

## Calcareous nannoplankton biozonation of the Thanetian Stage (Palaeocene) in the type area

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**ABSTRACT**—The Thanetian Stage in the type area is composed of the Thanet Formation, the Woolwich Bottom Bed and the Oldhaven Beds. The Thanet Formation at the stratotype localities in southeastern England contains calcareous nannoplankton Zones NP 6/7 and NP 8. The Woolwich Bottom Bed and Oldhaven Beds are not zonable in the type area. The marine “Bottom Bed” of the Woolwich and Reading Beds is, however, assignable to Zone NP 9 outside the type area (at Clarendon Hill in Wiltshire).

### INTRODUCTION

Among the chronostratigraphic units, “stages” serve the stratigrapher particularly well. Stages represent time intervals short enough to be used in local or regional correlation, yet still have the potential for use in worldwide correlation. The original Tertiary stages were defined in Europe during the 19th century; original or subsequently designated stratotypes and reference sections for these stages are located in various Western European countries.

The Thanetian stage is the most widely used (i.e., “standard”) stage for the uppermost Palaeocene. Any correlation of rock sequences from elsewhere in the world to the Thanetian Stage depends on an accurate knowledge of the biozonation of the Thanetian stratotype and reference sections. The calcareous nannoplankton zonation of the Thanetian in the type area (southeastern England) has been contentious. The purpose of this paper is, therefore, to examine the nannoplankton in the formations composing the Thanetian in the type area, in an attempt to refine the biozonation of the type Thanetian. Martini’s (1971) calcareous nannoplankton zonation will be used in this study. We do not consider units such as ‘Selandian’ or ‘Sparnacien’ and their relationship to the type Thanetian; problems of such units in terms of nomenclature and correlation are considered by Berggren *et al.* (in press).

### STRATIGRAPHIC BACKGROUND

#### Lithostratigraphy

Prestwich (1852) coined the term “Lower London Tertiaries” for the rock units between the Chalk and the London Clay. For the oldest of these – the marine silts, marls and sands immediately overlying the Chalk – he introduced the term “Thanet Sands”. Prestwich

did not cite a type section, but stated that the Thanet Sands were “. . . best exhibited, and marked by organic remains, in part of the Isle of Thanet and immediately adjacent districts”.

The best exposures of the Thanet Formation, and the locality from which the Thanetian stage takes its name, are indeed on, and immediately adjacent to, the Isle of Thanet (an island in Roman times – now a peninsula) (Fig. 1). The lower members of the Thanet Formation are exposed in degraded sea cliffs at Pegwell Bay (Figs. 2 & 3), and the upper members are well exposed in the cliffs and foreshore at Herne Bay – Reculver (Figs. 4 & 5) on the Isle of Thanet. The lower part of the section at Herne Bay – Reculver overlaps the upper part of the section at Pegwell Bay by about 6 m (Curry, 1981).

Whitaker (1872, p. 56) divided the “Thanet Sands” into five lithological subdivisions designated as “beds a – e”. Whitaker (1872) also illustrated the relationships of these units in a hypothetical section drawn across London and Kent. Because of an error in drafting, this section was redrawn by Gardner (1883); both sections are figured in Ward (1977). Haynes (1956) proposed lithological and geographical names for Whitaker’s “beds”, and Cooper (1976) appended the lithostratigraphic rank “Member” to each of Haynes’ units within the Thanet Formation without further elaboration.

WHITAKER's bed	HAYNES' name
e	Reculver Silts
d	Pegwell Marls
c	Kentish Sands
b	Stourmouth Clays
a	Bullhead Flint Conglomerate

The Reculver Silts, Pegwell Marls and Stourmouth Clays occur in the eastern part of the Thanet outcrop area and interdigitate with the Kentish Sands to the

west. They are underlain over the whole outcrop area by the Bullhead Flint Conglomerate, which rests disconformably on Coniacian or Santonian Chalk. Ward (1977) reviewed previous work on the Thanet Formation and redescribed the classic section at Pegwell Bay (Fig. 1). He redefined the Bullhead Flint Conglomerate Member, renaming it the "Base-bed Member" and including in it the overlying 0.75–1.5 m of glauconitic sandy silt.

Ward (1979) also redescribed the Thanet, Woolwich and Reading, and Oldhaven formations at Herne Bay – Reculver, subdividing the section into "Units A – N". Debate has long existed concerning the boundary between the Thanet Formation and the overlying Woolwich and Reading Beds at Herne Bay. Prestwich (1854, p. 112) placed the boundary at the base of the *Corbula regulbiensis* Bed (= bed G of Ward, 1979) (Fig. 5), because the bed was coarser grained and more glauconitic than the units below. Gurr (1963, p. 419) described a horizon about 2.7 m above Prestwich's boundary where there is a more distinct lithological and

faunal break; Gurr's horizon is now generally used as the boundary (see Ward, 1979, for further discussion of the boundary problem).

From the Isle of Thanet, the Thanet Formation thins rapidly to the south and northwest (Hester, 1965). Curry *et al.* (1978) and Curry (1981) suggested that the top of the Thanet was bevelled by erosion prior to deposition of the overlying formations. The presence of derived blocks of shelly Thanet Formation in the pebbly base of the overlying formation at Swanscombe (Stamp & Priest, 1920, p. 193) supports this view. The maximum Thanet Formation thickness is between 25–33 m (Prestwich, 1852; Hester, 1965).

In 1854, Prestwich described the "Woolwich and Reading Series" (the second division of his "Lower London Tertiaries"). The term "Woolwich and Reading Series" evolved progressively in the literature from "Series" to "Beds" to "Formation" (see Stinton, 1975; Cooper, 1976; Curry *et al.*, 1978; and Curry, 1981, concerning relevant terminological changes). "Woolwich and Reading Beds" appears, however, to be the

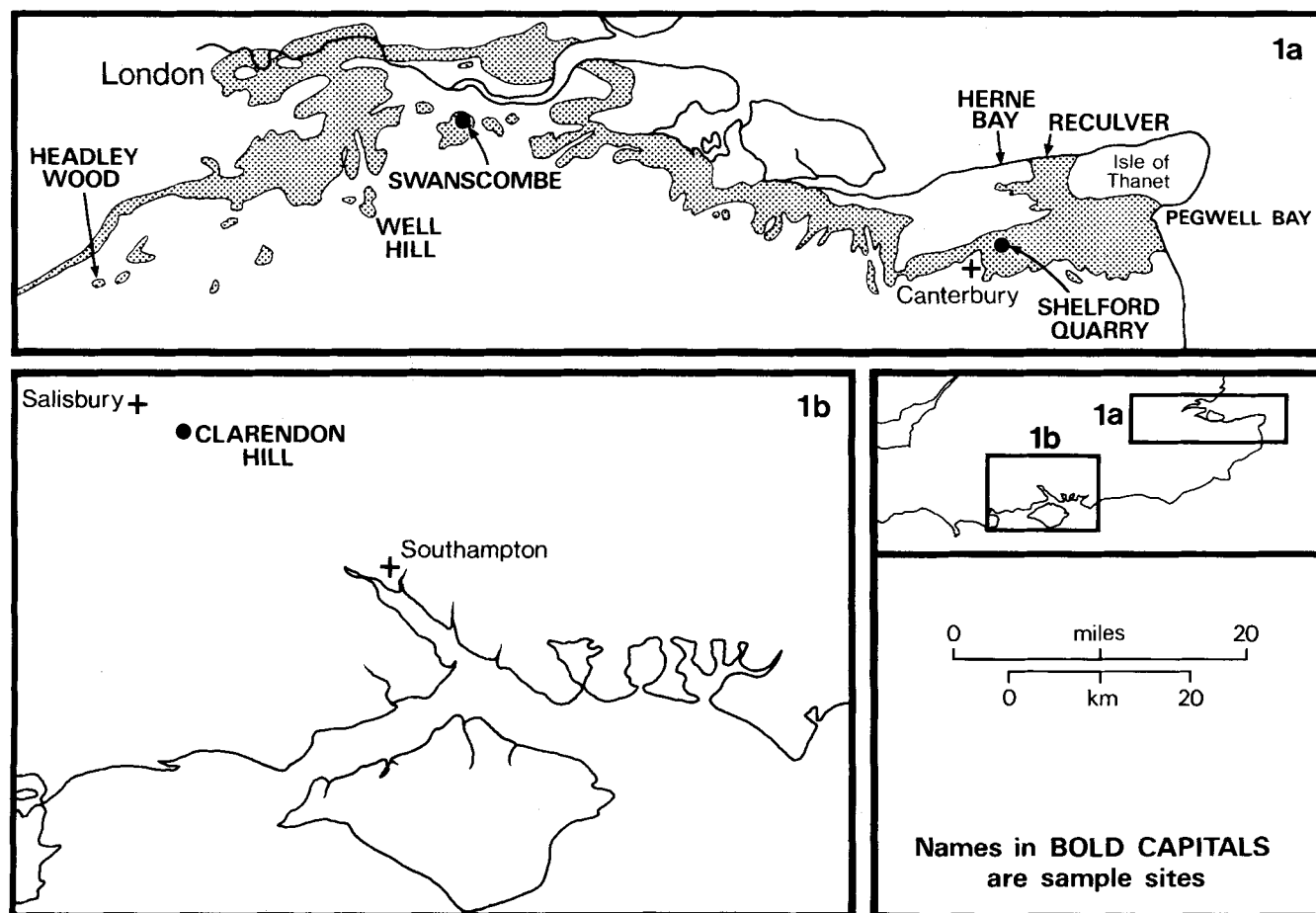


Fig. 1. Location map showing sampling and other localities mentioned in the text. Outcrop pattern of the Thanet Formation, Woolwich and Reading Beds and Blackheath and Oldhaven Beds indicated by stippled ornament.

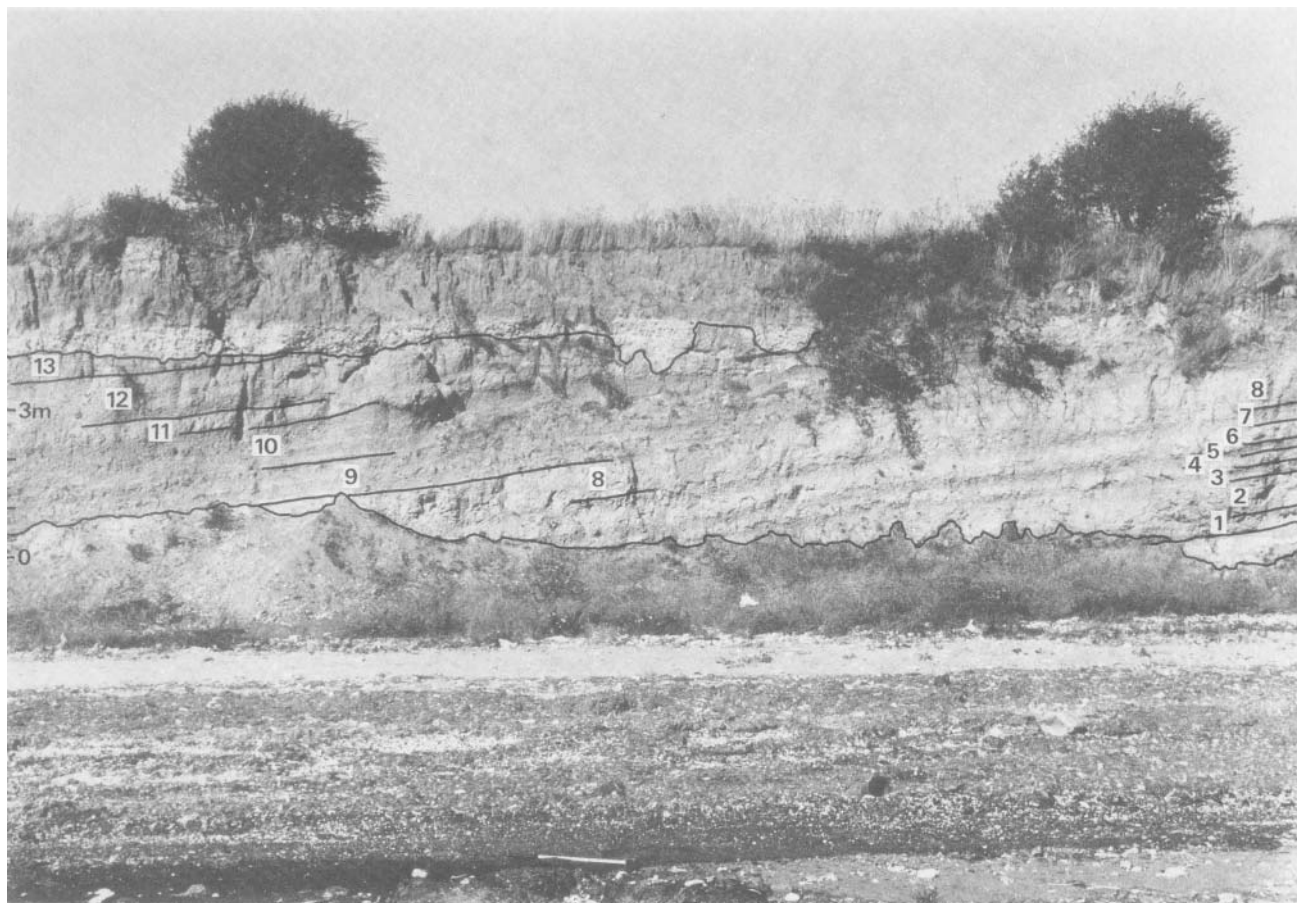


Fig. 2. Photograph of the Cliff End section at Pegwell Bay. Numbered beds correspond to those shown in Fig. 3.

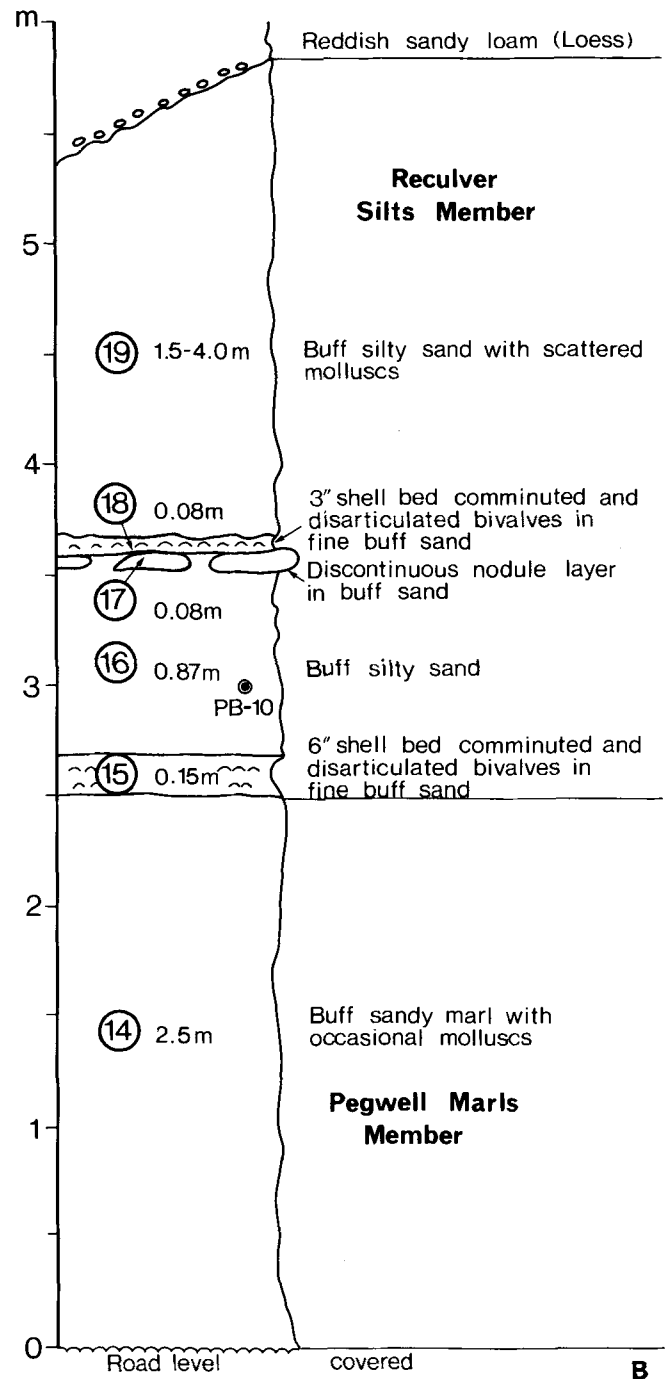
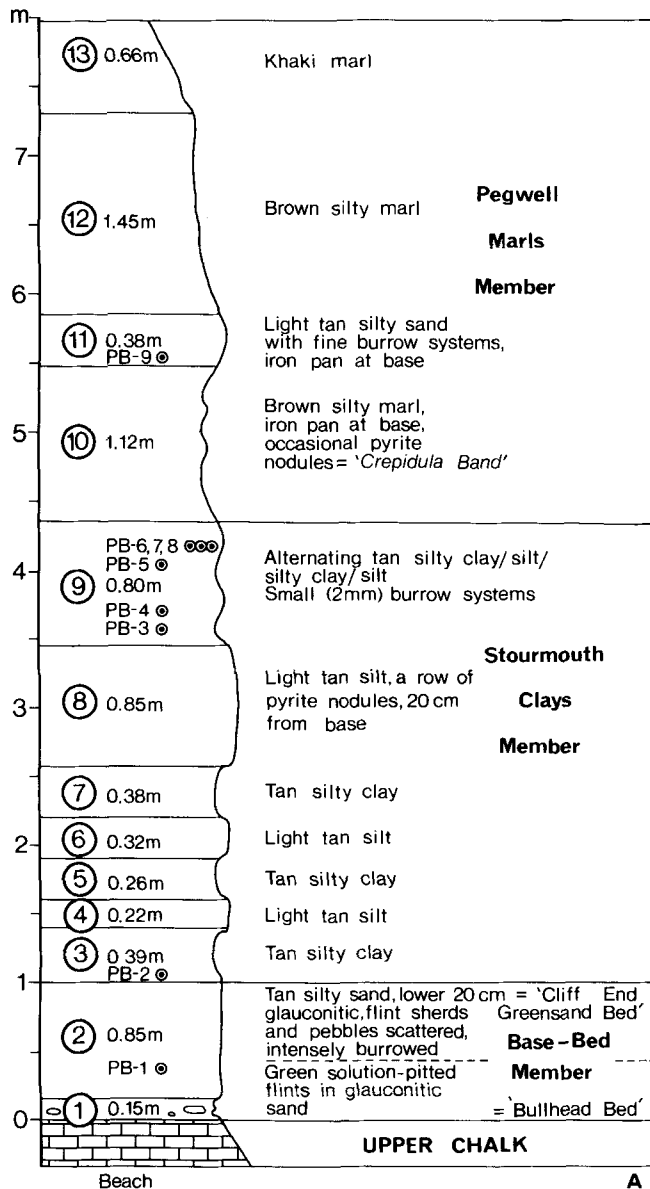
most commonly used term in the current literature (e.g. Ellison, 1983; Knox, 1984; Cox *et al.*, 1985). Hester (1965) demonstrated that the Woolwich and Reading Beds could be divided into three units: the mottled clays and fluviatile sands of the (1) "Reading Beds" which pass laterally into, overlie or interdigitate with, the (2) "Woolwich Shell Beds" which are laminated shelly estuarine and/or lagoonal clays. Both overlie the (3) "Woolwich Bottom Bed", which consists of up to 6 m of glauconitic sand containing one or more pebble beds.

The Woolwich Bottom Bed (which also includes what has been called the "Reading Bottom Bed") is exposed sporadically over the whole of the Woolwich and Reading outcrop area (Fig. 6). In lithology and thickness this basal unit is fairly uniform, although it does thin to the west. At Herne Bay – Reculver it consists of an olive-grey, silty clay with scattered pebbles and sharks' teeth at the base, overlain by 5 m of grey-green, intensely burrowed, silty sand. At Swanscombe (Fig. 1), the base is marked by a thick bed of rounded flint pebbles in a sandy matrix. To the south

and west of the London Basin, at Headley Heath and in the Hampshire Basin at Clarendon Hill (Fig. 1) respectively, the base is marked by an oyster bed in a silty glauconitic sand.

To the north and west of London, the Woolwich Bottom Bed is overlain by fluviatile, partly deltaic sands and freshwater mottled clays of the Reading Beds (Hester, 1965). In the London area, the Reading Beds interdigitate with the Woolwich Shell Beds, although the two lithologies are always distinct and recognisable. In the Hampshire Basin, the Reading "mottled clay", known locally as "Stamshaw Clay", usually rests on varying thicknesses of brown, deltaic sands and loams. A sandy facies, the "Reading Sands", thins to the east and persists in southern and southeastern London as a thin (about 50 cm thick) conglomeratic pebble bed (Fig. 6), which immediately underlies the Reading Clay.

In the London area and east into Kent, the Woolwich Shell Beds and the Woolwich Striped Loams (Whitaker, 1889) overlie the Woolwich Bottom Bed (Fig. 6). The maximum thickness of the Woolwich Shell Beds is



10 m; however, owing to subsequent erosion prior to deposition of the Striped Loams, this thickness is rarely preserved.

Whitaker (1866) proposed the name "Blackheath and Oldhaven Beds" for sand and pebble beds previously included by Prestwich in the London Clay Basement Bed. The Blackheath Beds crop out in northwestern Kent, where they comprise thick pebble lenses and shelly sands containing estuarine and marine fossils. They fill channels which in places cut through the entire "Lower London Tertiaries" to rest on the Chalk (Fig. 6). The precise position of the Blackheath Beds within a lithostratigraphic framework has been debated. Cooper (1976, p. 6) suggested that the

Fig. 3 A & B. Lithostratigraphic sections at Pegwell Bay. Lithostratigraphic Units 1–13 (circled) are exposed in the Cliff End (A) section (Fig. 2); Units 14–19 are exposed about 400 m to the southwest, in the Hoverport car park (B) section. Thickness of each unit is given to the right of the unit number. There is a gap of 7 m between units 13 and 14. PB-1, PB-2, etc., indicate where the samples shown in Table 2 were collected.



Fig. 4. Photograph of the cliff section at Herne Bay, 200 m east of Bishopstone Glen. Lettered beds correspond to those shown in Fig. 5.

Blackheath pebble beds are a western extension of the Oldhaven pebble bed, and the shelly sands are a facies of the Woolwich Beds in a position similar to the Striped Loams.

The Oldhaven Beds are well exposed in the sea cliffs and foreshore at Herne Bay – Reculver (Ward, 1979), at Shelford Quarry near Canterbury, and at the Blue Circle Cement Quarry near Swanscombe (Fig. 1). As with the Woolwich Bottom Bed, the Oldhaven Beds thin in a westerly direction; at Herne Bay about 6 m of marine, cross-bedded, glauconitic sands are exposed, whereas 60 km to the west at Swanscombe only 60 cm are present. The base of the Oldhaven Beds is irregular and is marked by a discontinuous pebble band (Fig. 5), often containing derived blocks of the Woolwich Beds. In eastern Kent, none of the Striped Loams and little of the Woolwich Shell Beds remain, and the Oldhaven Beds rest directly on the Woolwich Bottom Bed (Fig. 6). King (1981) separated the Oldhaven Beds from the

paralic Blackheath Beds and linked the Oldhaven Beds with lithologies previously loosely termed the “London Clay Basement Bed”, calling this unit the “Oldhaven Formation”.

#### Chronostratigraphy

As described earlier, Prestwich (1852) introduced the term “Thanet Sands”, and later (1854) the term “Woolwich and Reading Series” for rock units exposed between the Chalk and the London Clay in southeastern England. “Blackheath and Oldhaven Beds” was the name later proposed by Whitaker (1866) for sand and pebble beds previously included in the basal unit of the London Clay. Renevier (1873) subsequently applied the age-stage term “Thanetien” to the interval represented by those rocks occurring in England below the London Clay. In his discussion of lower Tertiary palaeogeography, Dollfus (1880) erected several new stage names. One of these was the “Sparnacien”, with the type section at Epernay in France. He included the

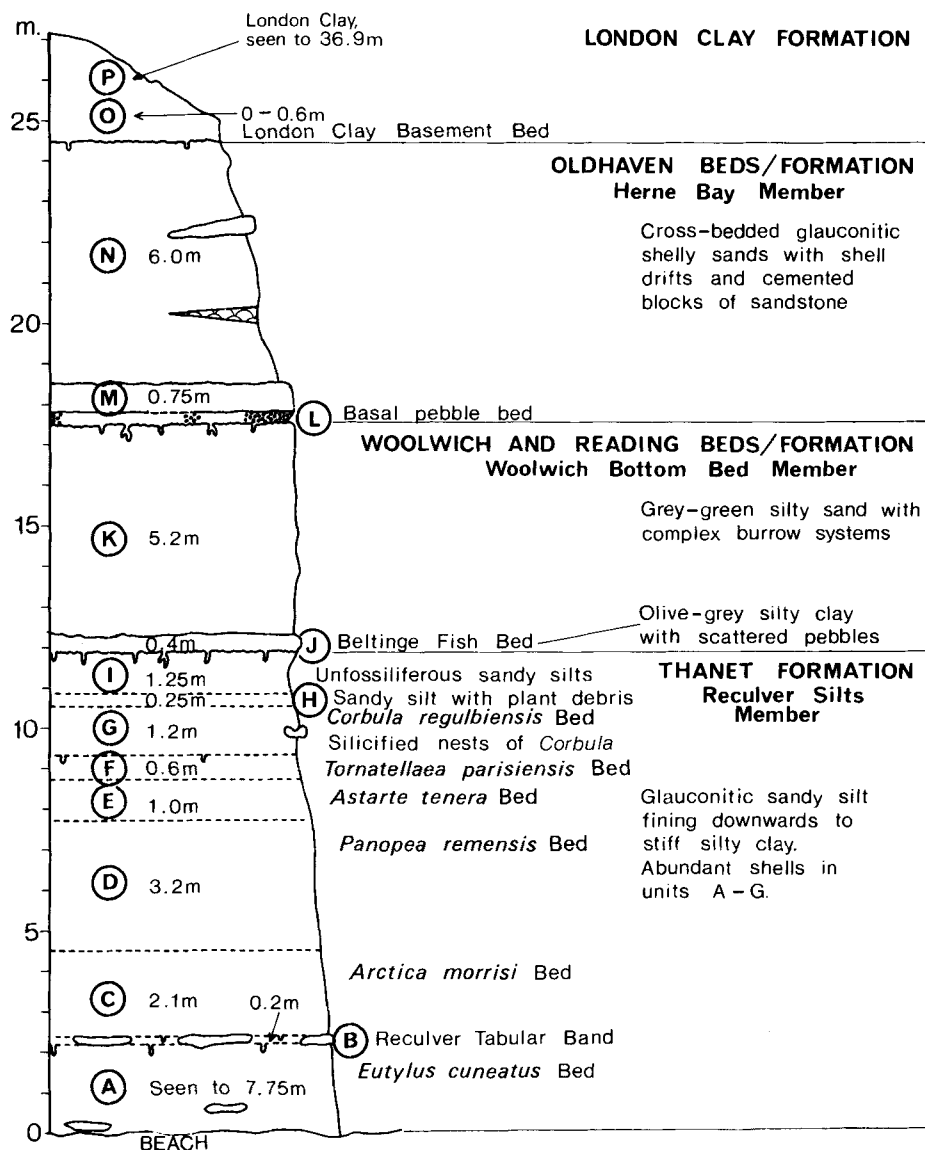


Fig. 5. Composite lithostratigraphic section at Herne Bay. Lithostratigraphic Units A-P are indicated by circled letters. HB-A, HB-B, etc., samples shown in Table 2 were collected near the middle of each unit, except for Units G and M. G1 in Table 2 was collected from the lower, silicified layer of Unit G, and M1 from the lower part of Unit M. Samples were collected from outcrops in the intertidal zone, where exposures are fresher than in the nearby cliffs shown in Fig. 4.

Woolwich and Reading Beds in this stage, together with equivalent units in France, but left the underlying Thanet beds in the Thanetian. Removal of the Woolwich and Reading Beds thus created a shortened and restricted Thanetian Stage, as compared with the Thanetian originally defined by Renevier.

Curry (1981) noted that "Thanetian" (English spelling) has almost always been used (in Britain) in the restricted sense of Dollfus. As no formal stratotype was proposed by Renevier or other early workers, Curry (1981) eventually designated the cliffs at Pegwell Bay

and Herne Bay - Reculver to be co-stratotypes for the stage (this definition excluded the overlying Woolwich Bottom Bed and Oldhaven Beds).

The Woolwich and Reading Beds and the Blackheath and Oldhaven Beds are, nevertheless, latest Palaeocene in age (Keen, 1978; Curry *et al.*, 1978; Hamilton, 1982). When used as the international stage for the uppermost Palaeocene, the Thanetian must therefore include the Woolwich and Reading Beds and the Blackheath and Oldhaven Beds (see, for example, Keen, 1978). Berggren *et al.* (in press) note that the

Sparnacian Stage is the biostratigraphic equivalent of the Woolwich and Reading Beds of England, and show the Sparnacian Stage stratotype as correlatable to the uppermost Thanetian in their fig. 3.

Berggren *et al.* (in press) draw attention to some fundamental problems with the Thanetian Stage. There is a significant biostratigraphic gap between the top of the underlying Danian Stage (the top of which is assigned to NP 3, NP 4 or NP 5, depending on the author consulted) and the base of the Thanetian (NP 7 or NP 8). Berggren *et al.* (in press) suggest that this problem can be solved by placing an as yet unnamed stage between the Danian and Thanetian, and/or that the Selandian be used as a standard stage spanning the entire post-Danian Palaeocene. The Selandian would therefore comprise the unnamed middle Palaeocene stage and the upper Palaeocene Thanetian Stage; it would also include the Sparnacian of France. (Additional discussion of the historical background and problems involving the Thanetian-Sparnacian-Selandian may be found in Berggren, 1971 and Perch-Nielsen & Hansen, 1981).

Hardenbol & Berggren (1978), Bignot & Cavelier (1981) and Curry & Odin (1982) have all used "Thanetian" in an expanded sense on their time scales, with the Thanetian lower boundary between NP 3 and NP 5. Haq (1983) placed the Selandian-Thanetian boundary at the NP 7 – NP 8 boundary. Berggren *et al.* (in press) consider the Thanetian *s.s.* to correspond essentially to NP 8, although noting the possibility of

NP 7 being present. On their time-scale diagram, however, they draw the lower Thanetian boundary within the upper part of NP 6, as suggested by magnetostratigraphic evidence. Hardenbol & Berggren (1978) and Berggren *et al.* (in press) placed the Thanetian-Ypresian boundary at the NP 9 – NP 10 boundary; Bignot & Cavelier (1981), Curry & Odin (1982) and Haq (1983) all placed it in the middle of NP 9.

#### Calcareous Nannoplankton Biostratigraphy

Bramlette & Sullivan (1961) listed several calcareous nannoplankton species from the type Thanetian, including the distinctive *Heliolithus riedeli*. Based largely on this species, they considered their "Biostratigraphic Unit 1" to be equivalent to at least part of the Thanetian (NP 8 – see, for example, Siesser (1983) for a correlation of Bramlette & Sullivan's units to Martini's (1971) NP Zones). Hay & Mohler (1967, p. 1520) confirmed the presence of *H. riedeli* in the Thanet Formation. Martini (1971) also assigned Zone NP 8 (*Heliolithus riedeli* Zone) to two samples he obtained from Reculver. No further work on the calcareous nannoplankton in the Thanetian type area was published until the work by Hamilton (1982). In that study, Hamilton recorded calcareous nannoplankton from seven samples collected at Pegwell Bay and Herne Bay – Reculver. Hamilton (1982) confirmed the assignment of NP 8 to the upper part of the Thanet at Herne Bay – Reculver, and noted *Discoaster multiradiatus* in the uppermost fossiliferous sample of the Thanet from

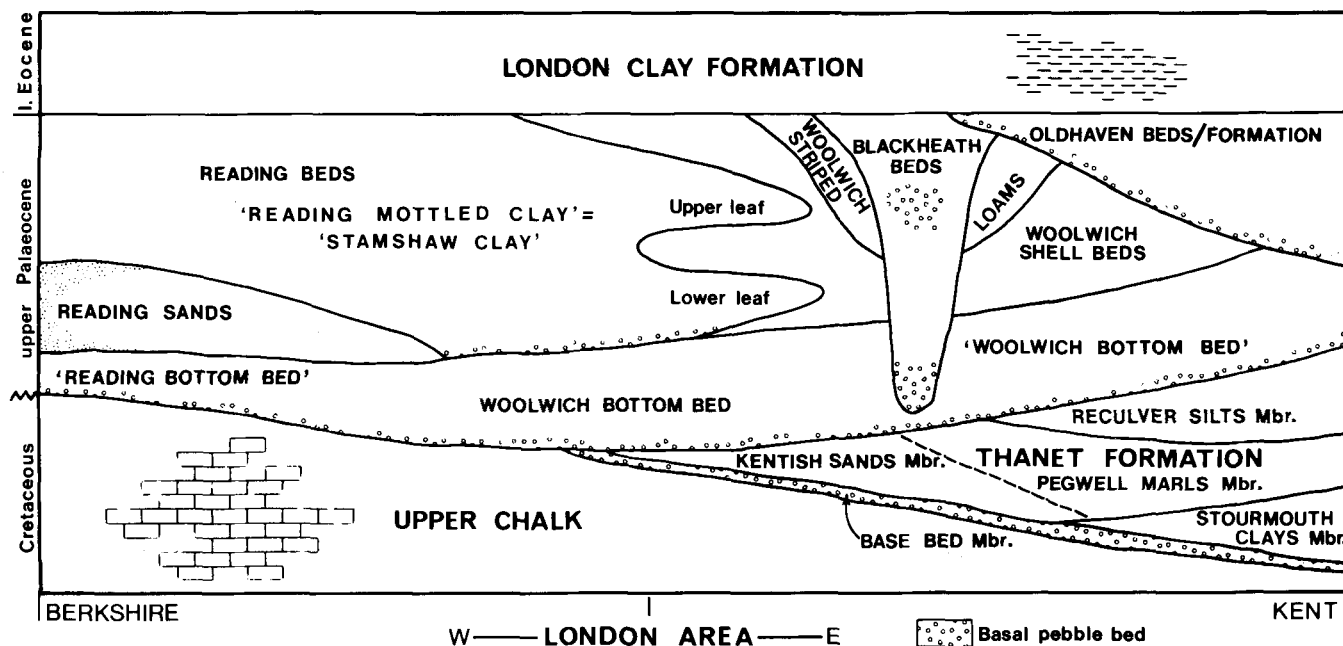


Fig. 6. Schematic cross section showing the stratigraphic relationships of the Thanetian Stage formations (between the Chalk and the London Clay) in southeast England. Not to scale.

Herne Bay. The first appearance of *Discoaster multiradiatus* Bramlette & Riedel, 1954 would indicate Martini's (1971) NP 9 Zone. Hamilton (1982) also recorded the presence of *D. multiradiatus* in a single sample from the Woolwich (Reading) Bottom Bed at Cold Ash Quarry, near Newbury (Fig. 1) in Berkshire.

More recently, as part of her study of the Palaeogene of all of northwestern Europe, Aubry (1983) re-examined the Thanetian sections at Pegwell Bay and Herne Bay – Reculver. Berggren *et al.* (in press), quoting Aubry (1983), raised a number of important questions concerning the presence of NP 9 in the Thanet and Woolwich and Reading Beds, suggesting, among other things, that *D. multiradiatus* may have been misidentified. They considered NP 9 to be undocumented in the Thanet and overlying Woolwich and Reading Beds.

Godfrey (1984) also examined the stratotype sections as part of an unpublished M.Sc. Diploma project report. As an extension of that study, Godfrey & Lord (1984) reported a re-examination of Hamilton's (1982) original sediment samples from which *D. multiradiatus* had been reported (the actual smear slide being no longer available). No specimens of *D. multiradiatus* could be found. Godfrey & Lord (1984) carefully re-collected samples from the type sections at Pegwell Bay and Herne Bay – Reculver. They reported finding a single specimen of *D. multiradiatus* from the Thanet Formation near the top of the Pegwell Bay section.

In an indirect correlation, Costa & Müller (1978) showed the presence of the dinoflagellate cyst *Deflandrea speciosa* Zone in the "Thanet Sands" and the *Apectodinium hyperacanthum* Zone in the "Woolwich Beds and Blackheath/Oldhaven Beds". These dinocyst zones correlate to Martini's (1971) NP 7/8 and NP 9 Zones, respectively.

Reference to work done on the Thanetian sections using other micro- and macrofossil groups may be found in Haynes (1956), Berggren (1971), Costa & Downie (1976), Ward (1977; 1979), King (1981), Curry (1981), and Berggren *et al.* (in press).

## CALCAREOUS NANNOPLANKTON IN THE STRATOTYPE FORMATIONS

We have again collected and examined samples from the stratotype localities at Pegwell Bay and at Herne Bay – Reculver (Fig. 1). We have also examined samples from sections at the Swanscombe Cement Quarry, the Shelford Quarry and the new Well Hall excavations (Tracey, 1986), as well as samples from several isolated localities (see Fig. 1).

Samples collected at Pegwell Bay and Herne Bay – Reculver contained reasonably good assemblages of calcareous nannoplankton fossils in the Thanet Formation. Samples collected from the Thanet elsewhere, and from the Woolwich and Reading Beds and Blackheath

and Oldhaven Beds everywhere, were essentially barren (a few reworked specimens only), with the exception of the Woolwich (Reading) Bottom Bed samples collected from Headley Heath and Clarendon Hill (Fig. 1).

Table 1 lists calcareous nannoplankton fossils we have found in the Thanetian in the type area. Bibliographical references for most of these species may be found in Loeblich & Tappan (1966, 1968, 1969, 1970a, 1970b, 1971 and 1973); for the remainder consult papers identified by an asterisk (\*) in the Reference List.

Distribution and relative abundance of calcareous nannoplankton occurring in the Thanet Formation and in the Woolwich Bottom Bed samples are shown in Table 2. Sample-collection levels are indicated on Figs. 3 and 5. Reworked Cretaceous specimens are present throughout the sections, but are not listed by separate species names in Tables 2. The Tertiary species *Biantholithus sparsus* is also present in most nannoplankton-bearing samples. This species is considered to become extinct in Zone NP 4 (Martini, 1971; Romein, 1979). We therefore believe this species is reworked in our samples.

In Table 2, abundance and preservation of specimens are indicated as follows: A = Abundant, more than 10 specimens of a single species per field of view at a magnification of  $\times 1000$ ; C = Common, 1 to 10 specimens per field; F = Few, one specimen per 2–10 fields; R = Rare, one specimen per 11–100 fields; V = Very Rare, one specimen per 101–1000 fields; G = Good preservation, overgrowth or dissolution effects rare; M = Moderate, a moderate amount of calcite overgrowth on specimens and dissolution of the more soluble species; P = Poor, overgrowth common and numerous species removed. Characteristic and/or stratigraphically important species are illustrated in Plates I–III. Smear slides and photographic negatives of specimens are stored in the Micropaleontology Collection, Department of Geology, Vanderbilt University.

## Biostratigraphy and Chronostratigraphy

In Martini's (1971) calcareous nannoplankton zonation, Zone NP 6 is defined as the interval between the first occurrence of *Heliolithus kleinpelli* and the first occurrence of *Discoaster gemmeus* (= *D. mohleri*); NP 7 is the interval between the first occurrence of *D. mohleri* and the first occurrence of *H. riedeli*. Zone NP 8 is the interval between the first occurrence of *H. riedeli* and the first occurrence of *D. multiradiatus*.

At Pegwell Bay, Aubry (1983) found only rare, poorly preserved specimens. Hamilton (1982) found *H. riedeli* in the Reculver Silts, high in the section, as did Godfrey (1984). Both assigned the Pegwell Bay section to Zone NP 8. No nannoplankton were found below the "*Crepidula* Band" (Fig. 3A) by previous workers. In this study, we were fortunate enough to find a thin

**Table 1.** Calcareous nannoplankton from the Thanetian Stage in the type area

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<i>Sphenolithus anarrhopus</i> Bukry & Bramlette, 1969
* <i>Markalius apertus</i> Perch-Nielsen, 1979
<i>Markalius astroporus</i> (Stradner) Hay & Mohler, 1967
* <i>Hornibrookina australis</i> Edwards & Perch-Nielsen, 1975
<i>Chiasmolithus bidens</i> (Bramlette & Sullivan) Hay & Mohler, 1967
<i>Braarudosphaera bigelowii</i> (Gran & Braarud) Deflandre, 1947
<i>Prinsius bisulcus</i> (Stradner) Hay & Mohler, 1967
* <i>Fasciculithus bitectus</i> Romein, 1979
<i>Fasciculithus bobii</i> Perch-Nielsen, 1971
<i>Heliolithus cantabriae</i> Perch-Nielsen, 1971
<i>Ericsonia cava</i> (Hay & Mohler) Perch-Nielsen, 1969
<i>Neochiastozygus concinnus</i> (Martini) Perch-Nielsen, 1971
<i>Chiasmolithus consuetus</i> (Bramlette & Sullivan) Hay & Mohler, 1967
<i>Thoracosphaera deflandrei</i> Kamptner, 1956
* <i>Discoaster drieri</i> Romein, 1980
* <i>Heliolithus elegans</i> (Roth) Romein, 1979
<i>Toweius eminens</i> (Bramlette & Sullivan) Gartner, 1971
<i>Thoracosphaera heimi</i> (Lohmann) Kamptner, 1920
<i>Discoaster helianthus</i> Bramlette & Sullivan, 1961
<i>Zygodiscus herlyni</i> Sullivan, 1964
<i>Micrantholithus inaequalis</i> Martini, 1961
<i>Fasciculithus involutus</i> Bramlette & Sullivan, 1961
<i>Neochiastozygus junctus</i> (Bramlette & Sullivan) Perch-Nielsen, 1971
<i>Semihololithus kerabyi</i> Perch-Nielsen, 1971
<i>Heliolithus kleinPELLI</i> Sullivan, 1964
<i>Prinsius martinii</i> (Perch-Nielsen) Haq, 1971
<i>Discoasteroides megastypus</i> Bramlette & Sullivan, 1961
<i>Discoaster mohleri</i> Bukry & Percival, 1971
<i>Toweius occultatus</i> (Locker) Perch-Nielsen, 1971
<i>Coccolithus pelagicus</i> (Wallich) Schiller, 1930
* <i>Toweius pertusus</i> (Sullivan) Romein, 1979
<i>Micrantholithus pinguis</i> Bramlette & Sullivan, 1961
<i>Zygodiscus plectopons</i> Bramlette & Sullivan, 1961
<i>Sphenolithus primus</i> Perch-Nielsen, 1971
<i>Heliolithus riedeli</i> Bramlette & Sullivan, 1961
<i>Ericsonia robusta</i> (Bramlette & Sullivan) Perch-Nielsen, 1971
<i>Thoracosphaera saxeae</i> Stradner, 1961
<i>Zygodiscus sigmoides</i> Bramlette & Sullivan, 1961
<i>Biantholithus sparsus</i> Bramlette & Martini, 1964
<i>Ericsonia subpertusa</i> Hay & Mohler, 1967
<i>Cruciplacolithus tenuis</i> (Stradner) Hay & Mohler in Hay, Roth, Schmidt & Boudreaux, 1967
<i>Toweius tovae</i> Perch-Nielsen, 1971
<i>Fasciculithus tympaniformis</i> Hay & Mohler, 1967

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(approximately 4 cm thick) nannoplankton-bearing layer, the top of which lies about 15 cm below the base of the *Crepidula* Band (Fig. 3A). The assemblage from this layer is shown as sample PB-8 in Table 2. This sample contains only a sparse assemblage, but is noteworthy in the number of *Heliolithus kleinPELLI* it contains (Pl. 2, figs. 2, 3) and in the total lack of *H. riedeli*. Higher in the Pegwell Bay section (in the

Reculver Silts; sample PB-10) and at Herne Bay – Reculver (samples HB-A to HB-F), *H. riedeli* is present as a frequent and ubiquitous component (indicating Zone NP 8), whereas *H. kleinPELLI* is absent or very rare (Table 2).

The presence of *H. kleinPELLI* and the absence of *H. riedeli* indicates a zonal assignment to NP 6/7. A lengthy search for *D. mohleri* in samples PB-8 (and in

**Table. 2.** Calcareous nannoplankton in the Thanet Formation and Woolwich Bottom Bed

	Pegwell Bay										Herne Bay														Headley Heath	Clarendon Hill	
	PB 1	PB 2	PB 3	PB 4	PB 5	PB 6	PB 7	PB 8	PB 9	PB 10	HB A	HB C	HB D	HB E	HB F	HB G1	HB G2	HB H	HB I	HB J	HB K	HB L	HB M1	HB M2			
ABUNDANCE	B	B	B	B	B	R	R	R	B	C	C	C	C	R	V	B	B	B	B	B	B	B	B	B		C	C
PRESERVATION						P	P	P		P	P	P	P	P	P											P	M
<i>S. anarrhopus</i>											V																
<i>M. apertus</i>											V																
<i>M. astroporus</i>										V																	
<i>H. australis</i>										R	F	R	R														
<i>C. bidens</i>										F	F	R	F												R		R
<i>B. bigelowi</i>											R	R															
<i>P. bisulcus</i>										R	R	R	R														
<i>F. aff. bitectus</i>													V														
<i>F. bobii</i>														V													
<i>H. cantabriae</i>										R	R	R		R													
<i>E. cava</i>										F	F	F	F	R											R		
<i>N. concinnus</i>										V	V																
<i>C. consuetus</i>											V		V												V		
<i>T. deflandrei</i>											V																
<i>D. drieri</i>										V																	
<i>H. cf. elegans</i>													R														
<i>T. eminens</i>										R	R	R	R												R		R
<i>S. kerabyi</i>										V	R																
<i>T. heimi</i>											R					V											
<i>D. helianthus</i>										V	V																
<i>Z. herlyni</i>										R	R																
<i>M. inaequalis</i>											F	R	R														
<i>F. involutus</i>								R		R	R	R	R	R											R		R
<i>N. junctus</i>											R		R														
<i>H. kleinPELLI</i>						V	R	R			V		V														
<i>P. martinii</i>										R	R	R	R														
<i>D. megastypus</i>										V																	
<i>D. mohleri</i>										R	R		R														R
<i>D. multiradiatus</i>																											R
<i>T. occultatus</i>										V																	R
<i>C. pelagicus</i>										R	F	R	R														F
<i>T. pertusus</i>										R	R	R	R														
<i>M. pinguis</i>											V		V														
<i>Z. plectopons</i>										R	R		R														
<i>S. primus</i>										V																	
<i>H. riedeli</i>										R	R	R	R	R	V												
<i>E. robusta</i>										V	V														V		
<i>T. saxea</i>											R		R														
<i>Z. sigmoides</i>										V																	
<i>B. sparsus</i>						R	R	V			R	R															R
<i>E. subpertusa</i>										V	V																
<i>C. tenuis</i>										V			V														
<i>T. tovae</i>									R	R	R	R	R														
<i>F. tympaniformis</i>							R	R		R			R	R													R
Reworked Cret. spp.							R	R		R	R	F	C			V		V						R	F		R

Key: B = Barren; V = Very Rare; R = Rare; C = Common; P = Poor preservation; M = Moderate preservation

additional samples subsequently collected from the same layer) was unsuccessful. The additional samples (PB-6 and PB-7) from this layer also contained *H. kleinpelli*, but again no specimens of *H. riedeli*. We can only conclude that the layer is (1) in Zone NP 6, or (2) that the layer is in Zone NP 7, but *D. mohleri* is not present because of environmental or diagenetic reasons. Convincing proof for NP 6 versus NP 7 seems unlikely to come from further study of our samples; we have therefore chosen to make a conservative assignment of NP 6/7 to this layer. Subsequent resampling of the section above and below the *H. kleinpelli* layer found no further indigenous nannoplankton below the Reculver Silts Member (Fig. 3B).

At Herne Bay – Reculver, Zone NP 8 is present in the Thanet Formation from the base of the section (Unit A) to Unit F (Fig. 5). The uppermost Thanet, the Woolwich Bottom Bed and the Oldhaven Beds at Herne Bay – Reculver are barren or contain only very rare, reworked specimens. We did not find *Discoaster multiradiatus* in samples we collected at Pegwell Bay or at Herne Bay – Reculver. We made fresh preparations from the original samples of Godfrey (1984), and have examined the smear slides prepared by Godfrey (1984) and Godfrey & Lord (1984). We also examined the smear slides prepared by Godfrey (1984) from Hamilton's (1982) raw-sample material. We were unable to find *Discoaster multiradiatus* in any of these samples. A photograph of the single specimen noted as *D. multiradiatus* by Godfrey & Lord (1984) is shown in Pl. 2, fig. 12. Under crossed nicols, the specimen has a bright shield and a prominent extinction cross that extends to the edge of the shield, indicating that the specimen is a *Heliolithus*.

No definite zone could be assigned to the isolated sample from the Woolwich (Reading) Bottom Bed at Headley Heath. The sample from Clarendon Hill is, however, readily assignable to Zone NP 9, based on the co-occurrence of frequent *D. multiradiatus* (Pl. 2, figs. 5, 6) and *D. mohleri*. This evidence supports the dinocyst-based correlation by Costa & Müller (1978) of the Woolwich and Reading Beds to NP 9.

## CONCLUSIONS

The lithostratigraphic units composing the Thanetian Stage in the type area are the Thanet Formation, Woolwich Bottom Bed and Oldhaven Beds. At least the lowermost 4.2 m of the Thanet is assignable to Zone NP 6/7; the rest of the formation (at least from the Reculver Silts upwards) is assignable to Zone NP 8. The Woolwich (Reading) Bottom Bed at Clarendon Hill is assigned to Zone NP 9.

During the last few years there has been a sustained effort aimed at developing refined chronostratigraphic and geochronologic time scales (e.g., Curry & Odin, 1982; Berggren *et al.*, in press). The work reported

here is significant in that it allows more accurate positioning of the Thanetian Stage stratotype within a chronostratigraphic framework.

Common chronostratigraphic practice is to define the standard stages in terms of biozones, coinciding as far as possible (but often not precisely) with the biozonation of the stage stratotype. "Base defines Stage" in chronostratigraphy. The base of the Ypresian stage is in Zone NP 10 (Aubry, 1983). The "Thanetian Stage" as used in chronostratigraphy therefore extends upwards through Zone NP 9 to the base of the Ypresian Stage, even though the Thanetian Stage stratotype is no younger than NP 8. Zone NP 9 does, however, occur in Thanetian rocks elsewhere in Europe (Aubry, 1983), and in England in the Woolwich Bottom Bed (Hamilton, 1982; this study), but not at the Thanetian stage stratotype locality.

## ACKNOWLEDGEMENTS

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## Explanation of Plate 1

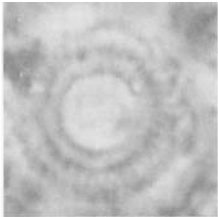
- Figs. 1, 2. *Sphenolithus anarrhopus* Bukry & Bramlette. Crossed nicols: fig. 1, 0° to polarizer; fig. 2, 45° to polarizer.  
Thanet Fm., Sample HB-A (×2850).
- Figs. 3, 4. *Markalius apertus* Perch-Nielsen: fig. 3, phase contrast; fig. 4, crossed nicols. Thanet Fm., Sample HB-A  
(×2850).
- Figs. 5, 6. *Markalius astroporus* (Stradner) Hay & Mohler: fig. 5, phase contrast; fig. 6, crossed nicols. Thanet Fm.,  
Sample HB-A (×2850).
- Figs. 7, 8. *Hornibrookina australis* Edwards & Perch-Nielsen: fig. 7, phase contrast; 8, crossed nicols. Thanet Fm.,  
Sample HB-C (×2850).
- Figs. 9, 10. *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler: fig. 9, phase contrast; fig. 10, crossed  
nicols. Thanet Fm., Sample HB-A (×2000).
- Fig. 11. *Prinsius bisulcus* (Stradner) Hay & Mohler. Crossed nicols. Thanet Fm., Sample HB-C (×2850).
- Fig. 12. *Ericsonia cava* (Hay & Mohler) Perch-Nielsen. Crossed nicols. Thanet Fm., Sample HB-D (×2850).
- Fig. 13. *Thoracosphaera deflandrei* Kamptner. Crossed nicols. Thanet Fm., Sample HB-A (×2000).
- Fig. 14. *Discoaster* cf. *D. helianthus* Bramlette & Sullivan. Phase contrast. Thanet Fm., Sample HB-A (×2850).
- Figs. 15, 16. *Toweius eminens* (Bramlette & Sullivan) Gartner: fig. 15, phase contrast; fig. 16, crossed nicols. Thanet  
Fm., Sample HB-A (×2850).
- Figs. 17, 18. *Zygodiscus herlyni* Sullivan: fig. 17, phase contrast; fig. 18, crossed nicols. Thanet Fm., Sample HB-A  
(×2000).
- Fig. 19. *Micrantholithus inaequalis* Martini. Crossed nicols. Thanet Fm., Sample HB-A (×2850).
- Fig. 20. *Neochiastozygus junctus* (Bramlette & Sullivan) Perch-Nielsen. Phase contrast. Thanet Fm., Sample HB-D  
(×2850).



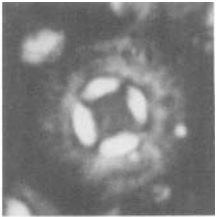
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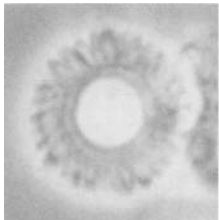
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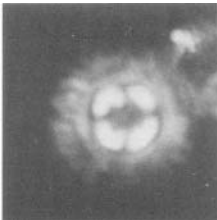
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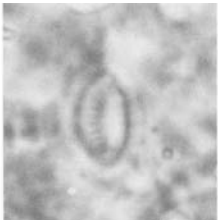
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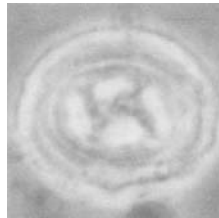
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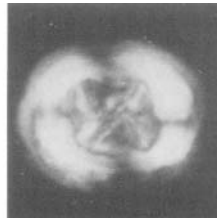
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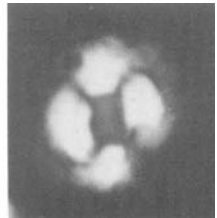
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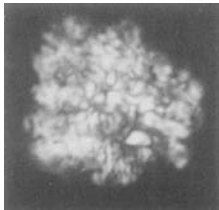
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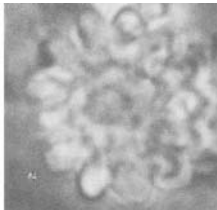
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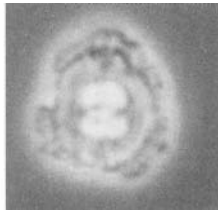
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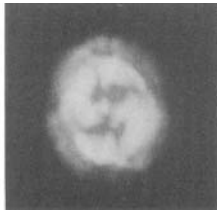
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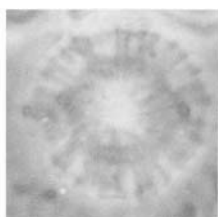
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### Explanation of Plate 2

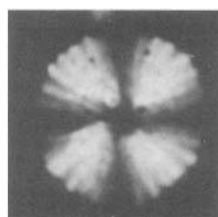
- Fig. 1. *Fasciculithus involutus* Bramlette & Sullivan. Crossed nicols. Woolwich Bottom Bed, Clarendon Hill sample (×2850).
- Figs. 2, 3. *Heliolithus kleinPELLI* Sullivan: fig. 2, phase contrast; fig. 3, crossed nicols. Thanet Fm., Sample PB–8 (×2000).
- Fig. 4. *Prinsius martinii* (Perch-Nielsen) Haq. Crossed nicols. Thanet Fm., Sample HB–C (×2850).
- Figs. 5, 6. *Discoaster multiradiatus* Bramlette & Riedel. Phase contrast. Woolwich Bottom Bed, Clarendon Hill sample (×2000).
- Fig. 7. *Coccolithus pelagicus* (Wallich) Schiller. Crossed nicols. Thanet Fm., Sample HB–A (×2850).
- Fig. 8. *Micrantholithus pinguis* Bramlette & Sullivan. Crossed nicols. Thanet Fm., Sample HB–A (×2850).
- Fig. 9. *Zygodiscus plectopons* Bramlette & Sullivan. Crossed nicols. Thanet Fm., Sample HB–D (×2850).
- Figs. 10, 11. *Heliolithus riedeli* Bramlette & Sullivan: fig. 10, phase contrast; fig. 11, crossed nicols. Thanet Fm., Sample HB–A (×2850).
- Fig. 12. *Heliolithus* sp. Crossed nicols. Thanet Fm., Sample 14 of Godfrey & Lord (1984) (×2850).
- Figs. 13, 14. *Ericsonia robusta* (Bramlette & Sullivan) Perch-Nielsen: fig. 13, phase contrast; fig. 14, crossed nicols. Thanet Fm., Sample HB–A (×2850).
- Fig. 15. *Thoracosphaera saxea* Stradner. Crossed nicols. Thanet Fm., Sample HB–A (×2850).
- Fig. 16. *Fasciculithus tympaniformis* Hay & Mohler. Crossed nicols. Thanet Fm., Sample HB–D (×2000).
- Figs. 17, 18. *Cruciplacolithus tenuis* (Stradner) Hay & Mohler: fig. 17, phase contrast; fig. 18, crossed nicols. Thanet Fm., Sample HB–D (×2000).
- Figs. 19, 20. *Toweius tovae* Perch-Nielsen: fig. 19, phase contrast; fig. 20, crossed nicols. Thanet Fm., Sample HB–A (×2850).



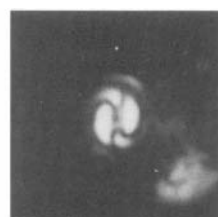
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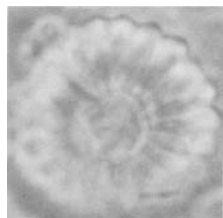
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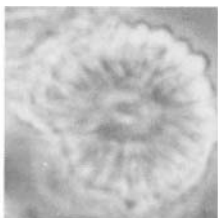
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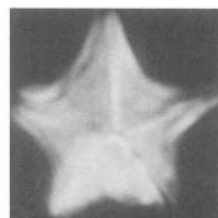
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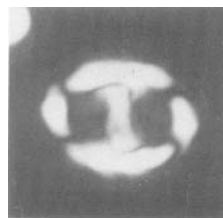
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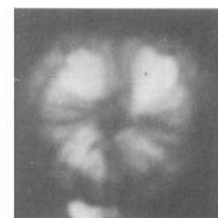
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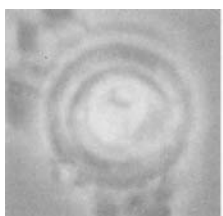
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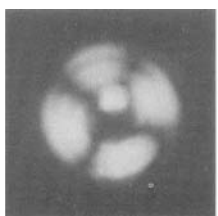
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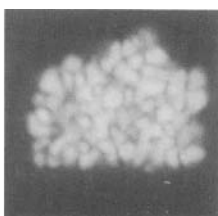
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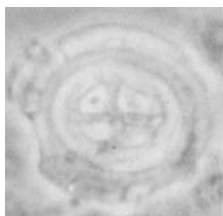
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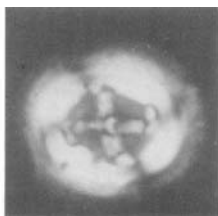
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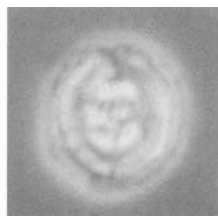
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### Explanation of Plate 3

Bar Scales = 2µm

Figs. 1, 2. *Chiasmolithus bidens* (Bramlette & Sullivan) Hay & Mohler: fig. 1, distal side; fig. 2, proximal side. Thanet Fm., Sample HB-A.

Fig. 3. *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre. Thanet Fm., Sample HB-A.

Fig. 4. *Ericsonia cava* (Hay & Mohler) Perch-Nielsen. Thanet Fm., Sample HB-A.

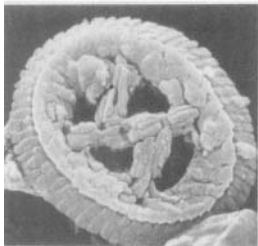
Fig. 5. *Micrantholithus inaequalis* Martini. Thanet Fm., Sample HB-A.

Fig. 6. *Discoaster mohleri* Bukry & Percival. Thanet Fm., Sample PB-10.

Fig. 7. *Micrantholithus pinguis* Bramlette & Sullivan. Thanet Fm., Sample HB-A.

Figs. 8, 9, 10, 11. *Heliolithus riedeli* Bramlette & Sullivan: fig. 8, top view; figs. 9, 10, 11, side views. Thanet Fm., Sample HB-A.

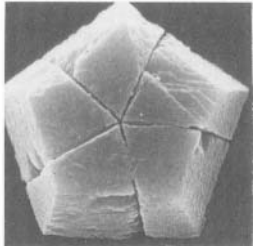
Fig. 12. *Toweius tovae* Perch-Nielsen. Thanet Fm., Sample HB-A.



1



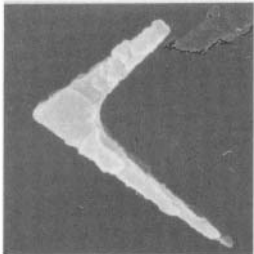
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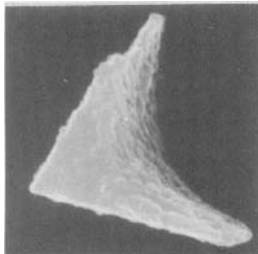
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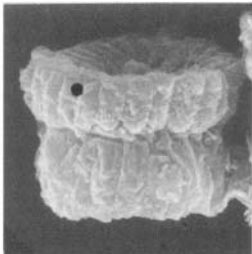
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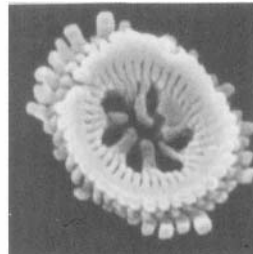
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