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The stratigraphical palaeontology of the Chalk of the South Downs - a contribution to the South Downs Memoir

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Foreword

This report describes the characteristic macrofossils and macrofossil biostratigraphy of the Chalk Group of the South Downs, based on published research and BGS surveys of Hampshire and Sussex between 1993 and the present. It is intended as a contribution to the forthcoming South Downs Memoir.

Acknowledgements

In the course of the last ten years of BGS survey work in the South Downs, C J Wood has provided much useful discussion and advice about the interpretation of Chalk macrofossils.

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This report describes the characteristic macrofossils of the Chalk Group of the South Downs in the context of the established macrofossil biozonation and Chalk Group lithostratigraphy. It summarises the results of BGS work and published literature, and gives details of localities where particular features were observed.

1 Introduction

Historically, the lack of a sophisticated lithostratigraphical classification for the Chalk Group provided great impetus to palaeontological research, in the hope that this would provide a more refined way of subdividing this broad interval. This process was hampered by the scarcity of ammonites, which usually provide the best means of biozonal classification in the Mesozoic, but which are usually poorly preserved in the Chalk. The aragonitic calcite that originally formed ammonite shells quickly broke down in the largely mud-free coccolith-rich ooze that comprises the bulk of the Chalk; only in the lower more argillaceous part of the formation (i.e. the Grey Chalk Subgroup) are their remains sufficiently abundant to be biostratigraphically useful. Instead, the evolving biozonal schemes for the Chalk made use of a variety of different fossil groups, some benthonic (e.g. echinoids, crinoids, bivalves and brachiopods) and some nektonic (e.g. ammonites and belemnites). The modern macrofossil biozonal scheme for the UK Chalk Group (Table 1) borrows many of the fossil names from the historical schemes, but their definition and interpretation is often different. This is particularly important to remember when reading old biostratigraphical accounts of the Chalk Group, since different authors defined the same zones in different ways (Table 2). More recently, as a result of painstaking collecting by many researchers, it has been possible to recognise a separate ammonite-based classification for the lower part of the White Chalk Subgroup (Table 1). The advantage of this ammonite-based scheme is that it is easier to correlate with internationally recognised biozonal schemes for the Late Cretaceous, and thus facilitate stratigraphical comparisons between widely separated successions. In addition to the macrofossil classification of the Chalk, foraminifera form the basis of a separate microfossil biozonal scheme that can be related to the standard macrofossil zones. In this way, even when outcrops are limited in size or are poorly fossiliferous, it is often possible to indirectly infer the presence of a macrofossil Zone or Subzone.

1.1 HISTORICAL DEVELOPMENT OF CHALK GROUP BIOSTRATIGRAPHY

The modern biozonal classification of the Chalk Group in the UK owes much to the early work of French geologists, and in particular Edmond Hébert and Charles Barrois. In 1863, Hébert showed that different horizons in the Chalk of northern France were characterised by different kinds of fossils, and used these observations to produce a biozonal classification scheme (Gale & Cleevely, 1989). This work was elaborated by Barrois, who in 1876 demonstrated that the macrofossil zonation established for the French Chalk could also be applied to the Chalk in England, and that these biozones could then be used to subdivide the English succession into three broad Stages, which then comprised the Cenomanian, Turonian and Senonian (Jukes-Browne & Hill, 1903). In 1899 Arthur Rowe published his famous seminal work on the evolution of the common Chalk echinoid *Micraster*, and emphasised the great practical value of evolutionary changes in the skeleton of this sea urchin for determining the biozonal assignment of horizons in the Chalk. Subsequently Rowe published extensively on the biozonation of English coastal Chalk sections (1902-1908). Although dismissive of the value of Chalk lithostratigraphy, Rowe often used lithostratigraphical marker-beds to delimit his biozones in coastal sections (Gale & Cleevely, 1989). Rowe's approach to Chalk stratigraphy spawned a host of papers that used palaeontology to classify and correlate numerous inland quarries and cuttings in the Chalk across southern England, and of particular importance for the South Downs was C. T. A. Gaster's study of the Chalk of Sussex (1924, 1929, 1937, 1939, 1944, 1951) and R M Brydone's work in Hampshire (1912). Both worker's went to extraordinary lengths to examine the chalk at numerous localities (including the debris from rabbit burrows !) in their respective areas, and both used this biostratigraphical data as the basis for constructing biozonal maps of the Chalk. The maps show the distribution of the different Chalk biozones across the South Downs, and have proved useful in more recent studies for the interpretation of geological structures (Mortimore, 1986b). In addition, these works also further refined the biozonal scheme for the Chalk by redefining some of Rowe's zonal concepts and recognising that some zones could be split into narrower intervals (Griffith & Brydone, 1911). Rowe's emphasis on the importance of biostratigraphical classification, coupled with the superficially homogeneous lithology of the Chalk, meant that real progress towards a more sophisticated Chalk lithostratigraphy had to wait until the development of carbonate sedimentology as a separate specialism in the 1960s and 70s (Gale & Cleevely, 1989).

With the development of an improved lithostratigraphical classification of the Chalk have come advances in its macrofossil biostratigraphy. Marker-beds (e.g. marls and flint seams) are an important element of the new lithostratigraphical scheme, and many appear to have formed synchronously across large parts of the Anglo-Paris Basin, making them an ideal framework against which to evaluate the ranges of a variety of different fossil groups that have not traditionally been viewed as biostratigraphically useful. Thus, while the nomenclature of the macrofossil zones has remained largely unchanged since the work of Gaster and Brydone, the degree to which some of these broad intervals can be informally subdivided has increased greatly. It is interesting to note the uncanny coincidence of the new Chalk Group lithostratigraphical boundaries with the boundaries of macrofossil zones (Table 1). This is not altogether surprising, as many of the zones are defined by benthonic species, so that major changes in facies might be expected to coincide with changes in the benthonic macrofauna. Normally the degree to which benthonic macrofossils are influenced by changes in facies is a disadvantage for biostratigraphy, however, the evidence provided by the ranges of key taxa with respect to marker-beds shows that changes in facies and fauna in the Chalk occurred almost synchronously across much of southern England. In this respect, the use of benthonic species for biostratigraphy confers a distinct advantage, as it allows quite accurate inferences about Chalk Group lithostratigraphy to be made from biostratigraphical interpretations. It is for this reason that Gaster and Brydone's respective biozonal maps of the Chalk of Sussex and Hampshire have proved so useful in the mapping of the new Chalk Group lithostratigraphy in the South Downs, since they provide a first approximation to the occurrence of the different lithostratigraphical units. Furthermore, their archived collections of fossils are available for reinterpretation in the context of new range data, and this has been done for nearly all of the South Downs area.

1.2 THE MODERN APPROACH TO CHALK GROUP BIOSTRATIGRAPHY

In the past, great emphasis was placed on the presence or absence of particular fossils for making biostratigraphical interpretations and for correlating successions. Modern thinking has moved away from this narrow approach, at least with respect to the Chalk Group, and instead emphasis is placed on the integration of different types of data to arrive at a solution to a problem. The advantage of this approach is that it helps to eliminate errors caused by incomplete fossil data, due either to lack of preservation or failure to find a particular biomarker. Thus, in correlating sections or boreholes, fossil ranges will be evaluated against lithostratigraphical features (e.g. presence of marker-beds) and perhaps also geophysical logs. Where macrofossil data is ambiguous, then foraminifera might provide the key to the interpretation, and vice-versa. A good example of the application of this correlation technique are the cliff sections at Holywell [TV 600 968], near Eastbourne. Across the Cenomanian-Turonian boundary at Holywell and other coeval UK successions, Gale et al (1993) demonstrated that there was a consistent relationship between changes in the the amount of the Carbon-13 isotope present in the Chalk and the pattern of biomarker occurrences, and further, that the same pattern could be traced to Pueblo, in the western USA (Fig. 1). This not only provides a firmer basis for making correlations, but gives greater confidence to the use of stable isotope curves for correlation in situations where biostratigraphical data is lacking. More recently, Gale (1995) examined the distinctive rhythmically-bedded successions that characterise the Cenomanian in the Anglo-Paris Basin, NW Germany and SE France. The rhythms comprise alternations of clay-rich (marls) and clay-poor (limestone) intervals that are believed to reflect regular fluctuations in the Earth's climate (Milankovitch Cycles). Gale (1995) produced a composite succession of chalk – marl couplets for the whole of the Cenomanian, and tested their correlation between basins using biostratigraphy, sequence stratigraphy (Robaszynski et al., 1998) and carbon isotope stratigraphy. Using this technique, Gale (1995) was able to show that in some basins erosion or non-deposition had produced gaps in the couplet succession, and that elsewhere the succession was greatly expanded.

Another aspect of Chalk Group biostratigraphy is Event Stratigraphy. This has more to do with the relative abundances of particular fossils through a succession rather than their total ranges, which might be quite broad. Ernst et al. (1983) showed how certain fossils had acme occurrences at particular horizons in the Cenomanian and Turonian succession of north-west Germany, and subsequently correlatives of these events have been recognised in the UK. Some of the fossils are long-ranging forms (e.g. oysters) that are not usually considered useful for biostratigraphy, but their abundance at a single level means that they form valuable correlation datum. In some cases, the abundance of a particular fossil group coincides with a distinctive and widespread lithostratigraphical marker-bed (e.g. the abundance of the large morphotype of *Micraster leskei* in the Lewes Marl - see 3.3 below), so that there can be no doubt about the synchroneity of this event across the depositional basin. Event Stratigraphy has even been extended to trace fossil occurrences in the Chalk, there being several basin-wide acmes of certain kinds of trace fossils, particularly *Thalassinoides* and *Zoophycos*, that are valuable for correlation (Mortimore & Pomerol, 1991).

More recently there has been much research on the taxonomy and stratigraphical distribution of inoceramid bivalves (Keller, 1982; Walaszczyk, 1992; Walaszczyk, 1996; Walaszczyk & Wood, 1998; Kennedy et al., 2000; Walaszczyk & Cobban, 2000; Wilmsen *et al*., 2001), mostly based on successions outside the UK. This extinct group of molluscs were largely ignored in historical accounts of Chalk faunas, mainly because their remains were often incomplete. However, there is now very good evidence to suggest that inoceramids were a rapidly evolving fossil group, with global distributions that makes their potential for biostratigraphy very great indeed. Biozonations based on inoceramids have been developed in Germany (Ernst *et. al*., 1983), Poland (Walasczyk, 1992) and the USA (Walaszczyk & Cobban, 2000). In the UK, Mortimore (1986a) and Mortimore & Pomerol (1996) illustrated the ranges of the most important species for biostratigraphy, and Gale (1995) illustrated an inoceramid biozonation for the lower part of the Chalk Group.

Finally, mention should be made of alternative macrofossil zonal schemes, particularly those based on belemnites and brachiopods. Christensen (1991) showed how a standard belemnite zonation developed for north-west Europe could be applied to southern England. However, successful use of this scheme requires complex statistical analysis of measurements of populations of belemnite guards, which restricts its widespread use. Brachiopods have also been used to subdivide the youngest Campanian and Lower Maastrichtian Chalk in Norfolk (Johansen & Surlyk, 1990), but this is stratigraphically higher than any Chalk preserved in the South Downs.

In the following account of the macrofossil biostratigraphy of the Chalk Group, the names of inoceramid bivalves are based on work that pre-dated the recent taxonomic and nomenclatural revisions detailed in the works cited above. Many of the species concepts used are based on the earlier work of Walasczyk (1992), but where possible the up-dated taxonomy is referred to.

2 Grey Chalk Subgroup

Unlike the White Chalk Subgroup, ammonites are relatively well preserved and common in the more argillaceous Grey Chalk Subgroup, and the biozonation of this interval is based on their occurrence. However, within this ammonite-based scheme, there are many important acmes of other fossils, especially bivalves and brachiopods, that are extremely valuable for correlation. The definitions of the biozones that comprise the subgroup, and their characteristic faunas are summarised in Table 3, and the key faunal events within each zone that are important for correlation are discussed below and shown in Fig. 2.

2.1 WEST MELBURY MARLY CHALK FORMATION

The West Melbury Marly Chalk Formation comprises, in ascending stratigraphical order, the *Mantelliceras mantelli*, *M. dixoni* and *Cunningtoniceras inerme* zones, the key biostratigraphical features of which are detailed below with selected examples of where some of these can be seen in the South Downs.

***Mantelliceras mantelli* Zone**: In the South Downs, the base of this zone is coincident with the base of the Chalk Group, and with the base of the Glauconitic Marl Member. Worn and phosphatised fossils characterise the base of the zone, reflecting the stratigraphical condensation associated with the basal Upper Cretaceous marine transgression. Locally, the sponge *Stauronema carteri* is abundant in the Glauconitic Marl, and gave it's name to a now defunct biozonal interval at the base of the Chalk. This part of the succession is well exposed at Cow Gap [TV 597 957], near Eastbourne, where the highly bioturbated contact with the underlying Gault includes derived Albian fossils (Mortimore, 1997), and at nearby Falling Sands [TV 593 954] fossils can be collected from nearly the whole of the Grey Chalk Subgroup (Mortimore, 1997). The lower part of the *M. mantelli* Zone belongs to the *Neostlingoceras carcitanense* Subzone (sensu Gale, 1995), characterised by a rather low diversity fauna which includes the bivalves *Aucellina* spp. and heteromorph ammonites such as *Idiohamites* and *Neostlingoceras*. At Treyford [SU 8277 1842], south-west of Midhurst, a basal Cenomanian fauna occurs in dark green glauconitic sandstone, inferred to represent a local facies of the Glauconitic Marl Member (Woods, 1994b). Further west, at East Meon [SU 6909 2195] and near Alton [SU 7319 3809 to SU 7329 3798], the *carcitanense* Subzone is moderately well exposed in the banks of old abandoned cart tracks, and locally the contact with the underlying Upper Greensand can be found (Woods, 1996a, c).

The middle part of the *M. mantelli* Zone is characterised by inflated forms of *Mantelliceras* and *Sharpeiceras schlueteri*, and belongs to the *S. schlueteri* Subzone (Gale, 1995). Formerly this subzone was incorporated into an expanded *N. carcitanense* Subzone (e.g. Wright & Kennedy, 1984; Gale & Friedrich, 1989). The fauna is much more diverse than the *N. carcitanense* Subzone, and contains an acme of large specimens of the bivalve *Inoceramus crippsi* (Gale, 1995), seen in collections from around Amberley [TQ 0230 1295] (Woods, 1994b) and further west, near East Meon [SU 6874 2228]. The ammonites *Schloenbachia* and *Hypoturrilites* are locally abundant at the top of the *S. schlueteri* Subzone, and are typically associated with a hard limestone, named 'M3' by Gale (1989) in the succession at Folkestone. This limestone was seen in field brash near Treyford [SU 8310 1840], south-west of Midhurst (Woods, 1994b).

The top of the *M. mantelli* Zone contains common compressed species of *Mantelliceras*, belonging to the *Mantelliceras saxbii* group, and is named the *M. saxbii* Subzone. Heteromorph species like *Anisoceras* and *Idiohamites* are absent (Kennedy, 1969), and the fauna is sometimes phosphatised due to an erosion event and subsequent marine transgression at the junction of the *M. mantelli* and *M. dixoni* zones (Gale, 1995).

***Mantelliceras dixoni* Zone**: The index ammonite, *M. dixoni*, is only present in the lower part of the zone (Robaszynski *et al*., 1998), but the interval is often more readily recognised by the presence of the bivalve *Inoceramus virgatus*, which is restricted to the zone, and has a biostratigraphically significant acme just below the middle of the zone (Gale, 1989, 1995). A limestone with abundant *Mantelliceras dixoni* immediately overlies the acme of *I. virgatus*, and is named the Dixoni Limestone ('M6' of Gale, 1989), and a little higher in the zone is an acme of the coarsely ribbed brachiopod *Orbirhynchia mantelliana*. The latter is the lowest of three widely developed acmes of *O. mantelliana* that occur in the Lower and Middle Cenomanian. At Southerham Grey Pit [TQ 426 090], near Lewes, a limestone bed with abundant *Turrilites scheuchzerianus* occurs about a metre above the acme of *O. mantelliana* in the *dixoni* Zone, and can be traced as a correlatable bioevent into continental Europe (Mortimore, 1997). There is no formal subdivision of the zone into subzones, but Gale (1995) recognised three faunal assemblages which from oldest to youngest comprise: (a) common *M. dixoni* and *M. saxbii*, with abundant *I. virgatus*; (b) diverse turrilitids, including *Mesoturrilites* spp.; (c) diverse *Mantelliceras* and rarer *Acompsoceras* and *Hyphoplites*.

***Cunningtoniceras inerme* Zone**: The ammonite index species ranges through the zone and into the base of the overlying *Acanthoceras rhotomagense* Zone (Robaszynski et al., 1998), in the base of the Zig Zag Chalk Formation. Over basin margins the zone is mostly absent due to erosion at the base of the *A. rhotomagense* Zone, but this is not generally the case in the South Downs. In the lower part of the zone, the brachiopod *O. mantelliana* is abundant, representing the second of three widely developed acmes of this brachiopod in the Cenomanian (Robaszynski et al., 1998). *Lyropecten* (*Aequipecten*) *arlesiensis* and *Oxytoma seminudum* are abundant in, and partly restricted to, a dark, silty marl coincident with the top of the acme of *O. mantelliana* (Gale, 1989). This marl was identified as the lower part of couplet B41 in Gale's (1995) cyclostratigraphical scheme for the Cenomanian.

***Acanthoceras rhotomagense* Zone** (basal part only): The index ammonite is restricted to the lower and middle parts of the zone, the base of which can be strongly erosive and re-work faunas from the underlying *C. inerme* Zone, although this is not generally the case in the South Downs. Two subdivisions of the zone are recognised and based on species of heteromorph ammonites, the *Turrilites costatus* Subzone, overlain by the *Turrilites acutus* Subzone. Only the basal part of the *T. costatus* Subzone belongs to the West Melbury Marly Chalk Formation.

At the base of the subzone, the bivalve *Inoceramus tenuis* is abundant in a hard limestone band (= top of couplet B43 of Gale, 1995; also known as the Tenuis Limestone), although this bed has been removed by erosion in basin-margin settings. In the Wessex Basin this bed is strongly feature-forming, and was used by Bristow et al. (1995) to define the junction between the West Melbury Marly Chalk and the Zig Zag Chalk. The Tenuis Limestone also occurs in the South Downs (e.g. Southerham Grey Pit, near Lewes, and near Bignor [SU 9897 1364, SU 9691 1498], south of Petworth (Mortimore, 1997; Woods, 1994c) , but the mapped base of the Zig Zag Chalk is usually more easily and consistently located with respect to an immediately overlying horizon, named the Cast Bed. Despite being much softer than the Tenuis Limestone, this distinctively silty bed is more commonly recognisable in field brash, as at East Worldham [SU 7410 3921], just east of Alton (Woods, 1996c), and around Alton itself [SU 7343 4010] (Woods, 1997b). The Cast Bed has a very distinctive fauna, including common small brachiopods (*Capillithyris squamosa*, *Grasirhynchia martini*, *Kingena concinna*, *Modestella geinitzi*) and the bivalves *Entolium orbiculare* and *Oxytoma seminudum*. Elements of this fauna were also collected in the late 19th century at Elsted [SU 8049 1888], south-west of Midhurst (Woods, 1993). The Cast Bed equates with the lower part of couplet C1 in Gale's (1995) cyclostratigraphical scheme for the Cenomanian. In basin-margin settings north of the South Downs, the fauna of the Cast Bed and some adjacent horizons is caught up in an erosive sandy deposit, named the Totternhoe Stone.

2.2 ZIG ZAG CHALK FORMATION

The Zig Zag Chalk comprises, in ascending stratigraphical order, most of the *A. rhotomagense* Zone , the *A. jukesbrownei* Zone and the *Calycoceras guerangeri* Zone. Their main features are discussed below, with selected examples based on BGS work in the South Downs.

***Acanthoceras rhotomagense* Zone:** The basal part of the zone, belonging to the *T. costatus* Subzone, occurs at the top of the West Melbury Marly Chalk Formation (see above). Above this, there are two faunal events that are useful for correlation. An acme of the brachiopod *Orbirhynchia mantelliana*, towards the middle of the subzone, represents the highest of three widely developed acmes of this brachiopod in the Cenomanian. The top of this *Orbirhynchia* horizon coincides with a limestone containing abundant remains of the heteromorph ammonite *Sciponoceras baculoides*, which is also common lower down in the *costatus* Subzone. In some previous accounts (Bristow *et al*., 1995, Fig. 50), the top of the *T. costatus* Subzone was made approximately coincident with the acme of *O. mantelliana* and *S. baculoides*, but in more recent work has been revised upwards (e.g. Robaszynski et al., 1998; Gale et al., 1999). The *costatus* Subzone, with common *Sciponoceras* and *O. mantelliana*, was seen near Cocking [SU 8868 1727], south of Midhurst (Woods, 1994b), and also occurs at the Balcombe Pit [TQ 462 085] (= Newington's Pit of Lake et al., 1987), near Lewes (Mortimore, 1997, Fig. 14), as well as in the coastal sections between Eastbourne and Beachy Head.

In contrast, the fauna of the *T. acutus* Subzone is quite limited, and of low diversity. The index ammonite is restricted to the lower part of the subzone, which is otherwise locally characterised by terebratulid brachiopods (e.g. *Concinnithyris subundata*) and, in the higher part, by the bivalve *Inoceramus atlanticus*. This interval is inferred to be represented in the lower part of the exposed succession at Butser Hill Quarry [SU 726 203], near Petersfield, and occurs at the Balcombe Pit, near Lewes (Lake et al., 1987; Mortimore, 1997).

***Acanthoceras jukesbrownei* Zone**: The zone contains locally abundant and large specimens of the index ammonite species, but usually rather poorly preserved as iron-stained chalky moulds. The bivalve *Inoceramus atlanticus* is abundant in the base of the *jukesbrownei* Zone (Gale, 1995), and a marl in the lower part of the zone contains an acme of the oyster *Pycnodonte vesiculare* that can be traced through to northern England and Germany (Gaunt et al., 1992). This marl, representing the basal part of a widespread calcarenitic chalk marker-bed in the Zig Zag Chalk named Jukes-Browne Bed 7, marks the change from *Inoceramus atlanticus* in the succession below to *Inoceramus pictus* above, both species locally occurring in the marl. The *jukesbrownei* Zone is well developed at Butser Hill Quarry, although the precise position of Jukes-Browne Bed 7 was difficult to determine when the sections were examined in 1994. Jukes-Browne Bed 7 is much more clearly seen in the coastal succession near Eastbourne (Falling Sands) and near Lewes (Southerham Grey Pit), the last named locality furnishing many large specimens of *A. jukesbrownei* (Mortimore, 1997).

***Calycoceras guerangeri* Zone**: Of all of the zones in the Grey Chalk Subgroup, this is usually the most sparsely fossiliferous, and the fauna that is present is typically fragmentary and poorly preserved. *Inoceramus pictus* is the only widespread and common fossil, although thin-tested echinoids are often found. In the middle of the zone there is a widely developed acme of the oyster *Amphidonte obliquatum* that can be traced through to German successions (Gale et al., 1999). The top of the *guerangeri* Zone is coincident with the Sub-Plenus Marls erosion surface, at the base of the Holywell Nodular Chalk Formation. The whole of the *guerangeri* Zone occurs at Butser Hill Quarry, although the succession is cut by numerous minor displacements which limits the exact correlation of sections. Similarly poorly fossiliferous chalk belonging to the *guerangeri* Zone was seen in the lower part of the Renoun Quarry [SU 7605 4490], north-east of Alton (Woods, 1997a).

3 White Chalk Subgroup

With the exception of the latest Cenomanian, the standard biozonation of the White Chalk Subgroup is based on a variety of non-ammonite taxa (Table 1). However, ammonite zones can be recognised alongside the standard macrofossil zones in the Turonian and basal Coniacian (Table 1), and there are some horizons (e.g. basal Holywell Nodular Chalk and middle Lewes Nodular Chalk) where their remains are quite common.

3.1 HOLYWELL NODULAR CHALK FORMATION

The standard macrofossil zones that comprise the Holywell Nodular Chalk Formation are, in ascending stratigraphical order, the *Metoicoceras geslinianum* Zone, the *Neocardioceras juddii* Zone and the *Mytiloides* spp. Zone. Their features are summarised on Fig. 3 and discussed in detail below, with selected examples of their occurrence and development in the South Downs.

***Metoicoceras geslinianum* Zone**: This zone was formerly stated to be coextensive with the Plenus Marls Member (e.g. Lake et al., 1987), but new evidence from the succession near Eastbourne (Mortimore & Pomerol, 1996) shows that the zone extends above the top of this horizon. The fauna of that part of the zone that equates with the Plenus Marls has been studied in detail (Jefferies, 1963; Wright & Kennedy, 1981), and reveals patterns of changing fauna corresponding with lithostratigraphical changes. Jefferies (1963) recognised 8 beds in the Plenus Marls, each characterised by a distinctive lithology and fauna, and correlatable over large parts of the Anglo-Paris Basin. The different subdivisions are easily studied at beach level near Beachy Head, where the Plenus Marls have one of their thickest developments (c. 8 m) in the UK (Mortimore, 1997, Fig. 23), and were also seen inland at a chalk pit [SU 6495 2125] near Old Winchester Hill, south-west of Alton (Woods, 1996a).

The lower part of the zone (Jefferies' beds 1 & 2) is characterised by large specimens of the oyster *Pycnodonte vesiculare*, and the brachiopod *Orbirhynchia multicostata* is common in Jefferies' Bed 1. In the middle and higher parts of the zone the belemnite *Praeactinocamax plenus* (after which the Plenus Marls are named) and the bivalves *Oxytoma seminudum* and *Lyropecten* (*Aequipecten*) *arlesiensis* are common (Jefferies, 1963). *P. plenus* was formerly used as a zonal index for this part of the Chalk succession, but, as Jefferies (1963) showed, this belemnite has a relatively restricted occurrence in his beds 4 to 6. In the top of the Plenus Marls, the brachiopod *Orbirhynchia wiesti* and the ammonite *E. septemseriatum* are characteristic (Lake et al., 1987). The ammonite fauna of the lower part of the Plenus Marls (beds 1-3) differs from that of the higher part (beds 4-8), that of the former including *Calycoceras naviculare* and *Puzosia* (*Anapuzosia*) *dibleyi*, as well as the zonal index; in the higher part, the zonal index occurs with *Euomphaloceras septemseriatum*, *Pseudocalycoceras dentonense* and *Sciponoceras* (Lake et al., 1987). The brachiopod *Monticlarella jefferiesi* is also generally typical of the Plenus Marls (Lake et al., 1987), and the bivalve *Inoceramus pictus* is more common than in the underlying Zig Zag Chalk.

Above the Plenus Marls, the top of the *M. geslinianum* Zone at Beachy Head occurs in intensely hard chalk representing the basal part of the Melbourn Rock. This interval contains two closely spaced acmes of the ammonite *Sciponoceras*, overlain by an abundance of the asteroid *Crateraster quinqueloba* (Gale, 1996).

***Neocardioceras juddii* Zone**: Apart from the zonal index, this narrow interval is characterised by coarsely rugate members of the *Inoceramus pictus* lineage, an abundance of the oyster *Pycnodonte vesiculare* between Meads Marls 1 and 2, and three acmes of the straight-shelled ammonite *Sciponoceras* that span the interval from below Meads Marl 3 to below Meads Marl 4; all seen in the Beachy Head succession (Gale, 1996). The lower part of this zone typically occurs in strongly indurated chalk representing the upper part of the Melbourn Rock. Inland, correlatives of these *Sciponoceras* acmes were seen in in an old chalk pit at Noar Hill [SU 7391 3195], south of Alton (Woods, 1996c), and at the Renoun Quarry [SU 7605 4490], north-east of Alton (Woods, 1997a), the latter showing that spines of the echinoid *Hirudocidaris hirudo* also appear to be locally characteristic of the *juddii* Zone.

***Mytiloides* spp. Zone**: This zone is used in the sense of Hopson et al. (1996) for the shell-rich chalks that comprise the bulk of the Holywell Nodular Chalk, formed of the abundant remains of various species of the bivalve *Mytiloides*. Previously this zone has been referred to as the *Inoceramus* (or *Mytiloides*) *labiatus* Zone, or in some older accounts (e.g. Jukes-Browne & Hill, 1903) as the *Rhynchonella cuvieri* Zone. Mortimore (1986a) used the term '*Mytiloides labiatus* Zone s.l.' , but this is not precisely coeval, since it includes both older and younger strata than those of the *Mytiloides* spp. Zone. The ammonite zonal equivalents of the *Mytiloides* spp. Zone are (in ascending stratigraphical order), the *Watinoceras devonense*, *Fagesia catinus*, *Mammites nodosoides* and basal *Collignoniceras woollgari* zones (Table 1).

The base of the *Mytiloides* spp. Zone is also the base of the Turonian Stage, defined by the first occurrence of the ammonite *Watinoceras devonense* in the proposed boundary stratotype at Pueblo, Colorado, USA (Bengtson, 1996). In the UK, *W. devonense* has been recorded from SE Devon (Wright & Kennedy, 1981), but elsewhere the appearance of species of the inoceramid bivalve *Mytiloides,* at the base of the *Mytiloides spp.* Zone*,* is a useful guide. In the absence of *W. devonense*, Gale (1996) defined the base of the Turonian at the top of the range of the ammonites *Sciponoceras gracile* and *S. bohemicum anterior*, since the disappearance of both of these species in Devon is coincident with the appearance of *W. devonense*. In the section at Beachy Head this horizon is just above Meads Marl 4 (Gale, 1996), the correlative of which is also inferred to be present in the succession at Noar Hill, south of Alton (Woods, 1996c – see above).

The succession at Gun Gardens [TV 587 954] is a much studied key reference section for the biostratigraphy of the *Mytiloides* spp. Zone (Mortimore & Pomerol, 1996; Gale, 1996; Mortimore, 1997). Near the base of the zone, *Mytiloides columbianus* (largely equivalent to *Mytiloides kossmati* of Kennedy, Walasczyk & Cobban, 2000, but possibly also including *Mytiloides puebloensis*) is the characteristic bivalve, and co-occurs with the brachiopod *Orbirhynchia cuvieri* and successively higher local records of the ammonites *Watinoceras*, *Fagesia* and *Mammites* (Mortimore & Pomerol, 1996). Slightly higher in the zone, *Mytiloides hattini* occurs, overlain by abundant *Mytiloides mytiloides* (may also include *Mytiloides ganuzaensis* and *Mytiloides aviculoides* of Kennedy, Walaszczyk & Cobban, 2000) to the top of the zone. This shell-rich interval was also well exposed (in 1994) in the lower part of the succession seen in the large chalk quarry at Cocking, south of Midhurst, and also in the Renoun Quarry, north-east of Alton (Woods, 1994b, 1997a). Unusually, the *Mytiloides* spp. Zone in the Renoun Quarry appears to contain the echinoid *Conulus subrotundus*, which is more typical of the *T. lata* Zone.

Additionally, Gale (1996) recorded two laterally persistent bio-markers in the *Mytiloides* spp. Zone at Beachy Head that are important for correlation. The lower of these is a bed with abundant remains of the microcrinoid *Roveacrinus communis*, present between Holywell Marls 2 and 3 in the lower part of the zone, and the higher is a band of *Mytiloides* shells encrusted with the serpulid *Filograna avita*, a little above the middle of the zone and also recorded in the succession at Glyndebourne [TQ 448 102], near Lewes (Mortimore & Pomerol, 1996).

Mortimore (1986a) made the top of the *Mytiloides* spp. Zone, and the top of the Holywell Chalk, coincident with the Malling Street Marls (also followed by Lake et al., 1987), but both lithostratigraphical and biostratigraphical boundaries were lowered to the Gun Gardens Main Marl by Mortimore & Pomerol (1996). The Gun Gardens Main Marl equates with the Lulworth Marl in Gale's (1996) log of the Beachy Head succession.

3.2 NEW PIT CHALK FORMATION

The New Pit Chalk Formation is rather poorly characterised by macrofossils, and equates with all but the highest part of the *Terebratulina lata* Zone, in the standard macrofossil scheme, and with the greater part of the *Collignoniceras woollgari* Zone and basal *Subprionocyclus neptuni* Zone of the ammonite-based scheme (Table 1).

The basal part of the *T. lata* Zone is characterised by thin-shelled, often rather poorly preserved bivalves belonging to the *Mytiloides hercynicus* - *subhercynicus* group of species. Unlike the underlying *Mytiloides* spp. Zone, their remains do not form shell detrital chalk. These bivalves often co-occur with large terebratulid brachiopods (including *Concinnithyris*), and the echinoid *Conulus subrotundus*, which ranges through the lower part of the *lata* Zone in Sussex (Mortimore, 1986a) (Fig. 3). This fauna occurs in the higher part of the succession at the Glyndebourne Pit, near Lewes, as well as in the Beachy Head reference section, at both localities associated with local records of the index ammonite *Collignoniceras woollgari* (Mortimore & Pomerol, 1996). There are also local occurrences of *M*. ex gr. *hercynicus* - *subhercynicus* around Upwaltham [SU 9448 1426; SU 9433 1415] , and in the BGS Duncton Quarry Borehole [SU 9520 1576] that are useful for locating the base of the New Pit Chalk Formation. Further west, in the large chalk pit at Cocking, south of Midhurst, the *T. lata* Zone represents the bulk of the succession in the middle and higher parts of the pit, and the fauna contains relatively common rhynchonellid brachiopods, including *Orbirhynchia* aff. *herberti* (Woods, 1994b). At Beachy Head, Gale (1996) also recorded a second acme of the microcrinoid *Roveacrinus communis* (the first occurring in the *Mytiloides* spp. Zone) at the inferred base of the *T. lata* Zone.

In the higher part of the *T. lata* Zone, corresponding to the interval containing the New Pit Marls and Glynde Marls, the fauna is characterised by common *Terebratulina lata*, and the bivalves *Inoceramus cuvieri* and *Inoceramus lamarcki* (Fig. 3). This part of the zone occurs at several of the classic localities near Lewes described by Mortimore (1986a, 1997), such as New Pit [TQ 4249 1120], Glynde [TQ 4497 0958] and Caburn [TQ 4473 0891], as well as much further west in the road cutting at Twyford Down, near Winchester. Gale (1996) recorded that *Inoceramus cuvieri* was upwardly replaced by *I. lamarcki* in the higher part of the *T. lata* Zone, but this has not been consistently seen in the field. The giant agglutinating foraminifera, *Labyrinthidoma* (clearly visible with the naked eye and referred to formerly as *Coskinophragma*) is also common in this part of the zone. The ammonite species *Romaniceras* (*Yubariceras*) *ornatissimum* and

Romaniceras deverianum occur at the levels of New Pit Marls 2 and 3 in Sussex (e.g. in the Glyndebourne Pit, near Lewes, and at Amberley and Firle [precise grid references not known for the latter two] (Wright & Kennedy, 1981; Mortimore, 1986a)). *R. deverianum* is the subzonal index for the lowest third of the *S. neptuni* ammonite Zone (Gale, 1996).

3.3 LEWES NODULAR CHALK FORMATION

The fauna of the Lewes Nodular Chalk is much richer and more diverse than the underlying New Pit Chalk, and includes common ammonites locally. In this interval several lithostratigraphical marker beds have distinct faunal associations, making them extremely useful for correlation. The standard macrofossil zones that comprise the Lewes Nodular Chalk Formation are, in ascending stratigraphical order, the *Terebratulina lata* Zone (highest part only), *Sternotaxis plana* Zone and *Micraster cortestudinarium* Zone. Their main features are summarised on Fig. 4, and discussed in detail below with selected examples of their occurrence in the South Downs.

***Terebratulina lata* Zone** (highest part only): The fauna of the highest part of the *T. lata* Zone is quite similar to that which occurs in the upper New Pit Chalk, and includes common *T. lata*, *Inoceramus cuvieri* and *I. lamarcki*. Very large and coarsely ribbed members of the *I. lamarcki* group, belonging to *I. lamarcki stuemckli* occur in the top of the zone. The echinoids *Sternotaxis plana* and *Micraster corbovis* 'of *lata* Zone type' (equivalent to the *Roweaster rowei* of Drummond, 1983) first appear in this interval, and *Labyrinthidoma*, which first occurs in the higher part of the New Pit Chalk in Sussex, has an acme occurrence in Southerham Marl 1, overlain slightly higher by an acme of the bryozoan *Bicavea rotaformis* (Mortimore & Wood, 1986). Southerham Marl 1 is distinctively thick (c. 150mm+) and plastic textured, and with its abundance of *Labyrinthidoma* is easily recognisable in sections, such as at the Bridgewick [TQ 431 113] and Caburn [TQ 447 089] pits near Lewes; in the lower part of the succession at Duncton [SU 9520 1576], south of Petworth (Mortimore, 1997; Woods, 1994a), and at East Tisted [SU 6980 3018], near Alton (Woods, 1996d). Late Turonian species of the bivalve *Mytiloides* appear in the succession just below Southerham Marl 1 and continue up to the top of the *S. plana* Zone. In the top of the *T. lata* Zone, *Mytiloides incertus* (equivalent to the *M. fiegei* of Mortimore, 1986a) is the characteristic form, and occurs in coeval successions in Germany, Poland and the USA (Walaszczyk, 1992; Walaszczyk & Wood, 1998; Walaszczyk & Cobban, 2000).

***Sternotaxis plana* Zone**: The lower part of the *plana* Zone, below the Lewes Marl, has a rich and diverse fauna comprising echinoids such as *Micraster leskei* 'small form' (equivalent to the *Eomicraster leskei minor* of Drummond, 1983), *Sternotaxis plana*, *Roweaster rowei* and *Gauthieria radiata*; the brachiopods *Cretirhynchia minor*, *Cretirhynchia cuneiformis*, *Orbirhynchia reedensis* and *Orbirhynchia dispansa*; gastropods (particularly *Bathrotomaria perspectiva*) and locally preserved ammonites such as *Scaphites*, *Sciponoceras* and *Allocrioceras*. The bivalve fauna includes the inoceramids *Mytiloides costellatus* (formerly *Inoceramus costellatus*), *M. incertus* and *M. striatoconcetricus*. The nodular chalks below the Lewes Marl in Sussex include locally preserved elements of the 'Reussianum Fauna', described by Woods (1896, 1897) from the 'Chalk Rock' of East Anglia (Lake et al., 1987). The Lewes Marl itself is characterised by an acme of the large morphotype of the echinoid *Micraster leskei* (equivalent to the *Eomicraster leskei magna* of Drummond, 1983), and overlies an interconnected network of tubular flints (Lewes Tubular Flints) that represent the fossilised burrows of soft-bodied organisms, formed during a protracted still-stand of sea-level in the Late

Turonian. The Lewes Flints and overlying Lewes Marl are traceable over a large part of the Anglo-Paris Basin, and in the South Downs can easily be examined at the Navigation Pit [TQ 425 100] near Lewes, and in Duncton Quarry [SU 9520 1576] further west.

Above the Lewes Marl, in the upper part of the *S. plana* Zone, further species of Late Turonian *Mytiloides* occur. These were mostly recorded as *M. striatoconcentricus* and *M. labiatoidiformis* by Mortimore (1986a) and in subsequent collecting by the BGS in Sussex and Hampshire. However, recent revisions to the taxonomy of the inoceramids from the Turonian / Coniacian boundary interval in Germany and USA (Walasczyk & Wood, 1998; Walasczyk & Cobban, 2000) suggest that newly described species concepts may fall within the parameters of these previous records of *M. striatoconcentricus* and *M. labiatoidiformis*. New forms of *Micraster* also occur above the Lewes Marl, the large form of *Micraster leskei* being successively replaced upwards by *Micraster precursor* (sensu Drummond, 1983) and *Micraster normanniae*.

Near the top of the *S. plana* Zone, the trace fossil *Zoophycos*, preserved as thin marly stripes or lenticular flints scattered through soft chalk, is abundant, and is named the Cuilfail Zoophycos after a locality near Lewes [TQ 425 100] where it well exposed. This distinctive horizon has been recorded at several localities in the South Downs (e.g. Downley [SU 752 177], near Petersfield; Duncton Quarry, near Petworth; Monkwood [SU 6832 2980], near Alton; Beeding Quarry [TQ 202 088], near Shoreham), and is traceable into northern France (Mortimore & Pomerol, 1991; Mortimore, 1997; Woods, 1994a, 1995a, 1996d). At and above this horizon, *Sternotaxis plana* is locally abundant, and is associated with giant *Sternotaxis placenta*. In the Navigation Hardgrounds and Navigation Marls at the top of the *S. plana* Zone, distinctively round-based forms of the echinoid *Echinocorys*, usually referred to *E. gravesi*, become abundant, and continue up into the overlying *M. cortestudinarium* Zone.

The base of the Coniacian Stage was placed just below the top of the *S. plana* Zone, at the base of the Navigation Hardground, by Bailey et al. (1984). In the UK, this probably remains the best horizon at which to define this stage boundary, where Coniacian bivalve faunas of the *Cremnoceramus* group first occur above the lowest undoubted Coniacian ammonite record (*Forresteria* (*Harleites*) *petrocoriensis*) in the Navigation Hardground (Bailey et al., 1984). However, new research shows that in less condensed successions, the boundary defined by newly adopted criteria (the first appearance of the inoceramid bivalve *Cremnoceramus rotundatus* (sensu Tröger non Fiege)), is below the first occurrence of *Forresteria* (*Harleites*) *petrocoriense*, but above the first occurrence of the genus *Cremnoceramus* (Kauffman et al., 1996). According to Bailey et al. (1984) there are no identifiable inoceramids or ammonites from the 5m of strata below the Navigation Hardgrounds in the UK, and although Mortimore (1997, p. 94) suggested that inoceramids from the Navigation Pit near Lewes might justify lowering the base of the Coniacian, this remains very uncertain (C J Wood, pers. comm., 2001). However, the upper *S. plana* Zone and basal *M. cortestudinarium* Zone have recently been recorded at newly discovered sections at Downley, near Petersfield, associated with rich inoceramid faunas and, significantly, the bivalve *Didymotis*. This is only the second record of *Didymotis* in southern England, but it is a well known bio-marker at the Turonian – Coniacian boundary in northern England and Germany (Whitham, 1991; Kauffman et al., 1996, Fig. 5). It is hoped that further research on the faunas from these sections will provide new insights into the development of the Turonian – Coniacian boundary in southern England.

***Micraster cortestudinarium* Zone:** The base of the *M. cortestudinarium* Zone is at the top of the Navigation Hardground in Sussex, and a short distance above this horizon there is the sudden appearance of abundant specimens of the bivalve *Cremnoceramus*, particularly the species *C. waltersdorfensis* and *C.deformis erectus* (equivalent to the *C. rotundatus* sensu Tröger non Fiege; Walaszczyk & Wood, 1998). In expanded successions outside the UK, *C. walterdorfensis* also has a limited occurrence in the top of the Turonian (Kauffman et al., 1996), but in the UK appears to be restricted to the lower Coniacian. *Micraster normanniae* continues up from the underlying *S. plana* Zone, and co-occurs with abundant *Echinocorys gravesi* up to the level of the Hope Gap Hardground (Mortimore, 1986a). At and above the Hope Gap Hardground *Micraster cortestudinarium* (equivalent to the *Micraster decipiens* of Mortimore, 1986a) replaces *M. normanniae* as the characteristic echinoid, and the fauna becomes notably sparser except for the inoceramid bivalve *Cremnoceramus crassus* and local occurrences of spines of the echinoid *Tylocidaris*. This part of the zone is seen in coastal sections at Hope Gap [TV 509 973] (from which the hardground takes its name), south-east of Seaford, and towards Seaford Head [TV 504 974] large *Cremnoceramus inconstans* occur within the Hope Gap Hardground (Mortimore, 1997). Inland, a rich *Micraster* and *Cremnoceramus* fauna was collected from at and below the presumed correlative of the Hope Gap Hardground near Bentworth [SU 6786 4133]. Near the top of the *M. cortestudinarium* Zone, as seen at Seaford Head [TV 494 977] and inland at Shoreham [TQ 202 088], *Micraster turonensis* replaces *M. cortestudinarium* and the trace fossil *Zoophycos* has another acme, overlain by sponge-rich nodular chalk (= Beachy Head Sponge Beds of Mortimore, 1986a).

3.4 SEAFORD CHALK FORMATION

The Seaford Chalk Formation is co-extensive with the ***Micraster coranguinum* Zone**, and has a sparser and less diverse fauna than that seen in the underlying Lewes Nodular Chalk. Despite being a very broad biozonal interval, the *M. coranguinum* Zone can be informally subdivided into lower, middle and upper parts, the main features of which are summarised in Fig. 5.

The lower *M. coranguinum* Zone encompasses the interval from the base of the zone to just above the Seven Sisters Flint, and is characterised by abundant, thick-shelled fragments of the bivalve *Platyceramus*. These shell fragments are scattered through the chalk, or more often, are concentrated into laterally persistent horizons. The large, flattened shells of *Platyceramus*, sometimes more than half a metre across, contrast with the thick, curved fragments of *Volviceramus involutus* which is the other characteristic fossil in this part of the zone. *V. involutus* is very abundant at the level of the Seven Sisters Flint, as seen in the cliffs and beach platform east of Birling Gap [TV 553959], at Seaford Head [TV 494 977], and inland at Beeding Quarry, Shoreham, making this an important marker-bed for correlation. More rarely, *Volviceramus koeneni* occurs just above the base of the zone in Sussex (Mortimore, 1986a), and there are also fragmentary undescribed forms of *Cremnoceramus* at this level, representing the last record of this bivalve that is so typical of the *M. cortestudinarium* Zone. The characteristic echinoid is *Micraster turonensis*, the index of the *coranguinum* Zone only occurring sporadically until above the Seven Sisters Flint (Mortimore, 1986a).

The middle part of the *M. coranguinum* Zone is the interval from just above the Seven Sisters Flint to the base of the Santonian Stage, which in Sussex, is coincident with the Michael Dean Flint (Mortimore, 1986a). The main feature of this interval is that it is almost totally barren of macrofossils, including the typically ubiquitous shell fragments of *Platyceramus*.

The upper part of the *M. coranguinum* Zone, from the Michael Dean Flint to the base of the Newhaven Chalk, has the richest and most diverse fauna of all the subdivisions. Echinoids are especially common, although many such as *Temnocidaris*, *Prionocidaris* and *Phymosoma* are quite long-ranging, and therfore not useful for biostratigraphy. The Coniacian – Santonian boundary, at the base of this highest part of the *coranguinum* Zone, is marked by two closely spaced acmes of the bivalve *Cladoceramus undulatoplicatus*. This very distinctive biomarker can be traced right across southern England and into continental Europe (Lamolda & Hancock, 1996). In the South Downs, the *Cladoceramus* horizon can be seen at beach level in the coastal succession at Seaford Head, and inland near Lewes [TQ 446 034; TQ 401 093], near West Meon [SU 6708 2695] (Woods, 1996d), and in road cuttings around Winchester [SU 4643 2740; SU

4968 2950 to 4965 2985] (Woods, 1998a, b). The brachiopod *Gibbithyris ellipsoidalis* also has a restricted range just above the base of the Santonian, and is relatively common in the succession at Kings Worthy [SU 4815 3200], near Winchester (Woods, 1998b), but apart from this, brachiopods are relatively rare in the *coranguinum* Zone. *Platyceramus* becomes common again in this part of the zone, and is very thick-shelled (>5mm) in the top of the zone, accompanied by occasional records of the distinctively shaped bivalve *Cordiceramus cordiformis*. *M. coranguinum* is more frequent than in the lower parts of the zone, but despite being the index species, is not of great biostratigraphical value because of its occurrence in the overlying *U. socialis* Zone. More useful is *Micraster* (*Isomicraster*) *gibbus*, with its distinctively conical form and low periproct, concentrated across the Coniacian - Santonian boundary (Drummond, 1983). The echinoid *Echinocorys scutata* becomes very enlarged and high-sided in the Santonian part of the *M. coranguinum* Zone, as seen in the lower part of the succession at Ropley [SU 6570 3050] (Woods, 1996d), although near the top of the zone, squatter forms, taller at the posterior margin of the apical plate than at the anterior end, are locally common. At some localities in the South Downs, particularly in the west of the region near Upper Wield [SU 6530 3877] (Woods, 1997b) *Conulus subrotundus* and *Conulus albogalerus* are concentrated at the top of the zone, and locally form a bed exclusively comprising their crushed and fragmentary remains.

3.5 NEWHAVEN CHALK FORMATION

Unlike the Seaford Chalk Formation, the Newhaven Chalk Formation contains a number of biozones, those near the base being easily recognisable and valuable for mapping. The zones, in ascending stratigraphical order are the *Uintacrinus socialis* Zone, *Marsupites testudinarius* Zone, *Uintacrinus anglicus* Zone, *Offaster pilula* Zone and basal *Gonioteuthis quadrata* Zone (Fig. 6). The lowest three zones are defined by stemless crinoids, and are sometimes collectively called the 'crinoid zones'. Most of these biozones have been recorded in the coastal succession near Seaford Head (Young & Lake, 1988). As shown by Bristow et al. (1997, Table 1), the top of the Newhaven Chalk is diachronous, sometimes occurring in the upper part of the *O. pilula* Zone, and elsewhere ranging up to the basal *G. quadrata* Zone.

***Uintacrinus socialis* Zone**: The *socialis* Zone is characterised by the disarticulated remains of the index crinoid. The small (c. 5 mm) irregularly polygonal pale grey calcite plates that form the calyx are the only really diagnostic part of the zonal fauna. Complete or semi-complete calyces of *Uintacrinus* are extremely rare in the UK, although they occur abundantly in parts of the USA. The much smaller brachial plates, that formed the crinoids' 'arms', are more common fossils, but differentiation from *Uintacrinus anglicus* is difficult. The brachials are recognisable as tiny rounded or oval discs with a small v-shaped notch on one side (Fig. 6). These features of *Uintacrinus* were well illustrated by Rasmussen (1961, Pls 58-59), and the zone can be found in coastal exposures at Splash Point [TV 491 981], near Seaford, and inland near Horndean [SU 747 156] and at Ropley [SU 6570 3050], near Alton, where the junction with the underlying *M. coranguinum* Zone is also seen (Mortimore, 1997; Woods, 1996d).

Apart from the index fossil, there is an acme of the belemnite *Actinocamax versus* in the *socialis* Zone, and the crinoid *Bourgueticrinus granulosus* is locally common at the top of the zone. Some of the *Echinocorys* from this level are forms in which the test is very flat-topped, as seen in the chalk pit at Ropley (above). Lake et al. (1987) recorded that the overlying *M. testudinarius* Zone contained a rich oyster fauna, but this is also a local feature of the *socialis* Zone, and includes *Pycnodonte vesiculare*, *Acutostrea incurva* and *Pseudoperna boucheroni*. The trace fossil *Zoophycos*, typically preserved in flint, occurs widely in the *socialis* Zone and overlying *M. testudinarius* Zone (Mortimore & Pomerol, 1991).

***Marsupites testudinarius* Zone**: The zonal index is a highly distinctive fossil, usually comprising the disarticulated polygonal plates of the crinoid calyx. They are much larger (up to 30 mm or more) and usually more numerous than the calyx plates of *Uintacrinus*, and may be smooth or highly ornamented with ridges and rows of granules (Fig. 6). The brachials are also larger than those of *Uintacrinus*. Complete or semi-complete calices of *Marsupites* are rare, but do occur in the South Downs, as at Arundel [TQ 037 085 - 038 088] and near West Meon [SU 6485 2534] (Woods, 1996b).This fossil has a global distribution, occurring synchronously in the USA, Europe and Australia, and its sudden extinction, at the top of the *M. testudinarius* Zone, is an international bio-marker for the Santonian – Campanian boundary (Gale et al., 1995). Young & Lake (1988) recorded that the size and degree of ornamentation of *Marsupites* calyx plates varied with stratigraphical position in the zone, those near the base being small and unornamented, becoming large and ornamented higher up, then large and unornamented, and finally small and ornamented in the top of the zone.

Apart from the zonal index, the other characteristic fossils are pyramidal forms of *Echinocorys*, named *E. elevata*, and abundant oysters, particularly *Pseudoperna boucheroni*. Longer ranging fossils that are locally common in the *testudinarius* Zone are the echinoid *Conulus*, the brachiopods *Cretirhynchia exsculpta* and *Terebratulina rowei*, and the belemnite *Gonioteuthis granulata*. Locally, abundant and thick-shelled *Platyceramus* also occurs, such that a cursory examination of such localities might lead to the mistaken identification of the *M. coranguinum* Zone

***Uintacrinus anglicus* Zone**: Unlike the global occurrence of *Uintacrinus socialis* and *Marsupites testudinarius*, *Uintacrinus anglicus* appears to be restricted to the English Chalk (Milsom et al., 1994), and defines a narrow zone, a few metres thick, above the *testudinarius* Zone. The only distinguishing feature of the zone are the small calyx plates, which are of polygonal or semi-polygonal outline and have folds around their edges (e.g. Rasmussen, 1961, pl. 58) (Fig. 6). Mortimore (1986a) recorded the echinoids *Echinocorys depressula* and *Echinocorys tectiformis* in the *anglicus* Zone, but only *E. tectiformis* was similarly recorded by Young & Lake (1988). This interval is rarely encountered, an exception being the coastal section at Splash Point, near Seaford (Mortimore, 1997).

***Offaster pilula* Zone:** The fauna of this zone is dominated by echinoids, the varied stratigraphical distribution of which permits subdivision into a lower *Echinocorys depressula* Subzone, and an upper Subzone of abundant *Offaster pilula*. Bivalves are rather infrequent, except for presumed fragments of *Platyceramus* and occasional *Cataceramus*.

In the *Echinocorys depressula* Subzone, the small, thin-tested echinoid *Offaster pilula* occurs infrequently, and the fauna is dominated by low domed *Echinocorys depressula* and more angulate *Echinocorys tectiformis*, the latter first occurring in the underlying *anglicus* Zone. The rich oyster fauna seen in the crinoid zones continues up into the base of the *depressula* Subzone (Fig. 6), as seen in a section near West Meon [SU 6497 2445] (Woods, 1996b).

In the Subzone of abundant *Offaster pilula* there is a succession of different forms of *Echinocorys*, and stratigraphical changes in the pattern of abundance of *Offaster pilula*, that allow further subdivision into three faunal 'belts', named in ascending stratigraphical order: Lower belt of *Offaster pilula*, Belt of *Echinocorys cincta* and Upper belt of *Offaster pilula*. In the lowest of these, *O. pilula* is abundant, and co-occurs with small *Echinocorys truncata*. Above this, *Offaster pilula* is scarce or absent, and *Echinocorys cincta* is the only common fossil, as seen on the coast west of Newhaven [TQ 445 000 to TV 435 998] (Mortimore, 1997) and in an old chalk pit near Soberton [SU 6123 1630], near Droxford, where *E. cincta* occurs above common *O. pilula* and *E. truncata* (Woods, 1995a; 1996b). Finally in the top of the *Offaster* *pilula* Zone, *Offaster pilula* again becomes abundant and co-occurs with un-named forms of *Echinocorys*, first described by Gaster (1924) and usually referred to as the 'large forms of Gaster' (Fig. 6). As well as their large size, these *Echinocorys* are distinguished by their thick tests, with a very evenly domed upper surface and flat base, separated by a sharply angled junction. In the topmost part of the *O. pilula* Zone, *Offaster* becomes much larger in size (+20 mm), and is seen in the coastal exposures west of Newhaven and inland near Winchester [SU 4277 2606] (Mortimore, 1997; Woods, 1998b), and these forms are named *Offaster pilula planatus*.

***Gonioteuthis quadrata* Zone** (basal part): The basal part of this zone, locally corresponding to the top of the Newhaven Chalk Formation, is characterised by the large *Echinocorys* morphotype of Gaster (1924) (see *O. pilula* Zone above), and very inconspicuous remains of the unusually shaped echinoid *Hagenowia blackmorei*. Because of its extremely fragile test, the most usually preserved part of *H. blackmorei* is the very small and fragile 'rostrum', which forms a tapering spine-like projection on the upper anterior surface of the test (e.g. Gale & Smith, 1982, Pl. 3, figs 7 & 8) (Fig. 6). The local abundance of this fossil has been used to recognise a basal subdivision of the *G. quadrata* Zone, named the 'Hagenowia Horizon' or '*Hagenowia* Subzone', as seen near North Lancing [TQ 184 062]; Gaster (1924, locality '2'). However, *Hagenowia* itself has rarely been found in the course of mapping the Chalk of Sussex and Hampshire, better guides to this interval being the recognition of the top of the underlying *O. pilula* Zone, and the base of the overlying *Applinocrinus cretaceus* Subzone (see below), both of which are faunally distinct. Just below the top of the *Hagenowia* Horizon, the large *Echinocorys* morphotype of Gaster (1924) is replaced by a small morphotype (the so-called 'small forms of Gaster'), which superficially resembles *Echinocorys depressula* or *Echinocorys cincta* from the *O. pilula* Zone.

3.6 CULVER CHALK FORMATION

The Culver Chalk Formation falls entirely within the ***Gonioteuthis quadrata* Zone**, which is divided into three faunally distinct intervals: the 'Hagenowia Horizon' or 'Subzone', at the base, overlain by the *Applinocrinus cretaceus* Subzone, and capped by an interval that has been termed 'post *Applinocrinus* beds' by Christensen (1991). Part or all of the Hagenowia Horizon may locally fall into the top of the Newhaven Chalk Formation (Bristow et al., 1997), and the top of the *cretaceus* Subzone appears to approximately coincide with the top of the Tarrant Chalk Member. The top of the overlying Spetisbury Chalk Member, and of the Culver Chalk Formation, is just below the top of the *G. quadrata* Zone, within the 'post Applinocrinus Beds' (Table 1).

The key features of the Hagenowia Horizon / Subzone were described above (**3.5**). It is overlain by the *A. cretaceus* Subzone, the index fossil of which is an extremely small stemless crinoid, the calyx being only clearly visible under a binocular microscope. In fact, the fauna of this subzone is dominated by small fossils, such as the serpulid *Conorca turbinella*, and bryozoans, which locally become so abundant that the chalk appears to be formed entirely of their remains, as seen near Horndean [SU 7458 1370] (Woods, 1995b). The lower part of the subzone contains a small subspecies of *Offaster pilula*, named *O. pilula nana*, and there are local occurrences of the similarly thin-tested echinoid *Galeola* (Bailey et al., 1984) (Fig. 7). The remainder of the subzonal fauna includes the small brachiopod *Cretirhynchia limbata* (sensu Gaster, 1924 non Schlotheim, 1813), echinoid spines (recorded as *Cidaris subvesiculosa* by Gaster, 1924), the zonal index belemnite *Gonioteuthis quadrata*, and the echinoid *Echinocorys marginata*. The small bivalve, *Neithea* (*N.*) *sexcostata*, although long-ranging, also seems to be common in the *cretaceus* Subzone, and the 'small-form' *Echinocorys* morphotype of Gaster (1924) ranges up from the top of the underlying *Hagenowia* Horizon (see above).

The *cretaceus* Subzone fauna occurs widely across the South Downs, but mostly at inland localities such as the small scattered chalk pits described by Gaster (1924) between Shoreham and Arundel, the relative stratigraphical positions of which were shown by Mortimore (1986b). A few of these were re-examined in the course of the new survey to assist in mapping of the boundary between the Tarrant and Spetisbury Chalk members, including the pits at Cote [TQ 1155 0643], near Worthing (Gaster's pit no. 17) and on Warningcamp Hill [TQ 046 076], near Arundel (Gaster's pit no. 24). The lower part of the pit at Warningcamp Hill has a very rich and diverse *cretaceus* Subzone fauna, including in addition to fossils already mentioned, oysters, small sponges (e.g. *Porosphaera patelliformis*) and the brachiopods *Terebratulina* and *Kingena*. Warningcamp Hill is the stratigraphically highest *cretaceus* Subzone fauna described by Gaster (1924), and the top of the pit contains the Tarrant / Spetisbury Chalk boundary. Further west, the *cretaceus* Subzone is seen at several key localities, including the lower part of the large chalk pit at Warren Down [SU 6045 0682], on Portsdown, and north-westwards near Bishops Waltham [SU 5646 1809] (Woods, 1996a, 1996b).

The 'post *Applinocrinus* beds' equate with the interval from the top of the *A. cretaceus* Subzone, coincident with the Whitecliff Flint in the South Downs (Bailey et al., 1983), to the top of the range of *Gonioteuthis*, marked by the Farlington Marls. However, the highest part of this interval, between the Portsdown Marl and Farlington Marls, belongs to the basal Portsdown Chalk Formation (see below).

There is relatively little to distinguish the lower part of the 'post *Applinocrinus* beds', except perhaps the increased frequency of inoceramid shell debris, moderately common brachiopods belonging to *Cretirhynchia* of the *intermedia – norvicensis* species group, and absence of abundant bryozoa. Like the *Hagenowia* Horizon, recognition of the faunally distinct adjacent horizons (in this case the top of the *A. cretaceus* Subzone and the base of the *B. mucronata* Zone) is a better guide to the occurrence of the 'post *Applinocrinus* beds'. The best exposures of this biozonal interval in the South Downs are in the large chalk pit at Warren Farm, on Portsdown, and at nearby Clapper Hill [SU 5900 0745], on the outskirts of Fareham (Woods, 1995a, 1996a, b). Only the highest part of the 'post *Applinocrinus* beds', belonging to the Portsdown Chalk, has a distinct fauna (see below).

3.7 PORTSDOWN CHALK FORMATION

The Portsdown Chalk Formation belongs to the topmost ***Gonioteuthis quadrata* Zone** and the lower part of the overlying ***Belemnitella mucronata* Zone** (Table 1), and is the youngest chalk in the South Downs.

The basal part of the Portsdown Chalk, between the Portsdown Marl and Farlington Marls, belongs to the higher part of the 'post *Applinocrinus* beds', at the top of the *G. quadrata* Zone. Within this interval, the belemnites *Gonioteuthis* and *Belemnitella* co-occur, as recorded near the top of the Warren Farm Quarry on Portsdown (Woods, 1995a, 1996a, b), and there is a distinctive *Echinocorys* morphotype, named *Echinocorys brydonei* Gale MS. Inoceramid shell fragments are relatively abundant at this horizon, and there is an acme of the trace fossil *Zoophycos* preserved in flint, named the Precy-Warren Farm Zoophycos Event after the the two localities (in France and the UK) where it is best developed (Mortimore & Pomerol, 1991) (Fig. 7).

The lower part of the *B. mucronata* Zone, at the top of the Chalk succession in the South Downs, is locally preserved on Portsdown. The base of the zone is correlated with the Farlington Marls (e.g. Mortimore 1986b) rather than the underlying Bedhampton Marls (e.g. Mortimore, 1986a).

The typical fauna comprises common inoceramid shell fragments, the belemnite *Belemnitella*, and small subconical forms of *Echinocorys*, named *E. subconicula*. Giant forms of the echinoid *Galeola* also occur locally (Mortimore, 1986a) (Fig. 7). The fauna is best developed at Farlington Redoubt [SU 6865 0644], on Portsdown, and includes *Echinocorys* aff. *conica* (Woods, 1995a), which typically occurs above *E. subconicula* elsewhere in the UK where more complete successions through the *B. mucronata* Zone are preserved (e.g. East Anglia, Wessex Basin, Northern Ireland). The *B. mucronata* Zone is inferred to occur near the top of the succession at Clapper Hill, near Fareham, where Brydone collected *Echinocorys subconicula* (Woods, 1995a).

Appendix 1 - Author citations for fossil species

Following standard taxonomic convention, author citations in parenthesis indicate that the genus currently applied to a species has changed since the date of it's original description.

Acanthoceras jukesbrownei (Spath, 1926)

Actinocamax versus Miller, 1823

Acutostrea incurva (Nilsson, 1827)

Amphidonte obliquatum (Pulteney, 1813)

Bathrotomaria perspectiva (Mantell, 1822)

Bicavea rotaformis Gregory, 1907

Bourgueticrinus granulosus Peron, 1887

Calycoceras naviculare (Mantell, 1822)

Capillithyris squamosa (Mantell, 1822)

Cidaris subvesiculosa d'Orbigny, 1850

Cladoceramus undulatoplicatus (Röemer, 1855)

Concinnithyris subundata (J Sowerby, 1813)

Conorca turbinella (J de C Sowerby, *)

Conulus albogalerus Leske, 1778

C. subrotundus (Mantell, 1822)

Cordiceramus cordiformis (J de C Sowerby, 1823)

Crateraster quinqueloba (Goldfuss, 1826)

Cremnoceramus crassus (Petrascheck, 1903)

C. deformis erectus (Meek, 1877)

C. inconstans (Woods, 1912)

C. rotundatus (sensu Tröger, 1967 non Fiege, 1930)

C. waltersdorfensis (Andert, 1911)

Cretirhynchia cuneiformis Pettitt, 1950

C. exsculpta Pettitt, 1950

C. intermedia Pettitt, 1950

C. limbata (sensu Gaster, 1924 *non* Schlotheim, 1813)

C. minor Pettitt, 1950

C. norvicensis Pettitt, 1950

Echinocorys scutata (Leske, 1778)

E. subconicula Griffith & Brydone, 1911

E. brydonei Gale MS

E. cincta Brydone, 1912

E. conica (Agassiz, 1840)

E. depressula Griffith & Brydone, 1911

E. elevata Brydone, 1912

E. gravesi (Desor, 1847)

E. marginata (Goldfuss, 1826)

E. tectiformis Brydone, 1912

E. truncata Griffith & Brydone, 1911

Entolium orbiculare (J Sowerby, 1817)

Eomicraster leskei magna Drummond, 1983

E. leskei minor Drummond, 1983

Euomphaloceras septemseriatum (Cragin, 1893)

Filograna avita (J de C Sowerby, 1844)

Forresteria (*Harleites*) *petrocoriensis* (Coquand, 1859)

Gauthieria radiata (Sorignet, 1850)

Gibbithyris ellipsoidalis Sahni, 1929

Gonioteuthis granulata (Blainville, 1827)

G. quadrata (Blainville, 1827)

Grasirhynchia martini (Mantell, 1822)

Hagenowia blackmorei Wright & Wright, 1949

Hirudocidaris hirudo (Sorignet, 1850)

Inoceramus atlanticus (Heinz, 1936)

I. costellatus Woods, 1913

I. crippsi Mantell, 1822

I. cuvieri J Sowerby, 1814

I. lamarcki Parkinson, 1819

I. lamarcki stuemckli Heinz, 1928

I. pictus J de C Sowerby, 1829

I. tenuis Mantell, 1822

I. virgatus Schlüter, 1877

Kingena concinna Owen, 1970

Lyropecten (*Aequipecten*) *arlesiensis* (Woods, 1902)

Mantelliceras dixoni Spath, 1926

M. saxbii (Sharpe, 1857)

Micraster (*Isomicraster*) *gibbus* (Lamarck, 1816)

M. coranguinum (Leske, 1778)

M. corbovis Forbes, 1850

M. cortestudinarium (Goldfuss, 1826)

M. decipiens (Bayle, 1878)

M. leskei (Desmoulins, 1837)

M. normanniae Bucaille, 1883

M. precursor sensu Drummond, 1983

M. turonensis (Bayle, 1878)

Modestella geinitzi (Schloenbach, 1866)

Monticlarella jefferiesi Owen, 1968

Mytiloides aviculoides (Meek & Hayden, 1860)

M. columbianus (Heinz, 1935)

M. costellatus (Woods, 1913)

M. fiegei (Tröger, 1967)

M. ganuzaensis (López, 1992)

M. hattini Elder, 1991

M. hercynicus (Petrascheck, 1903)

M. incertus (Jimbo, 1894)

M. kossmati (Heinz, 1930)

M. labiatoidiformis (Tröger, 1967)

M. mytiloides (Mantell, 1822)

M. puebloensis Kennedy, Walaszczyk & Cobban, 2000

M. striatoconcentricus (Gümbel, 1868)

M. subhercynicus (Seitz, 1934)

Neithea (*N.*) *sexcostata* (Woodward, 1833)

Offaster pilula (Lamarck, 1816)

O. pilula nana Brydone MS

O. pilula planatus Brydone, 1939 sensu Ernst, 1971

Orbirhynchia cuvieri (d'Orbigny, 1847)

O. dispansa Pettitt, 1954

O. herberti Pettitt, 1954

O. mantelliana (J de C Sowerby, 1826)

O. multicostata Pettitt, 1954

O. reedensis (Etheridge, 1881)

O. wiesti (Quenstedt, 1871 sensu Jefferies, 1961)

Oxytoma seminudum (Dames, 1874)

Porosphaera patelliformis Hinde, 1904

Praeactinocamax plenus (Blainville, 1825)

Pseudocalycoceras dentonense (Moreman, 1942)

Pseudoperna boucheroni (sensu Woods, 1913 non Coquand, 1859)

Puzosia (*Anapuzosia*) *dibleyi* (Spath, 1922)

Pycnodonte vesiculare (Lamarck, 1806)

Romaniceras (*Yubariceras*) *ornatissimum* (Stoliczka, 1864)

R. deverianum (d'Orbigny, 1841)

Roveacrinus communis Douglas, 1908

Roweaster rowei Drummond, 1983

Sciponoceras baculoides (Mantell, 1822)

S. bohemicum anterior Wright & Kennedy, 1981

S. gracile (Shumard, 1860)

Sharpeiceras schlueteri Hyatt, 1903

Stauronema carteri Sollas, *

Sternotaxis placenta (Agassiz, 1840)

S. plana (Mantell, 1822)

Terebratulina lata Etheridge, 1881

T. rowei Kitchin, 1900

Turrilites scheuchzerianus Bosc, 1925

Uintacrinus anglicus Rasmussen, 1961

U. socialis Grinnell, 1876

Volviceramus involutus (J de C Sowerby, 1828)

V. koeneni (Müller, 1888)

Watinoceras devonense Wright & Kennedy, 1981

(*: date to be added)

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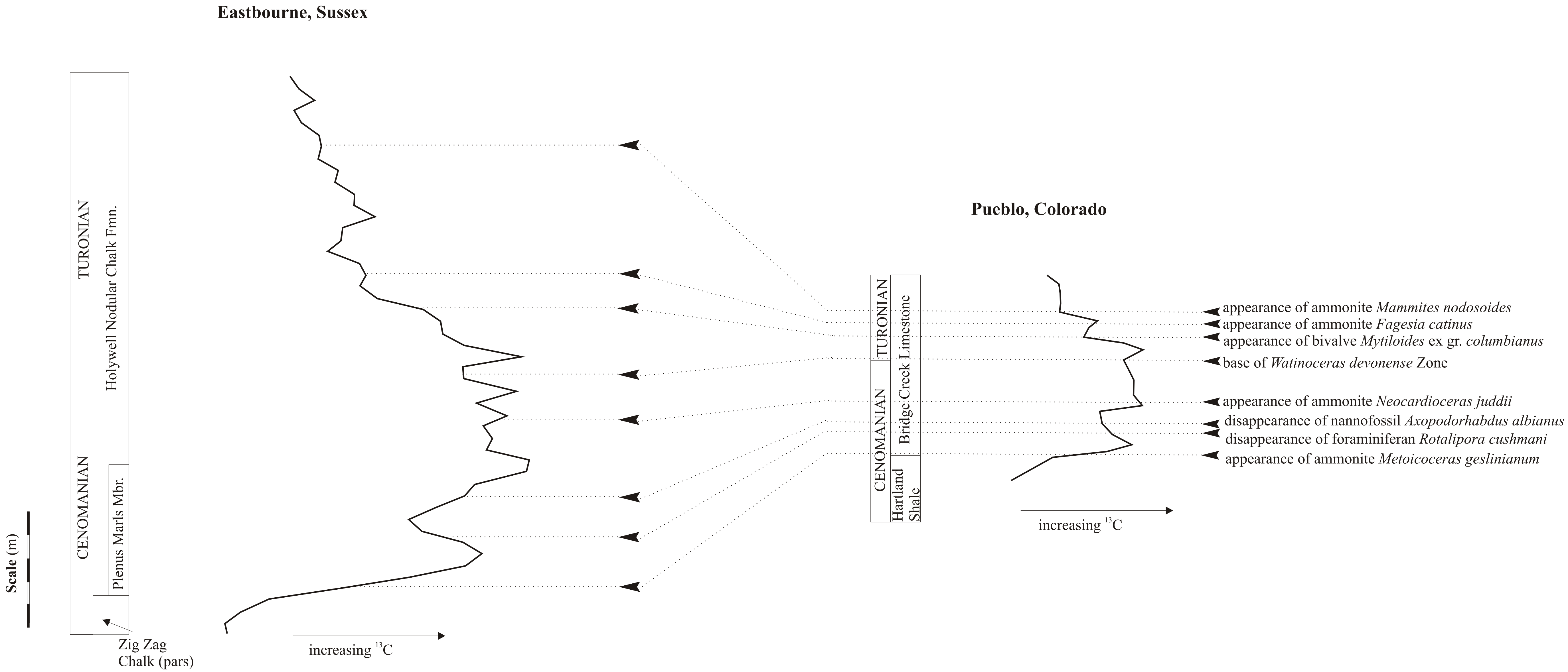


FIGURE 1. Correlation of the ^{13}C signatures across the Cenomanian - Turonian boundary at Eastbourne, Sussex and Pueblo, Colorado with respect to eight key bio-markers
(based on figures by Gale et al., 1993)

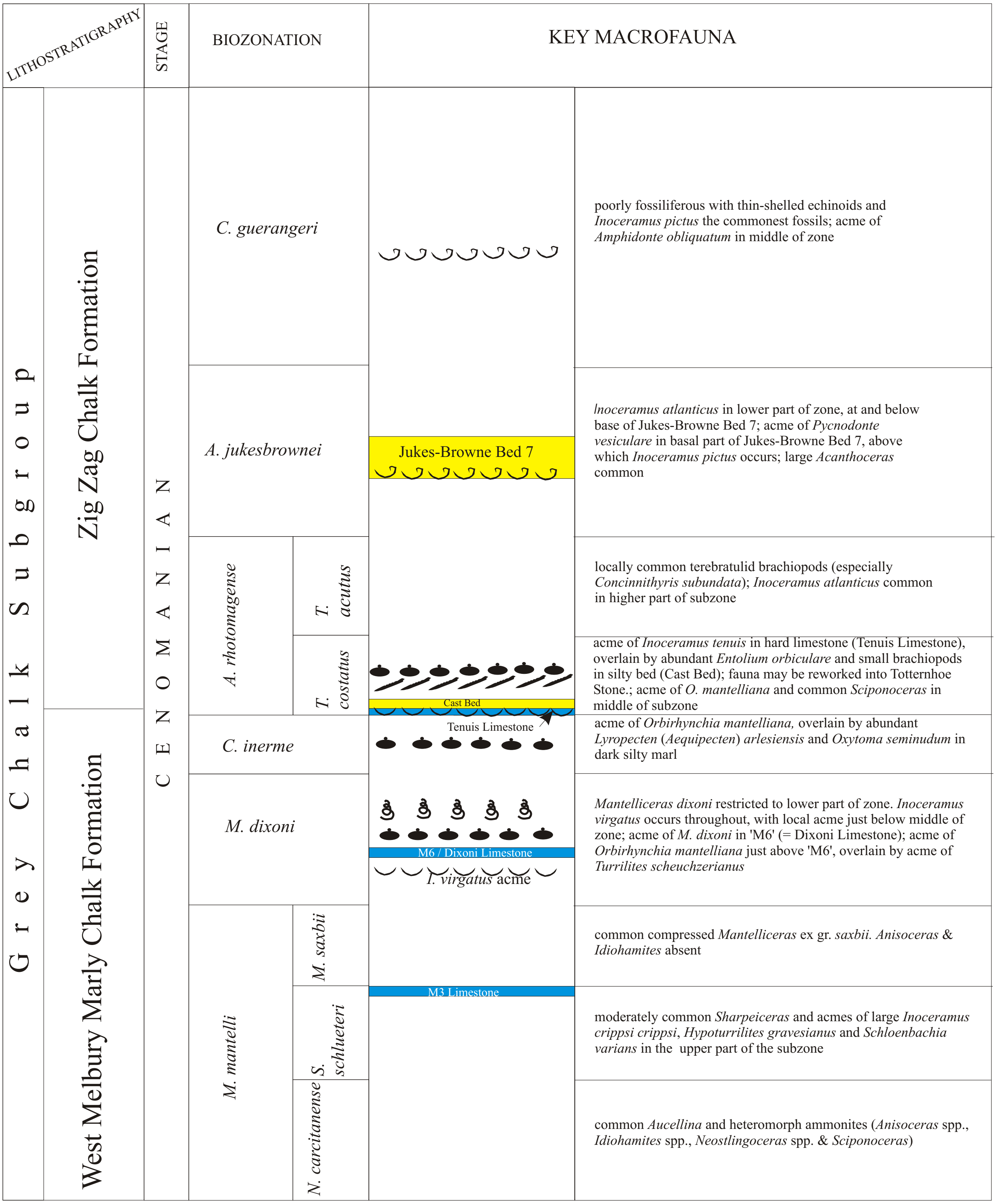
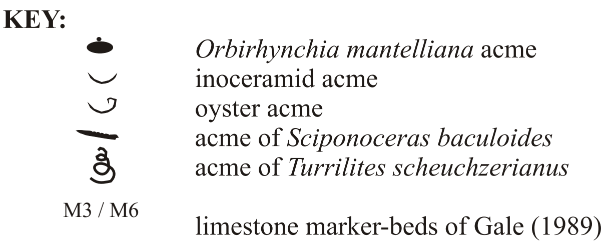


Figure 2. Key faunal characteristics of the Grey Chalk Subgroup.
(not to scale)



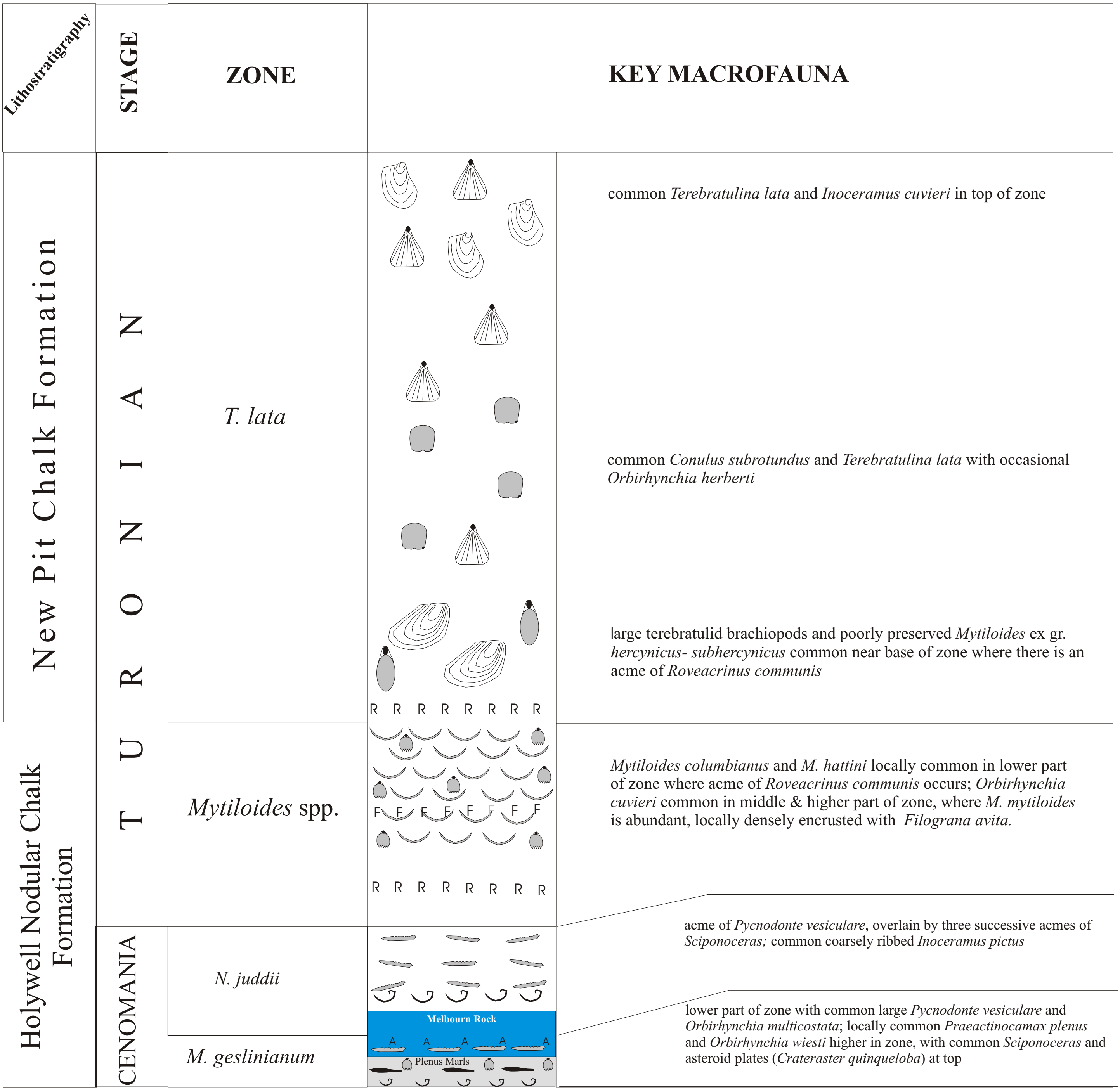
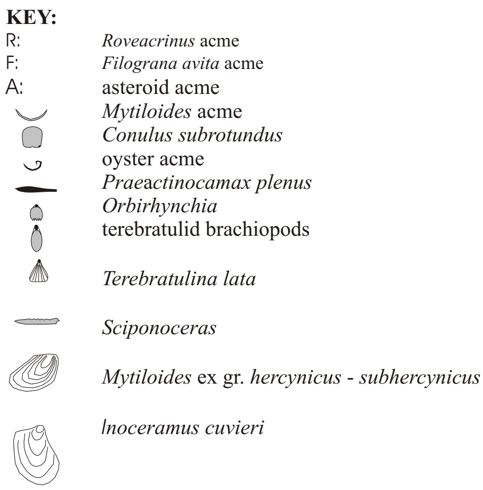


Figure 3. Key faunal characteristics of the Holywell Nodular Chalk and New Pit Chalk formations
(not to scale)



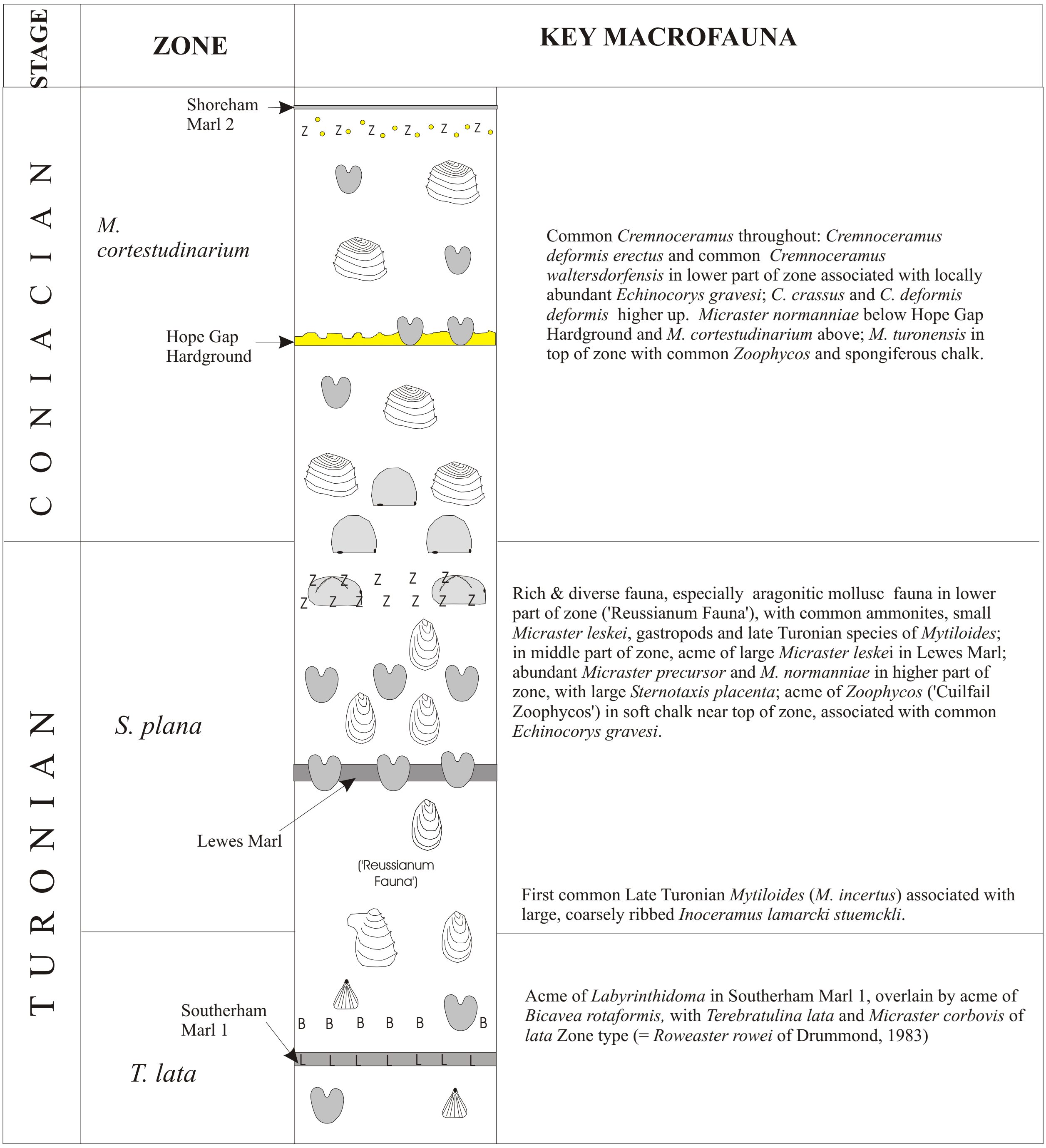


FIGURE 4. Key faunal characteristics of the Lewes Nodular Chalk Formation (not to scale)

KEY:

L: *Labyrinthidoma* acme
B: *Bicavea rotaformis* acme
Z: *Zoophycos* acme
Terebratulina lata
Micraster
Inoceramus lamarcki stuemckli
Late Turonian *Mytiloides* spp.
Sternotaxis placenta
Echinocorys gravesi
Cremnoceramus spp.
major sponge bed

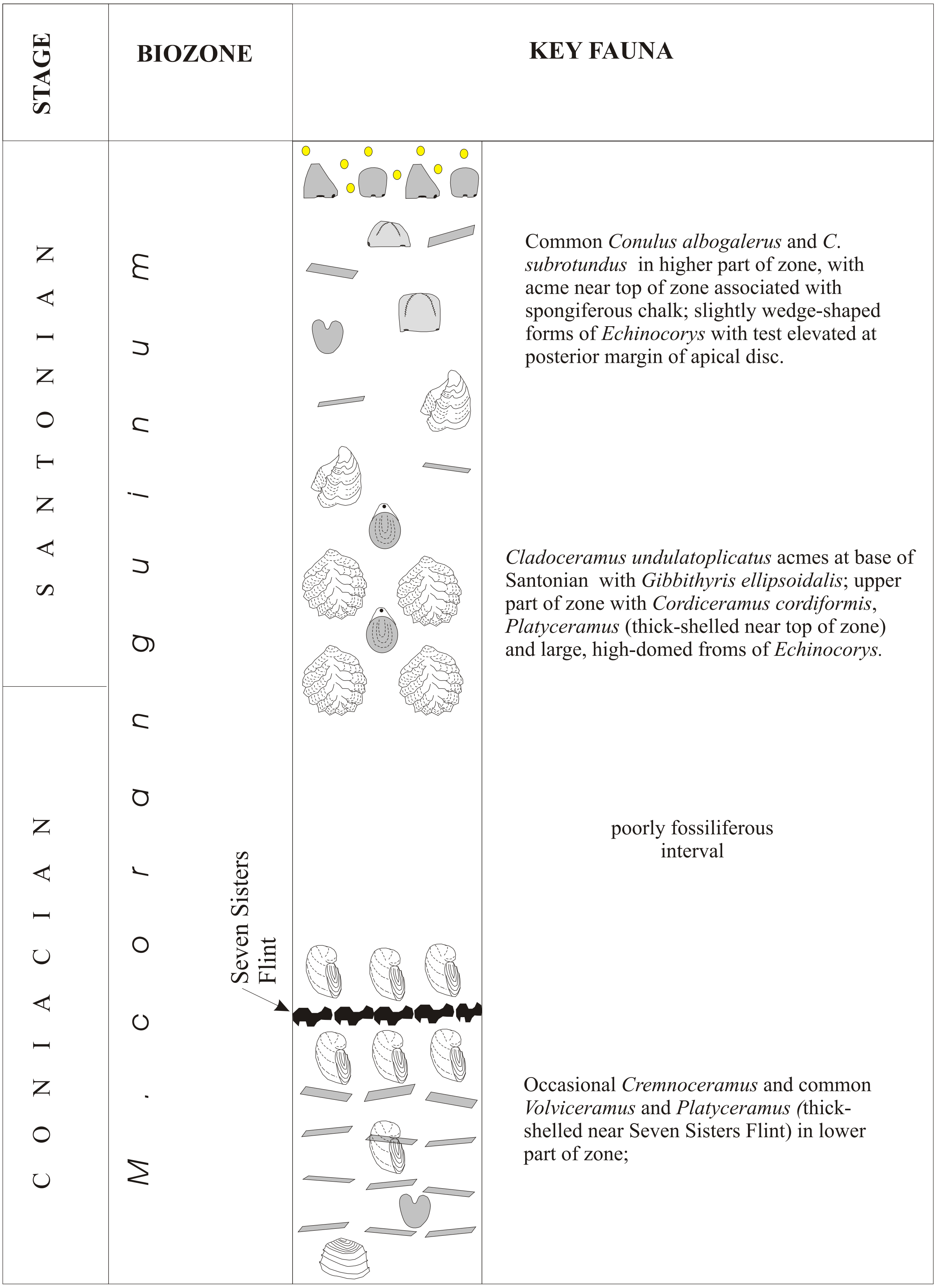
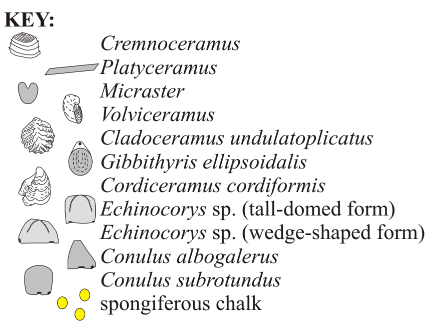


FIGURE 5. Biostratigraphical Summary of the Seaford Chalk Formation
(not to scale)



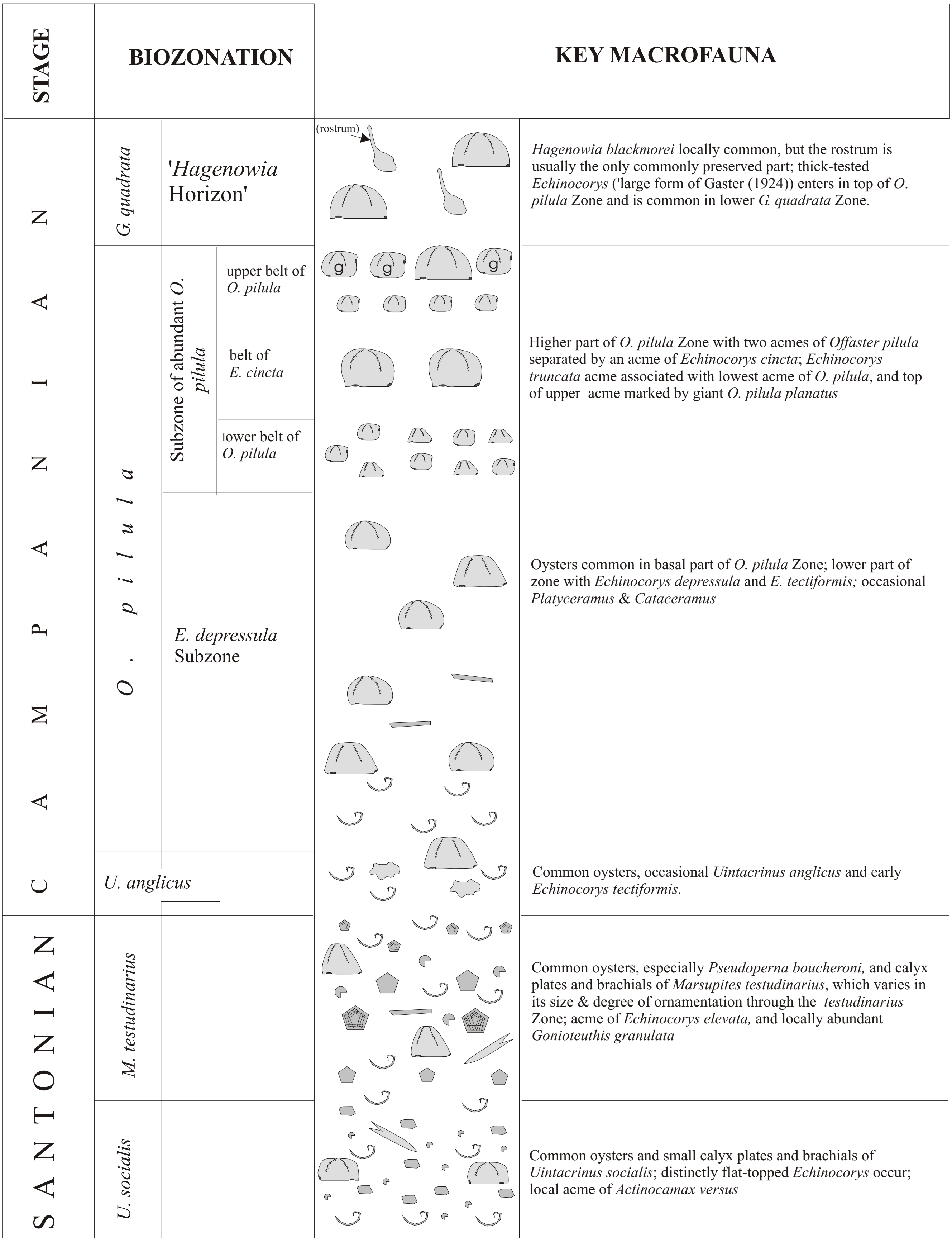
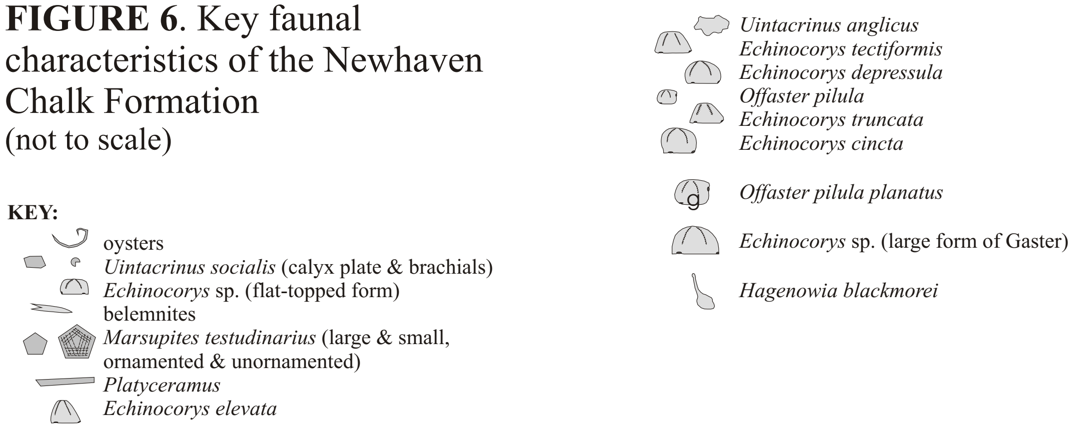


FIGURE 6. Key faunal characteristics of the Newhaven Chalk Formation
(not to scale)



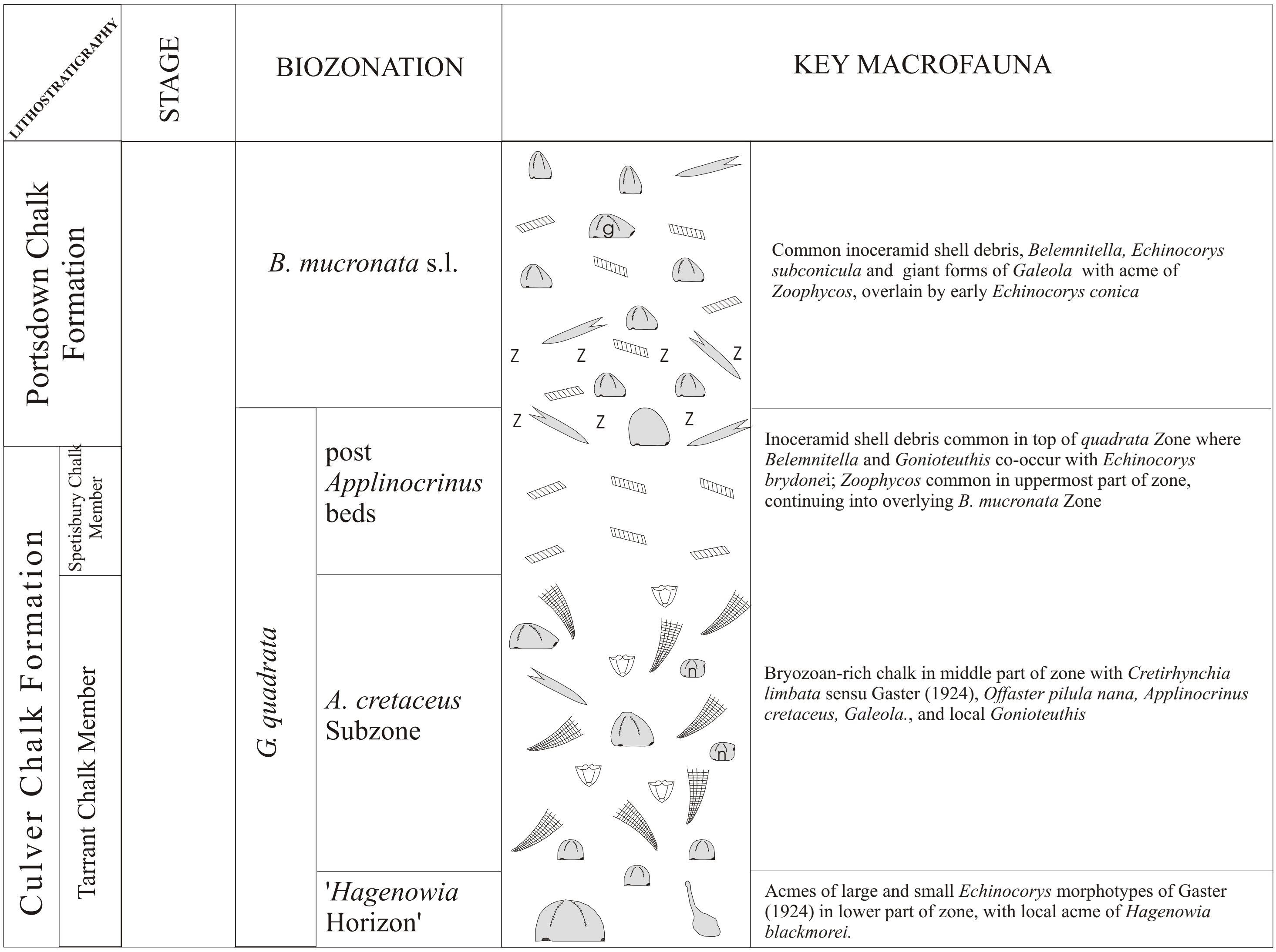
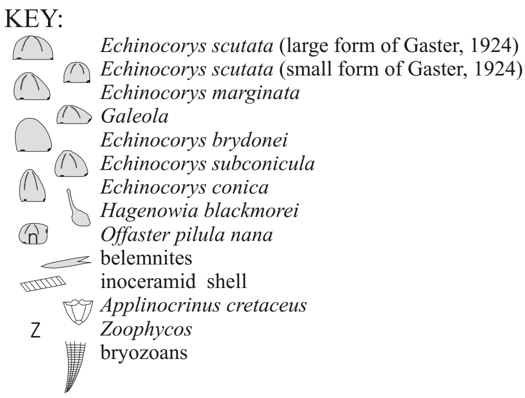


FIGURE 7. Key faunal characteristics of the Culver and Portsdown Chalk formations.
(not to scale)



STAGE	Standard UK Macrofossil biozones: ZONE	SUBZONE	Lithostratigraphy: Subgroup	Lithostratigraphy: Formation
CAMPANIAN	*B. mucronata*		White Chalk Subgroup	Portsdown Chalk Fmn.
CAMPANIAN	*G. quadrata*	Post *A. cretaceus*	White Chalk Subgroup	Culver Chalk Fmn.: Spetisbury Chalk Mbr
CAMPANIAN	*G. quadrata*	*A. cretaceus*	White Chalk Subgroup	Culver Chalk Fmn.: Tarrant Chalk Mbr
CAMPANIAN	*G. quadrata*	*Hagenowia* Horizon	White Chalk Subgroup	Culver Chalk Fmn.: Tarrant Chalk Mbr
CAMPANIAN	*O. pilula*	abundant *O. pilula*: upper belt of *O. pilula*; belt of *E. cincta*; lower belt of *O. pilula*	White Chalk Subgroup	Newhaven Chalk Fmn.
CAMPANIAN	*O. pilula*	*E. depressula*	White Chalk Subgroup	Newhaven Chalk Fmn.
CAMPANIAN	*U. anglicus*		White Chalk Subgroup	Newhaven Chalk Fmn.
SANTONIAN	*M. testudinarius*		White Chalk Subgroup	Newhaven Chalk Fmn.
SANTONIAN	*U. socialis*		White Chalk Subgroup	Newhaven Chalk Fmn.
SANTONIAN / CONIACIAN	*M. coranguinum*		White Chalk Subgroup	Seaford Chalk Fmn.
CONIACIAN	*M. cortestudinarium*		White Chalk Subgroup	Lewes Nodular Chalk Fmn.
TURONIAN	*S. plana*		White Chalk Subgroup	Lewes Nodular Chalk Fmn.
TURONIAN	*T. lata*		White Chalk Subgroup	Lewes Nodular Chalk Fmn. / New Pit Chalk Fmn.
TURONIAN	*Mytiloides spp.*		White Chalk Subgroup	Holywell Nodular Chalk Fmn.
CENOMANIAN	*N. juddii*		White Chalk Subgroup	Holywell Nodular Chalk Fmn.
CENOMANIAN	*M. geslinianum*		White Chalk Subgroup	Holywell Nodular Chalk Fmn.
CENOMANIAN	*C. guerangeri*		Grey Chalk Subgroup	Zig Zag Chalk Fmn.
CENOMANIAN	*A. jukesbrownei*		Grey Chalk Subgroup	Zig Zag Chalk Fmn.
CENOMANIAN	*A. rhotomagense*	*T. acutus*	Grey Chalk Subgroup	Zig Zag Chalk Fmn.
CENOMANIAN	*A. rhotomagense*	*T. costatus*	Grey Chalk Subgroup	Zig Zag Chalk Fmn.
CENOMANIAN	*C. inerme*		Grey Chalk Subgroup	West Melbury Marly Chalk Fmn.
CENOMANIAN	*M. dixoni*		Grey Chalk Subgroup	West Melbury Marly Chalk Fmn.
CENOMANIAN	*M. mantelli*	*M. saxbii*	Grey Chalk Subgroup	West Melbury Marly Chalk Fmn.
CENOMANIAN	*M. mantelli*	*S. schlueteri*	Grey Chalk Subgroup	West Melbury Marly Chalk Fmn.
CENOMANIAN	*M. mantelli*	*N. carcitanense*	Grey Chalk Subgroup	West Melbury Marly Chalk Fmn.

ammonite zonal equivalents not recognisable in the UK

Turonian & Early Coniacian ammonite biozonation in the UK Chalk Group

ZONE	SUBZONE
F. petrocoriense	
S. neptuni	*S. normalis*
S. neptuni	*S. neptuni*
S. neptuni	*R. deverianum*
C. woollgari	
M. nodosoides	
F. catinus	
W. devonense	

TABLE 1. The standard macrofossil biozonation of the Chalk Group in the South Downs, and its correspondence with international ammonite zones for the Turonian and basal Coniacian.
(not to scale)

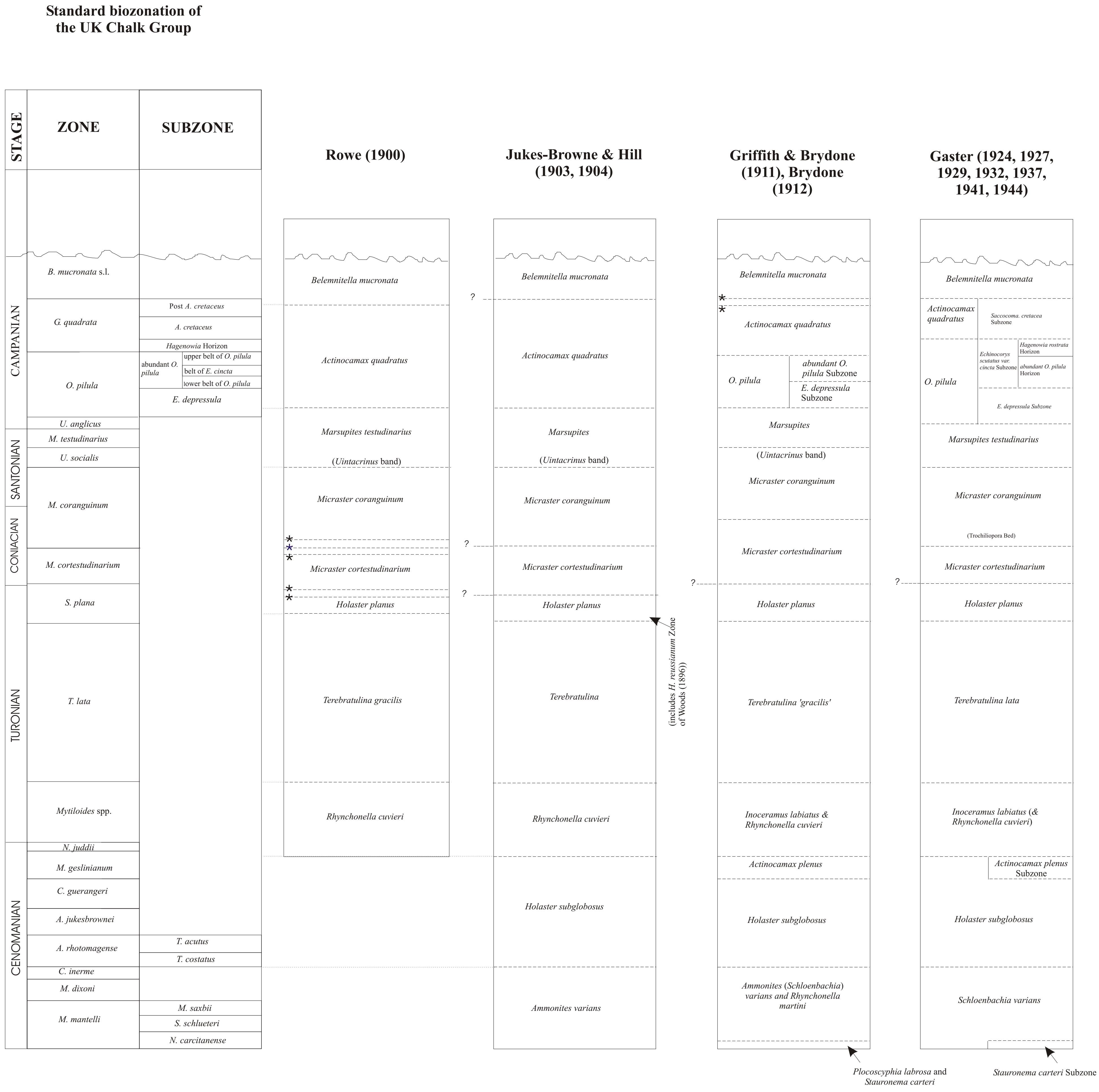
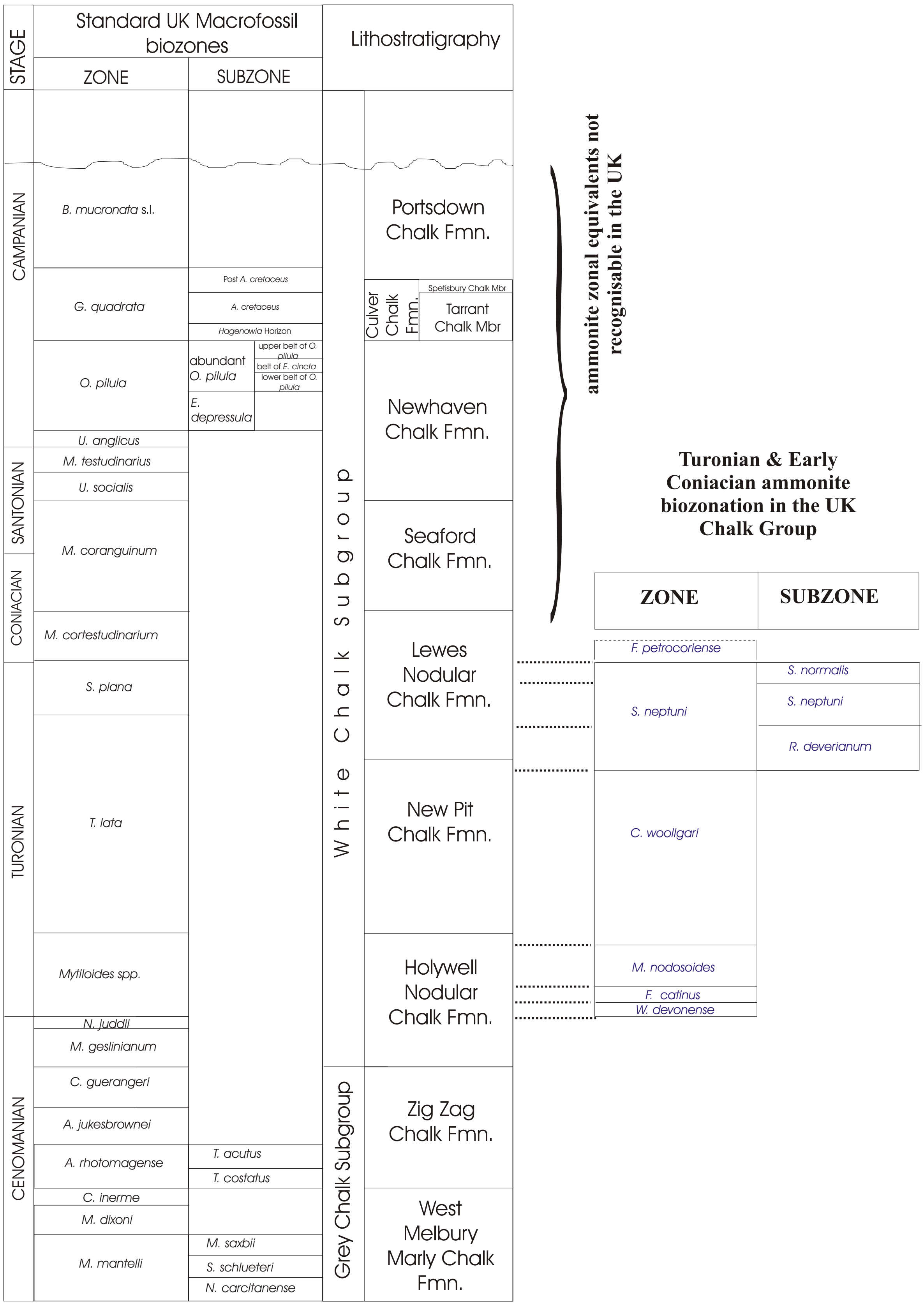


TABLE 2. Comparison of previous biozonal concepts and nomenclature in the Chalk Group with the currently accepted standard macrofossil zonation. (not to scale)

*: alternative position for biozonal boundary where previously used ambiguously or inconsistently

FORMATION	ZONE	DEFINITION	SUBZONE	DEFINITION	CHARACTERISTIC FAUNA
Zig Zag Chalk	*Calycoceras guerangeri*	The zone is coincident with the total range of the index species. In the South Downs, as elsewhere, the top of the zone is marked lithostratigraphically by the Sub-Plenus Marls erosion surface	None	——	Bivalves: *Amphidonte obliquatum* *Inoceramus pictus* Ammonites: *Parapuzosia* (*Austiniceras*) *austeni* *Calycoceras guerangeri* *C.* spp. *Eucalycoceras pentagonum* *Thomelites* spp. Echinoids: *Holaster* spp. (thin-shelled & fragmentary specimens)
	Acanthoceras jukesbrownei	The zone is coincident with the total range of the index species (Robaszynski et al., 1998)	None	——	Bivalves: *Inoceramus atlanticus* *I. pictus* *Pycnodonte vesiculare* Ammonites: *Acanthoceras jukesbrownei*
	Acanthoceras rhotomagense	The base of the zone is immediately below the first appearance of the index species. The top of the zone is immediately below the first appearance of *Acanthoceras jukesbrownei.* The index species ranges through the lower and middle part of the zone only (Robaszynski et al., 1998)	*Turrilites acutus*	The base of the subzone is immediately below the first appearance of the index species. The top of the subzone is immediately below the first appearance of the ammonite *Acanthoceras jukesbrownei*. The index species occurs in the lower part of the subzone only (Robaszynski et al., 1998)	Brachiopods: *Concinnithyris subundata* Bivalves: *Inoceramus atlanticus* Ammonites: *Acanthoceras rhotomagense* *Turrilites acutus*
			Turrilites costatus	The base of the subzone is immediately below the first appearance of the index species. The top of the subzone is immediately below the first appearance of the ammonite *Turrilites acutus*. The index species ranges through the lower and middle part of the subzone only (Robaszynski et al., 1998)	Brachiopods: *Capillithyris squamosa* *Grasirhynchia martini* *Kingena concinna* *Modestella geinitzi* *Orbirhynchia mantelliana* Bivalves: *Entolium orbiculare* *Inoceramus tenuis* *Oxytoma seminudum* Ammonites: *Acanthoceras rhotomagense* *Cunningtoniceras inerme* *Sciponoceras baculoides* *Turrilites costatus*
West Melbury Marly Chalk	*Cunningtoniceras inerme*	The base of the zone is placed immediately below the first appearance of the index species. The top of the zone is immediately below the first appearance of the ammonite *Acanthoceras rhotomagense* (Gale, 1995).The index species ranges right through the zone, and into the lower part of the overlying *A. rhotomagense* Zone (Robaszynski et al., 1998)	None	——	Brachiopods: *Orbirhynchia mantelliana* Bivalves: *Inoceramus schoendorfi* *Lyropecten* (*Aequipecten*) *arlesiensis* *Oxytoma seminudum* Ammonites: *Cunningtoniceras cunningtoni* *C. inerme*
	Mantelliceras dixoni	The base of the zone is placed immediately below the first appearance of the index species. The top of the zone is immediately below the first appearance of the ammonite *Cunningtoniceras inerme* (Gale, 1995).The index species is restricted to the lower part of the zone (Robaszynski et al., 1998).	None	——	Brachiopods: *Orbirhynchia mantelliana* Bivalves: *Inoceramus virgatus* Ammonites: *Acompsoceras* spp. *Hyphoplites* spp. *Mantelliceras dixoni* *M. saxbii* *M*. spp. *Mesoturrilites* spp.
	Mantelliceras mantelli	Zone defined as the interval from the appearance of *M. mantelli* to the appearance of *M. dixoni* (Gale, 1995). The base of the zone is coincident with the base of the Chalk Group over much of southern England (except parts of Dorset)	*Mantelliceras saxbii*	The base of the subzone is recognised by the appearance of common compressed ammonites of the *M. saxbii* group. The top of the subzone is immediately below the first appearance of *M. dixoni*. The index occurs in the *S. schlueteri* Subzone (inflated forms) and ranges into the *M. dixoni* Zone (Wright & Kennedy, 1984)	Brachiopods: *Orbirhynchia mantelliana* Bivalves: *Inoceramus virgatus* Ammonites: *Acompsoceras* spp. *Hyphoplites* spp. *Mantelliceras dixoni* *M. saxbii* *M*. spp. *Mesoturrilites* spp.
			Sharpeiceras schlueteri	The base of the subzone is immediately below the common occurrence of the ammonite *Sharpeiceras* spp., and the top of the subzone is immediately below the common occurrence of *Mantelliceras saxbii*	Bivalves: *Inoceramus crippsi* Ammonites: *Hypoturrilites gravesianus* *Mantelliceras* spp. *Schloenbachia* spp. *Sharpeiceras* spp.
			Neostlingoceras carcitanense	The base of the subzone is the base of the *M. mantelli* Zone, and the top of the zone occurs immediately below the common occurrence of *Sharpeiceras* spp. (Gale & Friedrich, 1989; Gale, 1995)	Sponges: *Stauronema carteri* Brachiopods: *Tropeothyris? carteri* Bivalvies: *Aucellina* spp. *Inoceramus anglicus* Ammonites: *Anisoceras* spp. *Idiohamites* spp. *Mantelliceras mantelli* *Neostlingoceras carcitanense* *Sciponoceras* spp.

TABLE 3. The definition and faunal characteristics of biozones in the Grey Chalk Subgroup (not to scale)


STAGE
Standard UK Macrofossil biozones
ZONE
SUBZONE
Lithostratigraphy
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
B. mucronata s.l.
G. quadrata
Post A. cretaceus
A. cretaceus
Hagenowia Horizon
O. pilula
abundant O. pilula
upper belt of O. pilula
belt of E. cincta
lower belt of O. pilula
E. depressula
U. anglicus
M. testudinarius
U. socialis
M. coranguinum
M. cortestudinarium
S. plana
T. lata
Mytiloides spp.
N. juddii
M. geslinianum
C. guerangeri
A. jukesbrownei
A. rhotomagense
T. acutus
T. costatus
C. inerme
M. dixoni
M. mantelli
M. saxbii
S. schlueteri
N. carcitanense
White Chalk Subgroup
Grey Chalk Subgroup
Portsdown Chalk Fmn.
Culver Chalk Fmn.
Spetisbury Chalk Mbr
Tarrant Chalk Mbr
Newhaven Chalk Fmn.
Seaford Chalk Fmn.
Lewes Nodular Chalk Fmn.
New Pit Chalk Fmn.
Holywell Nodular Chalk Fmn.
Zig Zag Chalk Fmn.
West Melbury Marly Chalk Fmn.
ammonite zonal equivalents not recognisable in the UK
Turonian & Early Coniacian ammonite biozonation in the UK Chalk Group
ZONE
SUBZONE
F. petrocoriense
S. neptuni
S. normalis
S. neptuni
R. deverianum
C. woollgari
M. nodosoides
F. catinus
W. devonense