ammonites to move freely between realms, but the late forms of the hoplitinid ammonites remained geographically restricted. Highly stressed late genera of the Hoplitinae resulted from the increased competition for ecological niches.

(iii) Turnover sequence boundaries: These sequence boundaries do not coincide with the boundaries of diversity zones, but are important for they record rapid changes in the overall ammonite distribution, and are shown as large-scale events on the changes of diversity plot (Fig. 7.1, Chart C).

The most rapid changes in the assemblage structures occur during the Douvilleiceratinid Diversity Zone and early part of the Hoplitid Diversity Zone. These periods are characterised by rapid changes of lithofacies, and several short-term turnover sequence boundaries. The earliest part of the Douvilleiceratinid Diversity Zone is marked by the influx of a north European fauna from Germany and Russia, but also the first appearance of the early Douvilleiceratinae, perhaps from areas to the west. The *kitchini* Subzone sequence boundary led to a turnover of the fauna. This involved the initiation of a new endemic evolutionary line and the strengthening of links with the Mediterranean Tethys, indicated by invasions of southern taxa through the sequence. The endemic forms developed rapidly, whilst the cosmopolitan forms remained relatively unaltered. The *steinmanni* Subzone sequence boundary led to large-scale turnovers in both the Anglo-Paris Basin and Mediterranean areas. The endemic fauna dominated in north-west Europe, although strong links with areas to the south are shown by the influx of the Mediterranean taxa during the succeeding *lyelli* Subzone. The *dentatus* Subzone sequence boundary led to the formation of a palaeoceanographical barrier between north-west Europe and Tethys. The installation of this barrier allowed the endemic ammonites to evolve unhindered in the Anglo-

Paris Basin. This situation remained through the remainder of the Mid Albian, and hence the low diversities of the Hoplitid Diversity Zone were established.

The Cheloniceratinid Diversity Zone is the only period not to be defined by a sequence boundary at its base. In this case, the diversification may be a result of maximum flooding and stronger interprovincial links. This maximum flooding is then followed by an extended period of regression. The earliest part of the Cheloniceratinid Diversity Zone is characterised by a mixed assemblage of the late endemic fauna and cosmopolitan taxa. As the Mid Aptian regression proceeded, the endemic fauna left the Anglo-Paris Basin, and the assemblage was dominated by genera that had their origin in other regions.

7.6 SUMMARY AND CONCLUSIONS

The ammonites provide an excellent means by which to both test sequence stratigraphical concepts and examine palaeogeographical changes. Although the evidence for transgressions is given in the stratal packing, it is not possible to distinguish different types of transgressive surface from lithological expression alone. However, the study of distributions of ammonites reveals that sequence boundaries may by accompanied by rapid diversification, contraction or turnover of the marine fauna. In all cases, large-scale geographical extensions of the fauna occur. Differences between the faunal distributions depend upon the position of the first flooding surface within a sequence. Also associated with the sequence boundaries are changes in the biogeographical assemblages, and these can demonstrate the periods at which links with other biogeographic realms were strengthened or weakened by sea-level changes.

Diversity analysis is not always, however, the most reliable form of analysis because every single documented occurrence of an ammonite is included. As a result some very rare records, perhaps only of a single ever find, are also plotted. The inclusion of these rare or perhaps erroneous records can affect the way in which the data are interpreted. Some of these problems are removed when the distributions from individual localities are plotted. For example, sequence boundaries at the base of the Middle Albian had very significant effects on the ammonite distributions that are not immediately obvious from the plots of the total data. Firstly, in the *steinmanni* Subzone, the palaeoceanographical and palaeogeographical conditions led to the evolution of important genera in both the north-west European and Mediterranean Provinces. The later *dentatus* Subzone sequence boundary led to the weakening of links between the provinces. Connections were fully restored in the early part of the Late Albian.

CHAPTER 8 FAUNAL SPECTRUM ANALYSIS

The analysis of ammonite diversities is the first step in the examination of relationships between sea-level change and the fluctuation of ammonites as numerical data. However, there have been few attempts to quantify faunal changes in terms of the actual numbers of ammonite taxa. Many micropalaeontological studies now consider to some degree the relative abundances of taxa or groups of taxa to establish biostratigraphical and biogeographical frameworks. Vast numbers of specimens can be obtained from a very small sample, but ranges of individual genera are often significantly longer than those of ammonites. It is clearly important to document the magnitude of faunal turnovers to understand the importance of events, but this approach has rarely been followed by ammonite workers.

Diversity analysis has shown that there were very few intervals at which the Anglo-Paris Basin was totally isolated from other faunal provinces during the Aptian and Albian. However, the strength of the links between areas varied in time. The changes in the importance of the individual taxa cannot be fully appreciated from diversity studies alone. In some circumstances the actual diversity of immigrants may be low, but the number of individuals high. Alternatively, the number of recorded genera may outnumber the endemic forms, yet these immigrants only contributed to a minority of the overall assemblage.

The analysis of faunal abundance spectra has been ignored by most macro-palaeontologists because collecting conditions and the acquisition of a viable data-set are limiting factors that are less prevalent for the micropalaeontologists. The beds are variably exposed, and the collection of material may be dependent upon external influences, e.g. on the Isle of Wight the best collecting conditions follow storms in the winter, when the beach may be stripped of shingle. There can be no escaping these factors, and the best has to be made of the conditions and exposure at any given time. Therefore, the results of abundance studies are always going to be a preliminary, and more and more detail can be given as further exposures appear and further collections are obtained.

Stratigraphic collections from the Aptian and Albian have been made for many years, and there are many cases where rarities have been turned up at certain horizons. However, the unquantified and selectively collected material cannot be used in this part of the study, which is based solely upon material that I have collected. There is now, however, the problem that my recorded assemblage is not representative, simply because it does not include all the known taxa. However, the shear fact that specific taxa are not recorded indicates their rarity and the use of

such taxa to infer certain palaeoceanographic and palaeogeographic situations can be misleading. The appearance or non-appearance of extremely rare taxa in my statistics would have little affect on the overall abundance data if the total number of taxa collected at a specific horizon were large enough. There are several horizons at which the abundance data are based upon a very small recovery of ammonites and the conclusion derived from these must be taken with some caution. However, further comparison with published data should help to eliminate some of the problems.

The use of museum and other collections is avoided in this study for the reasons outlined above. One can never be sure that the specimens have been collected unselectively by other workers, and collections tend to be biased towards prize specimens and rarities.

8.1 VERTICAL DISTRIBUTION OF THE FAMILIES

In this section the distribution in a vertical section of the different ammonite families are plotted as relative abundances. For this, one obviously requires a fairly continuous record of the ammonites in a particular section or composite section. In the Aptian, the only detailed collecting has been from Chale Bay on the Isle of Wight. Elsewhere successions are often more highly condensed and unfossiliferous, they are also poorly exposed. Fossiliferous Albian successions have been recorded from Folkestone, Addington and Borough Green, and Westerham in the Weald, Chamberlain's Barn, Double Arches and Munday's Hill in Bedfordshire, and Wissant in the Boulonnais. Other localities do exist, but these have failed to provide me with a more or less continuous successions, and collections have been from just one or two subzones.

8.1.1 Aptian

a. The Isle of Wight, Table 8.1, Fig. 8.1.

The obsoletus Subzone is represented in the highly fossiliferous, yet poorly ammonitiferous, Perna Member. In my examination of the beds of this member, I have only obtained one poorly preserved fragment of an indeterminate deshayesitid ammonite. However, I also have been able to examine material collected by local coastguard Dick Downes, who has several specimens of *Prodeshayesites* and *Deshayesites* from the Perna Member in his possession. These have all been obtained from the beds exposed near to Atherfield Point. In no published account, nor any collection that I have examined, is there any record of ammonites other than these two genera.

	Deshayesidae	Douvilleiceratidae	Ancyloceratidae	Oppeliidae
gracile	0	8	5	0
debile	0	14	13	0
meyendorffi	19	7	3	0
transitoria	10	8	15	0
grandis	21	10	18	0
deshayesi	23	6	3	0
callidiscus	46	7	2	1
kiliani	36	12	0	0
fittoni	16	0	0	0
obsoletus	12	0	0	0

 Table 8.1. The ammonites collected from Chale Bay,

 Isle of Wight.

For this investigation, I have managed to collect, or record in the field, ammonites from the *kiliani* Subzone to *gracile* Subzone. Although the distributions are restricted vertically through the section and may be particularly uncommon in some subzones, the collection is considered suitable to examine vertical changes in the faunal spectra.

Subzones above the *gracile* Subzone at Chale Bay are poorly fossiliferous, or apparently unfossiliferous. Correlations were made by Casey (1961) using sections near to Shanklin, where he recorded occasional ammonites. However, in my own limited study of these beds, I have been unable to find any ammonites from this higher part of the Upper Aptian.

Deshayesitidae: The most characteristic Aptian family is without a doubt the Deshayesitidae. In the lowest part of the succession, only members of this family have been recorded. Through the upper part of the *forbesi* Zone (*kiliani* and *callidiscus* Subzones) and lower *deshayesi* Zone (*deshayesi* Subzone), the Deshayesitidae comprised between 72% and 82% of the overall assemblage. The relative abundance declined to 42.86% in the *grandis* Subzone, and then again in the *transitoria* Subzone to 30.30%. A rapid increase of abundance in the *meyendorffi* Subzone (65.52%) was followed by the complete disappearance of the family before the start of the Late Aptian (*debile* and *gracile* Subzones).

Douvilleiceratidae: The family first appeared in the *kiliani* Subzone, and stayed throughout the remainder of the interval studied here. Changes in relative abundance were rapid during the early part of the family's range, from 25% of the assemblage when it first appeared, down to 12.5%



Figure 8.1. The vertical distribution of ammonite families at Chale Bay, Isle of Wight.

in the *callidiscus* Subzone. However, from the *deshayesi* Subzone until the top of the *meyendorffi* Subzone, the Douvilleiceratidae comprised between 20% and 25% of the

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assemblage. The Douvilleiceratidae suddenly increased to 51.85% of the assemblage in the *debile* Subzone and then to 61.54% in the *gracile* Subzone. This rapid increase in relative abundance followed the disappearance of the Deshayesitidae.

Ancyloceratidae: This family first appeared in the *callidiscus* Subzone, but only occurred in a minority (3.57%). It became more abundant in the following *deshayesi* Subzone, but still only reaching 9.09% of the total assemblage. The abundance of the family suddenly increased in the *grandis* Subzone (36.73%). It remained important during the *transitoria* Subzone, but declined in the *meyendorffi* Subzone. Another rapid increase is documented in the *debile* Subzone, and this is followed by a slight tailing off in the *gracile* Subzone. The importance of the heteromorphs in particular beds is reflected in the terminology used by the historical workers. Where *Tropaeum* comprises nearly 45% of the overall assemblage, in the *transitoria* and *debile* Subzones, Fitton (1847) applied the terms 'Lower' and 'Upper Crioceras Beds', whilst he used 'Scaphites Beds' (now the Small Ledge Member) to refer to beds yielding *Australiceras* in abundance.

Aconeceratidae: This family was reported to have occurred at several isolated horizons throughout the Aptian (Casey 1961). However, it has only been recorded with any certainty from the Crackers Member, and here it is represented by only 1 specimen (1.79% of the assemblage).

Unrecorded families: The only family not represented in my collection from the Isle of Wight is the Desmoceratidae, which appeared briefly, and as an extreme rarity, in the Crackers Member (lower part of the *callidiscus* Subzone).

b. Other sections

The absence of either fossiliferous or well-exposed successions means that data from other sections are not available. Rarities have been collected from Aptian beds in other parts of the basin, but unfortunately not enough ammonites to plot as faunal spectra. The higher beds of the Aptian are exposed at Patteson Court and Baulking, where ammonites are recorded. From both these localities, *Parahoplites* (Parahoplitidae) is by far and away the most dominant ammonite. The *nolani* Subzone was based formerly on just two specimens of *Nolaniceras*, but now includes Casey's (1961) records of *Hypacanthoplites* from Folkestone and recent acquisitions of this genus from Ashford. However, neither of these two localities are exposed at present, and sandy deposits of equivalent age are unfossiliferous. Only *Hypacanthoplites* has been recorded from the succeeding *anglicus* Subzone.

8.1.2 Albian

a. Folkestone, Table 8.2, Fig. 8.2.

Folkestone is the type section of the Gault Formation, and it is from here that the most detailed collection of Albian ammonites has been made. Condensation of the Lower Albian and lower part of the Middle Albian makes it difficult to separate subzones and some levels are particularly poorly fossiliferous. Although the upper part of the Albian is thickly developed and within a clay facies, it is rather poorly exposed, and notably poorly fossiliferous. Some considerable time was spent trying to obtain ammonites from this upper part of the Gault Formation, but the data are rather limited. Nonetheless, for most of their thickness, the Lower Albian sands and Middle and Upper Albian clays are unrivalled collecting ground for Albian ammonites.

Douvilleiceratidae: In the condensed 'Main mammillatum Bed' at Copt Point, the Douvilleiceratidae is by far and away the most abundant family. It makes up over 70% of the total assemblage, and is represented solely by the genus *Douvilleiceras*. There have been no further records of the Douvilleiceratidae above the *mammillatum* Zone at Folkestone.

Desmoceratidae: The Desmoceratidae are well-represented in the *mammillatum* Zone at Folkestone, where *Beudanticeras* comprises 17.96% of the assemblage. The family disappeared from this area prior to the start of the *dentatus* Zone. However, it returned, virtually unaltered, as a rarity in the *orbignyi* Subzone (not recorded in the present study) and persisted until the end of the *varicosum* Subzone.

Hoplitidae: The first of the Hoplitidae to be recorded from Folkestone occur within the *mammillatum* Zone. Here, early forms of the family (the Sonneratiinae) occurred rarely in a phosphatic nodule bed at the base of the *kitchini* Subzone (not recorded here) and then as a minority (4.37%) alongside the cosmopolitan taxa in the higher part of the zone. The Hoplitidae are believed to have shown a steady increase in abundance through the *steinmanni* and *lyelli* Subzones at the start of the Middle Albian but, because the condensed beds during this interval are poorly fossiliferous, my collection cannot confirm this. The *dentatus* Subzone nodule bed at Folkestone forms a junction between silty, sandy and glauconitic clays below, to far less silty clays above. Extensive collection from the nodule bed has furnished numerous specimens of *Hoplites* which co-existed with heteromorph ammonites. Later in the same subzone, *Hoplites* occurred alone. The total abundance of the Hoplitidae for the entire subzone reached 90.95%.

mammilli	dentatus	intermedi	niobe	subdeları	nitidus	daviesi	cristatum	orbignyi	varicosus	inflatum	fallax	perinflati	
ıtum		£	 	lei.		 			7			2	
147	0	0	0	0	0	0	0	0	0	0	0	0	Douilleiceratidae
37	0	0	0	0	0	0	0	18	1	0	0	0	Desmoceratidae
0	C		0	0	0	C	2	0	0	0	2	3	Lyelliceratidae
1	0	0	0	11	0	0	. 35	245	76	32	26	32	Brancoceratidae
0	0	s	0	0	0	0	0	0	0	0	0	0	Binneyitidae
9	543	99	83	172	124	57	790	146	37	17	10) 24	Hoplitidae
3	0	0	0	0	0	0	0	0	0	0	0	0	Cleoniceratidae
2	42	8	12	19	17	14	67	11	5	ω υ	2	1	Hamitidae
7	12	0	0	0	0	0	0	0	12	5	4	7	Anisoceratidae
0	0	0	0	0	0	0	0	0	0	0	0	1	Baculitidae
0	0	0	0	0	0	0	0	0	0	0		2	Scaphitidae

Table 8.2. The ammonites collected from Folkestone, Kent.

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Figure 8.2. The vertical distribution of ammonite families at Folkestone, Kent.

The Hoplitidae continued as the dominant family throughout the remaining clays of the Middle Albian (*intermedius* to *daviesi* Subzones) and lowest part of the Upper Albian (*cristatum* Subzone). Throughout this interval the family comprised between 85% and 90% of the assemblage, and this abundance was represented within three genera - *Anahoplites*, *Dimorphoplites* and *Euhoplites*. The relative abundance declined in the *orbignyi* Subzone, in which the family only comprised 34.76% of the overall faunal spectrum. Throughout the remaining Upper Albian clays, the Hoplitidae ranged between 22% and 35% of the spectrum.

Cleoniceratidae: The Cleoniceratidae occurred alongside the other members of the Hoplitaceae in the *mammillatum* Zone at Folkestone, but only as a minority (1.46%).

Lyelliceratidae: Specimens of the early Lyelliceratidae (*Tegoceras*) have been recorded from the *mammillatum* Zone of Folkestone (Casey 1961). It later evolved into *Lyelliceras*, species of which are then believed to occur within the *steinmanni* and *lyelli* Subzones in the lower part of the Middle Albian (Casey 1961; Owen 1975). However, none of these genera have been collected from Folkestone during the present study and are therefore believed only to have comprised a very minor accessory element. There is no record of the family above the *lyelli* Subzone until the start of the Upper Albian (*cristatum* Subzone), where a single specimen of *Neophlycticeras* has been recorded (0.23% of the assemblage). This genus is believed to have remained through the higher part of the Albian, but no records have been acquired by the present author. In the topmost part of the Albian, the *fallax* and *perinflata* Subzones, the family is represented by *Stoliczkaia* which makes up nearly 5% of the assemblage in each of these subzones.

Brancoceratidae: The Brancoceratidae are represented in the *mammillatum* Zone at Folkestone, but in the present investigation, only a single specimen of this family (*Oxytropidoceras*) has been recovered from the phosphatic nodules of the 'Main mammillatum Bed'. Owen (1971) recorded several horizons in the lower part of the Middle Albian at which the family made brief appearances; there is, however, no evidence for these in my collection until the *subdelaruei* Subzone. At this time, a very definite incursion of this Tethyan family occurred, represented by the genus *Mojsisovicsia* which comprised 5.45% of the assemblage. The Brancoceratidae then disappeared from the basin, to return again in the *cristatum* Subzone. The family became dominant during the *orbignyi* Subzone, and remained so for the rest of the Albian, when it comprised between 45% and 60% of the assemblage.

Hamitidae: The family occurred in the mammillatum Zone, but it was not until the dentatus

Subzone that it made a significant contribution to the overall assemblage. The hamitids remained for the remainder of the Albian, but are particularly well-known from the Mid Albian. In the *dentatus* Subzone, *Hamites* comprised 7.04% of the assemblage, but this increased slowly through the Mid Albian to a peak of 19.18% in the *daviesi* Subzone. Most records of the Hamitidae are from the phosphatic nodule beds that punctuate the clays. When these beds are fewer, in the Upper Albian, the abundance of the family declined, and it remained as a minority element through the rest of the interval.

Anisoceratidae: Early forms of the Anisoceratidae appeared in the *mammillatum* Zone at Folkestone. *Protanisoceras* comprised 3.40% of the faunal spectrum in this zone, but declined rapidly and disappeared in the early part of the Mid Albian. Later forms of the family (*Anisoceras, Idiohamites, Pseudhelicoceras*) returned in the Late Albian. It comprised about 10% of the assemblage from the *varicosum* Subzone to the top of the *perinflata* Subzone.

Baculitidae: The family is poorly represented in the Albian of Folkestone. Only a single specimen of *Lechites* has been collected from the upper part of the *perinflata* Subzone at this locality, although Casey (1966) recorded specimens from the *fallax* Subzone below.

Scaphitidae: The earliest Scaphitidae are recorded as ranging upwards from the middle part of the Late Albian (Casey 1966), but only 3 specimens have been collected by myself, and all of these from the *dispar* Zone (1 from the *fallax* Subzone and 2 from the *perinflata* Subzone).

Unrepresented families: The Parahoplitidae continued from the *tardefurcata* Zone into the *mammillatum* Zone. However, this family was greatly outnumbered by the other families, and has not been collected in the present study. The only other families not to be recorded in the Folkestone section are those that had their main areas of development outside of the basin and were swept into the area as a result of rapid transgressions. These were all considered to be strays, and the extreme rarity of the families may suggest that their appearance was the result of post-mortem drift. Examples of these stray taxa include the phylloceratids, lytoceratids, engonoceratids and gastroplitids.

b. Comparison with other sections

(i) Wissant, Table 8.3, Fig. 8.3.

Wissant only lies about 50 km to the south of Folkestone, and one would expect that the faunal spectra would remain similar between the localities. However, the proximity of the Boulonnais to the London-Brabant Landmass revealed by diversity studies may have had an effect on the assemblage structures.

	Binneyitiidae	Desmoceratidae	Brancoceratidae	Hoplitidae	Hamitidae	Anisoceratidae
inflatum	0	0	36	7	0	0
varicosum	0	0	89	39	1	3
orbignyi	0	0	65	33	1	2
cristatum	0	6	6	232	9	0
nitidus	0	0	0	60	2	0
subdelaruei	0	0	2	90	10	0
niobe	0	0	0	38	6	0
intermedius	1	0	0	16	1	0
dentatus	0	0	0	19	0	0

Table 8.3. The ammonites collected from Wissant, Boulonnais.

The general distribution pattern is similar to that seen at Folkestone, with the Hoplitidae dominating in the Mid Albian and the Brancoceratidae becoming increasingly important through the upper part of the Albian. However, at this section, the Brancoceratidae make up a higher percentage of the overall assemblage than at Folkestone. Heteromorphs are present throughout most of the succession, but are typically less common than at Folkestone to the north.

(ii) Addington/Borough Green, Table 8.4, Fig. 8.4.

Sections to the north-west of Folkestone have more expanded beds at the Lower-Middle Albian junction and the separation of the individual subzones is possible.

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Figure 8.3. The vertical distribution of ammonite families at Wissant, Boulonnais.

The *floridum* Subzone is dominated by the Douvilleiceratidae, with an important contribution by the Desmoceratidae. The early Hoplitaceae (Hoplitidae and Cleoniceratidae) make up 12.95% of the spectrum, whilst heteromorphs comprise only 3.53%, represented by the Anisoceratidae. In the succeeding *raulinianus* Subzone, the Desmoceratidae became more important at the expense of the Douvilleiceratidae. The relative abundance of the Hoplitidae increased slightly

	Douvilleiceratidae	Desmoceratidae	Cleoniceratidae	Hoplitidae	Anisoceratidae
dentatus	0	0	0	23	0
lyelli	0	0	0	0	0
steinmanni	0	0	0	0	0
puzosianus	2	3	0	10	1
raulinianus	3	5	0	1	0
floridum	45	26	4	7	3

Table 8.4. The ammonites collected from Addington andBorough Green, Kent.



Figure 8.4. The vertical distribution of ammonite families from Addington and Borough Green, Kent.

in this subzone, but more so in the following *puzosianus* Subzone (although only 10 specimens have been recorded). Both the Desmoceratidae and Douvilleiceratidae declined markedly through this subzone.

The *steinmanni* and *lyelli* Subzones, in the lower part of the Mid Albian, are both poorly fossiliferous and assemblage data are not available. However, a distinctive phosphatic nodule bed marks the start of the *dentatus* Subzone, and from this only specimens of *Hoplites* (Hoplitidae) have been collected.

(iii) Westerham, Table 8.5, Fig. 8.5.

The *floridum* Subzone in this pit contains an abundance of the Desmoceratidae that is greater than the Douvilleiceratidae. The abundance of both these families increased through the succeeding *raulinianus* Subzone. The Hoplitidae were a minority element through both these earlier *mammillatum* Zone subzones. Although the relative abundance of the Hoplitidae is shown to have increased in the *puzosianus* Subzone, this is based on just 2 specimens. The Douvilleiceratidae appeared again in the *steinmanni* Subzone, but only in a minority compared to the Hoplitidae. Then, in the *lyelli* Subzone, a sudden influx of the Tethyan Lyelliceratidae saw this family reach 50% of the faunal spectrum. The family disappeared suddenly, and in the *dentatus* Subzone only specimens of the Hoplitidae have been recorded.

Table 8.5. Th	e ammonites	collected from	n Westerham,	Kent
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	Douvilleiceratidae	Desmoceratidae	Lyelliceratidae	Cleoniceratidae	Hoplitidae	Anisoceratidae
dentatus	0	0	0	0	23	0
lyelli	0	1	7	0	. 6	0
steinmanni	1	0	0	0	12	0
puzosianus	0	:0	0	0	2	0
raulinianus	3	5	0	0	1	0
floridum	32	68	0	3	13	19
kitchini	0	0	0	0	0	0



Figure 8.5. The vertical distribution of the ammonite families at Westerham, Kent.

(iv) Leighton Buzzard area, Table 8.6, Fig. 8.6.

This area still displays Lower Albian beds that may be absent or poorly fossiliferous in the Weald. Particularly important is the presence of *regularis* Subzone ammonites that occur in the Shenley Member (although the best exposures of this member have now been worked out) or as a remanié at the base of the Gault Formation at Double Arches and Chamberlain's Barn. The remanié beds in this area have only yielded 9 specimens, but are dominated by the Lyelliceratidae (66.66%), alongside 11.11% Douvilleiceratidae and 22.22% Cleoniceratidae. Several other families have been recorded from the *regularis* Subzone, but these are represented by rare open-sea dwelling taxa that have not been collected during the present study, e.g.

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Phylloceratidae, Gaudryceratidae and Aconeceratidae (Casey 1961).

	Douvilleiceratidae	Desmoceratidae	Lyelliceraridae	Cleoniceratidae	Hoplitidae	Brancoceratidae	Anisoceratidae
varicosum	0	1	0	0	135	91	14
orbignyi	0	0	0	0	88	2	0
cristatum	0	0	0	0	5	0	0
daviesi	0	0	. 0	0	0	0	0
nitidus	0	0	0	0	0	0	0
meandrinus	0	0	0	0	0	0	0
subdelaruei	0	0	0	0	0	0	0
niobe	0	0	0	0	22	0	0
intermedius	0	0	0	0	7	0	0
dentatus	0	0	0	0	12	0	0
lyelli	0	0	0	0	0	0	0
steinmanni	0	0	0	0	0	0	0
bulliensis	0	0	0	0	0	0	0
puzosianus	0	0	0	0	0	0	0
raulinianus	0	0	0	0	0	0	0
floridum	3	7	0	0	1	0	0
kitchini	46	107	0	2	16	0	0
reaularis	1	0	6	2	0	0	0

Table 8.6. The ammonites collected from the Leighton Buzzard area, Bedfordshire.

The Douvilleiceratidae increased in abundance in the following *kitchini* Subzone, but the assemblage was dominated by the Desmoceratidae. The Cleoniceratidae continued as a minority, which occurred alongside the earliest examples of the Hoplitidae. A similar faunal spectrum has been recorded from the succeeding *floridum* Subzone, although the beds are on the whole more poorly fossiliferous.

Regression and erosion led to the removal of much of the higher Lower Albian sediments, and marine conditions were not fully restored until the *dentatus* Subzone. In this subzone, only the Hoplitidae are recorded, and it is this family that is represented through the rather poorly fossiliferous beds of the Middle Albian in this region. The earliest Late Albian erosion led to the removal of topmost part of the Middle Albian. From the succeeding transgressive deposits, I have only obtained a few specimens of the Hoplitidae. This family continued to dominate in the succeeding *orbignyi* Subzone, but was joined by the Brancoceratidae as a minority. The



Brancoceratidae became important in the *varicosum* Subzone, which is one subzone later than is evident in sections to the south (Folkestone and Wissant).

Figure 8.6. The vertical distribution of ammonite families in the Leighton Buzzard area, Bedfordshire.

8.2 PHYLOGENY OF THE APTIAN AND ALBIAN AMMONITES

The phylogeny of the ammonites in the Anglo-Paris Basin is well-established. The primary investigations regarding phylogeny appear in the monographs of Spath and Casey, and these have been updated by Wright (1958; 1981), Owen (1988a) and Amedro (1992). However, equally important as tracing roots and evolutionary trends in the ammonites is to establish the importance of their development in terms of abundance. Therefore, the phylogenies of the important ammonite families are plotted numerically. In the following figures (Fig. 8.7-8.11) the mean relative abundance of each genus is plotted as part of the total assemblage.

8.2.1 Hoplitidae, Fig. 8.7.

The Gault Formation of the Anglo-Paris Basin is typified by the Hoplitidae, a rapidly evolving group of endemic ammonites that at times co-existed with Tethyan taxa. The endemic forms rarely penetrated into the Mediterranean Province, but showed great diversity in NW Europe. The onset of shelf clay deposition allowed the development of the family through allopatric speciation. The variety of species and genera that typify the Gault Formation are unrivalled in any other region outside the Anglo-Paris Basin. The evolution of the Hoplitidae occurred in a number of stages, and each of these can be related to environmental or biological influences.

(a) The family first appeared in the *farnhamensis* Subzone, represented by the Sonneratiinae, but soon vanished and no abundance data exists. The Sonneratiinae are believed to have evolved from the desmoceratid genus *Uhligella*, and following their first abortive appearance, re-entered the basin at the base of the *kitchini* Subzone (Owen 1988a). These first members of the Hoplitidae characterised the *mammillatum* Zone, but only initially as a rare minority element of the total assemblage. This subfamily, however, contained within it rapidly evolving and closely related genera. By the *puzosianus* Subzone the Sonneratiinae had evolved to comprise several genera that were dominant over the cosmopolitan taxa.

(b) From the earliest trial genera burst forth a new rapidly evolving plexus in the lowest parts of the Middle Albian. The total number of ammonites preserved in the *steinmanni* Subzone is low, but here are seen the first of the Hoplitinae. A change in environmental conditions in the *lyelli* Subzone allowed a brief but significant influx of Tethyan fauna, which reduced the relative abundance of the Hoplitidae. However, a further change of environmental conditions at the start of the *dentatus* Subzone caused the rapid extinction of Tethyan genera, and the lack of competition from immigrant fauna allowed the early Hoplitinae to evolve unhindered.



Figure 8.7. The phylogeny and mean total relative abundance of the Hoplitidae in the Anglo-Paris Basin.

(c) Continued evolutionary development and the lack of competition allowed the family to reach a point of evolutionary stasis sometime in the middle part of the *loricatus* Zone (*intermedius*, *niobe* and *subdelaruei* Subzones). Above this point the relative abundance of each of the genera remained remarkably similar. The Hoplitidae had reached the acme of their development and were well-suited to the environmental conditions.

(d) The earliest part of the Late Albian saw an influx of well-developed brancoceratids from the south. Initially this had little effect on the evolution of the Hoplitinae, but as the fight for ecological niches increased through the sub-stage, so the development of more and more stressed genera occurred. This rapid evolution saw the development of several unproductive, short-lived genera. The endemic ammonites never regained their footing against the relatively stable brancoceratids and lyelliceratids.

8.2.2 Acanthocerataceae, Fig. 8.8.

Members of the Acanthocerataceae were best represented in Tethyan parts of France for much of their time-span. The Mediterranean Province is dominated by an assemblage of the Brancoceratidae, and this parallels the hoplitid dominated assemblage of the North European Province (Owen 1975).

(a) The earliest members of the Acanthocerataceae belong to the Leymeriellinae (Lyelliceratidae), and this family was best developed in the *tardefurcata* Zone of northern Germany. It evolved from the Desmoceratidae at about the same time as the first of the Hoplitidae developed. The already well-established taxa entered the Anglo-Paris Basin in the *regularis* Subzone. *Leymeriella* was the dominant ammonite during this subzone, but it did not persist into younger beds of the Anglo-Paris Basin.

(b) Although no records of the Leymeriellinae exist above the *regularis* Subzone, it is believed that it was this family that gave rise to the Lyelliceratinae and Brancoceratidae in the later part of the Early Aptian in areas to the south of the Anglo-Paris Basin. Connections with the Mediterranean area appear to have existed during the *mammillatum* Zone, and these allowed the northward penetration of the southern ammonites into north-west Europe. However, the influxes only occurred as minority elements during the interval.



Figure 8.8. The phylogeny and mean total relative abundance of the Acanthocerataceae in the Anglo-Paris Basin.

(c) Faunal turnover that paralleled the development of the Hoplitidae saw the evolution of *Lyelliceras* from *Tegoceras*, and there are records of both these genera in the Anglo-Paris Basin in the *steinmanni* Subzone. However, in the poorly exposed beds of this interval, I have been unable to collect any examples of these genera during the present investigation. The Lyelliceratidae stayed to evolve in the Anglo-Paris Basin, and became abundant in the *lyelli* Subzone.

(d) The Acanthocerataceae disappeared from the Anglo-Paris Basin in the *dentatus* Subzone, but continued to evolve throughout the Middle Albian further south. Short-lived incursions are believed to have occurred through the sub-stage, but I can only provide evidence for a single important immigration of *Mojsisovicsia* in the *subdelaruei* Subzone.

(e) The Brancoceratidae returned in the *cristatum* Subzone, where several genera appeared. This time the southern elements stayed in the Anglo-Paris Basin, and evolved rapidly.

8.2.3 Deshayesitaceae, Fig. 8.9.

(a) The first of the Deshayesitidae evolved from *Heteroceras* in the North Sea Basin, and migrated southward to first appear in the lowest Aptian sediments of southern England. The ammonites are rare, although other fossils abound in the Perna Member of the *obsoletus* Subzone. *Prodeshayesites* is the dominant genus, but this occurs alongside the earliest species of *Deshayesites* in the same subzone.

(b) Following upwards from the Perna Member, a succession of shelf muds developed. This allowed for the proliferation of the Deshayesitidae, and most particularly rapid speciation of *Deshayesites*. The genus became dominant in the *fittoni* Subzone, and *Prodeshayesites* was extinct prior to the end of the subzone. *Deshayesites* remained dominant throughout the deposition of the silty clays of the Atherfield Formation, and the assemblage is dominated by small and juvenile specimens.

(c) The clays that dominated in the lower part of the Aptian in southern England were gradually replaced by more sandy deposits. These conditions saw the introduction of several other ammonite families that were in direct competition with the Deshayesitidae for ecological niches. Although *Deshayesites* remained dominant, its relative abundance declined, and more extreme forms evolved. The ammonites are largely restricted to the more argillaceous horizons within a predominantly sandy succession, and in the final phase of its development, *Deshayesites* is


represented almost entirely by large adult specimens, although some juveniles did still persist.

Figure 8.9. The phylogeny and mean total relative abundance of the Deshayesitaceae in the Anglo-Paris Basin.

(d) Several transitional specimens of *Deshayesites* appeared throughout the *deshayesi* Zone (*deshayesi* and *grandis* Subzones), but the important evolutionary change to *Dufrenoyia* occurred suddenly at the base of the *transitoria* Subzone. In the predominantly sandy succession *Dufrenoyia* was largely restricted to the concretionary levels (Lower Crioceras Member). Like the late species of *Deshayesites*, most of the preserved specimens of *Dufrenoyia* are adults. More argillaceous sediments developed in the lower part of *meyendorffi* Subzone, and *Dufrenoyia* evolved more rapidly, with both large and small species represented. However, progressively more sandy sediments in the upper part of the *meyendorffi* Subzone were unfavourable to the continued development of the genus, which disappeared prior to the end of this interval.

(e) The Deshayesitidae persisted into younger deposits elsewhere. These later forms returned to the Anglo-Paris Basin in the *subarcticum* Subzone, represented by the Parahoplitidae. Unfortunately, the lack of suitable exposure and the general paucity of ammonites during the late part of the Aptian (*subarcticum* to *anglicus* Subzones) and earliest Albian (*farnhamensis* Subzone) means that no statistically viable representation of the assemblage has been collected from these levels. However, the supposed evolutionary development of the Parahoplitidae is shown on figure 8.9. Much of this evolution appears to have taken place outside of the Anglo-Paris Basin, and the successive genera were brought in as a result of the rapid transgressive episodes.

The Douvilleicerataceae range from the Lower Aptian into the lower part of the Middle Albian, although this range is not continuous in the Anglo-Paris Basin.



Figure 8.10. The phylogeny and mean total relative abundance of the Douvilleicerataceae in the Anglo-Paris Basin.

(a) The Roloboceratinae first appeared in the *kiliani* Subzone when shelf muds were deposited across the basin. *Roloboceras* was a common accessory to *Deshayesites* and it continued into the more arenaceous sediments that marked the start of the *callidiscus* Subzone.

(b) Argillaceous sedimentation recommenced rapidly in the upper part of the *callidiscus* Subzone, and the change of facies was marked by the sudden disappearance of *Roloboceras*. However, as a sandy facies returned in the *deshayesi* Subzone, so did the Douvilleiceratidae, having evolved in northern Europe and given rise to *Cheloniceras* (Cheloniceratinae). As with the other Lower Greensand Group ammonites, the distribution of *Cheloniceras* is discontinuous, and largely restricted to concretionary horizons. It was relatively common in the concretion beds through the *deshayesi* Zone (*deshayesi* and *grandis* Subzones) and part of the *furcata* Zone

(transitoria and lower meyendorffi Subzones).

(c) The sandy deposits at the top of the *meyendorffi* Subzone were unfavourable to the preservation of ammonites, and no records of *Cheloniceras* exist. However, in the lowest concretionary horizon of the Upper Crioceras Member (*debile* Subzone), *Cheloniceras* returned, having evolved to the subgenus *Epicheloniceras*. In the *martinioides* Zone (*debile* and *gracile* Subzones), *Ch.* (*Epicheloniceras*) was often the dominant genus in beds where ammonites are relatively rare.

(d) The environmental conditions changed rapidly at the base of the *subarcticum* Subzone, and *Cheloniceras* did not survive into the higher part of the Upper Aptian in the Anglo-Paris Basin. Its persistence elsewhere in the Tethyan realm, however, was followed by the development of *Eodouvilleiceras* and then *Douvilleiceras* (Douvilleiceratinae) in these areas.

(e) *Douvilleiceras* entered the Anglo-Paris Basin in the *regularis* Subzone. The genus proliferated in the early part of the succeeding *mammillatum* Zone (*kitchini*, *floridum* and *raulinianus* Subzones), and attained an abundance that was unmatched by any other of the ammonite genera except for *Beudanticeras* (Desmoceratidae). However, despite the large number of specimens, species were few, and *Douvilleiceras* showed little attempt to modify to the rapidly changing environmental conditions. As a result, its abundance declined through the upper part of the *mammillatum* Zone (*puzosianus* Subzone), and it finally disappeared before clays blanketed the entire Anglo-Paris Basin in the *dentatus* Subzone.

8.2.5 The heteromorph ammonites, Fig. 8.11.

The heteromorph ammonites appeared in two main developments during the Aptian and Albian. Firstly, the Ancylocerataceae that characterised Aptian strata, and then the Turrilitaceae that were common in the Albian. Between these two superfamilies was a gap during which time no true heteromorph ammonites existed.

(i) The Ancylocerataceae

(a) The Aptian heteromorphs all belong to the Ancyloceratidae, and the first genus to appear in the Lower Greensand Group was *Ancyloceras* in the *callidiscus* Subzone. Casey (1961) recognised that this genus was typically associated with open-sea dwellers, and it only occurred as a rarity of the overall assemblage.



Figure 8.11. The phylogeny and mean total relative abundance of the heteromorph ammonites in the Anglo-Paris Basin.

(b) Casey (1960) considered the evolution of the large ancyloceratid- and crioceratid-coiled taxa to be in parallel, and from *Ancyloceras* emerged *Tropaeum*, *Australiceras* and *Ammonitoceras*. He also recognised that *Australiceras* of the gigas group, which is the only species-lineage to appear in the Lower Greensand Group, gave rise to *Tropaeum*, whilst *Epancyloceras* formed an intermediate development between *Ancyloceras* and *Ammonitoceras*. *Epancyloceras* appeared as a rarity in the *deshayesi* Subzone, and this was followed by a sudden abundance of *Australiceras* in the grandis Subzone. *Tropaeum* then emerged in the following *transitoria* Subzone when it was very abundant, comprising over 40% of the total ammonite assemblage. It declined suddenly

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in the more sandy beds of the *meyendorffi* Subzone, but in the concretionary levels of the Upper Crioceras Member (*debile* Subzone) it returned to its former dominance. The abundance of *Tropaeum* declined through the *gracile* Subzone, and it persisted into the early part of the *subarcticum* Subzone. In the early part of the Late Aptian (*debile* and *gracile* Subzones), *Tropaeum* was joined by *Ammonitoceras*, which comprised up to 15% of the assemblage.

(c) The Helicancylinae are represented by only two genera that occur as rarities in the lower levels of the Lower Greensand Group. The family first appeared in the Barremian and, although it is a family that is generally associated with Tethyan regions, several specimens of *Toxoceratoides* have been collected from the Speeton Formation in Yorkshire (Rawson *in press b*). The first Lower Greensand Group occurrence of *Toxoceratoides* has now been found in the upper part of the *callidiscus* Subzone on the Isle of Wight, and this is one subzone earlier than recorded by Casey (1961). *Toxoceratoides* became more abundant in the following *deshayesi* Subzone. It gave rise to *Tonohamites* in the succeeding *grandis* Subzone and both genera are found together during this interval.

(ii) The Turrilitaceae

(a) A gap in the heteromorph record extends from the middle part of the *subarcticum* Subzone until the base of the *kitchini* Subzone, when *Hamites* appeared. This gap is believed to be shorter in other Tethyan areas, although there may be some interval in which no heteromorphs occur, and there is no apparent link between the ancyloceratids and the hamitids. However, during the period in which no heteromorphs appear to have existed, the strata are occupied by the Deshayesitaceae and Douvilleicerataceae, and both these superfamilies are considered to represent re-coiled heteromorphs (Lehmann 1981). Although the root of the Hamitidae does not appear to have been from the Ancylocerataceae, nor from the re-coiled heteromorphs, there is an argument that the later development of the heteromorphs was from the Neocomian genus *Leptoceras* (Wiedmann 1969; Lehmann 1981). It was also from this line that *Paraspiticeras* developed, and this eventually gave rise to *Douvilleiceras*. The origin of the Turrilitaceae may therefore be related, at a distant taxonomic rank, to the development of the Douvilleicerataceae.

(b) The Hamitidae are a constant feature of the faunal assemblage from their first occurrence in the Early Albian until the end of the Late Albian. The family, represented by *Hamites*, reached its acme in the Mid Albian, and its peak of abundance of nearly 20% was reached in the *daviesi* Subzone. After this time, *Hamites* declined rapidly in abundance, and continued as a rarity to the top of the interval studied.

(c) The earliest of the Anisoceratidae appeared soon after *Hamites*, and the earliest genus (*Protanisoceras*) was locally abundant in Lower Albian strata. The Anisoceratidae then only appeared as rarities through the Mid Albian, when the family was largely restricted to more southerly regions. However, it diversified in the late part of the Albian, and in the *fallax* and *perinflata* Subzones, *Anisoceras* and *Idiohamites* may each comprise nearly 10% of the assemblage.

(d) The typically Cenomanian families, the Baculitidae and Scaphitidae, evolved in the late part of the Albian, but only occur as rarities across most parts of the basin. They may be locally abundant in glauconitic and phosphatic beds in the Upper Greensand Formation of Dorset, and in the phosphatic remanié at the base of the Cambridge Greensand Formation to the north of the London Platform.

8.3 LATERAL ABUNDANCE CHANGES

In the Aptian, lateral facies changes occurred very rapidly, but ammonites are particularly uncommon. Occasional scattered records have been collected from the Lower Greensand Group that is developed outside of the Channel Basin, but only in the Atherfield section (Chale Bay) has a statistically viable assemblage been collected. The more basinal, and typically more argillaceous, facies of the Atherfield section contains both the greatest diversities and abundances of ammonites; the relative abundances of the cosmopolitan taxa and heteromorphs appear to be greater in this section than in any other locality of the Anglo-Paris Basin from the base of the *obsoletus* Subzone to the end of the *gracile* Subzone (Casey 1960-1980).

Above the gracile Subzone, a change towards a more estuarine facies in the Channel Basin led to the disappearance of many of the ammonites from the area. Although actual abundances are low at all localities of the Anglo-Paris Basin during the Parahoplitid Diversity Zone, the greatest collections have been made from the transgressive deposits in the centre of the Weald Basin (Surrey) and in the Bedfordshire Straits during the *nutfieldiensis* Zone. Higher in the same diversity zone, species of *Hypacanthoplites* were recorded from the glauconitic silts and clays that are developed in the basal part of the Folkestone Formation of Kent and the Boulonnais (*anglicus* Subzone), and then again briefly in the silty clays of Surrey, where the hoplitid *Farnhamia* also occurred (*farnhamensis* Subzone). In sandy deposits that are developed elsewhere, the beds are typically barren of ammonites.

The sudden deepening of the seas in the upper part of the tardefurcata Zone (regularis Subzone)

saw the sudden return to more fossiliferous beds as clay facies began to develop in parts of the Anglo-Paris Basin. Still, there are few remaining localities from which *regularis* Subzone ammonites can be collected, and the lateral distributions cannot be plotted. However, the exposure of fossiliferous beds in the following *mammillatum* Zone at several localities allows this analysis to be undertaken. Collections have also been made from different areas in the zones that followed, and the lateral distribution of ammonites has been plotted for as many of the subzones as possible.

8.3.1 The mammillatum Zone, Fig. 8.12.

There are often difficulties encountered with the subzonal division of the *mammillatum* Zone in areas of the basin, and several phases of transgression and regression may be incorporated into condensed phosphatic nodule beds. The lateral distribution of fauna is, therefore, plotted for the entire zone. Differences in the assemblage may in some cases be partly due to vertical changes rather than lateral differences between areas. However, it is known that the bulk of the ammonites from Westerham and Addington/Borough Green are from the *floridum* Subzone, whilst the *raulinianus* and *puzosianus* Subzone are rather poorly fossiliferous. At Folkestone, the three subzones are condensed into a single bed, but it is probably safe to assume that again, the majority of ammonites are from the *floridum* Subzone. The ammonites from Bedfordshire have, however, been collected predominantly from the *kitchini* Subzone, with some rare *floridum* Subzone elements incorporated. It is with this section, therefore, that some vertical difference is assumed.

Folkestone: The deposits of the upper part of the mammillatum Zone are condensed into the 'Main Mammillatum Bed' (Casey 1961; Owen 1992). Fossiliferous nodules are set within a coarse yellow sand. Most striking about the fauna in this bed is the predominance of *Douvilleiceras* over all other ammonite genera, and when combined with *Beudanticeras*, the cosmopolitan taxa comprise over 90% of the total fauna. Hoplitids, although diverse in terms of number of species, only comprise 5.5% of the assemblage, and the heteromorphs only 4%. Other genera, recorded by Casey (1961; 1959-1980), have not been collected by the writer and are considered to represent very rare accessories to the overall assemblage.



Figure 8.12. The lateral distribution of ammonite genera in the mammillatum Zone, with palaeogeography and lithofacies.

Addington: The mammillatum Zone deposits are more expanded in the pit at Addington, and the individual subzones are represented within separate phosphate nodule beds. However, although the lower part of the zone, particularly the *floridum* Subzone, is highly fossiliferous, the upper parts only contain very rare ammonites. The mammillatum Zone is represented within a predominantly argillaceous facies, but this can become very sandy at certain levels. In these beds, *Douvilleiceras* is still the dominant ammonite, but *Beudanticeras* is more abundant than at Folkestone. The endemic genera, *Sonneratia* and *Cleoniceras* are also more abundant, here comprising 12% of the total assemblage, but heteromorphs remain a rare accessory element.

Westerham: The most uncondensed deposits of the mammillatum Zone occur at Squerryes Main Pit at Westerham. Here, the sediments are within a predominantly argillaceous facies, but again most of the fauna has been collected from the lower part of the mammillatum Zone. Most striking about the fossil assemblage in this part of Kent is the predominance of the smooth-shelled desmoceratid genus *Beudanticeras* over the highly ornamented *Douvilleiceras*. However, it is these two genera again that dominate over all others, and make up 75% of the fauna. Also significant in these beds is the abundance of heteromorphs; *Protanisoceras* makes up 14% of the assemblage.

Bedfordshire: In the silty clays of the Bedfordshire *mammillatum* Zone, *Beudanticeras* is even more highly abundant over *Douvilleiceras*, and the two genera together comprise 96% of the total assemblage. The heteromorph ammonites appear to have totally avoided the Bedfordshire region during the *mammillatum* Zone.

Interpretation: Douvilleiceras, although abundant at all localities during the mammillatum Zone, is most important in areas in which a sandy facies was developed. On the other hand, *Beudanticeras* became more important in the more argillaceous deposits that are found at the base of the Gault Formation. Heteromorphs also seem to have preferred the clayey facies of the northern Weald, but did not appear in the marginal deposits of the Bedfordshire Straits during the interval. The rapidly evolving endemic fauna only occurred as a minor element in the strata that was characterised by a cosmopolitan fauna, although it appeared to have been locally more abundant in the more argillaceous of the facies; *Sonneratia* was most abundant in Bedfordshire and Westerham, and declined south-eastward to Folkestone. The overall diversity of the faunal spectra is, however, greatest at Folkestone and it declines to the north, through the Weald to Bedfordshire.



Figure 8.13. The lateral distribution of ammonite genera in the dentatus Subzone, with palaeogeography and lithofacies.

8.3.2 The dentatus Zone

Unfortunately successions at the base of the Middle Albian are generally unfossiliferous and the lateral changes in assemblages cannot be plotted. Ammonite diversities are known to be low in the *steinmanni* Subzone, which frequently yields only specimens of *Hoplites (Isohoplites)*. The next subzone of the Middle Albian is frequently unfossiliferous and condensed; in the eastern part of the Weald, only rare examples of *Protanisoceras* and *Hoplites* prove that the *lyelli* Subzone is present. At Westerham, a more diverse fauna has been collected, including an important assemblage of Tethyan ammonites. The most abundant *lyelli* Subzone fauna was recorded from the relatively uncondensed sediments of Small Dole, Sussex (Owen 1971). Here, dark grey clays alternate with lighter, fawn-grey clay. The fossil assemblages are noted to change between the darker and lighter bands, with hoplitinid ammonites dominating in the dark, and lyelliceratids most significant in the lighter bands.

The *dentatus* Subzone contains almost only endemic ammonites (Fig. 8.13). The nodule bed at the base of the subzone at Folkestone has yielded phosphatised examples of *Hoplites*, which occurs alongside the geographically widespread heteromorph ammonites (*Hamites* and *Protanisoceras*). Owen (1971) lists a fauna including the brancoceratids *Oxytropidoceras* and *Mojsisovicsia*; these genera are extremely rare and may represent a remanié of the underlying *lyelli* Subzone. Above the basal nodule bed, only *Hoplites* has been collected from Folkestone, whilst in Sussex, only 6 specimens of *Hamites* have been collected amongst the 492 specimens of *Hoplites* from the Rock Common Quarry at Washington. Although only 17 specimens have been collected from Courcelles in the Aube, the heteromorphs appear to be more abundant at this locality than in the Weald (comprising nearly 12% of the spectrum). In the other sections where a *dentatus* Subzone fauna has been collected, only specimens of *Hoplites* have been found (Westerham, Kent; Chamberlain's Barn and Munday's Hill, Bedfordshire; and Wissant, Boulonnais).

Interpretation: The steinmanni Subzone is unfossiliferous and poorly represented in a generally glauconitic, argillaceous facies. The fauna is very restricted, consisting predominantly of transitional forms of ammonite between the Early Albian Sonneratiinae and Mid Albian Hoplitinae. The Beudanticeratinae and Douvilleiceratinae persisted, but were less abundant than in the *mammillatum* Zone deposits. As deeper-water conditions developed in the *lyelli* Subzone, the Lyelliceratidae evolved rapidly, and at times this family became dominant. It was not until the transgression at the base of the *dentatus* Subzone that less condensed, and more widely distributed, clays were deposited. The endemic fauna proliferated, whilst the Tethyan ammonites

disappeared from the Anglo-Paris Basin. The ammonite assemblages became almost identical across the basin as clays blanketed the area. The heteromorphs, however, appear to be more or less confined to the deeper water areas of the Anglo-Paris Basin.

8.3.3 The loricatus Zone

(i) The intermedius Subzone, Fig. 8.14.

Folkestone: The intermedius Subzone of Folkestone contains a more diverse fauna than found in the dentatus Subzone below. The evolution of Anahoplites from Hoplites defines the base of the subzone, and it is this latter genus that dominates in the assemblage. The first species of Dimorphoplites appeared towards the top of the subzone, but only comprised 2.61% of the assemblage at Folkestone. Heteromorphs were relatively rare, and no brancoceratids appear in my collection. The Aconeceratidae made a short-lived appearance in this subzone, represented by Falciferella (Owen 1971).

Wissant: Collection from the *intermedius* Subzone at Wissant was less intensive than that of Folkestone, and the beds were not particularly well-exposed. However, in the limited data set, a similar assemblage structure to that of Folkestone was recorded. The main difference between the two areas was the increased importance of *Dimorphoplites* at Wissant (nearly 10%), whilst the heteromorphs (*Hamites*) were less common.

Bedfordshire: The *intermedius* Subzone sediments of Bedfordshire only carry a highly restricted fauna. Owen (1972) suggested that the lack of specimens may be due to the chemical conditions leading to their dissolution. Not only is the frequency of ammonites low, but so is the diversity and in the seven specimens recorded from this area, only *Anahoplites* is present.

Interpretation: Clay sedimentation continued in the *intermedius* Subzone, and the area of deposition may have extended as the seas deepened. The lack of competition from southern faunas allowed for the evolution of the Hoplitinae, which spread across southern England and northern France. The more condensed sediments of Wissant appear to have developed in a slightly shallower-water environment than at Folkestone, and the abundance of the heteromorphs is lower in northern France. The seas were shallower still in the Bedfordshire Straits, and the diversity of genera is far less than in the areas further south.



Figure 8.14. The lateral distribution of ammonite genera in the intermedius Subzone, with palaeogeography and lithofacies.

(ii) The niobe Subzone, Fig. 8.15.

Folkestone: Dimorphoplites became more abundant in the niobe Subzone, whilst the already well-established Anahoplites declined. The first records of Euhoplites in my collection occur in this subzone. This genus probably evolved in the previous subzone but only occurred as a minority (Owen 1971). Hamites remained from the intermedius Subzone below and increased in relative abundance.

Wissant: The relative abundances of *Euhoplites* and *Hamites* are almost identical to those recorded from Folkestone to the north. However, *Dimorphoplites* is more abundant at Wissant, and this is at the expense of *Anahoplites*.

Bedfordshire: The *niobe* Subzone is poorly fossiliferous at Bedfordshire, although more ammonites have been yielded from the clays than from the subzone below. *Anahoplites* is the dominant genus here, although records of *Dimorphoplites* and *Euhoplites* also exist.

Interpretation: The Hoplitinae remained dominant as shelf mud deposition persisted. The greatest relative abundance of Anahoplites was in the Bedfordshire region, where it continued from the subzone below. The abundance of the later hoplitinid genera increased southward into the deeper-water environments of southern England and northern France. It was in these areas that the heteromorphs were also important, yet they still avoided the shallow waters to the north of the London Platform.

(iii) The subdelaruei Subzone, Fig. 8.16.

Faunal spectra from the *subdelaruei* Subzone are only plotted for Folkestone and Wissant, outside of these areas the sediments have often been removed as a result of the earliest Late Albian erosion.

Folkestone: The abundance of *Euhoplites* increased during the *subdelaruei* Subzone, whilst that of *Dimorphoplites* and *Anahoplites* declined. Each of the individual hoplitinid genera make up almost equal proportions, and appear to have existed comfortably with one another. Heteromorphs continued, with *Hamites* comprising almost 10% of the assemblage. An incursion of the brancoceratid genus *Mojsisovicsia* in this subzone is represented in under 6% of the spectrum.



Figure 8.15. The lateral distribution of ammonite genera in the niobe Subzone, with palaeogeography and lithofacies.



Figure 8.16. The lateral distribution of ammonite genera in the subdelaruei Subzone, with palaeogeography and lithofacies.

Wissant: The abundances of the individual hoplitinid genera are very similar to those of Folkestone, although *Dimorphoplites* still comprises the largest proportion of the assemblage. The brancoceratid and heteromorph ammonites are an important, yet minority, feature of the faunal spectrum.

Interpretation: The presence of relatively high sea-level during the *subdelaruei* Subzone produced assemblages that remained similar across the present day English Channel. The effects of the Brabant Landmass, that appears to have influenced the distribution of the heteromorphs, were apparently reduced during this period. The higher sea-levels at this time also allowed for a significant influx of Tethyan ammonites for the first time in the Middle Albian.

8.3.4 The lautus Zone

Sediments of the *lautus* Zone are of very restricted occurrence in the Anglo-Paris Basin, due to erosion at the start of the Upper Albian. In marginal parts of the basin, and in the Bedfordshire Straits, the *lautus* Zone and upper part of the *loricatus* Zone have been removed. It is at Folkestone that the fullest development of the *lautus* is recorded, and even here, the topmost part of the *daviesi* Subzone is presumed to be missing.

(i) The nitidus Subzone, Fig. 8.17.

Folkestone: The hoplitid ammonites from the *nitidus* Subzone show very little change in abundance from the subzone below. However, this disguises the fact that important faunal turnovers occurred at the base of this subzone. New species of both *Euhoplites* and *Dimorphoplites* appeared in this subzone, whilst species of *Anahoplites* remained relatively unaltered. These well-established ammonites attained a slightly greater relative abundance than in the subzone below. Heteromorphs increased in abundance, and comprise about 12% of the assemblage.

Wissant: The faunal turnover in the hoplitinid species is better illustrated by the relative abundances of the ammonites at Wissant. In this section, *Anahoplites* returned to being the dominant genus, whilst *Dimorphoplites* declined significantly. The heteromorphs also declined, from about 10% in the subzone below, to just above 3% during this interval.



Figure 8.17. The lateral distribution of ammonite genera in the nitidus Subzone, with palaeogeography and lithofacies.

Interpretation: Although the overall assemblages between Folkestone and Wissant continued to be represented by the same genera, the abundances of the individual genera altered significantly. The turnover of species that was prompted by TS20 is represented by differences in the assemblages between the two areas. In the slightly deeper-water region of Folkestone, the new species of *Dimorphoplites* made a greater impression on the overall assemblage than at Wissant. The regression that preceded TS20 may have increased the influence of the Brabant Landmass in the Boulonnais, and restricted the abundance of the heteromorphs.

8.3.5 The inflatum Zone

(i) The cristatum Subzone, Fig. 8.18.

Folkestone: The Hoplitidae remained dominant in the cristatum Subzone and this interval saw the evolution of Metaclavites. The brancoceratid ammonites reappeared for the first time since the subdelaruei Subzone, and these taxa had evolved significantly from their last appearance (Dipoloceras, Hysteroceras and Mortoniceras). The Desmoceratidae (Beudanticeras and Uhligella) and the Lyelliceratidae (Neophlycticeras) reappeared in this subzone, and these families had last been seen in the Early and earliest part of the Mid Albian respectively. Despite the diversity of genera, the combined contribution of the Tethyan\cosmopolitan genera only comprised 6% of the overall assemblage. The abundance of the heteromorphs fell from the subzone below.

Wissant: The proportions of each of the individual hoplitid genera at Wissant are similar to those of Folkestone, although the overall relative abundance of the family is somewhat higher at Wissant. Both the diversity and abundance of the Brancoceratidae, Lyelliceratidae and Desmoceratidae are lower than at Folkestone to the north.

Bedfordshire: In Bedfordshire, beds of the *cristatum* Subzone are presently very poorly exposed at Munday's Hill. Only a very few ammonites were collected from these levels during the present investigation, and these were represented only by specimens of *Euhoplites*. Because it is felt that the number of ammonites collected from the *cristatum* Subzone of Bedfordshire was too small to obtain any reliable abundance data, the faunal spectrum is not plotted here.



Figure 8.18. The lateral distribution of ammonite genera in the cristatum Subzone, with palaeogeography and lithofacies.

Interpretation: Transgression TS21 at the start of the *cristatum* Subzone allowed Tethyan\ cosmopolitan taxa to enter the Anglo-Paris Basin from the south. The greatest diversity of these taxa is recorded from Folkestone where fairly deep-water conditions prevailed. Wissant is believed to have lain closer to the boundary landmasses, and the abundance and diversity of the Tethyan taxa was reduced. Although the actual number of ammonites collected from Leighton Buzzard may be too low to establish a reliable faunal abundance spectrum, the area does appear to have been dominated by the hoplitinids, whilst the brancoceratids and heteromorphs may not have penetrated this far north, into the shallows of the Bedfordshire Straits.

(ii) The orbignyi Subzone, Fig. 8.19.

Folkestone: The ammonite diversity changed only slightly from the subzone below in terms of number of ammonite genera collected (increasing from 11 to 13 genera recorded), yet the relative abundances changed very significantly. The Brancoceratidae were represented by several genera, of which *Hysteroceras* was dominant. It was the heteromorph families, however, that showed the most rapid diversification during this subzone, and several new genera appeared, particularly within the Anisoceratidae (*Pseudhelicoceras, Idiohamites* and *Anisoceras*).

Wissant: A lower diversity of ammonites is recorded from Wissant. Despite this, the Brancoceratidae comprise a greater proportion of the assemblage than at Folkestone (*Hysteroceras* and *Mortoniceras* make up over 64% at Wissant, whilst these genera and *Dipoloceras* and *Prohysteroceras* comprise only about 56% of the assemblage at Folkestone). The heteromorph ammonites are, however, both less diverse and abundant at Wissant than at Folkestone.

Sevenoaks: The diversity of ammonites also declined northward of Folkestone, and only three genera have been collected from the repetitive succession of light-grey clay, punctuated by many levels of phosphatic nodules that is found at Sevenoaks. Of the three genera, the brancoceratid genus *Hysteroceras* dominates, and *Euhoplites* comprises a similar proportion of the assemblage to that seen at Folkestone. However, although the diversity of the heteromorph ammonites is low, the single genus *Anisoceras* comprises almost one third of the faunal spectrum.

Bedfordshire: The decline of ammonite diversity continued northwards, and in the Bedfordshire Straits only a very few genera are recorded. At Munday's Hill, near Leighton Buzzard, *Euhoplites* was the dominant genus, and the brancoceratid *Hysteroceras* only appeared as a minority element. No heteromorphs have been collected from the *orbignyi* Subzone here.



Figure 8.19. The lateral distribution of ammonite genera in the orbignyi Subzone, with palaeogeography and lithofacies.

Interpretation: The deepest water environments would have been in the Weald Basin, and the greatest diversity of genera at Folkestone indicates this. It is surprising that the beds at Sevenoaks should yield such a restricted fauna. However, this area lay close to the westernmost margin of development of the Upper Albian Gault Formation. Later in the Late Albian, the shallow-water Upper Greensand Formation extended into areas just to the west of this locality. This development was progressive, and foreshadowed by the development of silty clays in the lower levels of the Gault Formation. The strata laid down near to Sevenoaks, therefore, may have been deposited in shallower-waters than those of Folkestone during the *orbignyi* Subzone. The dominance of the heteromorphs in this area occurs in a facies that contains many levels of phosphatic nodules; it is in these beds that heteromorphs are consistently more common than those that are found crushed in clay. Leighton Buzzard, in Bedfordshire, lay in shallows close to the margin of Gault Formation deposition, and this limited the ammonite distributions. Links with areas to the south of the London Platform certainly existed, but the seas may have shallowed considerably across the ancient massif, and this limited the northward spread of the Brancoceratidae.

(iii) The varicosum Subzone, Fig. 8.20.

Folkestone: No specimens of Anahoplites persisted into the varicosum Subzone. Although Metaclavites continued, the hoplitid ammonites were dominated by Euhoplites and Epihoplites, and the family comprised about 26% of the total assemblage. The Brancoceratidae continued to dominate the spectrum, and several of the later genera increased in relative abundance, particularly Prohysteroceras and Mortoniceras. The various anisoceratid heteromorphs continued to proliferate, and increased in relative abundance from the subzone below.

Wissant: The assemblage in the *varicosum* Subzone of Wissant remained virtually unaltered from the subzone below, with the brancoceratid genera *Hysteroceras* and *Mortoniceras* dominating, and the hoplitids comprising under one third of the faunal spectrum. The heteromorphs only comprised about 3% of the assemblage during this interval.

Bedfordshire: The faunal spectrum is dominated by *Euhoplites*, which comprises over 56% of the total assemblage. However, the Brancoceratidae infiltrated the area north of the London Platform in numbers for the first time in the Late Albian, and the combined contribution of *Hysteroceras*, *Prohysteroceras* and *Mortoniceras* reached almost 37%. The heteromorph ammonites also appeared during this interval, and contributed to over 5% of the assemblage.



Figure 8.20. The lateral distribution of ammonite genera in the varicosum Subzone, with palaeogeography and lithofacies.

Interpretation: The continued deepening of the seas allowed the ammonite distributions to level out across the basin. Although the greatest diversity of ammonites still occurred at Folkestone, the differences between this section and Wissant were smaller than they had been during the earlier subzones. The further retreat of the landmasses during the interval allowed the brancoceratids and heteromorphs to spread more widely into Bedfordshire than had previously been allowed.

(iv) The inflatum Subzone, Fig. 8.21.

Folkestone: The Hoplitidae decreased in abundance during the *inflatum* Subzone, although the family diversified to give rise to several late genera. The abundances of the individual brancoceratid genera evened out somewhat, although it was *Prohysteroceras* that was the dominant genus. *Hamites* persisted into this subzone, but it was very much in a minority to the Anisoceratidae.

Wissant: The ammonite diversity decreased southward to Wissant. In this section the Hoplitidae were reduced to two genera (*Epihoplites* and *Callihoplites*), that comprised under 16% of the faunal spectrum. The Brancoceratidae were also represented by only two genera (*Mortoniceras* and *Prohysteroceras*) and these made up the remaining 84% of the assemblage. No heteromorphs have been recovered from the section at Wissant.

Interpretation: There appears to have been a considerable shallowing of the seas prior to the deposition of clays in the *inflatum* Subzone. This reduced the diversity and numbers of ammonites in both the Folkestone and Wissant sections. The alteration to the environment prompted the evolution of late forms of the Hoplitidae. However, the Brancoceratidae were well-established and continued to dominate in both areas. The heteromorphs, however, appear to have avoided the shallower seas that developed in the Boulonnais.

8.3.6 The dispar Zone

The clays of the *dispar* Zone at Folkestone contain only scarce ammonites. The assemblage continued to be dominated by the Brancoceratidae, and several evolutionary developments occurred within this family, whilst the Hoplitidae continued to decline. This decline in abundance was when diversification occurred, but with the evolution of unsuccessful end-forms.



Figure 8.21. The lateral distribution of ammonite genera in the inflatum Subzone, with palaeogeography and lithofacies.

Many of the collections of ammonites from the upper part of the Albian have been from the Upper Greensand Formation of Dorset and Cambridge Greensand Formation of Cambridgeshire. The paucity of exposure of fossiliferous Upper Greensand Formation has prevented a statistically viable collection from these beds. However, where the topmost part of the Upper Albian is preserved in a clay facies, ammonites are exceedingly rare, while in the calcareous sand of the Upper Greensand Formation, they are far better represented though still uncommon. The fauna is dominated by a cosmopolitan assemblage, comprising the lyelliceratid genus *Stoliczkaia*, and the brancoceratid genus *Mortoniceras*. It was suggested by Amedro (1992) that this cosmopolitan fauna may constitute up to 70% of the assemblage during the *dispar* Zone in the Upper Greensand Formation developed near to Mertsham in Surrey. The hoplitids are represented by a diverse assemblage of turrilitids, scaphitids, and baculitids, that continued to characterise the Upper Cretaceous.

8.4 SUMMARY AND CONCLUSIONS

A definite link between ammonite diversities and abundance data exists. The problems relating to the unusually high diversities recognised in the earlier chapter can be clarified by the examination of faunal abundance spectra. The diversity zones closely tie in with these abundance data, which can then be analyzed in terms of sea-level changes. The relationship between the abundances, diversity zones and the sea-level events is shown in Figure 8.22. This figure shows the abundances of the different biogeographic groupings of the ammonites through the Aptian and Albian. The non-heteromorph Tethyan/cosmopolitan ammonites are grouped together, whilst the heteromorphs are plotted separately despite them also being geographically widespread.

Figure 8.22 clearly displays the two main developments of both the endemic and heteromorph ammonites. Tethyan\cosmopolitan taxa were present through much of the Aptian and Albian. The relative abundance of the individual elements varies considerably with the changes of sea-level.

The first period of endemic ammonite evolution corresponds to the Deshayesitid Diversity Zone and extends into the lower part of the Cheloniceratinid Diversity Zone. In the later period, the endemic taxa were gradually outnumbered by more geographically widespread ammonites as the environmental conditions worsened. Heteromorphs became locally abundant.



Figure 8.22. A correlation between the biogeographic distribution of ammonites, diversity zones and sequence stratigraphy.

An extended period of regression led to the disappearance of most of the ammonites from the Anglo-Paris Basin. When transgression restored marine conditions to many marginal areas, and opened up links with northern basins via the Bedfordshire Straits there were few ammonites remaining to then take hold in the newly created ecological niches. Although sea-level was rising during the *subarcticum* Subzone, many of the areas of the Anglo-Paris Basin formed a very shallow-water environment. The facies are indicative of an estuarine or marginal environment, in which the extreme conditions were unfavourable to both the evolution and preservation of ammonites. During this time only cosmopolitan ammonites existed, that did not seem to be bound by environmental factors, but these could not really take a hold in the basin. This is the interval represented by the Parahoplitid Diversity Zone.

A second endemic development commenced in the lower part of the Albian, in the Douvilleiceratinid Diversity Zone, when sea-levels began to rise more rapidly. The steady deepening of the seas of the Anglo-Paris Basin allowed taxa that were derived from a Tethyan root to enter the Anglo-Paris Basin and then evolve separately. Other geographically widespread forms also entered as sea-levels rose and these well-developed forms filled most of the ecological niches. However, conditions were continuously changing as sea-level fluctuated, and the evolution of the endemic taxa showed various changes to adapt to the environment.

The endemic taxa started to dominate over the cosmopolitan taxa in the Hoplitid Diversity Zone. A brief incursion of the Tethyan genus *Lyelliceras* occurred early in the Mid Albian; it evolved alongside the hoplitids and became most abundant. However, this evolution was short-lived, and the installation of palaeoceanographic barriers in the lower part of the Middle Albian allowed proliferation of the endemic fauna. This situation remained through the remaining part of the Hoplitid Diversity Zone. All the typical genera had evolved by the *niobe* Subzone; the endemic fauna stabilized following the earlier burst of evolutionary activity, and competition between the taxa was reduced.

The removal of the barriers to migration in the later part of the Albian allowed for the reappearance of Tethyan ammonites that had evolved outside the Anglo-Paris Basin, and this marked the start of the Brancoceratid Diversity Zone. The links with Tethys became stronger as sea-levels stepped upwards, and the Tethyan ammonites soon became both diverse and abundant as they began to evolve within the Anglo-Paris Basin.

On a smaller scale, the differences in abundance of the different genera at selected points from around the basin reflect the differences in water-depth and energy conditions that existed between areas. Periods of high sea-level are reflected by the homogenization of the distributions, whilst greater differences between the assemblages existed when the relative sea-level was lower. Structural highs, particularly the Anglo-Brabant Massif, played an important role in influencing the ammonite distributions, even when they had been largely transgressed by the Gault sea. The Anglo-Brabant Massif provided a barrier between the Weald Basin and the Bedfordshire Straits, halting first the northward progression of the heteromorphs and then the brancoceratids. However, rising sea-levels through the upper part of the Albian (*varicosum* Subzone) reduced the effects of the massif significantly and allowed the freer movement of ammonites from the south to the north.

The effects of the same massif were also seen to a more limited extent between Folkestone and Wissant. These two areas almost certainly enjoyed open connections with one another, yet the diversity of ammonites in the Boulonnais was consistently lower than seen across the present day English Channel at Folkestone. It is assumed that Wissant lay closer to the Brabant Landmass than Folkestone, and within an embayment created by the Artois Axis. This effectively reduced the diversity of genera, although frequently very similar familial abundances are recognised. Few data exist for the poorly exposed Albian sections of the Aube, but the published records suggest that this area should display abundances similar to, although more diverse than, those seen at Folkestone (e.g. Colette *et al.* 1982).

CHAPTER 9. CONCLUDING DISCUSSION

9.1. STRATIGRAPHICAL CONCLUSIONS

The correlation of Lower Greensand Group strata is dependent upon poorly fossiliferous deposits and some mistakes have been made using the assumption that lithostratigraphical and biostratigraphical units are coincident. Both the frameworks have been revised for the Aptian and Albian, and new measurements and ammonite records have been documented (Chapters 3, 4 and 5). The examination of the individual lithological units within a sequence stratigraphical framework, has allowed the definition of genetically related packages of strata. By combining the sequence stratigraphical approach with lithostratigraphical and biostratigraphical methods, strata have been accurately correlated around the basin (Chapter 6). In using this sequence stratigraphical approach, I have determined a basin-wide succession of events for the whole of the Aptian and Albian, and this comprises 23 transgressive surfaces and 11 sequences (Table 6.2, Fig. 6.17).

The sequence stratigraphical methods that have been employed to examine sea-level changes in the Anglo-Paris Basin show that the shelf environment was characterised by short-term transgressive episodes. Coarsening upward cyclicity suggests that each rapid transgression is followed by an interval of slower sea-level rise, standstill or fall. Although other interpretations of the cause of sedimentary cyclicity may exist, such as climate change and local tectonics (as well as alternative sea-level histories), the significant faunal turnovers associated with the transgressive surfaces suggests that these are the product of at least regional sea-level change. Examination of faunal evidence from other parts of the geological column (e.g. House 1993) show that similar events have occurred through time. Likewise, the widest geographic spreads of taxa tend to be associated with these transgressive surfaces.

In the upper part of the Aptian and lower Albian, the best place to examine the larger-scale sealevel events has proved to be in the Leighton Buzzard area in the Bedfordshire Straits. By utilising the combined approaches of lithostratigraphy, biostratigraphy, and sequence stratigraphy, I have established a sequence of events and in doing so have modified the lithological succession there, which has been misinterpreted in recent published accounts (e.g. Eyers 1990; 1992). The Chamberlain's Barn Member ('Red Sands') has been recorded as pre-dating the major *regularis* Subzone erosion surface (TS14) in previous studies. However, there is strong evidence to suggest that, despite forming prior to the 'Shenley Limestone', the Chamberlain's Barn Member was deposited after the *regularis* Subzone sea-level event. A basin and swell topography then developed, leading to rapid lateral facies changes in the subsequent deposits. I propose that the sequence of events at the Lower Greensand Group to Gault Formation junction is as follows (Fig. 9.1):

(i) The Stone Lane, Heath and Reach and Munday's Hill Members developed to a greater or lesser extent across the region, and these beds were deposited prior to the earliest part of the *regularis* Subzone.

(ii) In the earliest part of the *regularis* Subzone, a phase of erosion occurred, that is equivalent to Casey's (1961) 'mid-*tardefurcata* Zone tectonics'. This formed a strong erosion surface, which cut down into the earlier members and removed them to varying degrees. The Munday's Hill Member and a large part of the Heath and Reach Member were removed from the areas away from Shenley Hill.

(iii) The erosion surface was transgressed in the later part of the *regularis* Subzone (TS14). Red sands of the Chamberlain's Barn Member were deposited in the trough regions, representing the initial phase of rapid transgression. As the seas deepened further, a period of sediment starvation ensued in which a veneer of (Shenley) limestone developed on the swells. This limestone is partially preserved on the swell areas.

(iv) A further phase of erosion occurred prior to the deposition of the first *kitchini* Subzone sediments. This erosion maintained the basin and swell topography in the area and led to the break up of the limestones.

(v) In the *kitchini* Subzone, further transgression (TS15) occurred. The fragments of limestone were incorporated into coarse iron-cemented sands ('carstone') in the more marginal localities to form the Shenley Member, whilst Gault Formation silty clay deposition commenced in the basinal areas. In Chamberlain's Barn Quarry, rare fragments of limestone are found alongside remanié *regularis* Subzone ammonites at the base of the Gault Formation. These fragments have no surrounding "carstone" matrix and are, therefore, believed to have been swept into the trough from the surrounding swell areas prior to the commencement of the *kitchini* transgression.

(vi) A further phase of erosion at some time after the *floridum* Subzone led to a planation of the beds, and these were finally overstepped in the *dentatus* Subzone (TS18) by a less silty Gault facies that was developed across the area.



Figure 9.1. The sequence stratigraphy of the Lower Greensand Group to Gault Formation junction in the pits near to Leighton Buzzard.

9.2. AMMONITE BIOGEOGRAPHY AND THE SEA-LEVEL CURVE

Transgressive episodes across the shelf are characterised by a rapid spread of the marine biota. During the intervening periods of standstill or slow shallowing, the faunal changes are slower as gradual evolutionary developments and background extinctions occurred.

Ammonite diversities have been plotted, and comparisons made between the published records and the collected fauna (Figs. 7.1 and 7.2). By defining the levels at which the diversity showed the greatest change, I have been able to define diversity zones (Chapter 7, section 7.3). Abundance spectra plotted for individual sections allow a further detailed discussion on changes in ammonite distribution through time, and the evolutionary developments of important taxa are also considered numerically (Chapter 8, sections 8.1 and 8.2). A definite link with the sea-level events has been established.

Compilation of all the ammonite data suggests that different magnitudes of sea-level change occurred, although these are not immediately apparent from the facies changes alone (Figs. 7.15, 8.22). It is using all these data that I am able to present a sea-level curve, representing the relative changes of sea-level that occurred basin-wide (Fig. 9.2).

The most striking feature of the curve is that it is not smoothed, and is similar in character to the first 'saw-toothed' curves of the Exxon workers (Vail *et al.* 1977). However, the main difference between this curve and that of the earlier studies is that it is 'saw-toothed' in the other direction, with almost instantaneous sea-level rises as opposed to sea-level falls. This is because the transgressions in the shelf area are preceded by stratigraphic gaps, the length of which cannot be resolved. The gap is equivalent to the lowstand, or even transgressive, systems tract, which would have developed at the continental margin. If these deposits were included, it is believed that a smoother curve would result.

Because lowstand deposits are missing from the sequence, faunal turnover events are accentuated. Low diversity assemblages would have been likely in these first transgressive deposits, and the abundances of endemic genera would presumably have been high. This low diversity, predominantly endemic assemblage could have spread across the shelf as the sea-levels rose, and is associated with the first transgressive surface (low diversity and turnover sequence boundaries). When the first transgressive deposits correspond with a later flooding episode (possibly the maximum flooding surface) the diversity of the ammonites is much higher, and the relative abundances of endemic and cosmopolitan taxa vary considerably (high diversity and

SUB-BIOZONES

FAUNAL SPECTRUM ANALYSIS

SEQUENCE STRATIGRAPHY



Figure 9.2. Diversity zones, biogeographic abundances and the proposed sea-level curve.

turnover sequence boundaries). As sea-levels reached their highest points, differences between the assemblages between areas decreased and the influence of structural and topographic highs diminished.

9.3. AMMONITES AND FACIES DISTRIBUTIONS

Lateral facies changes controlled the distribution of ammonite taxa around the basin. Particular genera favoured certain facies, and ammonite distributions varied considerably over what is, in global terms, a very limited geographic area. Most interestingly, there is an apparent facies control on the distribution of some of the cosmopolitan taxa (such as the desmoceratids, douvilleiceratids and heteromorphs). Although these ammonites are believed to have occupied a wide range of ecological niches throughout the world, they still appear to be somewhat limited by facies. In the Early Albian, both the Douvilleiceratidae and Desmoceratidae dominated in the assemblage (Chapter 8). However, despite their ubiquitous distribution through the basin, the smooth-shelled desmoceratids preferred quieter conditions and are abundant in argillaceous facies, whilst the douvilleiceratids were more common in higher-energy sandy facies (section 8.3). For much of their range, the heteromorphs were most diverse and abundant in the transgressive beds in the more basinal regions (sections 7.4 and 8.3).

It is believed that the ammonites led a predominantly nekto-benthonic mode of life, and this would explain the dependence on facies of many forms (Lehmann 1981). Changes in environmental conditions, that are demonstrated by facies changes, prompted the evolution and developments of certain taxa (section 8.2). This link between the environment and evolution is best demonstrated by the endemic ammonites which developed in two definite intervals (Fig. 9.2). Both these periods of evolution occurred, at least initially, whilst a clay facies was predominant. The facies represent quiet shelf environments in which low energy conditions persisted. During the extended periods of clay sedimentation, the endemic fauna evolved rapidly and was often the most abundant. The generic diversity within the endemic forms may have been low, but the number of both species and individuals was always high.

The first endemic development was within the deshayesitids in the Lower Aptian Atherfield Formation. However, links with other faunal provinces appear to have existed throughout the Aptian, and geographically widespread taxa also occurred alongside the restricted ammonites. As conditions deteriorated, the diversities and abundances of the cosmopolitan ammonites increased. Although these geographically widespread ammonites were still dependent on facies, their distributions were not confined to the same extent as the endemic forms, and became more
abundant as sea-levels fell. The return of shelf mud deposition in the Albian allowed the Hoplitidae to evolve, whilst the presence of palaeoceanographic barriers in the middle part of the stage restricted the appearance of Tethyan genera. The decline in abundance of the hoplitids in the Upper Albian was less to do with worsening environmental conditions as it was to do with competition with cosmopolitan ammonites as links with Tethys were restored.

Heteromorph ammonites also developed in two main stages. These taxa are almost always restricted to phosphatic nodule beds in the Aptian, and are more common in these types of beds in the Albian. The greatest diversification of the heteromorphs occurred in the *dispar* Zone of the Late Albian, and the new taxa are described mainly from the phosphatic and glauconitic beds from the Upper Greensand Formation, and the remanié beds at the base of the Cenomanian Cambridge Greensand Formation.

Facies not only limited the distribution of endemic versus Tethyan/cosmopolitan ammonites, but also controlled the size of the taxa. In the clay facies of the Atherfield and Gault Formations, rapidly evolving species commonly only reached a small size. However, in the more arenaceous beds of the Ferruginous Sands and Hythe Formations, the ammonites often became very large indeed. The presence of the very large adults and the almost total absence of juveniles in this facies suggests that throughout the whole of the Aptian and Albian at least, different ecological conditions were required by the ammonites at various stages of growth. Juvenile and small species were established in the deeper water environments, whilst large adult varieties were dominant in higher energy settings. The lack of competition faced by some of the Aptian genera may have accounted for their great size. However, these taxa are generally restricted to the transgressive beds within a succession; the sudden deepening of the seas would have allowed the adult forms to temporarily invade the shelf, whilst the juveniles remained further out to sea.

9.4. COMPARISON OF AMMONITE DISTRIBUTIONS WITH CALCAREOUS NANNOFOSSILS

The distribution patterns seen in the Aptian and Albian ammonites may be compared with those of other fossil groups, to establish whether similar distributions occur. Little work has been done in the poorly fossiliferous Lower Greensand Group, where the other fossil groups are frequently as limited as the ammonites. However, the Gault Formation, being preserved in a predominantly clay facies, has been studied for the distribution of several fossil groups, and particularly interesting are the relative abundances of the calcareous nannofossils. Recent studies have examined the palaeogeographical affinities of the planktonic microfauna, and these have shown

a good correspondence with the ammonite distributions. In these studies, the varying abundances of high latitude (cool-water) and low latitude (warm-water) species have been examined.

A recent study of the biogeographical distributions of calcareous nannofossils by Crux (1991) at Munday's Hill in Bedfordshire has revealed that high latitude species, such as Repagulum parvidentatum, Seribiscutum primitivum and S. matalosus, had their greatest relative abundance during the Middle Albian (dentatus to niobe Subzones). Those nannofossils that preferred low latitudes, such as Rhagodiscus achlyostaurion, R. asper and R. splendens, despite always being in a minority, were most abundant in the topmost part of the *niobe* Subzone, topmost *cristatum*, the orbignyi and varicosum Subzones. They showed a decline in the upper part of the Munday's Hill succession, this perhaps belonging to the inflatum Subzone (Crux 1991). Erba et al. (1989) recognised that R. parvidentatum decreased in abundance in the orbignyi Subzone in the Folkestone area, whilst an equivalent decrease did not occur until the varicosum Subzone in Bedfordshire (Crux 1991). The latter author suggested that the decrease was diachronous, occurring first at lower latitudes. This same pattern is recognised within the ammonite fauna, which diversified one subzone later in Bedfordshire than in southern England and northern France, although open-water connections between the areas is revealed by the presence of rare cosmopolitan genera. It has been suggested by Erba et al. (1987) that a transgressive episode in the early part of the Late Albian displaced Arctic water-masses. The effect of this water displacement occurred first in southern England and then later in Bedfordshire.

9.6. SUGGESTIONS FOR FUTURE WORK

The ammonite database allows a good statistical analysis to be undertaken for some stratigraphical levels. However, there is a marked lack of data from beds in the upper part of the Aptian and lowest Albian, where abundances are very poorly known, whilst the whole Aptian requires further examination to establish lateral changes in relative abundance.

The Lower Greensand Group is poorly exposed at the present time, and the investigations have been limited to the few localities in which these strata can still be seen. As the outcrop is discontinuous, certain assumptions have been made, although these are backed up by published accounts. Quarrying operations will probably never be as extensive as earlier in this century, reflecting increasing use of synthetic materials. However, the development of roads seems to be a long-term factor. Most particularly, the widening operations of the M25 Motorway are already beginning to open up fresh sections through Lower Cretaceous sections of the Weald. These cuttings may provide evidence to confirm, or otherwise, the interpretations put forward in this study.

The events recorded are all from the shelf deposits of the Anglo-Paris Basin. With a more extended study, into the Mediterranean Province and beyond, global events can be sought out, and long-range migrations of ammonites established. A global database can observe the changes of ammonite assemblages in terms of sea-level change and study more sufficiently the relationship to environment.

An interesting feature of the ammonite assemblages of the Anglo-Paris Basin is the distribution of the heteromorphs. A detailed study of the dispersal of these forms through time and space is required. This could link their complicated coiling, disjunct distributions and evolution to environmental conditions.

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PLATES

EXPLANATION OF PLATE I

Fig. 1. *Tropaeum bowerbanki* (Sowerby), Ferruginous Sands Formation (Lower Crioceras Member, Bed 5), Chale Bay, Isle of Wight (*transitoria* Subzone, Cheloniceratinid Diversity Zone). Dn 3437 (Author's colln). x 0.36.

Fig. 2. *Hamites cf. intermedius* (Sowerby), Gault Formation (East Wear Bay Member, Bed 2), Folkestone, Kent (*cristatum* Subzone, Brancoceratid Diversity Zone). Dn 1391 (Author's colln). x 1.

Fig. 3. *Idiohamites tuberculatus* (Sowerby), Gault Formation, (East Wear Bay Member, Bed 4) Folkestone, Kent (*orbignyi* Subzone, Brancoceratid Diversity Zone). Dn 3412 (Author's colln). x 1.



PLATE I

EXPLANATION OF PLATE II

Fig. 1. Tropaeum bowerbanki, details as Plate I, Fig. 1, portion natural size.

PLATE II



EXPLANATION OF PLATE III

Fig. 1. *Deshayesites grandis* (Spath), Ferruginous Sands Formation (Small Ledge Member), Chale Bay, Isle of Wight (*grandis* Subzone, Cheloniceratinid Diversity Zone). W.H. Fitton Colln. GSM 85907. x 0.57 (from Casey 1960-1980).





EXPLANATION OF PLATE IV

Fig. 1. *Dufrenoyia* sp. (Burckhardt), incomplete body chamber (a) side, (b) venter, Ferruginous Sands Formation (Brown's Down Member, Bed 1), Chale Bay, Isle of Wight (*transitoria* Subzone, Cheloniceratinid Diversity Zone). Dn 3429 (Author's colln). x 1.

Fig. 2. Parahoplites cunningtoni (Casey) Holotype, Iron Sands (Faringdon Formation), Seend, Wiltshire (cunningtoni Subzone, Parahoplitid Diversity Zone). E.C. Davey Colln. OUM. K184 (from Casey 1960-1980).

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EXPLANATION OF PLATE V

Fig. 1. *Cheloniceras (Cheloniceras) cornuelianum* (d'Orbigny), Hythe Formation, Hythe, Kent (Cheloniceratinid Diversity Zone). Casey Colln. GSM. Zm 2231. x 1 (from Casey 1960-1980).

Fig. 2. Cheloniceras (Epicheloniceras) martinioides (Casey), Ferruginous Sands Formation (Ladder Chine Member, Bed 3), Chale Bay, Isle of Wight (gracile Subzone, Cheloniceratinid Diversity Zone). Dn 4319 (Author's Colln). x 1.

Fig. 3. *Douvilleiceras mammillatum*, (Casey). Folkestone Formation (Main mammillatum Bed, Bed 27), Folkestone, Kent (*mammillatum* Zone, Douvilleiceratinid Diversity Zone). Dn 2987 (Author's colln). x 1.

Fig. 4. Beudanticeras newtoni (Casey), Gault Formation (Copt Point Member, Bed 2), Chamberlain's Barn, Bedfordshirë (kitchini Subzone, Douvilleiceratinid Diversity Zone). Dn 70 (Author's colln). x 1.

Fig. 5. Anahoplites planus (Mantell), Gault Formation (Copt Point Member, Bed 9), Folkestone, Kent (*niobe* Subzone, Hoplitid Diversity Zone). Dn 1005 (Author's colln). x 1.

Fig. 6. *Mojsisovicsia spinulosa* (Spath), Gault Formation (Copt Point Member, Bed 11), Folkestone, Kent (*subdelaruei* Subzone, Hoplitid Diversity Zone). Dn 1361 (Author's colln). x 1.

Fig. 7. *Hysteroceras orbignyi* (Spath), Gault Formation (East Wear Bay Member, Bed 4), Folkestone, Kent (*orbignyi* Subzone, Brancoceratid Diversity Zone). Dn 1392 (Author's colln). x 1.

Fig. 8. *Stolickaia dorsetensis* (Spath), Upper Greensand Formation, White Nothe, Dorset (*fallax* Subzone, Brancoceratid Diversity Zone). Dn 497 (Author's colln). x 1.

