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A marker band folgen stratigraphy for the Cenomanian Chalk of England and its extension to northen Germany and France

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ABSTRACT:

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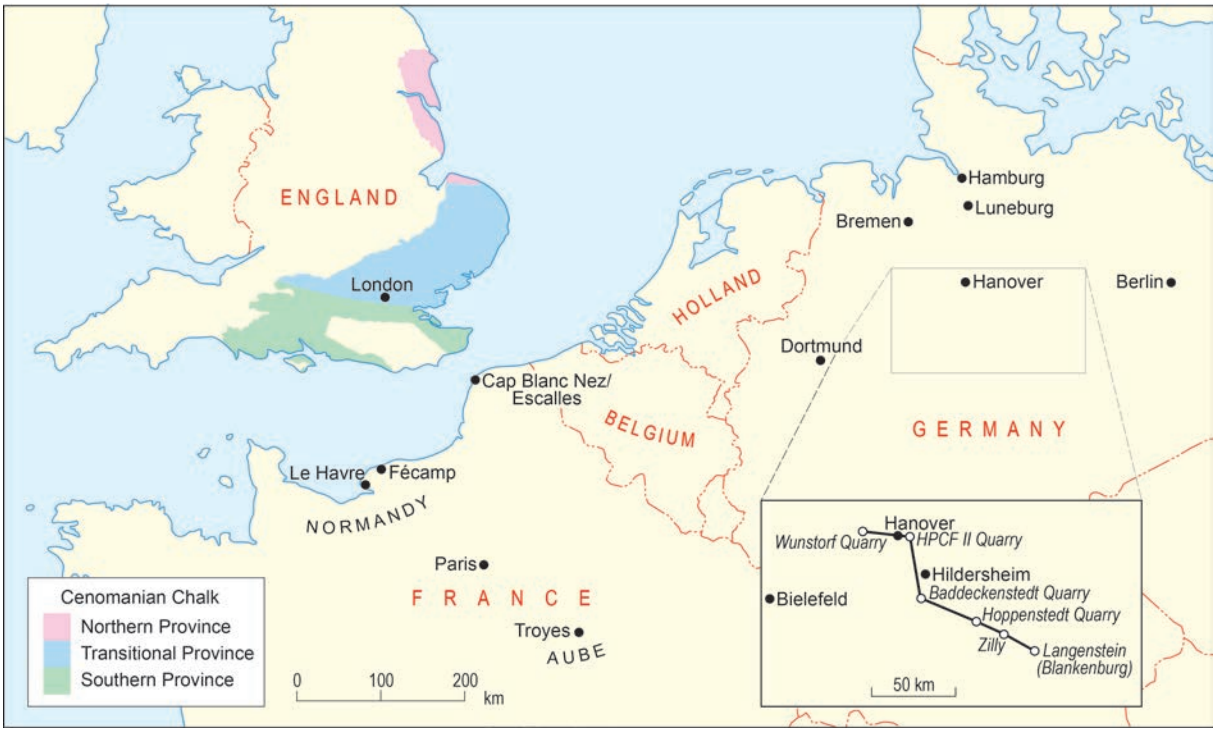
A novel stratigraphical scheme within the Folge Concept is described for the Cenomanian Chalk of England that is particularly suitable for investigating the regional changes in the lithofacies, diagenesis, geochemistry, and mineralogy of the sediments of the Chalk Sea leading up to the Cenomanian–Turonian Oceanic Anoxic Event. It is based on "isochronous" marker bands defined largely by calcitic macrofossil assemblages, and it avoids problems caused by the poor or non-preservation of ammonite assemblages and lateral changes in chalk lithofacies. Eight folgen are based on one, two, or more marker bands. Their sequences, lithologies and calcitic macrofossil assemblages are described from 33 exposures in the Northern Chalk Province of England. The folgen are named, in ascending order, the Belchford, Stenigot, Dalby, Bigby, Candlesby, Nettleton, Louth and Flixton, after villages in Lincolnshire and Yorkshire, England. The folgen are traced throughout the Transitional and Southern Chalk provinces of England. They are present in the Cenomanian chalk of northern Germany and northwest France. Regionally, an individual folge may display considerable vertical and lateral variation in general lithology and lithofacies whilst still maintaining their defining marker bands. The possibility of further refinement to the scheme is discussed.

Key words: Cretaceous; Cenomanian chalk; Folge stratigraphy; Marker bands; England; Northern Germany; Northwest France; Cenomanian–Turonian Anoxic Event.

INTRODUCTION

The Cenomanian period (93.9–100.5 Ma: Gale *et al.* 2020) reflects the transition, both in the oceans and marginal seas, during which the world's "normal" atmospheric conditions changed to those that led to the development of the Chalk Sea. In England, a late Albian Sea characterized by varied sands, muds, volcanic detritus and ferruginous calcareous muds changed to one dominated by the detritus of the Coccolithophoridae and other calcite-secreting planktonic organisms with little continental detritus that persisted for ~35 million years (65–100 Ma). The new stratigraphical scheme put forward is to facilitate the understanding and detailed study of the major changes in the Cretaceous Earth's surface and atmospheric conditions associated with the development of the Chalk's biological "calcium carbonate extraction factory" leading up to the initiation of the Cenomanian–Turonian Oceanic Anoxic Event. It provides time equivalent packets of strata throughout much of the Cenomanian chalk of western Europe that allows the changing regional conditions to be studied (Text-figs 1, 2).

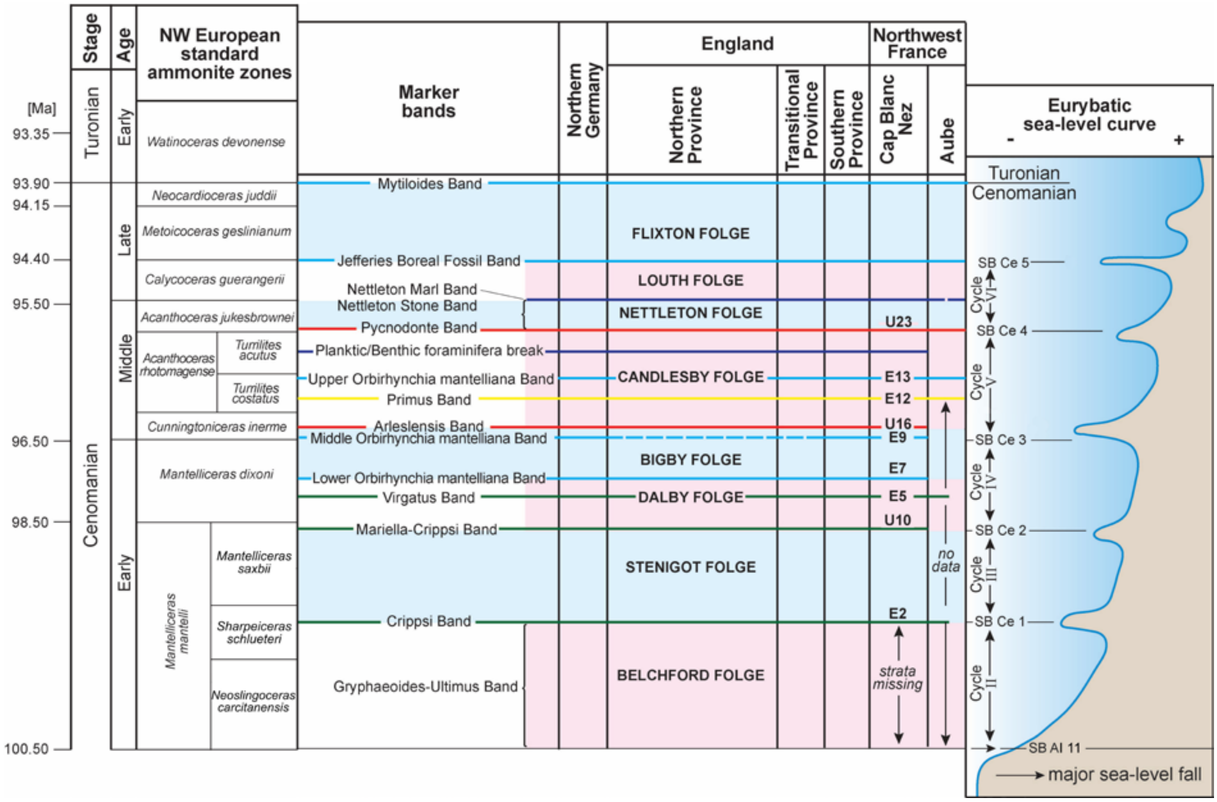
The forerunner of the present scheme, based upon eight stratigraphical units referred to as "**members**", was first established in the Northern Chalk Province of England (Jeans 1980; Jeans *et al.* 2015, 2021). It avoided the problems posed by (1) the poor preservation of ammonites in much of the Chalk facies, and (2) regional diachronous changes in lithofacies



Text-fig. 1. Cenomanian provinces of England and locations in northern Germany and northwest France. Based in part on Wilmsen (2007, text-fig. 1).

and diagenesis associated in part with the oscillations in the transgression of the Cenomanian Chalk Sea. These members are now referred to as **Folgen** for the following reasons. Subsequently to the establishment of the "**member scheme**" of Jeans (1980), the Cenomanian Chalk of England has been subdivided into a number of regional formations including several members defined by their different lithologies – the same is the case in Germany and France. The "**members**" of Jeans (1980) can no longer be considered to be formal lithostratigraphical units as important lateral changes in chalk lithofacies occur as they are traced into the Transitional and Southern Provinces of England and into northern Germany and France. There was a strong element of various types of stratigraphy in the original "**members**" but the guiding character on which the eight unit scheme was based are bands of calcitic macrofossils, a common component at particular levels. The scheme does not fit comfortably into the definitions of either allostratigraphy, cyclostratigraphy, lithostratigraphy or biostratigraphy. Its subdivisions are as or even more refined than those provided by ammonite biostratigraphy and isotope stratigraphy. The question is what should these eight subdivisions be called? A rather similar situation has developed in the German Triassic Buntsandstein Group with its complicated regional and vertical lithological variation. Here the application of a variety of stratigraphical methods has allowed a sequence of time-related units to be recognised (Röhling *et al*. 2018). These units are referred to as **Folgen** (singular **Folge**, meaning *sequence*, *succession*). It is the general similarity to this style of stratigraphy that the eight units of our scheme for the Cenomanian Chalk of western Europe are referred to as **Folgen** – they are the precise equivalents of the original members of Jeans (1980).

The paper consists of four parts. The first reviews the history of the present litho-stratigraphical scheme used in England for subdividing and mapping the Cenomanian Chalk and then considers the development and nature of the new scheme. The second part is the detailed description of the Cenomanian Chalk of the Northern Province using the new scheme and demonstrates how it extends throughout the Transitional and Southern provinces and into northern Germany and northwest France. The third part defines the marker horizons more precisely and discusses their limitations, and the fourth considers further possible refinement of the scheme.



Text-fig. 2. The extent of the eight folgen of the Cenomanian Chalk strata and their inter-regional marker bands in England, northern Germany and northwest France. Their relationship is shown to (a) lithofacies Cycles II-VI of the Northern Chalk Province, (b) the sequence stratigraphy of northern Germany and northwest France, and (c) the standard ammonite zones for northwest Europe. Based in part on Janetschke *et al.* (2015), Amédro and Robaszynski (1999). Radiometric dates are based on Ogg *et al.* (2012).

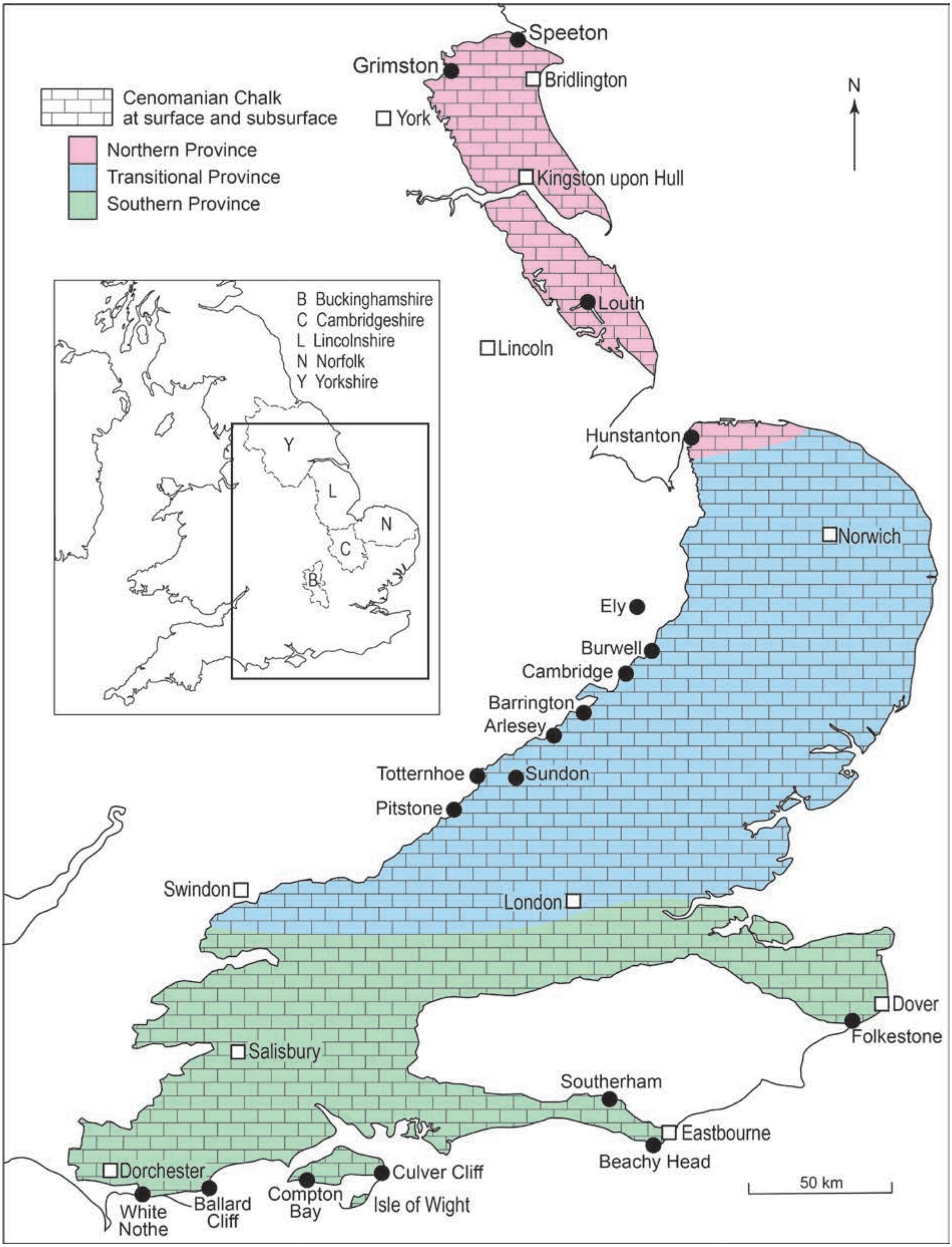
GENERAL SETTING OF THE CENOMANIAN CHALK OF ENGLAND

Three provinces are recognized in the Upper Cretaceous of England (Text-fig. 3). The Southern and Transitional provinces are part of the Anglo-Paris Basin and are characterized by relatively thick, poorly cemented chalk laid down in a region of some tectonic instability. In contrast, the Northern Province is part of a stable offshore platform (sometimes referred to as the Midland Platform or Shelf) characterized by thinner, well cemented chalk with a layer-cake stratigraphy. The platform's northern margin was an active fault linked to the Flamborough Head Fault Zone and the North Sea Dowsing Fault system, both still active in Paleocene times (Roberts *et al*. 2020). The northern bounding fault separated the thin platform succession from the thicker sequence in the Speeton Basin. Within the platform sequence there is some evidence of minor differential movement expressed as lateral variation in stratal thickness and facies.

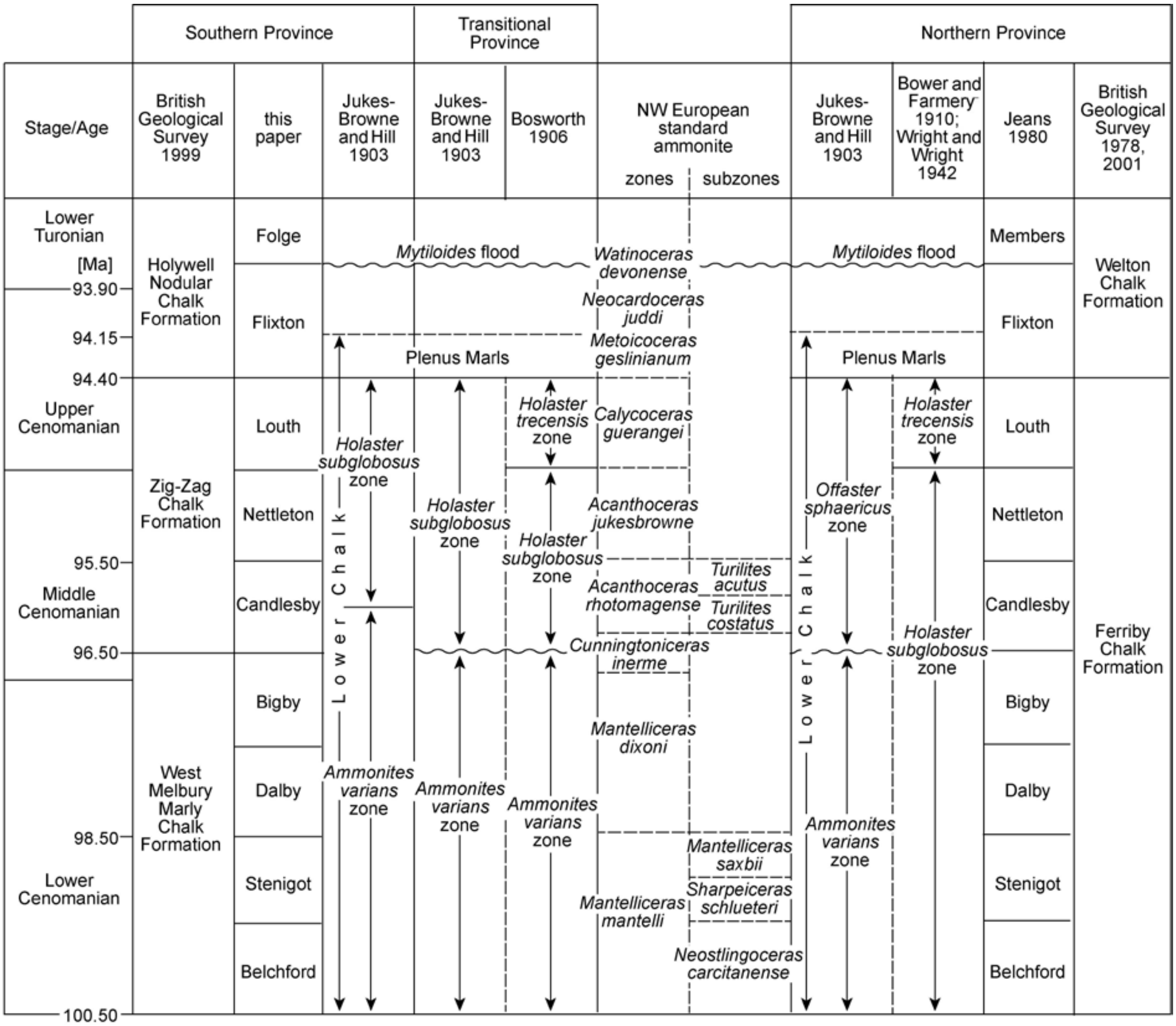
HISTORY OF THE CURRENTLY USED FORMATIONAL SCHEME

The establishment of Cenomanian strata in England stems from the recognition by the great French Chalk stratigrapher Charles Barrois (1876) that the Upper Cretaceous Chalk of England and Ireland contained the same fossil zones that had been established in France and Germany, and that these zones could be grouped into the three stages – the lower *Cenomanian*, the middle *Turonian*, and the upper *Senonian* – that had been proposed by d'Orbigny (1847, 1850, 1852) based upon changing fossil faunas. Although this finding was initially not accepted by English geologists, it was subsequently shown by Jukes-Browne and Hill (1903) to be correct and that the English Chalk could be divided into three equivalent and mapable units (Lower, Middle and Upper Chalk), approximately equivalent to d'Orbigny's three stages.

The original subdivision of the Cenomanian Lower Chalk was established by Jukes-Browne (1880, 1887), Whitaker *et al.* (1893), and Jukes-Browne and Hill



Text-fig. 3. Distribution of outcrop, subcrop and the provinces of the Cenomanian Chalk of England. The insert shows county names mentioned in the text. All locations and key localities in the Transitional and Southern provinces are shown.



Text-fig. 4. Correlation between the new eight-folgen scheme for the Cenomanian Chalk of England and the present and previous formational and zonal schemes used by the British Geological Survey (Wood and Smith 1978; Bristow *et al*. 1999; Rawson *et al.* 2001) and other researchers.

(1896, 1897) in the counties of Buckinghamshire and Cambridgeshire, now part of the Transitional Chalk Province (Text-fig. 3). The stage was divided into three units (Text-fig. 4). The main mass from the base up to a conspicuous and widespread erosion surface near its top, was divided into two units by the Totternhoe Stone or Burwell Rock, a horizon of sandy silt-grade chalk, often pebbly, resting on an erosion surface that may cut down up to 10–30 m into the underlying strata (see also Gale and Kennedy 2022). The lower of these divisions was named the *Schloenbachia varians* Zone, the upper one the *Holaster subglobosus* Zone, both after particular fossils that were supposed to be both charactistic and present. The Totternhoe Stone (or Burwell Rock) was included in the base of the *Holaster subglobous* Zone. Above the erosion surface near the top of the formation was a thin, distinctive marly horizon, the *Actinocamax plenus* Zone named after the belemnite *Praeactinocamax plenus*, which is widespread in these strata.

Systematic study of the Lower Chalk of the Northern Chalk Province started with Hill (1888) when he traced its tripartite division from Norfolk to the Yorkshire coast. Jukes-Browne and Hill (1903) were less successful in applying their zonal scheme to the Southern Province where the Totternhoe Stone and its erosion surface were absent. A palaeontological correlation between the *Schloenbachia varians* and *Holaster subglobosous* zones was attempted but this ended up at a level well up in the main mass of the *Holaster subglobosus* Zone of the type area (Text-fig. 4). In the Northern Province (Lincolnshire, Yorkshire) where the lateral continuation of the Totternhoe Stone (the Grey Bed) was recognized, Jukes-Browne and Hill retained the *Schloenbachia varians* Zone for the strata beneath the Grey Bed but referred to the upper division as the *Offaster sphaericus* Zone. Correlation at the topmost part of the sequence, the *Actinocamax plenus* Zone, was satisfactory as this thin horizon of marls and its relationship to the underlying chalk is generally similar to that in the Transitional and Southern Provinces. Bosworth (1906), working in the Transitional Chalk Province, was first to point out the shortcomings of this scheme. He suggested that the *Holaster subglobosus* Zone should be divided into two, the lower one named after the thick shelled *Holaster subglobosus* and an upper zone named after the thin shelled *Holaster trecencis* (Text-fig. 4). In Lincolnshire, Bower and Farmery (1910) found the scheme similarly unsatisfactory, suggesting that Bosworth's upper zone, the *Holaster trecensis* Zone, should be retained but Bosworth's lower *Holaster subglobosus* Zone should include the *Schloenbachia varians* Zone of Jukes-Browne and Hill (1903) and of Bosworth (1906). Wright and Wright (1942) suggested that the zonal scheme put forward by Bower and Farmery (1910) should be used for the Lower Chalk of Yorkshire.

The remapping of the English Chalk by the British Geological Survey started in Lincolnshire during the 1970s (Wood and Smith 1978) with emphasis placed on defining mapable units based on lithology, thus benefiting greatly the main users of their maps, applied earth scientists. For the Cenomanian chalk stratigrapher, the mis-correlations of the earlier schemes were corrected, but instead of the Cenomanian chalks remaining within a single formation extending over the whole of England, the harder and more dense chalks of the Northern Province were separately mapped in two formations (Ferriby Formation, part Welton Formation), whereas the softer less dense chalks and marls of the Transitional and Southern Provinces were included in three different formations – West Melbury Marly Chalk Formation, Zig Zag Chalk Formation, and part of the Hollywell Nodular Chalk Formation (Bristow *et al.* 1997; Text-fig. 4). These changes did not find full favour with some Chalk stratigraphers (Gale and Hancock 1999; Bristow *et al.* 1999).

NEW FOLGE SCHEME

This stratigraphic subdivision evolved during the 1960s first in the Northern Chalk Province of England and was then extended to the Transitional and Southern provinces. It was based upon the recognition of (1) stratal cyclicity, (2) marker bands of varying extent based on calcitic macrofossil assemblages or lithological characteristics, and (3) the pulse fauna concept (Jeans 1967, 1968, 1980; Jeans *et al.* 2021, p. 109; Peake and Hancock 1961, 1970). As a result, eight members – the folgen of this paper – were defined (Jeans 1980).

The pulse fauna concept reflected the repeated occurrence of components of a particular fossil assemblage at various levels in the Cenomanian chalk of the Northern Province. This was either in association with the earlier stages of lithological cycles or with changes in the chalk lithofacies. This conceptual fauna, actually a fossil assemblage, was made up of various belemnites (*Neohibolites*, *Praeactinocamax*, *Actinocamax*, *Belemnocamax*), bivalves (*Oxytoma*, *Aequipecten*, *Entolium*, *Plagiostoma*, *Mantellum*), inoceramids of the "*Inoceramus crippsi*" group and the brachiopod *Orbirhynchia*. Individual pulse faunas contain one or more of these elements. Two groups of faunal elements were postulated; one came from outside the European area, the other of more local origin. It was argued that the "pulse faunas" represented geologically "instantaneous" events reflecting sudden changes in the depth of the Chalk Sea perhaps associated with regional changes in tectonic setting or ice ages. This caused connections to other oceanic regions from which mobile exotic species – the pulse fauna – either as adults (e.g. belemnites) or perhaps as larva (bivalves, *Orbirhynchia*) flooded in, causing them to extend their distribution and disrupting local faunas. Its first use was as a framework for mineralogical, geochemical and lithological studies (Jeans 1968, 1980) but the scheme was specifically unrelated to the accepted biostratigraphical correlation at the time (see later *Problems of ammonite zonation in the Northern Province*).

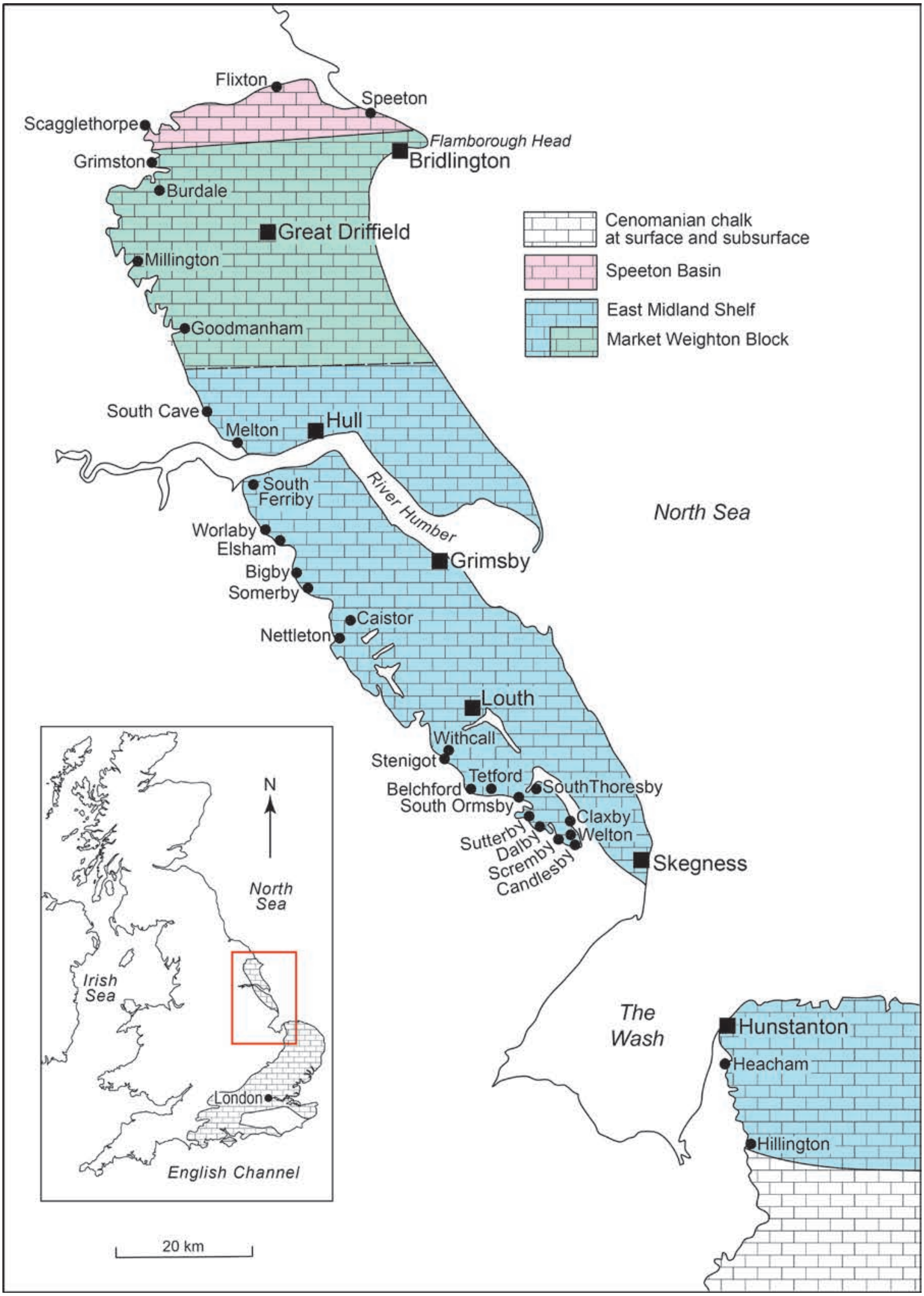
The "isochronous" nature of these pulse faunal invasions (the marker bands of this paper) was demonstrated in the Cenomanian chalk of northern Germany as the result of the "Mid-Cretaceous Events" major IGCP project (no. 58) that started in 1975. Ernst *et al.* (1983) described a sequence of geological "Eco-Events" represented by abundances of particular fossils that occurred at specific horizons within a stratigraphical framework based on inoceramid and cephalopod (ammonite, belemnite) zonation. Most of these "Eco-Events" were already recognized as marker bands in the Cenomanian of the Northern Province in England but without the tight ammonite-based biostratigraphical control needed to demonstrate their geologically "isochronous" character. These findings provided the stratigraphical framework that allowed the application of methods of sequence- and isotope-stratigraphy (Robaszynski *et al*. 1998; Jarvis *et al*. 2006) to be tested and fuelled the birth of Cenomanian cyclo-stratigraphy (Gale 1990, 1995; Gale *et al*. 1999). In Germany it allowed the unraveling of the complex lithofacies bordering the margins of the Chalk Sea and its transition to the near shore, brackish water and fresh water settings (Wilmsen *et al.* 2005; Janetschke *et al.* 2015).

METHODS OF INVESTIGATION

The recognition of marker bands and the stratal cyclicity that established the eight folgen stratigraphy for the Cenomanian Chalk is based upon detailed fieldwork in the Northern Chalk Province of England. This was carried out mainly between 1961–1965 and in 1974. Thirty-three surface exposures (Text-fig. 5; Table 1) were systematically investigated bed-by-bed with their calcitic macrofossil assemblages being collected quantitatively (Jeans 1967). These included the

Northern province localities	National grid references	Literature references
Belchford	TF/310760	Dobsworth (1996)
Bigby	TA/059078	Jeans *et al.* (1991, fig.10)
Burdale	SE/871627	Jeans *et al.* (2014), Dobsworth (1996)
Caistor	TA/123002	Bower and Farmery (1910, pit 39?)
Candlesby I	TF/455681	Bower and Farmery (1910, pit 37)
Candlesby II	TF/460682	Bower and Farmery (1910, pit 10), Dobsworth (1996)
Claxby	TF/449717	Jukes-Browne (1887, pp. 45-46)
Dalby	TF/405706	possibly Ussher (1890, p. 116)
Elsham I	TA/028130	Jeans *et al.* (2014)
Elsham II	TA/038131	Jeans *et al.* (1991, figs 10, 11), Dobsworth (1996), Jeans *et al.* (2014), Jeans *et al.* (2021, text-fig. 13)
Flixton	TA/039791	Jeans (1973, p.421), Jeans (1980, p. 114, fig. 14)
Goodmanham	SE/898429	Wright and Wright (1942, pit 70), Jeans (1973, p. 422)
Grimston Hill	SE/854671	Jukes-Browne and Hill (1887), Jefferies (1963)
Heacham	TF/687368	Peake and Hancock (1961),
Hunstanton	TF/673413-679425	Jeans in Peake and Hancock (1970 Reprint of Geology of Norfolk), Gallois (1994), Mortimore *et al.* (2001, pp. 389–395), Xiufang *et al.* (2014a)
Louth I	TF/324876	
Louth II	TF/324877	
Melton	SE/973273	Jeans (1973, p. 420), Mortimore *et al.* (2001, pp. 393, 396–398)
Melton Bottoms	SE/973273	Whitham (1991)
Millington	SE/842532	Jeans (1973, p. 422)
Nettleton	TF/125981	
Scagglethorpe	SE/847721	Hill (1888, p. 337), Jeans (1973 p. 423)
Scremby	TF/440688	Jukes-Browne (1887, pp. 44–45), Bower and Farmery (1910, pits 35–36)
South Cave	SE/925328	Wright and Wright (1942, pit 21)
South Ferriby	TA/000216	Bower and Farmery (1910, pits 32–34), Jeans *et al.* (1991, fig. 10, 2014)
South Ferriby Middlegate Quarry	SE/992204	Schlager *et al.* (1987), Hart and Leary (1989), Hart *et al.* (1993), Paul *et al.* (1994)
South Thoresby	TF/405772	Jukes-Browne (1887, p. 52), Bower and Farmery (1910, pit 19), Jeans *et al.* (2014)
Speeton	TA/161751-184746	Jeans (1967 figs 38, 42), Jeans (1973 fig. 3), Jeans (1980 fig.16), Mitchell (1995), Paul *et al.* (1994), Mortimore *et al.* (2001, pp. 413–415), Mortimore (2014, fig. 4.13 – sequence above the Six-Band Group has been mislabeled)
Stenigot	TF/262820	
Sutterby	TF/386725	Judd (1867, p. 231), Jukes-Browne (1887, p. 47), Jukes-Browne (1900, p. 307)
Tetford	TF/329759	Jukes-Browne (1887, p. 54), Bower and Farmery (1910, pit 24), Jeans *et al.* (1991, figs 10, 12, 2014)
Welton (Welton Le Marsh)	TF/451691	Jeans *et al.* (1991, fig. 10), Jeans *et al.* (2014)
Withcall	TF/282835	Bower and Farmery (1910, pit 31)
Worlaby	TA/017141	Judd (1867, p. 233), possibly Ussher (1890, p. 117)

Table 1. Localities, national grid references, and literature for the Cenomanian Chalk of the Northern Province.



Text-fig. 5. Distribution of the Cenomanian Chalk at the surface and sub-surface in the Northern Province of England and in the adjacent part of the Transitional Province showing the locations and the extent of the Midland Shelf, Market Weighton Block, and the Speeton Basin.

Transitional province localities	National grid reference	Literature references
Ely	TL/694821	Gallois (1988, pp. 57-58)
Barrington	TL/395507	Gale and Kennedy (2022)
Cambridge (Cherry Hinton)	TL/485558	Forbes (1960)
Arlesey	TL/189346	Wood (1992)
Sundon	TL/041272	Hopson *et al.* (1996)
Totternhoe	TL/985222	Shepherd *et al.* (1994, fig. 38)
Pitstone	SP/935145	Sumbler and Wood (1992), Gale and Kennedy (2022)
Southern province localities		
Folkestone	TR/2533383–306396	Jeans (1968), Gale (1989), Mortimore *et al.* (2001), Wright *et al.* (2017, p. 478), Gale and Kennedy (2022)
Eastbourne (Beachy Head)	TV/590951	Jeans (1968), Mortimore *et al.* (2001), Wright *et al.* (2017, p. 479)
Southerham	TQ/427090	Mortimore *et al.* (2001), Wright *et al.* (2017)
Culver Cliff, Isle of Wight	SZ/630854	Jeans (1968), Mortimore *et al.* (2001), Wright *et al.* (2017, p. 484)
Compton Bay, Isle of Wight	SZ/350855	Jeans (1968), Mortimore *et al.* (2001), Wright *et al.* (2017, p. 484)
Ballard Cliff	SZ/040811–046812	Jeans (1968), Jukes-Browne and Hill (1903, p. 95), Wright *et al.* (2017, p. 486)
White Nothe	SY/772806	Jukes-Browne and Hill (1903, p. 98), Jeans (1968)

Table 2. Localities, national grid references, and literature for the Cenomanian Chalk of the Transitional and Southern provinces.

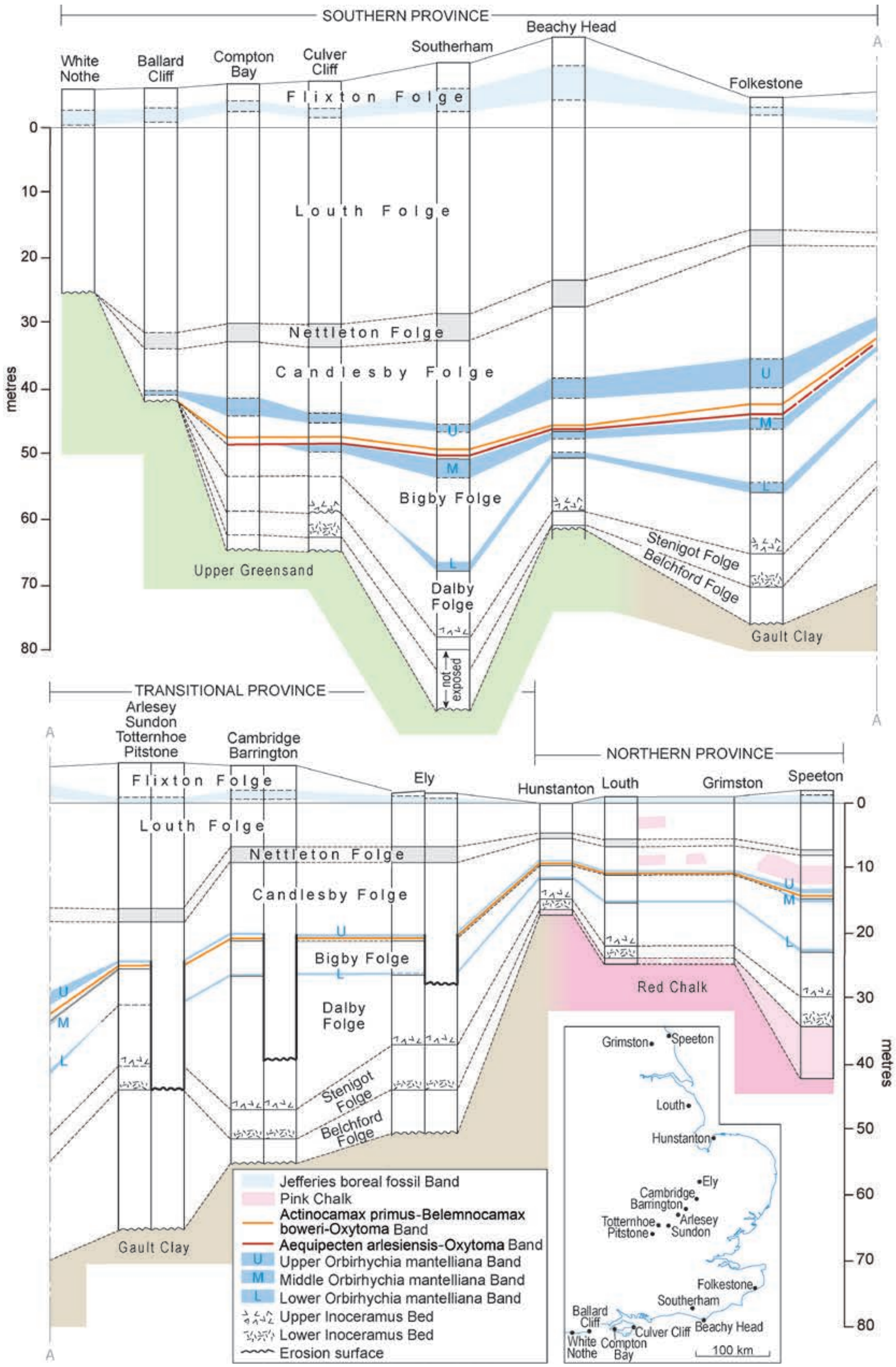
complete shelf and basinal sequences at, respectively, South Ferriby and the Speeton Cliffs (Jeans 1980). Many of the inland exposures are either no longer available, seriously degraded, and their loss has not been replaced by new ones. The Albian Red Chalk was included so as to identify the role and timing that local faulting may have played in controlling the sedimentary pattern of the overlying Cenomanian strata. Ladders allowed inaccessible parts of quarry faces to be examined, and where necessary, trenching and excavations were carried out (e.g., Jeans 1973).

Great care was taken to ensure that the effects of late-stage diagenesis, interstratal slip, pressure dissolution, and differential weathering on the original bed-to-bed relationships were identified. These problems are particularly evident at (1) the junction of the Albian Red Chalk and the overlying Belchford Folge in the reduced sequences of the Midland Shelf, and (2) within the Variegated Marls of the Flixton Folge at the base of the Welton Formation. Such difficulties have in the past caused miscorrelation on a regional scale (see later).

Subsequently, research was also carried out in the Transitional and Southern Provinces at Barrington, Folkestone, Eastbourne, Isle of Wight, Ballard Cliff and White Nothe (Text-fig. 3). This was supplemented by accounts of borehole sequences, inland Chalk pits, and coastal exposures by Gale (1989, 1990, 1995), Gallois (1988, 1994), Hopson *et al.* (1996), Kennedy (1969, 1970), Mortimore *et al.* (2001), Shephard-Thorn *et al.* (1994), Sumbler and Woods (1992), Woods (1992), and Wright *et al.* (2017). Additional investigation of the calcitic macrofossil assemblages of various marker bands were carried out to define them more precisely – sacks of chalk were brought back to the laboratory and systematically broken up collecting the complete assemblage.

Problems of ammonite zonation in the Northern Province

Ammonites are generally absent or poorly preserved in the Cenomanian chalk of the Northern Province except in the Ammonite Beds of the Candlesby Folge on the Midland Shelf. Here the chalk matrix has undergone lithification prior to aragonite dissolution (Jeans 1980, pp. 131–134). Ammonite zonation has been assigned to the section at South Ferriby but this is based upon Wood (in Gaunt *et al.* 1992) and does not reflect actual ammonite assemblages found at this location or elsewhere in the Northern Province – they have been deduced from an integrated analysis of the macrofossil biostratigraphy in all three provinces. At Speeton, in the expanded Cenomanian sequence ammonites are even rarer than in the Shelf area; in the strata equivalent to the Ammonite Beds, poorly preserved ammonites occur and Paul *et al.* (1994, p.727) have identified *Acanthoceras rhotomagense*, *Sciponoceras baculoides* and *Turrilites costatus*, a Middle Cenomanian assemblage similar to that from the Ammonite Beds. During the field investigation of the Northern Province, ~40 ammonite fossils were collected from various levels but excluding the Belchford Folge, the upper part (White Bed) of the Stenogot Folge, the Louth Folge and the Flixton Folge. They were submit-



Text-fig. 6. Correlation in the Cenomanian Chalk of the Northern, Transitional and Southern provinces of England based upon Folgen and inter-regional marker bands.

ted to W.J. Kennedy for identification without details of their horizon except that they had been collected from the Lower Chalk of the Northern Province. Included in his identifications were two specimens of *Acanthoceras* sp. from the Lower Inoceramus Bed (Stenigot Folge and another two from the Turrilitoid Plane in the Dalby Folge. These identifications were agreed upon independently by C.J. Wood and were accepted by J.M. Hancock (Peake and Hancock 1970) as demonstrating that the Lower Inoceramus Bed was of Middle Cenomanian age, a possibility that earlier had been discussed by Peake and Hancock (1961, p. 302). Wood (in Kent 1980, p. 97) still maintained that the chalk sequence from the Lower Inoceramus Bed up to the base of the Grey Bed was of Middle Cenomanian age and this included the Stenigot, Dalby and Bigby Folgen. It was more than ten years later when it was accepted (Wood in Gaunt *et al.* 1992, p. 86) that these beds were actually of Early Cenomanian age.

CENOMANIAN FOLGEN STRATIGRAPHY OF ENGLAND

Fourteen marker bands (Table 3) were used to define the eight folgen of this new scheme in the Northern Province and its extension to the Transitional and Southern provinces (Text-fig. 6). Further details of the marker bands are considered later. General correlation within the Northern Province is in Text-fig. 7. The arrangement of the eight new folgen in different parts of the Northern Province are illustrated in the following figures: Text-fig. 8 shows the sequence at South Ferriby – the stratotypes of the Ferriby Formation and the basal part of the overlying Welton Formation (Wood ad Smith 1978): Text-fig. 9 shows the basinal sequence at Speeton, originally described in Jeans (1980); Text-fig. 10 shows the sequences of Inland Yorkshire/central Lincolnshire and in the Hunstanton cliffs.

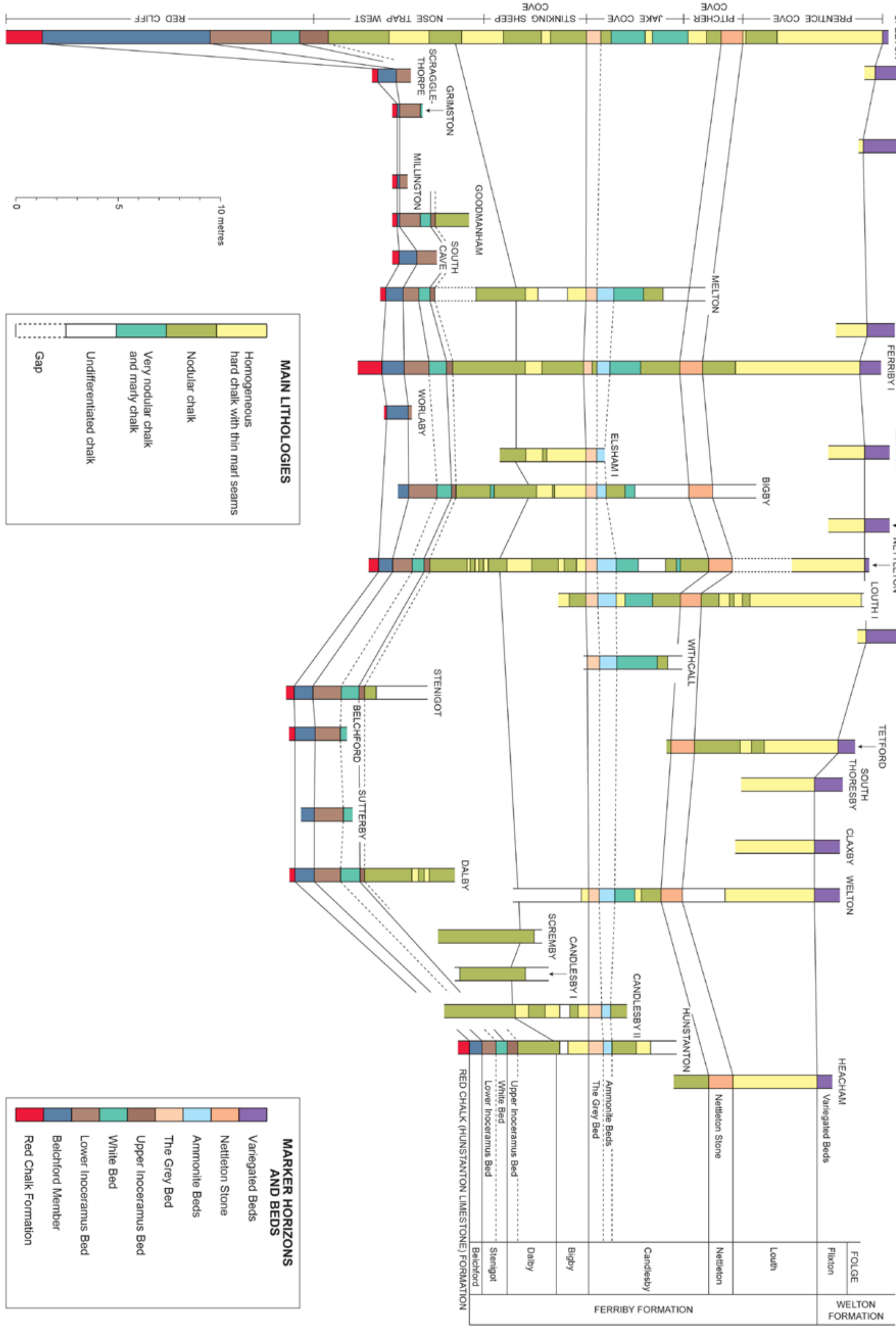
BELCHFORD FOLGE

This folge is defined by the stratigraphical extent of the Gryphaeoides/Ultimus Band (Text-fig. 6). It is placed in the *Neostingoceras carcitanense* Subzone (lower *Mantelliceras mantelli* Zone) based upon ammonite assemblages from Folkestone (Gale 1989) and Culver Cliff (Wright *et al.* 2017) – however, there are no reliable ammonite assemblages from the Northern Province. In the Northern Province, the Belchford Folge is the upward-fining Cycle II of Jeans (1980) and the base may reflect the initiation of depositional sequence Ce I or the sequence boundary SB Al 11 (Jeans *et al.* 2021; Text-fig. 2). Its strata are included in both the Ferriby (Northern Province) and the West Melbury Marly Chalk (Transitonal and Southern Provinces) formations.

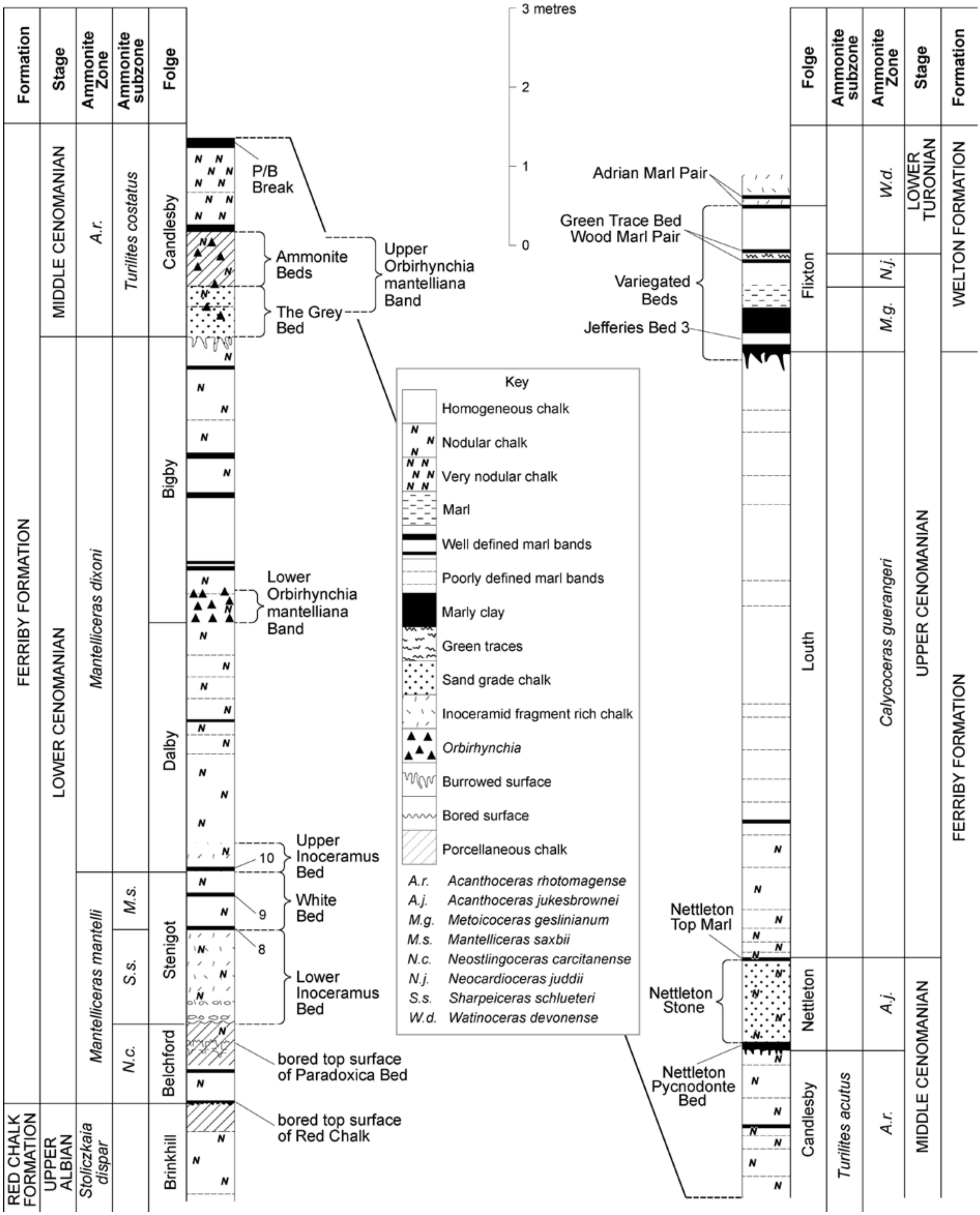
Regional variations in lithology reflect in part the different lithofacies of the underlying Upper Albian strata (Text-fig. 6). In the Northern Province the Belchford Folge consist of pink and red chalky limestone that overlie the Hunstanton Red Chalk Formation. In the Transitional and Southern Provinces, where this Folge overlies the Gault Clay, it consists of greyish marls and marly chalks, sometimes with a basal glauconitic horizon rich in volcanoclasts (Barrington, Folkestone; Jeans *et al.* 1982). Where the

Marker bands	Ammonite zone/subzone
Mytiloides Band	*Watinoceras devonense* Zone
Jefferies Boreal Fossil Band	*Metoicoceras geslinianum* Zone
Nettleton Marl Band	*Acanthoceras jukesbrownei* Zone/*Calycoceras guerangueri* Zone
Nettleton Stone Band	*Acanthoceras jukesbrownei* Zone
Pycnodonte Band	*Acanthoceras jukesbrownei* Zone
Planktonic/benthonic Break	*Acanthoceras rhotomagense* Zone, *Turrilites acutus* Subzone
Upper Orbirhynchia mantelliana Band	*Acanthoceras rhotomagense* Zone, *Turrilites costatus* Subzone
Primus Band	*Acanthoceras rhotomagense* Zone, *Turrilites costatus* Subzone
Arlesiensis Band	*Cunningtoniceras inerme* Zone
Middle Orbirhynchia mantelliana Band	*Mantelliceras dixoni* Zone/*Cunningtoniceras inerme* Zone
Lower Orbirhynchia mantelliana Band	*Mantelliceras dixoni* Zone
Virgatus Band	*Mantelliceras dixoni* Zone
Mariella/Crippsi Band	*Mantelliceras dixoni* Zone, *Mantelliceras saxbii* Subzone
Crippsi Band	*Mantelliceras mantelli* Zone, *Sharpeiceras schlueteri* Subzone
Gryphaeoides/Ultimus Band	*Mantelliceras mantelli* Zone, *Neostingoceras carcitanense* Subzone

Table 3. Inter-regional marker bands and their ammonite zonation used in the folgen stratigraphy of the Cenomanian strata of England.



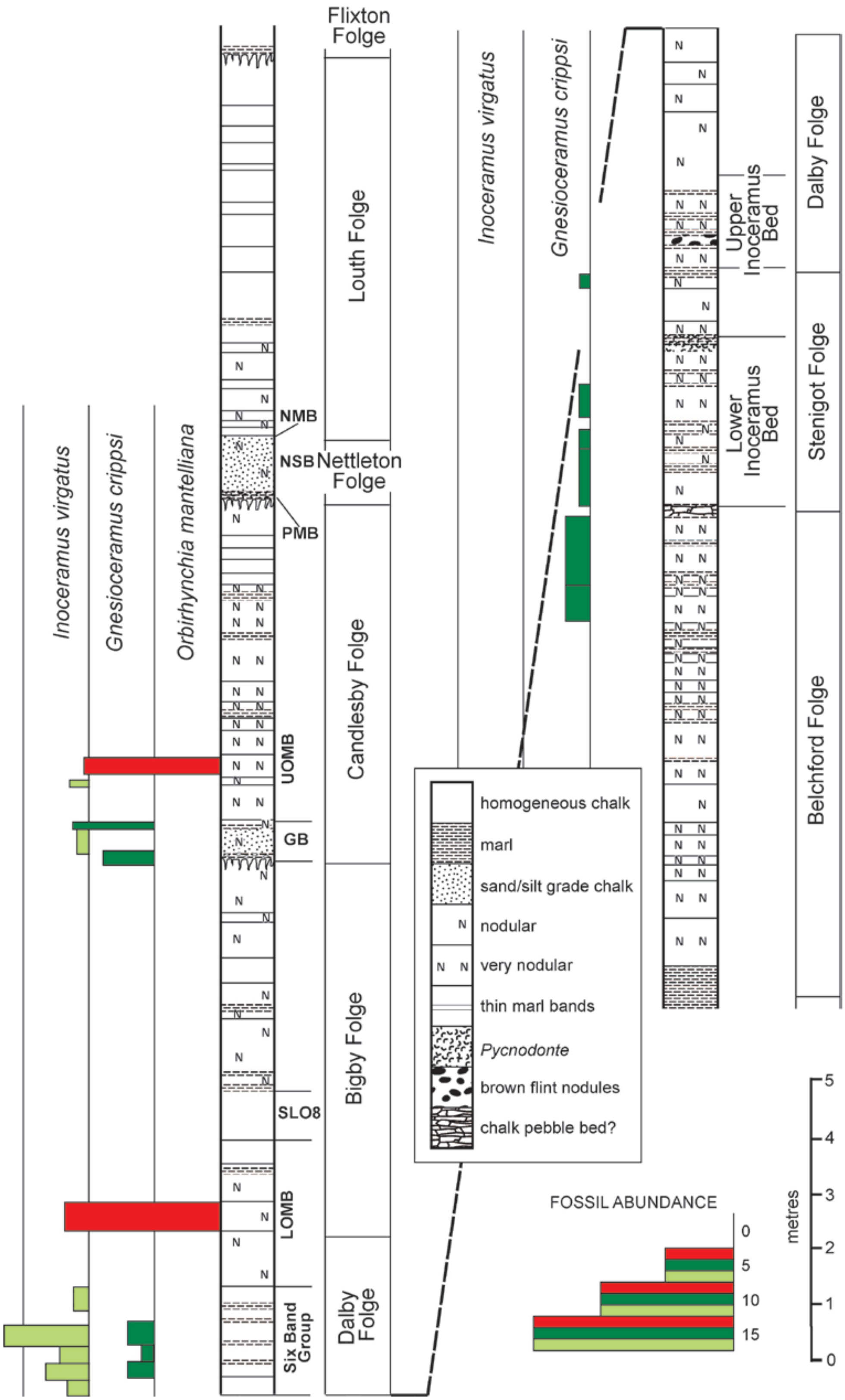
Text-fig. 7. Lithological variation in the Cenomanian Chalk (Ferriby Formation) in the Northern Province, England



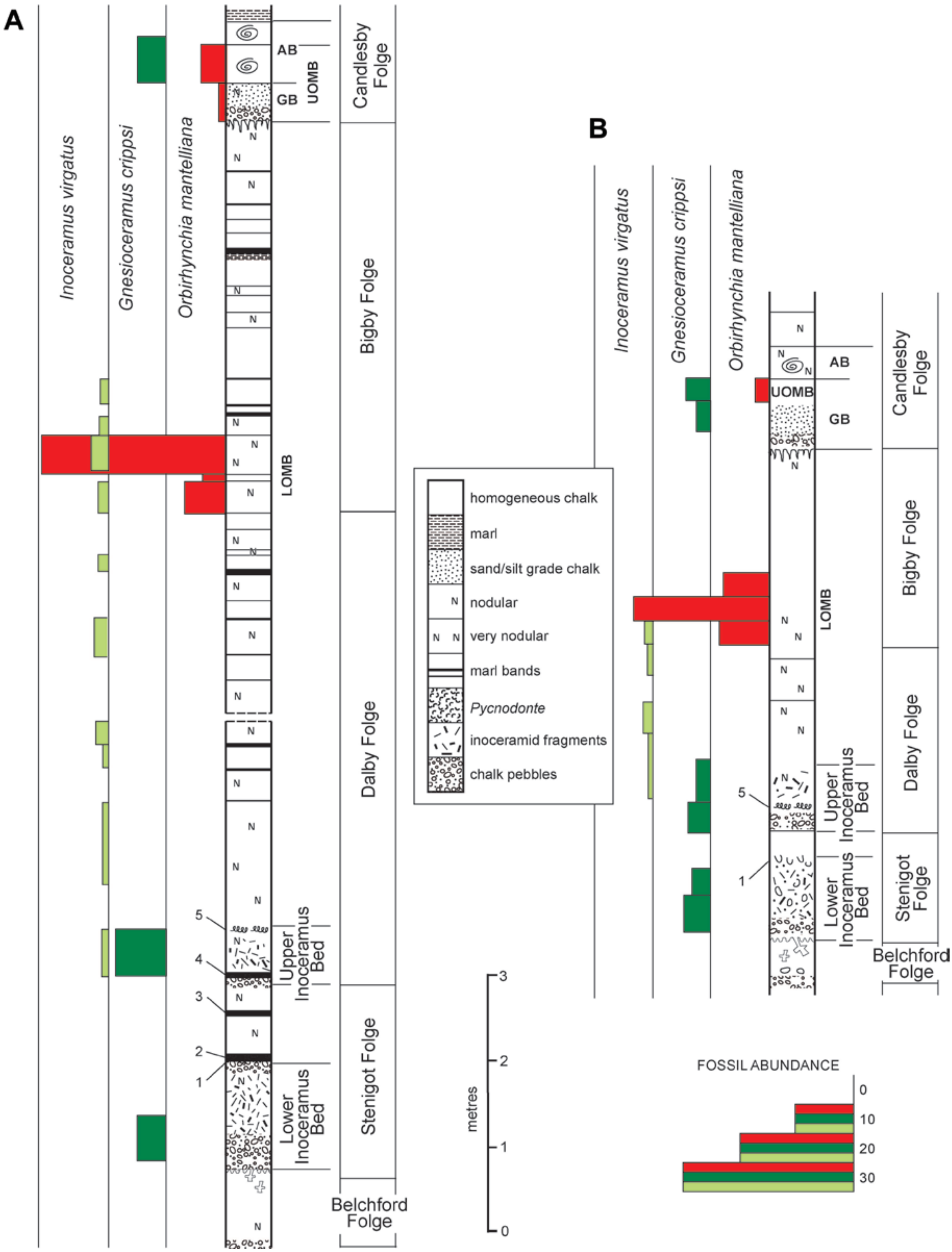
Text-fig. 8. Relationship between the eight Cenomanian folgen and the Ferriby Formation and the basal part of the Welton Formation at South Ferriby, Lincolnshire.

Belchford Folge overlies the Upper Greensand (e.g., Ventnor, Isle of Wight), it consists of sandy glauconitic chalk.

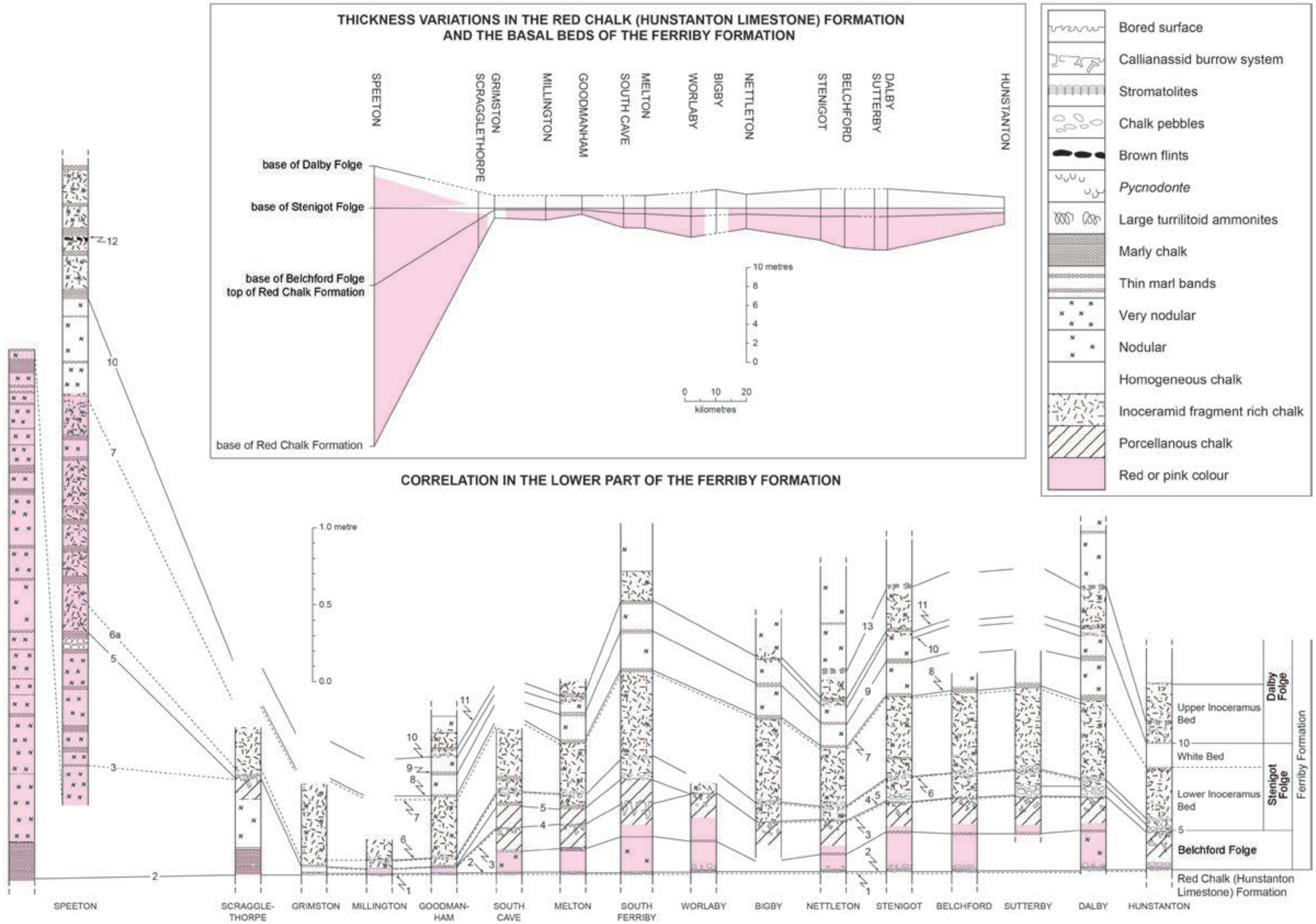
Northern Province: The Belchford Folge displays two facies – the reduced sequences on the Midland Shelf and the expanded sequence in the Speeton



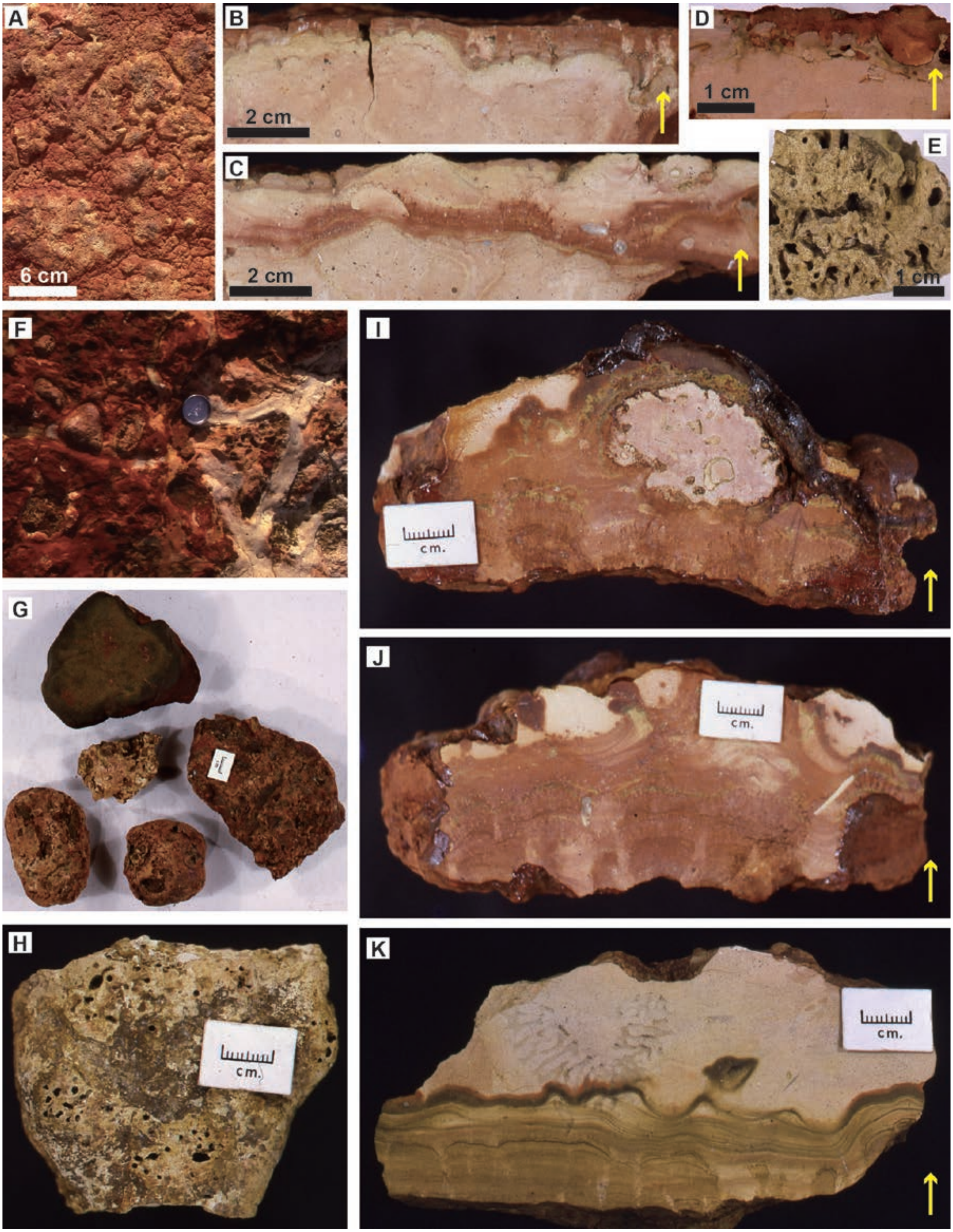
Text-fig. 9. Lithological sequence of the Cenomanian folgen in the cliffs at Speeton, Yorkshire. The distribution of *Inoceramus virgatus* and *Gnesioceramus crippsi* is shown in relation to various marker bands. Key for marker bands, see Text-fig. 10.



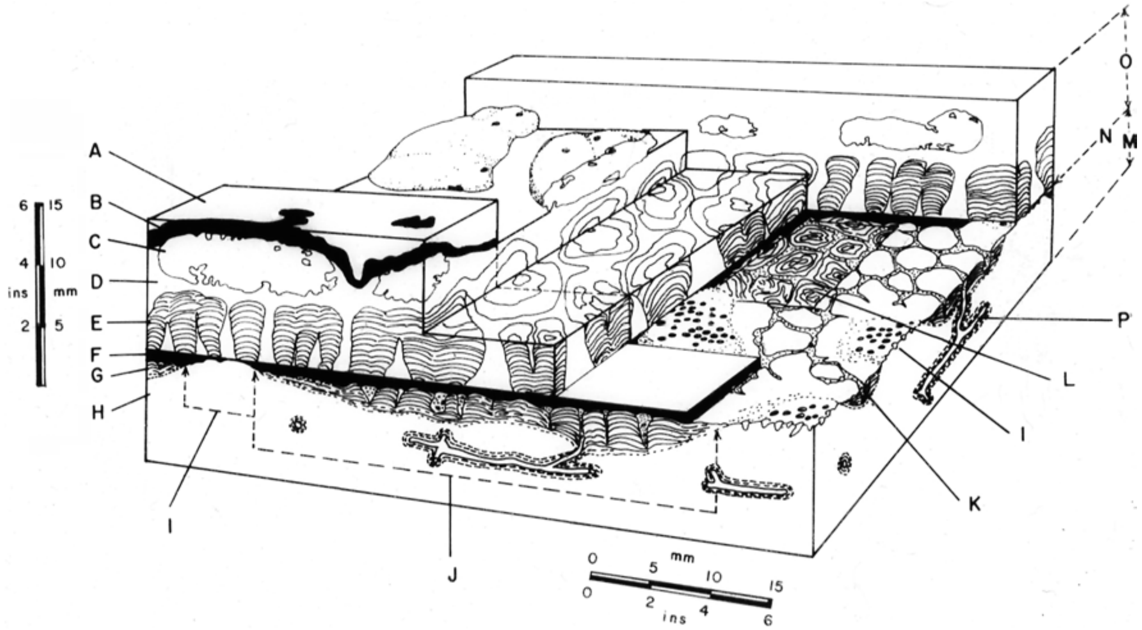
Text-fig. 10. Lithologcal sequences of the Cenomanian folgen from inland Lincolnshire (A) (see Text-fig. 8 for uppermost part) and Yorkshire (B), and from the Hunstanton Cliffs, Norfolk. The distribution of *Inoceramus virgatus* and *Gnesioceramus crippsi* is shown in relation to various marker bands. 1 – Lower Pycodonte Bed; 2 – Marl I; **3** – Marl II; 4 – Marl III; 5 – Turrilitoid Plane; GB – Grey Bed (Totternhoe Stone); AB, Ammonite Beds; PMB, Pycnodonte Band; NSB – Nettleton Stone Band; NMB – Nettleton Marl Band; LOMB – Lower Orbirhynchia mantelliana Band; UOMB – Upper Orbirhynchia mantelliana Band.



Text-fig. 11. Correlation chart showing the distribution of red and pink chalk and lithological marker horizons in the lower part of the Cenomanian chalk (Belchford, Stenigot and Dalby folgen). 1 – Bored top of Red Chalk Hunstanton Limestone Formation; 2 – Base of Belchford Folge; 3 – Upper limit of *Aucellina gryphaeoides*; 4 – Bored top of Spongia paradoxica Bed; 5 – Base of Stenigot Folge and Lower Inoceramus Bed; 6 – Band of abundant holasterid echinoids; 6a – as 6 with chalk pebbles; 7 – Lower Pycnodonte Band; 8 – Marl Band I; 9 – Marl Band II; 10 – Base of Dalby Folge, base of Upper Inoceramus Bed; 11 – Marl Band III; 12 – Brown Flint Band; 13 – Turrilitoid plane. Insert: Thickness variations and distribution of red and pink colour in the Belchford and Stenigot folgen (Ferriby Formation) and in the underlying Hunstanton Red Chalk Formation (Upper–Middle Albian).



Text-fig, 12. Sedimentary features at the top of the Red Chalk and the base of the overlying Belchford Folge. A – Red Chalk, Hunstanton, top surface showing areas of bored lithified limestone and stromatolite "crust"; B, C – Red Chalk, Hunstanton: vertical sections through the stromatolite "crust", the underlying pale pink limestone, and its bored upper surface; D, E – Red Chalk, Rosin Hill: bored top surface of the Red Chalk. F. Base of the Paradoxica Bed, Hunstanton: plan view showing the basal stromatolite columns, the overlying band of bored pebbles and callianaspid burrows; G, H – Bored limestone pebbles and a sandstone pebble from the pebble bed near the base of the Paradoxica Bed; I, J, K – Vertical section through the base of the Paradoxica Bed showing the stromatolite columns cross-cut by late diagenetic banded iron oxide staining that encompasses a bored pebble (I) and cross-cuts a fossil sponge (K).

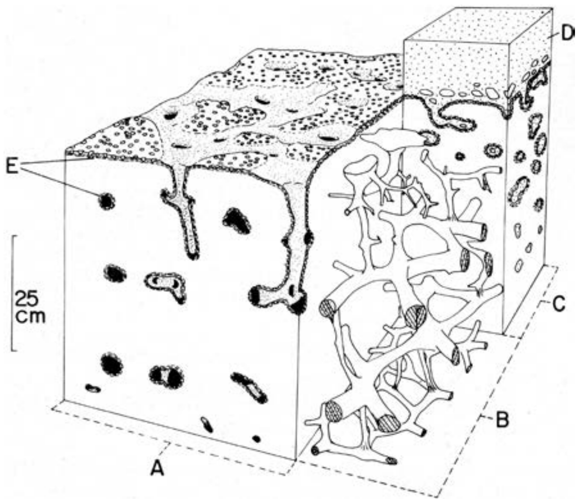


Text-fig. 13. Block diagram of the structure and inter-relations between the top of the Red Chalk Formation and the base of the Paradoxica Bed at Hunstanton, Norfolk. A – Pink chalk at the base of the Paradoxica Bed; B – Hard brown ochre to brown iron oxide layer formed by the replacement of chalk during late non-intrinsic diagenesis – running parallel to this are numerous very fine ochreous bands that cross-cut earlier diagenetic structures; C – Pebbles of pink limestone extensively bored and glauconite stained. Up to 18 cm in maximum dimension; D – Basal chalk of the Paradoxica Bed infilling between stromatolite columns; E – Stromatolite columns of alternating thin dark green glauconitic clay layers and thicker reddish calcareous layers; F – Friable red clay with brown stained sand grains and small pebbles; G – Stromatolite layer at the top of the Hunstanton Red Chalk Formation consisting of irregular sheets or vertical columns (polygonal in plan) of alternating thin (approximately 0.1 mm) ochreous to red carbonate layers; H – Pale pink chalky laminae with irregular, vertically elongated patches of coarse sand grains: gradational junction with G; I – Higher surfaces penetrated by undistorted borings or burrows (1–1.5 mm diameter) – surfaces, borings and burrows coated by blackish green glauconite skins [<1mm thick]; J – Topographic lows (up to 19 mm below the higher bored regions) on the top surface of the Red Chalk; K – Reticulated network of soft pink chalk with numerous sand grains and small pebbles infilling between stromatolitic columns; L – Horizontal section through stromatolites showing internal structure; M – Top part of the Red Chalk; N – Junction of Red Chalk and Ferriby Formation; O – Basal part of Paradoxica Bed; P – Undistorted sediment filled reticulated burrow system with Liesegang glauconite staining of its walls, paling into the matrix, connected to slightly distorted sediment-filled tubes (1–2 mm diameter) with walls stained by thin skin of blackish-green glauconite.

Basin (Text-fig. 11). The Midland Shelf facies is best preserved in southern Lincolnshire where it consists generally of two divisions. A lower one (Text-figs 12, 13) consisting of a complex sequence of stromatolitic layers (Text-fig. 12A, B, C, I, J, K) associated with very early lithification (Text-fig. 12B, C), periods of boring (Text-fig. 12D, E, H), erosion (Text-fig. 12A, C) and glauconitisation, and a final phase of deposition of possibly ice-transported pebbles and cobbles (Text-fig. 12G; Jeans and Platten 2021). The structures produced during this phase of very restricted deposition were then over-printed by Liesegang zones of iron oxide at a latter stage of diagenesis (Text-fig. 12I, J, K).

The upper division of the Midland Shelf facies is a porcellanous chalk containing a branching system of glauconite-stained, sediment-filled callianassid burrows (Jeans *et al.* 2014b, p. 310), forming the Paradoxica or Spongia paradoxica Bed (Text-fig. 14). These burrows may be filled with a grey, more marly, gritty chalk similar in general lithology to the overlying Lower Inoceramus Bed. The burrows open out into unbored depressions at the top of the Paradoxica Bed and these are surrounded by the bored flat top surface of the bed (Text-fig. 14).

In southern Lincolnshire, the Belchford Member varies in thickness from ~0.30 to 0.52 m. Traced southwards over the Wash Line it thins even more. At Hunstanton it is ~50 cm thick, the lower zone of reddish brown/pink nodular chalk is hardly developed (Jeans *et al.* 2014, fig.8) and the greater part of the member consist of the porcellanous Paradoxica Bed with its bored top surface. Traced northwards, the Belchford Folge thins to <1 cm over the Market Weighton Block and consists of variably coloured (pink, white, ochreous) porcellanous chalk with a

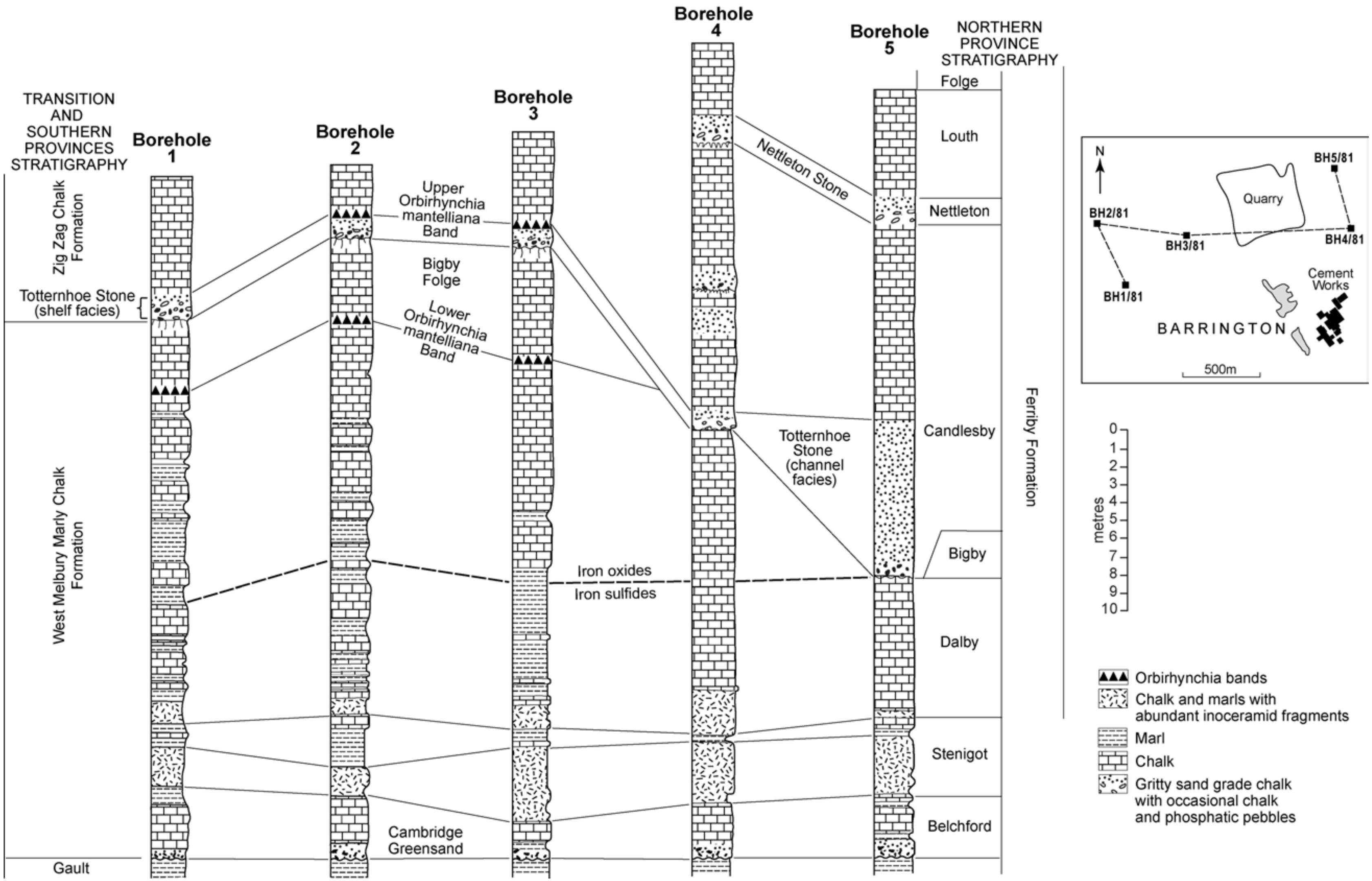


Text-fig. 14. Structure of the Paradoxica Bed at Hunstanton prior to pressure dissolution. A – Original form when exposed on the Chalk seafloor with a bored flat surface and the unbored depressions leading into the glauconite stained callianaspid burrow system (Jeans *et al*. 2014b); B – Excavated system of burrows now infilled with grey gritty chalk; C – The relationship between the Paradoxica Bed and the overlying Lower Inoceramus Bed; D – Basal part of the Paradoxica Bed; E – Liesegang zones of glauconite staining.

hummocky top surface (possibly originally algal-bound) with traces of borings. The basal stromatolite layer, the overlying pebble bed, and the "*Spongia paradoxica*" structure are absent. The section recorded by Mitchell (1996, p. 163, fig. 2) from the classic Market Weighton quarry differs from Jeans (1973, fig. 2) in that neither the bored top surface of the Red Chalk is recorded nor the overlying basal beds (beds 8, 9, 10) that represent the Belchford Folge. Mitchell (1996) suggests that the Lower Inoceramus Bed of the overlying Stenigot Folge has overstepped the Belchford Folge and rests directly on the Hunstanton Red Chalk Formation. The more complete sequence (Jeans 1973) suggests that this is incorrect and the Belchford Folge is represented by Beds 8, 9 and 10. North of the Market Weighton Block, the sequence thickens rapidly and is ~4.4 m on the coast at Speeton, where it is represented by reddish brown nodular chalks with some marl bands. The basal pebble bed and stromatolite layers are absent. The base of the Folge is recognised by the conspicuous change in the terebratulid fauna from one dominated by biplicate forms (*Biplicatoria* gen.) to uniplicate forms (*Concinnithyris* gen.) (Jeans 1973, 1980; see Mitchell 1995, p. 297) and by anomalies in the bulk $^{13}C/^{12}C$ values (Mitchell 1995, fig. 11). Its top is marked by a conspicuous porcellanous white chalk, perhaps the local representative of the Paradoxica Bed. The last occurrence of *Aucellina gryphaeoides* occurs ~1 m below this bed whereas in the reduced inland sequences and at Hunstanton it occurs throughout the Paradoxica Bed. Complete or partial sections of the Belchford Folge (Text-fig. 11) have been recorded at Hunstanton, Dalby, Sutterby (part), Belchford, Stenigot, Nettleton, Bigby, Worlaby, South Ferriby I, Melton, South Cave, Goodmanham, Millington, Grimston, Scagglethorpe, and Speeton.

Transitional and Southern Provinces: The Belchford Folge is easily traced south and westwards as far as the region around Dunstable in Berkshire. In the Ely borehole no. 15 (Gallois 1988, p. 60) the base is placed at the junction of the glauconitic basement bed and the Gault and its top at 22.55 m the depth at which the first *Gnesioceramus crippsi* comes in. In the boreholes at Barrington near Cambridge (Text-fig. 15), the Belchford Folge is 2–4 m thick and includes the Cambridge Greensand; the base is marked by the erosion surface at the top of the Gault Clay and the top by the incoming of the flood of *G. crippsi*. In the Sundon Borehole this Folge proved to be exceptionally thick (~22 m). It is seen next in the coastal sequence at Folkestone where it has been described in some detail by Kennedy (1969) and Gale (1989). The Belchford Folge rests unconformably on the underlying Gault Clay and consists of glauconitic marl containing rare *Aucellina gryphaeoides*; the top is taken at level 2b of Kennedy (1969, fig. 2) where *Gnesioceramus crippsi* occurs in abundance. The Glauconitic Marl at Beachy Head (Eastbourne) and on the Isle of Wight (Culver Cliff, Compton Bay) is assigned to the *Neostlingoceras carcitanense* Subzone (Wright *et al.* 2017): the presence within it of *Aucellina gryphaeoides* has been recorded by Jukes-Browne and Hill (1903, p. 87) although not mentioned by either Kennedy (1969) or Mortimore *et al*. (2001, p. 77).

The extent to which the Belchford Folge is represented in the inland regions of southeast and southern England is not known as systematic collections of the calcitic macrofossil assemblages are either unavailable or unrecorded. There is a scattering of records of *Aucellina gryphaeoides* in the "Chloritic" (i.e., Glauconitic) Marl reported by Jukes-Browne and Hill (1903) from inland Hampshire and Sussex as well as from the Isle of Wight in the upper part (Bed 5) of the "Chloritic" Marl at Ventnor-Bonchurch-St Lawrence, Brook and Compton Bay. My own collecting in 1965–1966 in the glauconitic marl at (1) Folkestone demonstrated *Aucellina gryphaeoides* to be the dom-



Text-fig. 15. Five cored boreholes at Barrington: Correlation and general lithology in the Belchford, Stenigot, Dalby, Bigby and Candlesby folgen in the Transitional Province displaying (1) the channel and shelf facies of the Totternhoe Stone, (2) the relationship between members and the subdivisions used by the British Geological Survey in their mapping of the Cenomanian Chalk of the Transitional and Southern provinces, and (3) the ground water oxidation front which is an important factor in the colour of the chalk.

inant component in a sparse bivalve assemblage with *Entolium orbicularis*, *Anomia* and *Ostrea*, and at (2) Culver Cliff it is a major component of the bivalve assemblage in the basal metre of the sequence that is dominated by *Entolium orbiculare*. There is general correlation between the frequency of *Aucellina gryphaeoides* and lithofacies. It is much more frequent in the silty to clay-grade marl and chalk lithofacies than the glauconitic sand lithofacies of this member (Ely, Gallois 1988, p. 60; Barrington, Mortimore *et al*. 2001, p. 305; Sundon, Shephard-Thorn *et al*. 1994; Folkestone, Aycliff Borehole, C.J. Wood in Gale 1989, p. 77). A possible explanation is that the thin-shelled *A. gryphaeoides* with its gryphaeate left valve was best adapted to living in fine-grained sediments, and once dead their shells were subjected to the strong currents under which the glauconite sands were deposited and were usually broken into unrecogniseable fragments.

STENIGOT FOLGE

The base of the Stenigot Folge is defined by the Crippsi Band and its top by the base of the Mariella/Crippsi Band. The Stenigot Member represents lithofacies cycle III of Jeans (1980), its base reflects the initiation of depositional sequence Ce II and its top is sequence boundary SB Ce 2 (Jeans *et al.* 2021; Text-fig. 2). The Stenigot Folge is placed in the *Sharpeiceras schlueteri* Subzone of the *Mantelliceras mantelli* Zone based on ammonite assemblages from Folkestone (Gale and Friedrich 1989) and Hunstanton (Mortimore *et al*. 2001, p.392). Its strata are part of both the Ferriby (Northern Province) and the West Melbury Marly Chalk (Transitional and Southern Provinces) formations. The inoceramid fossil assemblage is dominated by *Gnesioceramus crippsi* with occasional Inoceramus *reachensis* Etheridge and rare *Inoceramus anglicus conjugalis* and possibly *Inoceramus hoppenstedtensis* (Jeans 1967; Kennedy 1969; Gallois 1988; Gale 1989; Shephard-Thorn *et al.* 1994; Mortimore *et al.* 2001; Mitchell 2019). The Stenigot Folge is readily recognisable throughout the Northern and Transitional Provinces as far south as Cambridge and Bedfordshire (Text-fig. 6). In the expanded sections of the Southern Province it is represented at Folkestone and Culver Cliff (Isle of Wight). Whether the Stenigot Folge is present at Eastbourne (Beachy Head) or at Compton Bay (Isle of Wight) is uncertain, perhaps only the result of the incomplete collecting of the calcitic macrofossil assemblages. Further work is needed to determine the extent to which the Stenigot Folge has survived reworking as the Chalk facies transgressed westwards onto the Cornubian Upper Greensand Ridge.

Northern Province: The Stenigot Folge displays two facies – a reduced sequence on the Midland Shelf and a somewhat expanded sequence in the Speeton Basin (Text-fig. 11). In south Lincolnshire, it is ~1 m thick and consists of a lower unit (0.7 m) of grey, coarse-grained inoceramid-rich chalk (1st or Lower Inoceramus Bed, Jeans 1968, 1973, 1980) with a thin regional marker band the Lower Pycnodonte Band (Lower Ostrea Band of Jeans 1967) separating it from the upper unit, the White Bed, a bed of white nodular chalk with infrequent inoceramid fragments containing two thin persistent detrital marl bands (Marls I and II, Jeans 1980, fig. 3) that can be traced as far north as Goodmanham. The Lower Inoceramus Bed is largely made of inoceramid prisms with lesser amounts of large fragments and whole valves that are usually stained green by glauconite. Whole inoceramid valves occur abundantly at various horizons lying parallel to the bedding. Glauconite-stained pebbles, often distorted by compaction, are abundant at the base of this bed and from which poorly preserved ammonites have been collected (Jeans 1967, fig. A42: see earlier discussion of identification). Mortimore *et al.* (2001, p. 392) mention a specimen of *Sharpeiceras schlueteri* Hyatt collected by Andy Gale from this bed. About 15 cm above the base of the Lower Inoceramus Bed is a ~10 cm band of abundant *Holaster* echinoids.

When the Stenigot Folge is traced southwards across the Wash Line to Hunstanton, both the lower and upper divisions thin to 0.4 m and 0.17 m, respectively. The two marl bands are no longer present. Associated with this lateral thinning is an increase in the proportion of inoceramid prisms and fragments. When the Stenigot Folge is traced northwards into south Yorkshire, there is no appreciable variation in thickness. There is a slight thinning over the Market Weighton Block, but then both units thicken markedly northwards. At Speeton, the Lower Inoceramus Bed is represented by 1.5 m of inoceramid fragment-rich, whitish grey nodular chalk and marls with pink or purple marl wisps (Text-figs 11, 16). Glauconite staining is absent, chalk pebbles are rare or absent. The band rich in *Holaster* near the base has expanded to 0.5 m. The combined Marl Band I and the Lower Pycnodonte Band have expanded to ~6 cm and are of a pale pink colour. The upper division, the White Bed, is represented by 0.6 m of nodular and very nodular chalk. Marl Bands II and

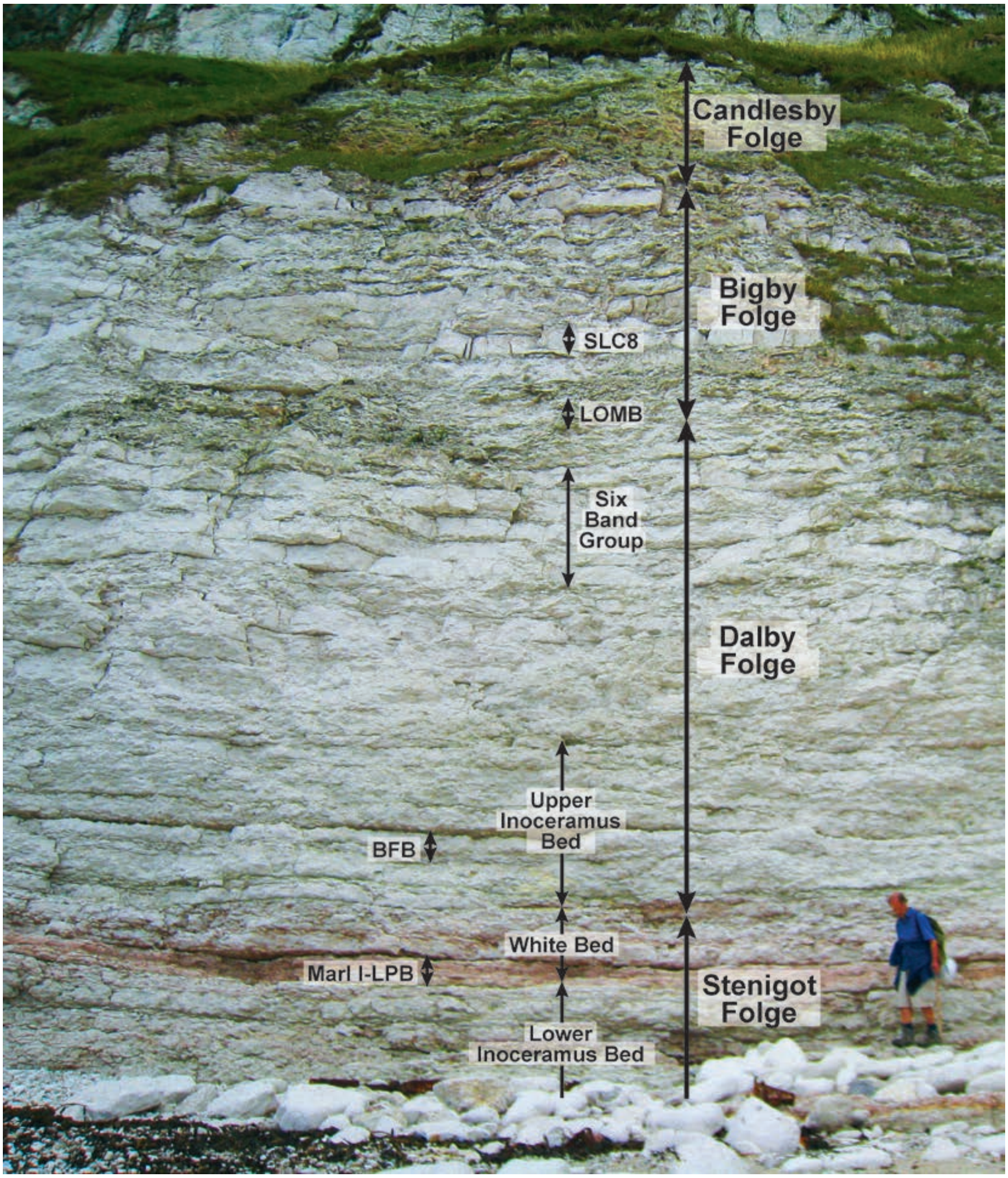
III, last seen at Goodmanham, are no longer recognisable in the expanded section at Speeton. Complete sections of the Stenigot Folge have been recorded at Hunstanton, Dalby, Stenigot, Nettleton, Bigby, South Ferriby, Melton, Goodmanham, and Speeton – incomplete sections at Sutterby, Belchford, South Cave, Millington, Grimston and Scagglethorpe.

Transitional and Southern Provinces: The Stenigot Folge can be traced southwards as far as Bedfordshire (Text-fig. 6). In the Ely borehole no. 15, the base of the member is at 22.5 m, the depth at which the first *Gnesioceramus crippsi* flood comes in; its upper limit is at 14.50 m at the base of the Upper Inoceramus Bed. In the Barrington boreholes near Cambridge, this Folge is well defined in all five boreholes (Text-fig. 15) It is present in the Leighton Buzzard region (Shephard-Thorn *et al.* 1994). The Folge is represented in the coastal sections of the Southern Province although there are problems in differentiating between the Lower and Upper Inoceramus Beds. At Folkestone, the influx of large *Gnesioceramus crippsi* in the basal part of the Chalk Marl section shown in Gale and Friedrich (1989, fig. 4) is taken to represent the Lower Inoceramus Bed. The top of this Folge is taken within the *M. saxbii* Subzone when *Inoceramus virgatus* first appears among the thin-shelled *Inoceramus crippsi* and *Inoceramus reachensis.* This is at the 11-metre-level in fig. 2 of Gale (1989, p. 77). At Eastbourne (Beachy Head), the base of the Lower Inoceramus Bed occurs at the ~10.5 m level in fig. 3.111 of Mortimore *et al.* (2001, p. 250); the Upper Inoceramus Bed may be represented within the *Mantelliceras saxbii* Subzone as represented in Wright *et al.* (2017, fig. 192).

DALBY FOLGE

The base of this folge is defined by the Mariella/Crippsi Band (Upper Inoceramus Bed) and the top by the base of the Lower Orbirhynchia mantelliana Band. The lowest part belongs to the *Mantelliceras saxbii* Subzone (upper *Mantelliceras mantelli* Zone) whereas the main part of Dalby Folge, which is divided into two by the Virgatus Band, belongs to the lower half of the *Mantelliceras dixoni* Zone. The Dalby Folge represents the lower half of the upward-fining lithofacies cycle IV of Jeans (1980), its base marks the the initiation of depositional sequence Ce III and whereas its top lies within Ce III at the level of the Lower Orbirhynchia mantelliana Band in the *Mantelliceras dixoni* Zone (Text-fig. 2). Its strata are included in both the Ferriby (Northern Province) and the West Melbury Marly Chalk (Trasitional and Southern Provinces) formations. The inoceramid fossil assemblage of the Upper Inoceramus Bed is generally thin-shelled and has been identified by various authors to contain *Inoceramus reachensis, Inoceramus* ex gr. *virgatus*, *Inoceramus hoppenstedtensis*, *Inoceramus reachensis* or *schoendorfi* (Whitham 1991, fig. 4) , and *Gnesioceramus crippsi* (Jeans 1967; Gallois 1988; Mortimore *et al*. 2001; Whitham 1991; Mitchell 2019).

Northern Province: Over the Midland Shelf, the Dalby Folge thins from >4.5 m in south Lincolnshire to 4.5 m in south Yorkshire. Lack of exposure has not allowed any thickness changes to be related to the Market Weighton Block although the Lower Chalk section at Acklam (Hill 1888) suggests that it may be reduced. North of the Market Weighton Block, the Dalby Folge thickens, reaching 7.8 m in the Speeton Cliffs. In southern Lincolnshire, it consists of the Upper Inoceramus Bed (at least 0.6 m) made of grey gritty chalky limestone rich in inoceramid fragments, similar in general lithology to the Lower Inoceramus Bed. At its base, a band of glauconite-stained pebbles show signs of compaction. Large fragments and whole valves of inoceramids are common with their internal surfaces often stained by glauconite. The Upper Inoceramus Bed rests sharply on the White Bed of the underlying Stenigot Folge and it passes upwards into nodular chalks interbedded with thin, impersistent marl seams and beds of homogeneous chalk that form the main body of the folge. About 15 mm above the base of the Dalby Folge there is a thin persistent detrital marl band (Marl Band III, Text-figs 8, 11) that cannot be recognised in the expanded sequence at Speeton. Another regional marker band is the Turrilitoid Plane, a horizon of abundant internal casts of large turrilitoid ammonites, best developed at Hunstanton, that occurs at or a little above the top of the Upper Inoceramus Bed; it has been traced as far north as Nettleton (Text-fig. 11). When the folge is traced southwards across the Wash Line to Hunstanton, it is only 2.5 m thick, Marl III is no longer present and the Upper Inoceramus Bed, with its well-developed Turrilitoid Plane, passes up into gritty chalk. At Speeton, the Upper Inoceramus Bed is 0.8 m thick, consisting of nodular chalk with impersistent marl seams and abundant inoceramid fragments. This bed contains the Brown Flint Band (Jeans 1980; Jeans *et al.* 2016) and passes gradually upwards into nodular chalk (3.0 m) with occasional inoceramid fragments, and these, in turn, are over-



Text-fig. 16. Cenomanian strata, Pink Cliff, Speeton. A largely inaccessible but complete section from the middle part of the Stenigot Folge to the Nettleton Folge. Note the disturbed nature of much the chalk of the Stenigot, Dalby and Bigby Folgen with stratification being picked out by occasional less damaged homogeneous chalk beds and pronounced marls including a persistent pink marl bed associated with the Lower Pycnodonte Bed. The upper division of the Stenigot Folge, the White Bed of the Midland Platform, is represented by pink marl and chalk. LPB – Lower Pink Band; BFB – Brown Flint Band; LOMB – Lower Orbirhynchia mantelliana Band; SLC8 – prominent chalk bed of Mitchell (1996a, fig.2; see Text-fig. 7). Person approx. 1.60 metre tall. Photo. 2010.

lain by the Six Band Group (Text-figs 9, 16), i.e., six prominent beds of homogeneous chalk, together 2.0 m thick. Overlying this is a ~1.1 m sequence of nodular chalks with the Lower Orbirhynchia mantelliana Band resting on it. Complete sections were recorded at Hunstanton, Candlesby II, Nettleton, Bigby, South Ferriby I, Melton, and Speeton – incomplete sections at Candlesby, Scremby, Stenigot, Elsham I, and Goodmanham.

Transitional and Southern Provinces: The Dalby Folge with the Upper Inoceramus Bed (Mariella/Crippsi Band) at its base and the Lower Orbirhynchia mantelliana Band at the top can be traced through the Transitional Province into the Southern Province (Text-fig. 6). It has been recorded in the Barrington boreholes (Text-fig. 15) and in the chalk pits in the Leyton Buzzard region (Shephard-Thorn *et al*. 1994). Locally, in the Ely and Barrington boreholes (Gallois 1988; Text-fig. 15) and in the Totternhoe region, it has been partly or totally lost by erosion preceding the deposition of the Candlesby Folge (Shepherd-Thorn *et al*. 1994; Gale and Kennedy 2022). In the Southern Province, identification of the base of the Dalby Folge is problematic in the coastal sections as the distribution, abundance and species of *Inoceramus* have only been touched upon in studies where the ammonite assemblages have been the main concern. At Folkestone, the lower limit of the Folge is best located at the level where the Inoceramid population becomes generally thin-shelled and is joined by *Inoceramus virgatus*.

BIGBY FOLGE

The base of the Bigby Folge is defined by the Lower Orbirhynchia mantelliana Band and the top by either the upper limit of the Middle Orbirhynchia mantelliana Band or the base of the Arlesiensis Band. It includes a major part of the *Mantelliceras dixoni* Zone and part of the overlying *Cunningtoniceras inerme* Zone based on ammonite assemblages from Folkestone and Eastbourne (Kennedy and Gale 2017). The Bigby Folge represents the upper part of lithofacies cycle IV of Jeans (1980) and the upper part of the deposition sequence Ce III and its top is marked by sequence boundary SBCe3 (Text-fig. 2). Its strata are part of the Ferriby (Northern Province) and the West Melbury Marly Chalk (Transitonal and Southern) formations. The extent to which this folge is preserved is very variable as it has been extensively affected by erosion and down-cutting by lithofacies Cycle V that marks the base of the overlying Candlesby Folge. The Middle Orbirhyncha mantelliana Band is essentially missing over the shelf region of the Northern Province as well as in parts of the Transitional and Southern provinces. This down-cutting has in places removed much or all of the Bigby Folge and part of the underlying Dalby Folge (Text-fig. 6). Gale and Kennedy (2022) provide details of how this is related to the scheme of ammonite zonation.

Northern Province: The Bigby Folge consists of a series of interbedded nodular and homogeneous chalk beds with thin impersistent marl seams displaying an overall increase in the proportion of homogeneous chalk compared to the underlying Dalby Folge. The upper marker bands for the member – the Middle Orbirhynchia mantelliana Band and the Arlesiensis Band – are typically missing other than for the occasional trace of their former presence. In southern and central Lincolnshire, the folge varies in thickness from 3.6 to 4.2 m showing no consistent pattern of variation. Poor exposure has not allowed changes in thickness to be recognised as it is traced northwards onto the Market Weighton Block. Hill's (1888) record of the Lower Chalk section at Acklam suggests there could be considerable thinning. North of the Market Weighton Block, the Bigby Folge thickens and is represented by 6.4 m of interbedded nodular and homogeneous chalk, at Speeton often with a pale pink or purplish hue with a prominent bed of white chalk (Bed SLC8 of Mitchell 1996) ~ 2 m above the base (Text fig. 16). Southwards from Lincolnshire, the folge thins across the Wash Line and is represented by ~1.7m of rather gritty chalk at Hunstanton.

Complete sections of the Bigby Folge have been recorded at Hunstanton, Nettleton, Bigby, Elsham I, South Ferriby I, Melton, and Speeton – incomplete sections at Candlesby I, Candlesby II, Scremby, Dalby, Stenigot and Louth I.

Transitional and Southern Provinces: The Bigby Folge displays two general lithofacies, a lower clay-rich one often displaying alternations of marl and chalk, and an upper more chalky unit that is usually poorly fossiliferous for either calcitic macrofossils or ammonite assemblages. The upper unit displays little obvious lithological variation as any subtle difference in clay contents are usually masked by pale ochreous staining resulting from the oxidation of FeS_2. Sections in the lower lithofacies of the Bigby Folge are poorly represented in the regional literature. In many inland pits, now disused, only the upper part of the member was exposed as this was of commercial use for agricultural purposes or for the production of lime. In contrast, where Portland cement was manufactured, such as at Barrington (Text-fig. 15), the complete folge with the underlying chalk and the Gault Clay were utilized. It is unfortunate that the Lower Orbirhynchia mantelliana Band was not known to Kennedy (1969) in his extensive study of the inland exposures of the Lower Chalk of SE England which included the Portland cement pits at Bluebell Hill, Burham and the Holborough Cement Works, both in Kent. It was only later that the extent of this band became generally known. It is now recorded from chalk pits in the Leyton Buzzard area (Shephard-Thorn *et al*. 1994), Folkestone (Gale

1993; Mortimore *et al.* 2001, p. 266), Eastbourne (Mortimore *et al.* 2001, fig. 3.111, p. 250; Wright *et al.* 2017, p. 479) and Southerham (Mortimore *et al.* 2001, p. 243; Wright *et al.* 2017, p. 481). The Lower Orbirhynchia mantelliana Band is present at Culver Cliff (Andy Gale, personal communication 2022) on the Isle of Wight, but so far has not been identified at Compton Bay. Further to the west at Ballard Cliff (Punfield Cove) and White Nothe, the Bigby Folge is absent and has been completely overstepped by stratigraphically higher strata.

CANDLESBY FOLGE

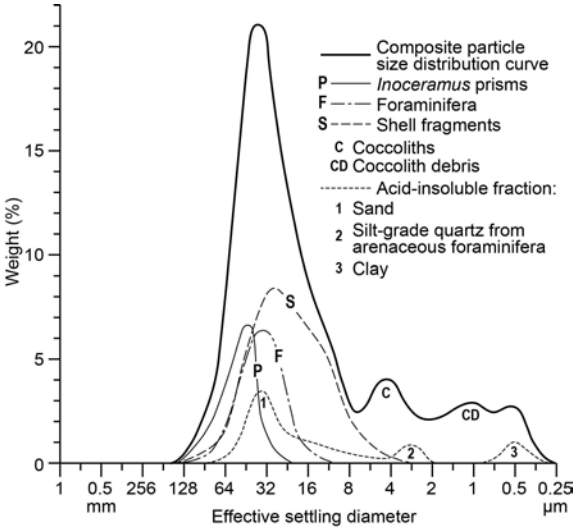
The base of the Candlesby Folge is defined by the Arlesiensis Band and its top by the base of the Pycnodonte Band. There are three internal inter-regional marker bands – in ascending order, the Primus Band, the Upper Orbirhynchia mantelliana Band, and the Planktonic/benthonic Break. The Candlesby Folge represents lithofacies cycle V of Jeans (1980), its base marks the initiation of depositional sequence Ce IV and its top is SB Ce 4 (Jeans *et al.* 2021; Text-fig. 2). The Candlesby Folge represents the upper part of the *Cunningtoniceras inerme* Zone, the *Turrilites costatus* and the *Turrilites acutus* subzones (*Acanthoceras rhotomagense* Zone) and, at its top, possibly the very base of the overlying *Acanthoceras jukesbrownei* Zone. The strata of the Candlesby Folge are part of the Ferriby (Northern Province) and the Zig Zag Chalk (Transitional and Southern Provinces) formations.

Northern Province: The Candlesby Folge varies considerably in thickness, but still displaying relatively thinner sequences over the Midland Shelf when compared to the Speeton Basin. It is 4 m at Hunstanton, 3.6 m at Welton, 4.5 m at Louth II, 6.0 m at Nettleton, 4.7 m at South Ferriby, and 6.5 m at Speeton (Text-fig. 7). There is considerable regional vertical variation in lithofacies. The base is marked by a burrowed surface at the top of the Bigby Folge. The burrows are usually preserved distorted by compaction, being filled with gritty chalk from the overlying Grey Bed. Locally at Bigby, these burrows are preserved green-stained and undistorted due to the development of a local patch of early lithification prior to compaction. The basal Grey Bed (0.6–0.7 m) consists gritty chalk with small chalk pebbles concentrated at its base, which may be phosphatized and glauconite-stained. Its thickness remains constant over the whole province. Although there has been regional erosion and condensation throughout the Northern Province, localized channeling has not developed as early lithification may have protected the underlying chalk sediment. The fossil assemblages of the Primus Band and remnants of the underlying Arlesiensis Band occur in the Grey Bed over the Midland Shelf; traces of the Arlesiensis Band have been recorded at Melton, Yorkshire where Whitham (1991, p. 224) has recorded *Lyropecten* (*Aequipecten*) *arlesiensis* in the lower part of the Grey Bed. At Speeton the sequence is expanded with the Grey Bed containing remnants of the Middle Orbirhynchia mantelliana Band and the Arlesiensis Band assemblages (Paul *et al.* 1994; Mortimore *et al.* 2001) whereas the Primus and the Upper Orbirhynchia mantelliana bands occur in the chalk above (see below).

The overlying Ammonite Beds (0.5–0.9 m; Text-fig. 7) in Lincolnshire and southern Yorkshire contain the main part of the Upper Orbirhynchia mantelliana Band and consist of one or two beds of porcellanous nodular chalk. Small and large ammonites are abundant usually preserved as internal casts with slight glauconite staining displaying type 4(3) lithification (Jeans 1980, p. 98). Large ammonites are often associated with populations of large terebratulid brachiopods that must have colonized their outer surfaces as they rested on the sea floor before burial. At Speeton the Ammonite Beds are still recognizable as an expanded sequence consisting of nodular chalk with poorly preserved small and large ammonites although specific identifications have now been attempted (*Turrilites costatus*, *Sciponoceras baculoide*, *Acanthoceras rhotomagense*; Paul *et al.* 1994, p. 11).

The Ammonite Beds are overlain by a series of marls, nodular marls and very nodular chalk that pass upwards into nodular chalk; these are reddish brown in central and much of south Lincolnshire, south Yorkshire and at Speeton (Text-fig. 6; Jeans *et al.* 2016, text-fig. 6) where they represent the Lower Pink Band of Bower and Farmery (1910). Within this sequence the Planktonic/Benthonic Break is located in a prominent marl band (Text-figs 8, 9, and 22). Outside this area of coloured chalk, these strata, when fresh, are a bluish grey caused by the presence of iron sulfide, or, if oxidized, they are tinted with ochreous/rusty hues. Above the Planktonic/Benthonic Break the sequence becomes less nodular and at Speeton includes beds of homogeneous chalk.

When the Candlesby Folge is traced southwards from southern Lincolnshire there is no evidence that it thins across the Wash Line. The Grey Bed and the overlying Ammonite Beds are present at Hunstanton, but in the cliff exposure the higher part of this Folge is inaccessible for close examination; there is, how-



Text-fig. 17. Particle size distribution curves for the total sample and the various components of the Burwell Rock (Candlesby Folge), Burwell, Cambridgeshire (after Black 1980, p. 65).

ever, a complete section recorded in the Hunstanton borehole (Gallois 1994, fig. 39). Complete sections of the Candlesby Folge have been recorded at Candlesby II, Welton, Louth I, Nettleton, Bigby, South Ferriby I and Speeton – incomplete sections at Hunstanton, Withcall, Elsham and Melton.

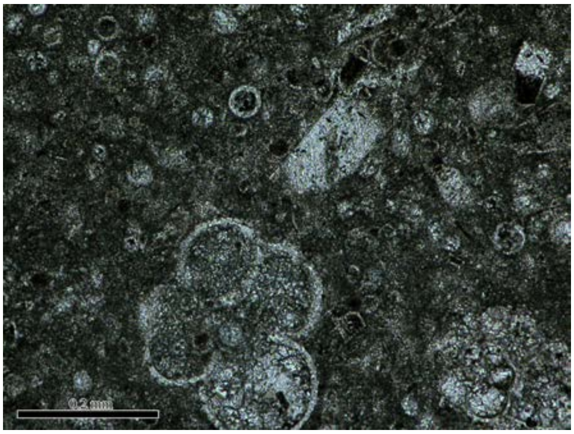
Transitional and Southern Provinces: The Candlesby Folge thickens considerably as it is traced into the Transitional Province. The Grey Bed expands into the Burwell Rock or Totternhoe Stone – an arenaceous silt grade chalk (Text-fig. 17) – with evidence of it filling deep channels in the underlying Bigby, Dalby and Stenigot folgen in the Ely, Burwell, Barrington and Totternhoe areas (Text-fig. 4; Gale and Kennedy 2022 for a recent account). In this area of channeling, the Arlesiensis Band is known only from Arlesey (Woods 1899–1913, p. 94; Wood 1992), whereas the overlying Primus Band, Upper Orbirhynchia mantelliana Band, and Planktonic/Benthonic Break are represented sometimes as a condensed remainé deposit. For example, at Pitstone the basal 30 cm of the Totternhoe Stone contains *Actinocamax primus* in association with *Oxytoma*, *Orbirhynchia mantelliana* and a host of other bivalves. The overlying 30–90 cm zone contains *Orbirhynchia mantelliana* which is particularly abundant in the upper half. The 90–120 cm zone contains phosphatized *Orbirhynchia mantelliana,* suggesting the local reworking of this band in adjacent areas as has been reported by Gale and Kennedy (2022, fig. 7) in the region between Chinnor and Barton. The main part of the member consists of rather characterless off-white chalk, sometimes with an ochreous tint, more or less uncemented, with wispy or thin seams of marl of limited lateral extent. In the Barrington boreholes there is no visible evidence of the alternating chalk-marl facies with the acetic acid insoluble residues dominated by the clay fraction decreasing continuously from 17% at the base of the member to 7% at the top. At Chinnor, near Pitstone (Text-fig. 6.) the sequence above the Totternhoe Stone include some darker grey marl bands, 0.1–0.3 m thick, occurring at intervals of 1–2 m – reflecting the lateral transition to the alternating chalk-marl facies that is so typical of this member in the Southern Province (Sumbler and Woods 1992).

There is a general regional lithofacies change and thickening in the Candlesby Folge between the Transitional Province and the Southern Province. The Southern Province is dominated by the alternating chalk-marl facies that is well exposed in the coastal cliffs of southern England. Channeling, comparable to that associated with the Totternhoe Stone, occurs at Southerham (Text-fig. 6; Mortimore *et al.* 2001). The five defining markers – the Arlesiense Band, the Primus Band (“Cast Bed” of Wright and Kennedy 2017), the Upper Orbirhynchia mantelliana Band, the Planktonic/Benthonic Break, and the Pycnodonte Band – are present in the stratigraphically extended sections at Folkestone, Eastbourne, Southeram, and the Isle of Wight (Text-fig. 6; Gale 1990, 1995; Mortimore *et al*. 2001; Wright and Kennedy 2017; Gale and Kennedy 2022).

The Candlesby Folge at Ballard Cliff is incomplete with the Arlesiensis and Primus bands missing as the result of the westward overstepping of the Cenomanian sequence onto the Upper Greensand Ridge (Text-fig. 4; Jeans 1968, Gale and Kennedy 2022, p. 248). Numerous inland records of chalks belonging to the Candlesby Folge with the occurrence of the Upper Orbirhynchia mantelliana Band in southeast and southwest England are to be found in Kennedy (1969, 1970).

NETTLETON FOLGE

This folge consists of three inter-regional marker bands – the Pycnodonte Band at the base, the Nettleton Stone Band forming the main part, and the Nettleton Marl Band at the top. The Nettleton Stone Band (Text-fig. 18) is a very distinctive bed of coarser grained chalk. The base of the folge – the base of the Pycodonte Band – represents the initiation of



Text-fig. 18. Thin-section of the arenaceous silt-grade well-cemented chalk of the Nettleton Stone Band, Taylor Cove, Speeton (Text-fig. 22). This band has a high bulk specific gravity (2.52; porosity 6.70%, acid insoluble residue by weight 5.10%).

lithocycle VI of Jeans (1980) and the low and transgessive tracts of SB Ce 5 (Text-fig. 2). The Nettleton Folge is part of the Ferriby (Northern Province) and Zig Zag Chalk (Transitional and Southern Provinces) formations. It represents the *Acanthoceras jukesbrownei* Zone based on very restricted and poorly preserved ammonite assemblages (Wright *et al.* 2017) – none were found during fieldwork in the Northern Province. The upper limit of the folge, marking the incoming of finer grained chalks of the Louth Folge, is associated with an important change in the fossil echinoderm assemblages with the replacement of the mixed thick-/thin-shelled *Holaster subglobosus* populations with thin-shelled *Holaster trecensis* (Jeans 1967, p. 29: Jeans 1968, fig. 2).

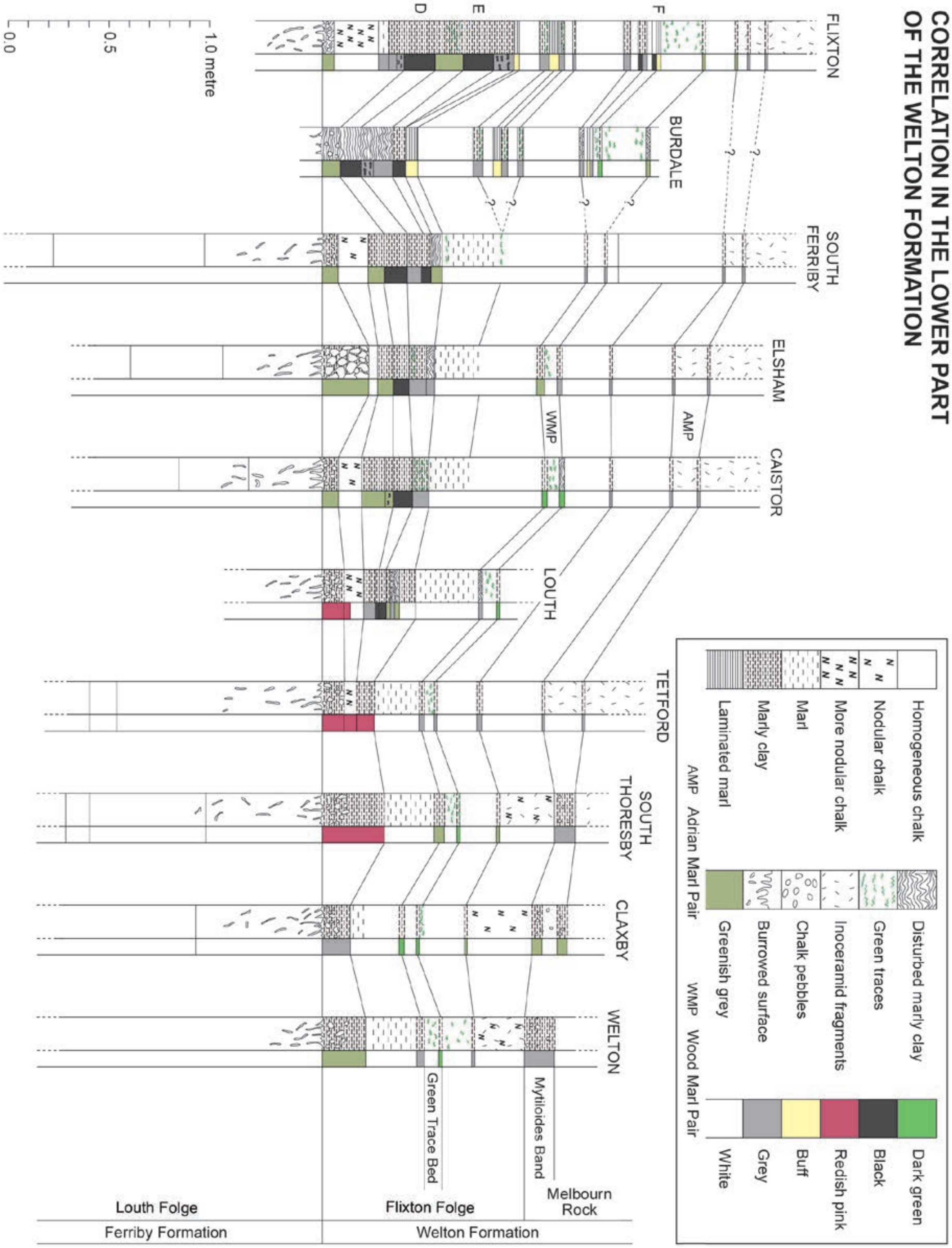
Northern Province: The total thickness of the Nettleton Folge is ~1.10m and it shows no more than a few centimetres variation throughout the province (Text-fig. 7). It is the first Cenomanian Folge to display no systematic difference in thickness between the sequences of the Midland Shelf and the Speeton Basin. The basal unit, the marly Pycnodonte Band, has been referred to in Lincolnshire as the *Gryphaea* Band by Bower and Farmery (1910), and more recently as the Upper *Ostrea* Band or the upper *Pycnodonte* Band (Jeans 1967, p. A29; Jeans 1980) to differentiate it from the lower *Pycnodonte* Band within the Stenigot Folge. The contact between the Pycnodonte Band and the top of the Candlesby Folge is sharp with the marl filling burrows in the underlying chalk sometimes in association with glauconite traces. The overlying Nettleton Stone Band is of hard grey gritty nodular chalk (0.45 m: Text-figs 19, 22), forming the main mass of the member. The top is defined by the thin Nettleton Marl Band (5–6 mm). Complete sections of the Nettleton Folge have been recorded at Heacham, Welton, Tetford, Louth I, Nettleton, Bigby, South Ferriby and Speeton.

Transitional and Southern Province: The Nettleton Folge thickens as it is followed into the Transitional and Southern Provinces where it reaches 2–3 m in the coastal sections of Folkestone, Eastbourne, Isle of Wight and Ballard Cliff (Text-fig. 6) and it displays characteristic scratch marks (Kennedy 1967). At Barrington (Text-fig. 15) this unit is ~1.5 metre thick. At White Nothe, the upper limit of the folge is represented in the sandy basement beds of the chalk sequence by the characteristic change in the echinoderm assemblages. In some recent literature (eg. Mortimore *et al.* 2001; Wright *et al.* 2017), the Nettleton Stone Band has been referred to as "Jukes-Browne Bed 7" based upon its description at Folkestone by Jukes-Browne and Hill (1903). It is uncertain whether the Pycnodonte Band is fully represented in the Southern Province; it is recorded at Folkestone (Mortimore *et al.* 2001, fig. 3.119) but is not mentioned either by Mortimore *et al.* (2001) or Wright *et al.* (2017) in their sections from Eastbourne, Southerham, or the Isle of Wight.

LOUTH FOLGE

The base of the Louth Folge is defined by the top of the Nettleton Marl Band and its top by the base of Jefferies Boreal Fossil Band which is at the erosion surface at the base of the Plenus Marls in the area under consideration. It is the upper and major part of upward-fining lithocycle VI of Jeans (1980), representing (1) the transition to the most offshore chalk lithofacies rich in coccoliths, and (2) part of the transgressive and the highstand tracts of depositional sequence Ce 5 (Text-fig. 2). The strata of the Louth Folge span the upper part of the *Acanthoceras jukesbrownei* Zone and the whole of the *Calycoceras guerangeri* Zone. Ammonites are very rare and are typically poorly preserved. This folge represent part of the Ferriby (Northern Province) and the Zig Zag Chalk (Transitional and Southern) formations.

In the Northern Province, this member is typically pale pink in colour (Upper Pink Band of Bower and Farmery 1910), containing finely divided hematite as the colouring pigment. This has been preserved as the result of the sediment not having undergone anoxic intrinsic diagnesis, although it has been modified by



Text-fig. 19. Correlation chart in the Flixton Folge within the Welton Formation, Northern Province.

late diagenetic sulfidization in zones cross-cutting the stratigraphy (Jeans *et al*. 2016). Whereas in the Transitional and Southern provinces anoxic conditions during intrinsic diagenesis dissolved all the iron oxides and hydroxides to form ferrous sulfides.

There are reports of bands of the encrusting oyster *Amphidonte* at a number of locations that are here considered to be local or, at the best, regional marker bands similar to the late highstand bioevents of Wilmsen (2012). At Speeton, Mortimore *et al.* (2001) records such a band ~1 m above the base of the Folge where it is associated with *Inoceramus pictus* – the presence of this band has not been noted by the present author either here or elsewhere in the Northern Province. In the Transitional Province, such a band is reported by Sumbler and Woods (1992, p. 116) at a level just above the top of the local representative of the Nettleton Folge. In the Southern Province, an abundance of *Amphidonte* has been noted by Wright *et al.* (2017) at varying distances from 5.5 to 10 m above the base of the Louth Folge at Folkestone, Eastbourne and Culver Cliff – may be equivalent to the *Amphidonte* Event of northern Germany (Ernst *et al*. 1983) and to Event R17 at Cap Blanc Nez in France (Amédro and Robaszynski 1999).

Northern Province: The thickness of the Louth Folge over Lincolnshire and Yorkshire varies from about 6 to 7 m (Text-figs 6, 7) and this is unrelated to the Midland Shelf, Speeton Basin or the Market Weighton Block. The Louth Folge consists of a lower part (1–2 m) dominantly of nodular chalks, but interbedded with homogeneous chalks, that passes up into an upper division (~5–6 m) of homogeneous chalk. South of the Wash Line, it thins and is represented by ~4 m of soft white chalk at Heacham (Norfolk). In parts of central and southern Lincolnshire, the upper division is coloured pale pink and ochreous (Jeans *et al*. 2016, text-fig. 6) and forms the Upper Pink Band of Bower and Farmery (1910); outside this region, this chalk typically contains rusty patches marking the location of former ferrous sulfide nodules, often giving a khaki tint to the strata. Complete sections of the Louth Folge have been recorded at Heacham, Welton, Tetford, Louth I, South Ferriby I and Speeton – incomplete sections at Claxby, South Thoresby, Louth II, Caistor, Nettleton, Elsham II, South Ferriby, Burdale, and Flixton.

Transitional and Southern Provinces: Lithologically, the Louth Folge consists dominantly of fairly homogeneous chalk with bands of more or less conspicuous marly chalk (Mortimore *et al*. 2001; Wright and Kennedy 2017). The definition of the marly chalk beds varies considerably from poor to good, tending to be less well defined up-section. The colour is either slightly ochreous, tinted through oxidation of ferric sulfide or has a grey or bluish grey tinge due to iron sulfides. It thickens markedly through the Transitional Province into the Southern Province where it attains thicknesses of over 30 m at Compton Bay and Ballard Cliff (Text-fig. 6). Jukes-Browne and Hill (1903, p. 37) refer to this unit at Folkestone as the White Bed (Bed 8), a term that has been applied to this interval at various localities by Mortimore *et al.* (2001), Ellison *et al.* (2004), and Mortimore (2021). The term Louth Member has been used extensively by Jeans *et al.* (2015, text-fig. 3; 2021).

FLIXTON FOLGE

The base of the Flixton Folge is defined by the base of Jefferies Boreal Fossil Band – usually at or close to the base of the Plenus Marls sequence of Jefferies (1963). The top is marked by the first appearance of *Mytiloides* and its fragments – the Mytiloides Band – or the Mytiloides Flood as it is often affectionately named. The Flixton Folge is largely late Cenomanian in age but extends into the earliest Turonian; it includes the *Metoicoceras geslinianum* and *Neocardioceras juddi* zones and the lower part of the *Watinoceras devonense* Zone. The Flixton Folge represents lithofacies cycle VII and the deposition sequence of Ce 6 (Jeans *et al*. 2021; see Text-fig. 2) – it forms the lower part of the Welton Chalk Formation in the Northern Province and the lower part of the Holywell Nodular Chalk Formation in the Transitional and Southern Provinces.

Lithologically, there are conspicuous differences between the sequences of the Northern Province and those to the south, but both can be divided into a lower and upper unit. In the Northern Province, the lower unit (Variegated Marls of Wood and Mortimore 1995) consist of thinly bedded, variably coloured marl, marly chalk and chalk that may contain red and ochreous horizons as well as black bands with enhanced contents of organic carbon (Text-fig. 19). In contrast, the upper unit consists of chalk subdivided by thin marls that are overlain by the chalks containing the Mytiloides Flood. Both units are included in the lower part of the Welton Chalk Formation (Text-fig. 4). In the Transitional and Southern provinces, the two units of the Flixton Folge have a rather different appearance, they are both placed within the Hollywell Nodular Chalk Formation. The lower one, the Plenus Marls Member, may be much thicker than in the Northern Province. At Eastbourne, it is up to 8–9 m thick and consists of thick alternations of more and less marly chalk with no evidence of the fine lamination or the black and colour bands of the Northern Province; it has been divided by Jefferies (1962, 1963) into 8 beds. The upper unit, part of the Melbourn Rock Member, consists of alternations of hard chalks rich in shell fragments and calcispheres with thin more marly horizons. Precise correlation between the provinces has only recently been achieved (summarized in Jeans *et al*. 2021, text-fig. 4). Gale (1995, p. 193) and Mortimore *et al.* (2001, p. 384) have suggested that both Whitham (1991) and Jeans *et al*. (1991) were incorrect to consider the Variegated Marls to be the correlative of the Plenus Marls, and that the black bands lay actually within the *Neocardoceras judii* Zone. This, however, has proved incorrect as all the main black bands (A, B, C, D, E) are within the *Metoicoceras geslinianum* Zone (Jefferies Beds 1–8) (Jeans *et al.* 2021, text-fig. 4).

Northern Province: The Flixton Folge is part of the Welton Chalk Formation. It includes strata that have been variously referred to as the Belemnite Marls (Jukes-Browne and Hill 1903), or the *Plenus* Marls (Jefferies 1963), or the Black Band (Wood and Smith 1978), or the Plenus Marls/Black Band, or the Variegated Marls (Wood and Mortimore 1995). They have been much studied both stratigraphically (Jefferies 1963; Hart and Leary 1989; Jeans *et al.* 1991; Hart *et al.* 1993; Dobsworth 1996; Wood and Mortimore 1995: Wood *et al.* 1997) and geochemically (see Jeans *et al*. 2021 for summary). Text-fig. 19 shows the detailed variation in lithology between Welton in south Lincolnshire and Flixton in Yorkshire. The lower unit, the Variegated Marls of Wood and Mortimore (1995), consists predominantly of partially laminated coloured marls, clayey marls, and occasional beds of chalk or nodular chalk that passes up into the upper unit of chalk interbedded with marls, and this in turn is overlain by chalks full of shell debris including *Mytiloides*. The marls are usually of wide extent and provide an internal stratigraphy within the member (Text-fig. 16; Jeans *et al*. 2014, text-fig. 5). The stratal colours – reddish pink, black, buff, green, greenish grey, greyish green – vary both stratigraphically and regionally (Text-fig. 16). The Flixton Folge is absent at Heacham in North Norfolk and the Melbourn Rock with *Mytiloides* rests directly on the top of the strata of the Louth Folge. At Welton, its total thickness is ~1 m and it increases northwards by the intercalation of additional beds of marl and chalk, reaching a thickness of 2 m at Flixton (Jeans *et al*. 2021, text-fig. 13). Of particular importance is the Green Trace Bed, a level of dark green glauconite traces which has been followed from Welton in south Lincolnshire to Flixton in east Yorkshire as this marks the Cenomanian/Turonian boundary (Jeans *et al*. 2021, p. 112). In parts of south and central Lincolnshire (South Thoresby, Tetford Hill), the lowest and thickest marl seam is reddish brown in colour, contains chalk pebbles, and marks the base of the folge. To the north of Louth and to the south of South Thoresby, the basal reddish pink marls pass laterally into greyish green marls such as seen at Welton. At higher levels in the sequence, similar greyish green marls occur, both could represent the late diagenetic alteration (sulfidization) of previously red-pigmented marls (Jeans *et al.* 2016). At Louth, black and grey marls appear above this reddish unit and these thicken northwards, increasing in number, and in Yorkshire they are joined by thinly laminated buff marls. The C_{org} values of the acetic acid insoluble residues from black bands range from 0.2 wt % (Melton Ross: Jeans *et al*. 2021) through 0.4 wt % (Louth) and 4.8 wt % (South Ferriby) to 15.6 wt % (Flixton, Jeans *et al*. 2021, p. 126); whereas background values for the acetic acid insoluble residues from non-black marls and chalks are in the general range 0.1 to 0.3 wt %. Complete sequences of the Flixton Folge have been recorded at Welton, Claxby, South Thoresby, Tetford, Louth, Caistor, Elsham, South Ferriby I, South Ferriby II, Burdale and Flixton – an incomplete section at Nettleton.

Transitional and Southern Provinces: The lower unit of the Flixton Folge, the Plenus Marls Member, and the overlying unit, the Melbourn Rock Member of the Holywell Nodular Chalk Formation, have been described by Jukes-Browne and Hill (1903) from many locations. Jefferies (1962, 1963) has recognized eight beds that could be traced throughout the main part of the Transitional and Southern Provinces with various beds being cut out in Cambridgeshire and the Norfolk region as the northern margin of the Transitional Province is approached. Lithologically, the sequence consists of alternations of marls, marly chalk and chalk – the lower part is dominated by marl but this becomes less dominant as the sequence is ascended. The overlying lithological unit, part of the Melbourn Rock Member, consists of alternations of hard chalks rich in shell fragments and calcispheres with thin more marly horizons. The incoming of *Mytiloides* occurs at the level of the Holywell Marl no. 1 in the lower part of the Turonian *Watinoceras devonense* Zone, the actual Cenomanian–Turonian boundary is placed 2 m below, between Mead Marls 4 and 5 (Mortimore and Pomerol 1996, p. 423; Mortimore *et al.* 2001; Jeans *et al.* 2021, Text-fig. 7). The variation in thickness of the Flixton Folge in the Transitional and Southern provinces used for the construction of Text-fig. 6 has been based on Jukes-Browne and Hill (1904), Jefferies (1963), Jeans *et al.* (1991), Mortimore *et al.* (2001), Jeans *et al.* (2021) as well as on unpublished data.

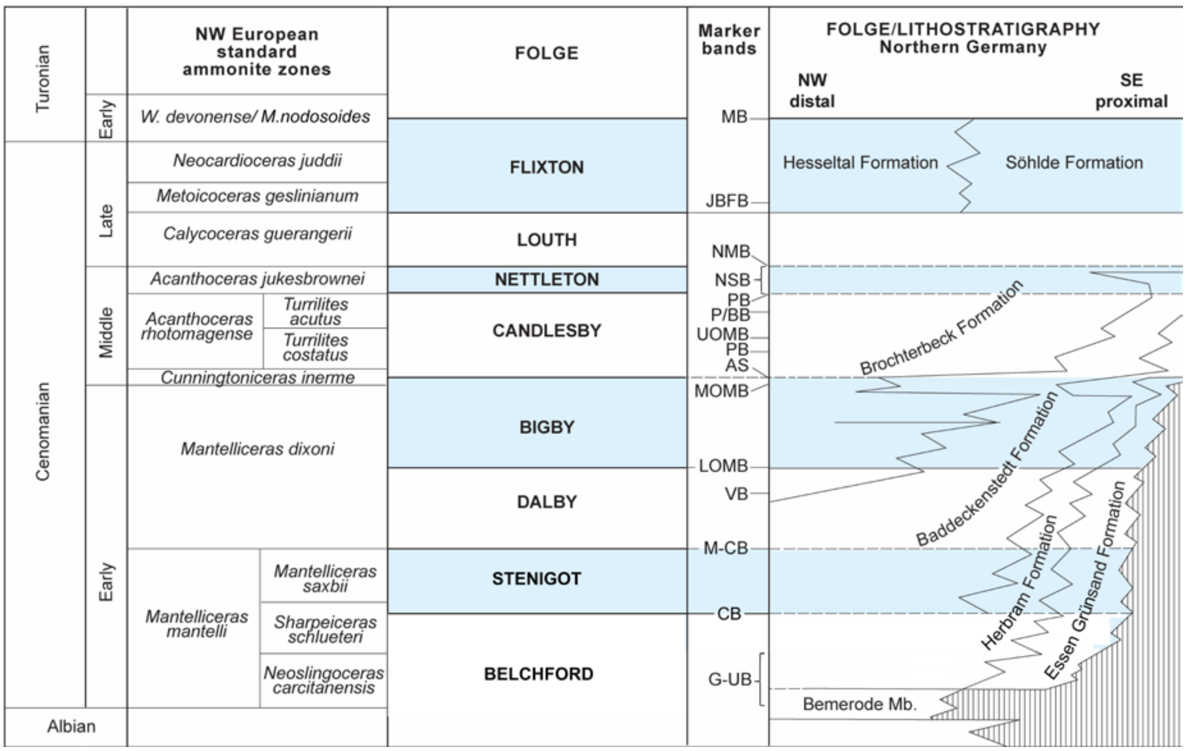
FOLGE STRATIGRAPHY OF THE CENOMANIAN CHALK OF NW EUROPE

There is sufficient published evidence to demonstrate that the folge-based stratigraphy developed in England can be recognized in Germany and France. Text-fig. 1 shows the localities. Text-fig. 2 summarises the international extent of the eight-folgen scheme.

Northern Germany

The extension of the new folge stratigraphical scheme into northern Germany reflects the considerable research associated with, and following on from the development of event stratigraphy by Ernst *et al.* (1983). There is now a plethora of detailed accounts of the inter-relationship between litho- and biostratigraphy in the Cenomanian strata that provide a framework that can support, in addition, a folge-based stratigraphy (e.g., Kemper 1984; Kaplan and Best 1985; Ernst and Rehfeld 1998; Niebuhr *et al.* 1999; Wilmsen 2003, 2007; Wilmsen and Wood 2004; Wilmsen and Voigt 2006; Wilmsen *et al.* 2021). Text-fig. 20 summarises the extension of the eight folgen scheme to the regionally varying lithologies expressed in the six transgressive formations that now represent the Cenomanian strata of northern Germany. To what extent are the various marker bands, other than the Gryphaeoides/Ultimus Band, preserved in the near-shore Essen Grünsand Formation is not known.

Belchford Folge: This folge starts with the *Neohibolites ultimus/Aucellina gryphaeoides* Event of Ernst *et al.* (1983) that represents the transgressive surface of depositional sequence Ce I. It is most fully developed in the distal parts of the northern Münsterland and in the Hannover region within the lower part of the Herbram Formation. Here in the basin centre the clayey



Text-fig. 20. Interpretative and predictive lithofacies model showing the distribution of the eight Cenomanian folgen in relation to the lithological formations of northern Germany. Based in part on Wilmsen (2007, text-fig. 2). G-UB – Gryphaeoides/Ultimus Band; CB – Crippsi Band; M-CB – Mariella/Crippsi Band; VB – Virgatus Band; LOMB – Lower Orbirhynchia mantelliana Band; MOMB – Middle Orbirhynchia mantelliana Band; AS – Arlesiensis Band; PB – Primus Band; UOMB – Upper Orbirhynchia mantelliana Band; P/BB – Planktonic/benthonic Break; PB – Pycnodonte Band; NSB – Nettleton Stone Band; NMB – Nettleton Marl Band; JBFB – Jefferies Boreal Fossil Band; MB – Mytiloides Band.

Bemerode Member (~40 m) represents continuous deposition during latest Albian to earliest Cenomanian time (Ernst *et al.* 1983; Kemper 1984; Niebuhr *et al.* 1999; Wilmsen 2003; Wilmsen and Wood 2004, fig. 2; Wilmsen 2007, text-fig. 2; Bornemann et al. 2017). The Aucellina–Ultimus Band is associated with the oldest part of the transgressive Essen Grünsand Formation.

Stenigot Folge: This folge is represented in the northwest of the region by the upper part of the Herbraum Formation, which to the southeast passes laterally into the Essen Grünsand Formation (Text-fig. 20). Mass occurrences of *G. crippsi* with disarticulated valves are reported in the uppermost *Sharpeiceras schlueteri* Subzone at Luneburg, Germany by Wilmsen *et al.* (2021) in strata considered to just pre-date sequence boundary SB Ce 1.

Dalby Folge: As the Upper Cretaceous facies transgression is followed from the northwest to the southeast, the Dalby Folge is represented first by the lower part of the Baddeckenstedt Formation, then by part of the Herbram Formation, and finally by part of the Essen Grünsand Formation (Text-fig. 20). The Mariella/Crippsi Band is considered to be the equivalent of the *Mariella* Event of northern Germany, which is recorded in the lowermost part of the *M. dixon* Zone in the Beddeckenstedt quarry near Salzgitter (Kaplan and Best 1985; Ernst and Rehfeld 1998) and at Hoppenstedt (Wilmsen and Wood 2004, p. 215). The Virgatus Band occurs throughout Münsterland, and in the Hils- and Sack-Synclines and the Salzgitter-Hannover region of Lower Saxony (Ernst *et al*. 1983; Wilmsen 2008). The association of the Virgatus Band with a group of homogeneous fine-grained chalk beds has been noted by Wilmsen and Wood (2004, fig. 8) and Wilmsen (2008) at Wunstorf, Baddeckenstedt and Hoppenstedt. The Lower Orbirhynchia mantelliana Band is known from the chalk of southeast, northwest and northeast Münsterland and also in the Hils- and Sack-Synclines and the Salzgitter-Hannover region of Lower Saxony (Ernst *et al*. 1983; Wilmsen 2003).

Bigby Folge: This folge is represented in the northwest of the region by the lower part of the Brochterbeck Formation. Traced further to the southeast, it is progressively replaced by the Baddeckenstedt Formation, then the Herbram Formation and finally by the Essen Grünsand Formation (Text-fig. 20). The Lower Orbirhynchia mantelliana Band occurs in the chalk of southeast, northwest and northeast Münsterland and in the Hils- and Sack-Synclines and the Salzgitter-Hannover region of Lower Saxony (Ernst *et al*. 1983). The Arlesiensis Band (presence of *Inoceramus schoendorfi*) and the Middle Orbirhynchia mantelliana Band (presence of *Orbirhynchia mantelliana*, *Orbirhynchia* sp.) are present at Wunstdorf (Wilmsen *et al*. 2007, fig. 10), whereas their absence at Hoppenstedt (Wilmsen and Wood 2004, fig. 4) is probably related to either non-deposition or the erosive base of the Candlesby Folge.

Candlesby Folge: In the northwest and central part of the northern Germany, the Candlesby Folge is represented in the Brochterbeck Formation, further to the southeast first by the Baddeckenstedt Formation and then by the Herbram Formation (Text-fig. 20). The Arlesiensis Band (presence of *Inoceramus schoendorfi*) and the Middle Orbirhynchia mantelliana Band (presence of *Orbirhynchia mantelliana*, *Orbirhynchia* sp.) are present at Wunstdorf (Wilmsen *et al*. 2007, fig. 10). The Primus Band ("*Actinocamax primus* Event") was recognized by Ernst *et al*. (1983) and has been described more recently at Hoppenstedt (Wilmsen and Wood 2004, fig. 4; Wilmsen and Rabe 2008) and at Wunstdorf (Wilmsen *et al.* 2007). The Upper Orbirhynchia mantelliana Band was not recognised by Ernst *et al.* (1983) but has subsequently been identified by Wilmsen and Wood (2004) in the Baddeckenstedt Formation (Pläner Limestones) at Hoppenstedt. The Planktonic/ Benthonic Break – broadly corresponding to the "Mid-Cenomanian Event" of Ernst *et al.* (1983) – has been recognised in southwest and southeast Münsterland as well as in the Hils- and Sack-synclines and in the Hannover and Salzgitter area of Lower Saxony. Its presence at Hoppendstedt is recorded by Wilmsen and Wood (2004, fig. 4).

Nettleton Folge: This folge is mainly represented by the Brochterbeck Formation although in the SE of the region it is probably forms part of the Baddeckenstedt Formation (Text-fig. 20). The Pycnodonte Band ("*Pycnodonte* Oyster-Event") is present in southeast, northwest and northeast Münsterland and also in Lower Saxony in the Hils- and Sack- synclines, and in the Salzgitter-Hannover region (Ernst *et al.* 1983); it has been discussed in detail by Wilmsen and Voigt (2006; see later). At Hoppenstedt, the Nettleton Stone Band is represented by a massive bed (~ 1.8 m thick) of slightly marly chalky limestone, illustrated by Wilmsen and Wood (2004, fig. 4), and at Zilly by a similar bed approx.1.5 m thick (Wilmsen 2007, fig. 6).

Louth Folge: The Louth Folge is represented in the upper part of the Brochterbeck Formation where it forms the most chalk-dominant part of the sequence consisting of nodular to flaser-bedded limestones passing up into fine-grained chalky limestones with few thin marl seams (Text-fig. 2). Its base is marked by the prominent marl band (Nettleton Marl Band equivalent, see above) defining the top of the underlying Nettleton Folge and its top by the marked facies change at the base of the Hesseltal and Söhlde formations, both containing the Plenus Bed and *Chondrites* Event in its lower part (Ernst *et al.* 1983). Wilmsen (2007, text-fig. 6) illustrates the stratigraphic context in a sequence of sections from Wunstdorf, HPCF quarry, Baddeckenstedt, Hoppenstedt and Zilly.

Flixton Folge: This is represented in the Hesseltal and the Söhlde Formations where the *Actinocamax plenus*-Event with its basal *Chondrites* layer has been recognized by Ernst *et al.* (1983) in southwest Münsterland and in the Hils- and Sack- synclines, and in the Salzgitter-Hannover region of Lower Saxony (see also Wiese *et al.* 2009). It occurs in a sequence of alternating marls and chalky limestones with a lithofacies distribution comparable to the Northern Province in England. The proximal lithofacies with red and greenish marls and nodular limestones being linked to the Söhlde Formation ("Rotpläner") and the distal lithofacies with numerous black bands associated with the Hesseltal Formation ("Schwarzschiefer"). The cored borehole at Wunstdorf (Voigt *et al.* 2008, fig. 2) penetrated an expanded Hesseltal Formation of alternating black shales, grey to green marls, and marly limestones as well as light grey limestones. These are capped by limestones representing probably the lower of the three *Mytiloides* Events described by Ernst *et al.* (1983, fig. 4) and this straddles the junction of the Lower Turonian *Watinoceras devonense* and the *Mammites nodosoides* zones. Similarly, in the Söhlde Formation at its type locality the earliest of the *Mytiloides* Events is in the lowest part of the *Mammites nodosoides* Zone (Wiese 2009, fig. 5). This suggests that the Mytiloides Marker Band that defines the top of the Flixton Member in England has limited inter-regional reliability and cannot, on present evidence, be considered as "isochronous".

NW France

The folgen-based scheme is clearly defined in the coastal sections at Cap Blanc Nez where the Cenomanian lithofacies sequence is similar to that at Folkestone (Wright *et al.* 2017). The sequence and its palaeontology have been described in considerable detail by Amédro and Robaszynski (1999, fig. 4) and Amédro et *al.* (1978). It is divided into five formations – Strouanne, Cran, Petit Blanc-Nez, and Escailles, Crupes – and the uppermost part is included in the Grand Blanc-Nez Formation. Comparison with the distal sequence in northern Germany (Text-fig. 2) shows a general similarity. The basal metre of the Strouanne Formation is richly glauconitic – similar to Folkestone and the Essen Grünsand Formation of Germany. This interval could represent the Belchford Folge but neither *Aucellina gryphaeroides* nor *Neohibolites ultimus* are recorded. The overlying part of the Strouanne Formation, the Petit Blanc-Nez Formation, the Cran Formation and the lower half of the Escailles Formation are lithologically equivalent to the Baddeckenstedt Formation of northern Germany. The upper half of the Escailles Formation is lithologically equivalent to the Brochterbeck Formation of northern Germany, consisting of massive chalk beds with occasional thin marl bands and seams. The Crupes Formation, consisting of marls and chalk, is similar to the Plenus Marls of the Southern Province of England. The great majority of the marker bands used to define the Cenomanian folgen in England and northern Germany are present, it is only the Belchford Folge and its defining fossil assemblage that appears to be missing (Text-fig. 2). The extent to which these folgen are represented throughout the Cenomanian Chalk of northern France is not clear. Amédro and Robaszynski (1999, fig. 8) have demonstrated the marker bands from the Candlesby, Nettleton and Louth folgen in the Cenomanian chalk of the Aube region at Montmorency-Beaufort Presles (Text-fig. 2). Otherwise there is little published evidence. In contrast, Jefferies (1963) managed to trace the Boreal Fossil Marker Band around both north-east and north-west France (Cap Blanc Nez, Bellignies, Crésanigues, Cernay-en-Dormois, and Cap d'Antifer) and this suggests that the other marker bands are still unrecorded.

INTER-REGIONAL MARKER BANDS OF ENGLAND, GERMANY AND FRANCE

Nomenclature

The marker horizons of this new scheme are referred to as marker bands following their earlier description in England (e.g., Bower and Farmery 1912; Jeans 1980), and not as "Events" as is the custom in Germany (Ernst *et al.* 1983) – Wilmsen (2012) has already pointed out that the use of "Events" as a stratigraphical term is unfortunate. There is also the problem that some of these "Events" as originally described were a combination of two unrelated aspects of the strata. For example, the Lower Cenomanian *Inoceramus virgatus/Schloenbachia* "Event" associates a calcitic fossil bivalve of relatively wide stratigraphical extent with a set of diagenetic conditions necessary for the preservation of the aragonitic shells of *Schloenbachia*, a widely occurring Cenomanian ammonite genus. What happens with variable diagenetic conditions and shells of ammonites leave no trace in the strata? An *Inoceramus virgatus* Event stripped of its other defining character, thereby losing some of its use for marker band correlation. In this account such couplings are avoided, and in this instance this "Event" becomes the **Virgatus Band** – a level in the *Mantelliceras dixoni* Zone where this inoceramid may be particularly abundant and dominates the fossil inoceramid population (Text-figs 9, 10). For similar reasons the *Orbirhynchia/Schloenbachia* "Event" becomes the **Lower Orbirhynchia mantelliana Band** and the *Praeactinocamax plenus–Chondrites* "Event" becomes the **Jefferies Boreal Fossil Band** so as to include other characteristic members of the calcitic fossil assemblage associated with *Praeactinocamax plenus*. The names of these inter-regional marker bands have been chosen for brevity and to reflect their first recognition. Preference has been given to the specific name of the fossil after which the band is referred to in order to avoid the complication of any future changes in its generic name. For example, the three Orbirhynchia bands were originally referred to as Orbirhynchia Bands 1, 2a and 2b (Jeans 1968, fig. 2), these are now referred to as the Lower, Middle and Upper Orbirhynchia mantelliana bands. It is, however, quite possible that a number of similar *Orbirhynchia* species may be involved and could be specific to individual bands (see below) so their nomenclature has been stabilized by referring to them as the Lower, Middle and Upper Orbirhynchia mantelliana bands.

Limitations

The inter-regional marker bands used in this folge-based stratigraphy reflect faunal invasions or widespread rapid changes in marine conditions. They are referred to as "isochronous" as (1) they are generally as refined as, or more refined than ammonite zones (if preserved) with their individual mean duration of 1 Myr (House 1985; Weedon 1985), and (2) in some instances (e.g., Lower Orbirhynchia mantelliana Band) they represent only three or four chalk-marl alternations each of 21 ka (see later). Truly isochronous correlation is only possible with aerial ash-falls that can be individually characterised and as such have not been identified in the European Cenomanian chalk in spite of considerable searching. An important question is whether the original and the present extent of particular inter-regional marker bands are controlled by ecological factors or by lithofacies? The Lower and Upper Orbirhynchia mantelliana Bands are represented in England in a full range of "chalk" facies ranging from chalk, through marly chalk, marls to sandy chalk with or without glauconite. In north-west France, it is not clear from the literature whether, for example, these markers occur in the sandy Cenomanian chalk sequences. At Le Havre, Jukes-Browne and Hill (1903, p. 258) suggested that the apparent absence of a number of common Lower Chalk fossils – including *Rhynchonella mantelliana* (Orbirhynchia mantelliana bands) – was more apparent than real and related to differences in nomenclature. Some idea of the extent to which a preservation factor may be important can be judged by (1) Jefferies's (1963) success in tracing the Boreal Fossil Band with its damage resistant guards of *Praeactinocamax plenus* over both north-east and north-west France, (2) Gale and Christensen's (1996) discovery of *Praeactinocamax plenus* in the Tethyan region in SE France, (3) Wilmsen *et al*. (2010) finding the same belemnite in the non-chalk Lower Danubian Cretaceous Group in southern Germany.

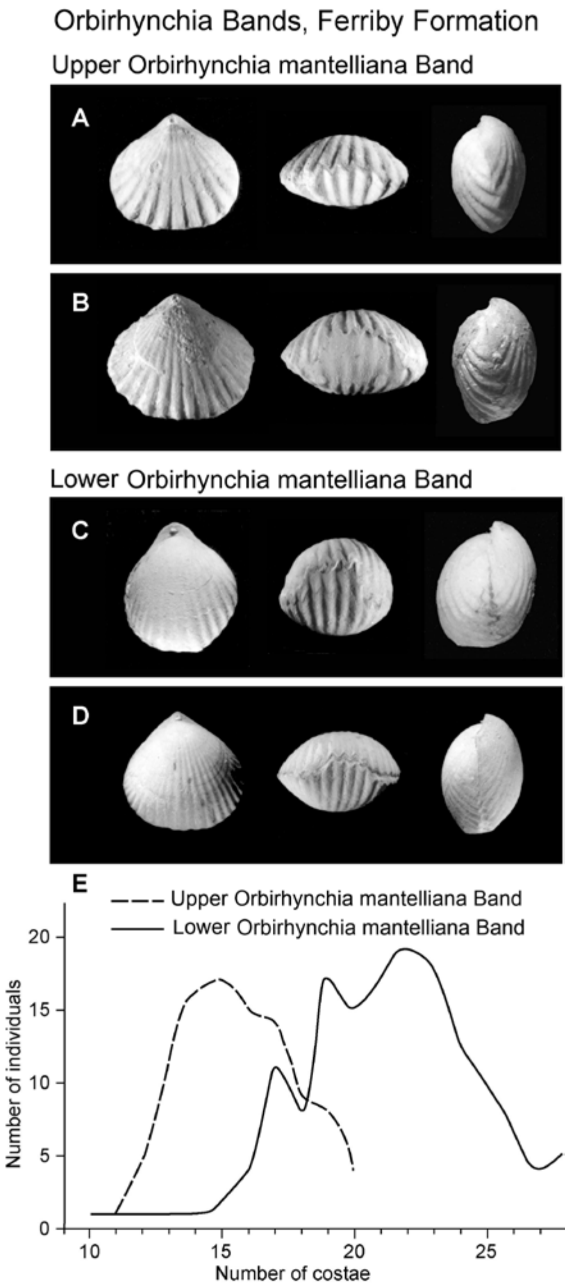
Gryphaeoides/Ultimus Band: This is a series of strata, regionally varied in lithology, representing the Belchford Folge that are characterized by the small gryphaeate bivalve *Aucellina gryphaeoides* (identified as *A. coquandiana* in Whitham 1991) and the belemnite *Neohibolites ultimus.* It is restricted to the *Neostlingoceras carcitanense* Subzone (lower *Mantelliceras mantelli* Zone) at the base of the Cenomanian in England although there are occasional records of *A. coquandiana* above this level in the Lower Inoceramus Bed (Whitham 1991). This fossil association, originally referred to as the *ultimus/Aucellina* Event in northern Germany, was first noted by Ernst *et al.* (1983). Later the term was applied to the Northern Province of England (Mortimore *et al.* 2001, pp. 277, 350). *Neohibolites ultimus* is relatively common in the Northern Chalk Province but is rare in the Transitional and Southern provinces.

Crippsi Band: This marker band is within the *Sharpeiceras schlueteri* Subzone of the *Mantelliceras mantelli* Zone. It is represented by the Lower Inoceramus Bed of the Northern and the Transitional Provinces (Text-figs 8, 9, 10, 11), consisting largely of the fragmental remains and single valves of *Gnesioceramus crippsi* (*Inoceramus crippsi* of Wood 1899–1912) mixed with glauconite stained chalk pebbles. At Folkestone it occurs as a conspicuous concentration of *Gnesioceramus crippsi* – the flood abundance of "*Inoceramus*" *crippsi* of Shephard-Thorn *et al*. (1994, p. 62) – in the upper part of the *Sharpeiceras schlueteri* Subzone between levels M2 and M3 (Gale 1989, figs 2, 4) and at Cap Blanc Nez in France where it is matched with Event 2 (Text-fig. 2) by Amedro and Robasznski (1999, fig. 4). Mass occurrences of *G. crippsi* with mainly disarticulated valves are reported in the uppermost *Sharpeiceras schlueteri* Subzone at Lüneburg, Germany by Wilmsen *et al.* (2021) in strata considered to just pre-date SB Ce 1 (Text-fig. 2). This is interpreted as a late highstand bioevent below storm wave base that when traced laterally into the basin margins has been reworked by storm wave action forming bioclastic concentrations such as the Lower Inoceramus Bed. Such an interpretation can be applied to the occurrence of the Crippsi Band in the expanded Cenomanian sequence at Speeton (Text-fig. 9) where *Gnesioceramus crippsi* appears first in the upper part of the Belchford Member and then contributes greatly to the inoceramid fragments of the overlying Lower Inoceramus Bed. In France, Amédro *et al.* (2012) has recorded this horizon in the Channel Tunnel borehole (Manche PM 8141) in the Straits of Dover and in seqences at Cap Blanc Nez, St Jouin (Bec de Caux), and at Vanault-les-Dames (F1) in the Marne Department.

Mariella/Crippsi Band: This is within either the uppermost part of the *Mantelliceras saxbii* Subzone or the very base of the overlying *Mantelliceras dixoni* Zone. It consists of the Upper Inoceramus Bed of Jeans (1980), an inoceramid fragment and shell-rich interval with some whole valves that occurs throughout the Northern and at least part of the Transitional Province. It is dominated by *Gnesioceramus crippsi*, but *Inoceramus virgatus* makes its first appearance here (Text-figs 9, 10). In the southern part of the Northern Province the Upper Inoceramus Bed contains a horizon of poorly preserved large turrilitoid ammonites (*Hypoturrilites*?) associated with specimens of *Mariella*, including *M.* cf. *essensis* (Geinitz). This level is considered to be the equivalent of the *Mariella* Event of northern Germany that occurs in the lowermost part of the *M. dixoni* Zone in the Teutoberger Wald (Kaplan and Best 1985), the Beddeckenstedt quarry near Salzgitter (Ernst and Rehfeld 1998) and at Hoppenstedt (Wilmsen and Wood 2004, p. 215). At Folkestone, it is correlated with a level between M4 and M5 of Gale (1989, fig. 2) within the *Mantelliceras saxbii* Subzone. At Cap Blanc Nez in France, it is Event 4 (Text-fig. 2) of Amedro and Robaszynski (1999, fig. 4).

Virgatus Band: This marker band occurs within the Dalby Folge (*M. dixoni* Zone) between the Upper Inoceramus Bed and the Lower Orbirhynchia mantelliana Band. Regionally, it is not necessarily particularly well defined. It is characterized by an abundant inoceramid assemblage dominated by *Inoceramus virgatus* with only a minor proportion of *Gnesioceramus crippsi*. Text-figs 9 and 10 show its distribution and composition at three locations in the Northern Province and its relationship to the Lower Orbirhynchia mantelliana Band. It was first recognized in northern Germany (Ernst *et al.* 1983) and is recorded from the Transitional and Southern provinces (Gale and Kennedy 2022, figs 6, 7) as well as in France at Cap Blanc Nez where it is referred to as Event E5 (Text-fig. 2) by Amedro and Robaszynski (1999, fig. 4). In the Anglo-Paris Basin (Southerham), the Virgatus Band is restricted to couplets B13–18 (Gale 1995 p. 184). At some locations, the band is associated with a group of beds of homogeneous fine-grained chalk such as the Six Band Group at Speeton (Text-figs 9, 16) and "The Bank" at Folkestone, Southerham, Beachy Head and Compton Bay (Mortimore *et al*. 2001 fig 3.119, fig. 3.111, fig.3.60). The Virgatus Band and its associated group of homogeneous fine-grained beds of chalk are also present at Wunstdorf, Baddeckenstedt and Hoppenstedt in northern Germany where it characterizes the maximum flooding zone of depositional sequence DS Ce 3 (Wilmsen and Wood 2004, fig. 8; Wilmsen 2008).

Lower Orbirhynchia mantelliana Band: Biostratigraphicaly positioned within the *Mantelliceras dixoni* Zone, this marker band defines the junction of the Dalby with the overlying Bigby Folge. It is characterised by the presence and abundance of *Orbirhynchia mantelliana* with a distinctive assemblage structure (Text-fig. 21). The band is thin, ranging from approximately 0.5–1.10 m. At Folkestone, it is associated with couplets B19–22 (Gale 1995, p. 184), whereas at Southerham Grey Pit near Eastbourne, it occurs in couplets B19–21 (Gale 1995, fig.4). It is recorded in northern Germany as the *Orbirhynchia* Event (Ernst *et al*. 1983) or the *Orbirhynchia/Schloenbachia* Event (Wilmsen 2003; Wilmsen *et al.* 2005) and in France as Event 7 (Text-fig. 2) at Cap Blanc Nez (Amédro and Robaszynski 1999, fig. 4).



Text-fig. 21. Histograms showing the pattern of costae numbers in *Orbirhynchia* from the Lower and Upper Orbirhynchia mantelliana bands in the Northern Province of England.

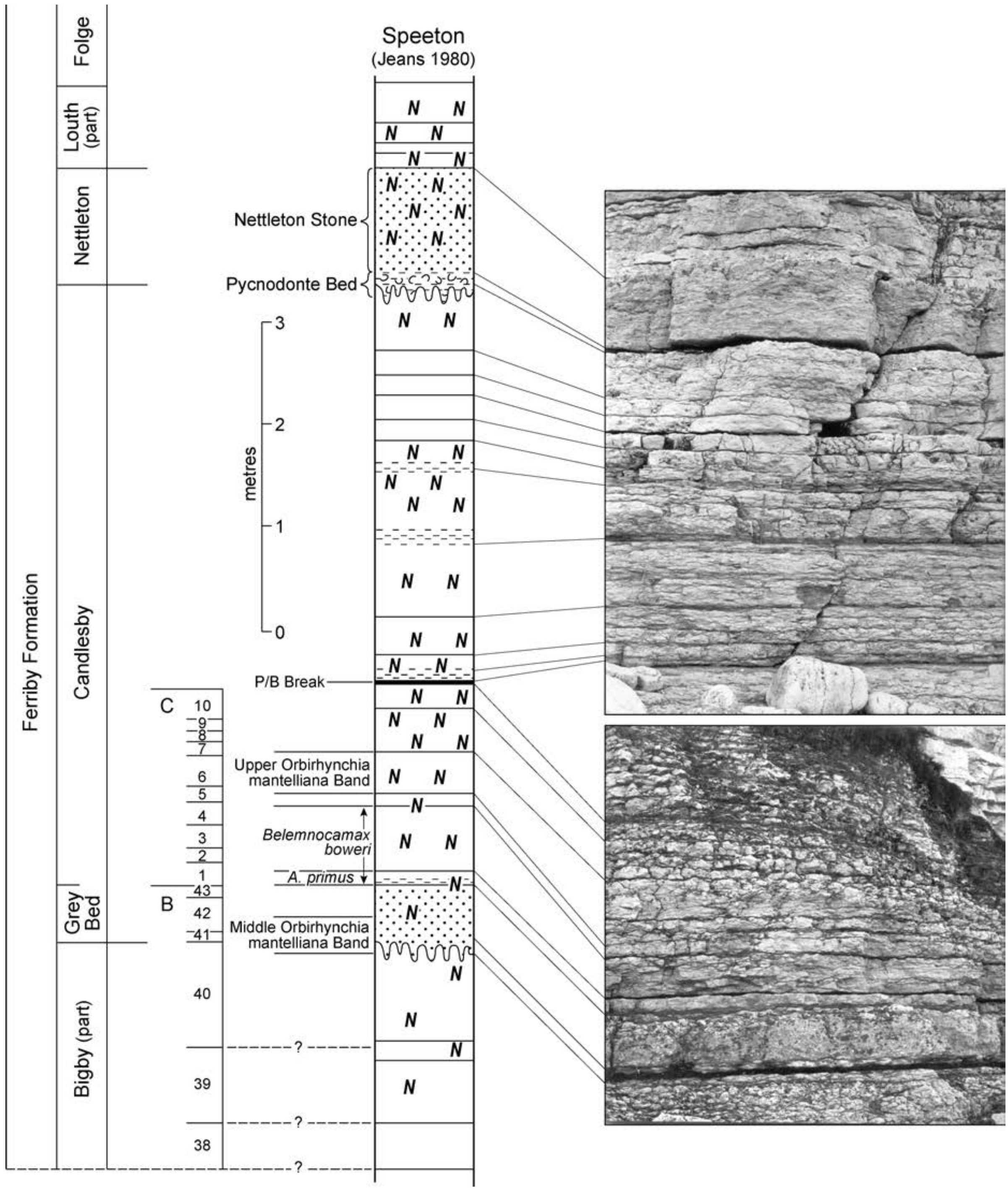
Middle Orbirhynchia mantelliana Band: This marker band straddles the top of the *Mantelliceras dixoni* Zone and part of the overlying *Cunningtoniceras inerme* Zone, i.e., it was deposited across the lower–midde Cenomanian boundary. The band is characterized by an abundance of *Orbirhynchia mantelliana* but there is no information about its assemblage structure. At Folkestone, where this band is best preserved, it marks the very top of the Bigby Member and overlaps with the Arlesiensis Band at the base of the Candlesby Member. At Folkestone, it spans couplets B35 to 41, and at Southerham B36 to 41 (Gale 1995). Evidence suggests that it was regionally present throughout both the Transitional and Northern Provinces but has been very largely lost by erosion prior to the deposition of the Candlesby Folge. At Speeton, remnants of the band are represented by the very rare occurrence of *Orbirhynchia* in the Grey Bed (Paul *et al.* 1994; Mitchell 1996; Mortimore *et al*. 2001, p. 417; Wilmsen and Wood 2004, fig. 7). The Middle Orbirhynchia mantelliana Band has been recorded at Wunstdorf in northern Germany (Wilmsen *et al*. 2007, fig. 10), and in France it is recorded by Amédro and Robaszynski (1999, fig. 4) as Event 9 in the Cap Blanc Nez sequence (Text-fig. 2).

Arlesiensis Band: This marker band is within the *Cunningtoniceras inerme* Zone and forms the upper part of the Middle Orbirhynchia mantelliana Band. It is characterised by *Lyropecten* (*Aequipecten*) *arlesiensis*, *Oxytoma seminudum*, *Inoceramus schoendorfi* (*Gneisoceramus crippsi* is the dominant inoceramid), and *Orbirhynchia mantelliana*. At Folkestone, the *Lyropecten* (*Aequipecten*) *arlesiensis*: *Oxytoma seminudum*: *Entolium orbiculare* ratio is 13:17:11. It is the lowest of the internal marker bands in the Candlesby Member and has been best preserved in basinal areas where pre-Candlesby erosion was at a minimum. It occurs in the lower part of Couplet B41 (Gale 1995, p.185) at Folkestone, Southerham and in the Culver Cliff section of the Isle of Wight. In the Transitional Province, *Lyropecten* (*Aequipecten*) *arlesiensis* is present in the channel facies of the Totternhoe Stone (Woods 1899, p. 194; Wood 1992). In the Platform region of the Northern Chalk Province, there is evidence of the band with records of *Lyropecten* (*Aequipecten*) *arlesiensis* and *Oxytoma* from the lower part of the Grey Bed at Melton, Yorkshire (Whitham 1991). The *Arlesiensis* Band is represented at Speeton (Paul *et al.* 1994) but of the diagnostic bivalves only *Inoceramus schoendorfi* is recorded. At Wunstorf in the Lower Saxony Basin of northern Germany, it has been identified by Wilmsen *et al.* (2007) whereas at Baddeckensted and Hoppenstedt, its absence is probably related to the erosive base of the Candlesby Folge. Gale (1995, p. 184) reports the band from Escalles in northern France. Paul *et al.* (1994, p. 711) claim that it can be traced throughout the Anglo-Paris Basin. There is doubt about its occurence at Cap Blanc Nez and in the Aube where this band is referred to as Event 12 (Text-fig. 2), characterised by an abundance of *Entolium* with no mention of *Oxytoma* or *Aequipecten arlesiensis. Entolium orbiculare* is widespread in the Lower and Middle Cenomanian chalk in England. Although it is an important bivalve component of the Arlesiensis Band, occurring in approximately equal proportions to *Pecten arlesiensis* and *Oxytoma* (*Oxytoma seminudum* 17: *Entolium orbiculare* 11: *Pecten arlesiensis* 13), it occurs in the overlying Primus Band as the dominant component of the bivalve assemblage (see later).

Primus Band: This fossil band is developed within the lower *Turrilites costatus* Subzone of the *Acanthoceras rhotomagense* Zone of the Candlesby Member. It is characterized by *Praeactinocamax primus*, *Belemnocamax boweri*, *Oxytoma seminudum*, and *Entolium orbiculare*. At Folkestone, it forms the Cast Bed. The *Lyropecten* (*Aequipecten*) *arlesiensis*: *Oxytoma seminudum*: *Entolium orbiculare* ratio is 0:4:29. The Primus Band is associated with couplet C1 at Folkestone and can be followed westwards to Compton Bay, Isle of Wight (Gale 1995, fig. 8). In the Transitional and Northern provinces, it is associated with the Totternhoe Stone and Grey Bed and can be traced throughout the region. Until the report of *Actinocamax primus* from Melton, Yorkshire (Whitham 1991; Paul *et al.* 1994), it appeared that this belemnite was restricted to the Transitional and Southern Provinces whereas *Belemnocamax boweri* occurred only in the Northern Province with both species being present at Hunstanton. Text-fig. 22 shows that the stratigraphical distribution of these two belemnites at Speeton overlap but do not coincide. In northern Germany, the Primus Band is recognized as the *Actinocamax primus* Event (Ernst *et al*. 1983) with detailed data on the belemnite species provided by Christensen (1990). Wilmsen and Wood (2004, fig. 4) and Wilmsen and Rabe (2008) report it from Hoppenstedt (Text-fig. 1), including the record of *Belemnocamax. boweri*. A large fossil collection, likewise containing both belemnite species, from the type locality of the Primus Event at Wunstdorf (Text-fig. 1) has been described by Wilmsen *et al.* (2007, fig. 10), unfortunately without quantitative assessment of the relevant ratio of *Entolium orbiculare* to *Oxytoma* – it appears that *Oxytoma* is absent. The Primus Band has also been reported from the Teutoburger Wald by Christensen *et al.* (1992) and a new record from the Saxonian Cretaceous Basin has recently been added (Wilmsen *et al.* 2019). In France, the Primus Band is recognised at Escalles in the Boulonnais (Gale 1995, fig. 8). At Cap Blanc Nez and the Aube, it is probably represented by Event 12 of Amédro and Robaszynski (1999, fig. 4) as a band dominated by *Entolium orbiculare,* occurring beneath the Upper Orbirhynchia mantelliana Band.

Upper Orbirhynchia mantelliana Band: This marker band occurs within the upper *Turrilites costatus* Subzone, *Acanthoceras rhotomagense* Zone of the Candlesby Folge. The band occurs throughout the Northern, Transitional and the Southern Provinces (Jeans 1968; Kennedy 1969, 1970). Kennedy (1970) has recorded this band with either unphosphatized or phosphatised *Orbirhynchia* in the reduced Cenomanian sequences of southwest England. At Folkestone, the band is associated with couplets C2–10 and at Southerham with couplets C7–10 (Gale 1990, fig. 2). Regionally, the band varies considerably in thickness and the number of couplets it is recorded to include, ranging from nine at Folkestone, six at Compton Bay (Wright *et al.* 2017, fig. 196), four at Culver Cliff (Wright *et al.* 2017, fig. 195) to two at Speeton (Paul *et al.* 1994). In northern Germany, the Upper Orbirhynchia mantelliana Band is recorded at Hoppenstedt by Wilmsen and Wood (2004). In France, Amédro and Robaszynski (1999, figs 4, 8) have recorded this band as Event 13 at Cap Blanc Nez and in the Aube region (Text-fig. 2). Comparison of the *Orbirhynchia* fossil population of this upper band (Text-fig. 21) with that of the lower band shows it to be quite different in their pattern of costae numbers, suggesting a complex population perhaps containing more than one interbreeding group.

Planktonic / benthonic (P/B) Break: This is within the *Turrilites acutus* Subzone (*Acanthoceras rhotomagense* Zone) of the upper part of the Candlesby Folge. The break is marked by a conspicuous increase in the proportion of planktonic forms in the foraminiferal assemblages of the Cenomanian chalk in England that was first recorded by Carter and Hart (1975, 1977). It occurs in the Candlesby Folge at a level immediately above the Upper Orbirhynchia mantelliana Band. It is recognised throughout all three provinces although Mortimore *et al.* (2001, p. 393) suggests that it has been cut out by erosion at Melton, South Ferriby and Hunstanton in the Northern Province in spite of its known presence at South Ferriby (Text-fig. 8; Paul *et al.* 1994, fig. 4). It is recognised in northern Germany directly above the Mid-Cenomanian Event (Ernst *et al.* 1983; Wilmsen and Wood 2004). In France, this microfaunal change is not well defined in the Cenomanian of the Boulonnais (Amedro *et al.* 1978, table 3) with planktic foraminifera only becom-



Text-fig. 22. Middle Cenomanian sequence at Jake and Taylor Coves, Speeton showing the regional marker bands and contrasting the interpretations of the section by Jeans (1980, fig. 16) and Paul *et al*. (1994, fig. 11).

ing dominant within the upper part of the Escalles Formation (*Calycoceras naviculare* Zone) that is within the Louth Folge. In France, the Planktonic/benthonic Break should therefore not be relied upon as a marker band within the Candlesby Folge.

Pycnodonte Band: This marker band occurs within the *Acanthoceras jukesbrownei* Zone and defines the base of the Nettleton Folge. It is a marl band dominated by numerous grypheate left valves of small pycnodontid oysters. In the Northern Province, the band is relatively thin and pronounced at the base of the Nettleton Stone Band. Traced into the Transitional and Southern provinces, it expands in parallel with the overlying Nettleton Stone and the Nettleton Marl. Known in northern Germany as the *Pycnodonte* Oyster Event (Ernst *et al*. 1983) it has been discussed in detail by Wilmsen and Voigt (2006). Amédro and Robaszynski (1999, figs 4, 8) have recognised the Pycnodonte Band in the Cap Blanc Nez section at the base of their Event 16 as well as in the Aube region.

Nettleton Stone Band: This is a conspicuous band of arenaceous silty chalk (Text-figs 18, 22) in the *Acanthoceras jukesbrownei* Zone that can be traced throughout the Northern Province showing little variation in thickness (Text-fig. 7). It demonstrates considerable thickening as it is followed into the Transitional and Southern Provinces. It has a number of local names, the most used being "Jukes-Browne Bed 7" from its description in the Folkestone-Dover cliffs. The Nettleton Stone Band is host to various lenticular laminated structures, which Kennedy (1967) has interpreted as "scratch marks", representing possible feeding traces. In northern Germany at Hoppenstedt, it is represented by a massive bed (approx. 1.8 m thick) of slightly marly chalky limestone (Wilmsen and Wood 2004, fig. 4) and at Zilly by a similar bed approximately 1.5 m thick (Wilmsen 2007). In northwest France, it is recorded by Amédro and Robaszynski (1999) as Event 16 (Text-fig. 2) in the Cap Blanc Nez section and it is recognised in the Aube where it is described as "craie avec structures lamellaires".

Nettleton Marl Band: This is a thin conspicuous marl band marking the top of the Nettleton Stone in the Northern Province at or close to the contact between the *Acanthoceras jukesbrownei*/*Calycoceras guerangueri* zones. It reflects a widespread but minor regression of the Cenomanian Sea that was widely felt in the shallower water facies (Text-fig. 2). Traced southwards, it expands with the Nettleton Stone into a packet of strata that represents the uppermost part of the Nettleton Folge. In northern Germany, it is represented by a widespread band of marl, approximately 1.5 m above the Pycnodonte Band at Zilly that can be traced between Zilly and Wunstdorf, a distance of approximately 120 km (Wilmsen 2007, fig. 6). The Nettleton Marl is the horizon, at or above which throughout the Chalk Provinces of England, thick-shelled *Discoidea* and *Holaster* disappear, leaving an echinoid population dominated by the thin-shelled *Holaster trecensis* and *Discoidea cylindrica*. In England, in spite of variations in the expansion of the Nettleton Member and changes in the lithology of the overlying Louth Member, this correlation appears to hold. Indirect evidence suggests that it is present in France and possibly northern Germany. Whether this is only a facies-controlled change of faunas is not clear with thin-shelled echinoid faunas associated only with the most offshore chalks of the succeeding Louth Folge and its equivalents in Germany and France.

Jefferies Boreal Fossil Band: This marker band, biostratigraphically within the *Metoicoceras geslinianum* Zone, is characterized by *Praeactinocamax plenus*, *Lyropecten* (*Aequipecten*) *arlesiensis*, *Oxytoma seminudum*, *Orbirhynchia multicostata and Orbirhynchia wiesti*; it is confined to Jefferies Beds 1 to 6. The band has been traced by Jefferies (1963) throughout the Northern, Transitional and Southern provinces of England and northwest France. It is known to occur in northern Germany where part of the sequence (~Bed 3 and Bed 4) was referred to as the *Actinocamax plenus*-Event with a basal *Chondrites* layer (Ernst *et al.* 1983; see also Wiese *et al.* 2009). Furthermore, it has been recorded from the Danubian Cretaceous Group of southern Germany (Wilmsen *et al.* 2010). Where this band is most thickly developed such as at Eastbourne, Dover and Merstham, there is an internal stratigraphy with *Orbirhynchia multicostata* being confined to the lower part of the sequence and *Orbirhynchia wiesti* to the upper part. In France, Jefferies (1963) traced the Boreal Fossil Marker Band around both northeast and northwest regions (Cap Blanc Nez, Bellignies, Crésanigues, Cernay-en-Dormois, and Cap d'Antifer). The discovery of *Praeactinocamax plenus* in the Tethyan region in SE France (Gale and Christensen 1996) and in the Danubian Cretaceous Group of southern Germany (Wilmsen *et al.* 2010) poses the question of wheither the belemnite was accompanied by other members of the boreal fossil assemblage? Their absence could be owing to either their loss due to their more fragile structure and lower preservation potential or to their actual absence from the Boreal components of the invertebrate population represented by the Jefferies Boreal Fossil Band. In such situations, the use of the long-established term "*plenus* Event" (Ernst et al. 1983) is favoured.

Mytiloides Band: The base of the Mytiloides Band (*Mytiloides* Flood of Jeans *et al*. 2021, text-fig. 4) in England is either at the Cenomanian–Turonian boundary or within the lowest part of the overlying

Lower Turonian *Watinoceras devonense* Zone. It is a conspicuous and convenient marker horizon representing the base of Cycle VII (Jeans 1980) with the incoming of various members of the pulse fauna including *Mytiloides* and *Orbirhynchia cuvieri*. At Eastbourne, the Cenomanian–Turonian boundary has been placed by Mortimore and Pomerol (1996, p. 423) and Mortimore (2021) at this horizon. At Flixton, Yorkshire, the Cenomanian–Turonian stage boundary, based on nannofossil zonation, has been placed in bed 20 where it coincides with the Green Trace Bed (Liam Gallagher in Jeans *et al*. 2021, p. 112), ~45 cm below the base of the Melbourn Rock Member and the Mytiloides Band.

There is some evidence that the Mytiloides Band that defines the top of the Flixton Member in England has limited inter-regional reliability and cannot, on present evidence, be considered to be fully "isochronous". In northern Germany, the cored borehole at Wunstorf (Voigt *et al.* 2008, fig. 2) penetrated an expanded Hesseltal Formation of alternating black shales, grey to green marls, and marly limestones as well as light grey limestones. These are capped by limestones representing probably the lower of the three *Mytiloides* Events described by Ernst *et al.* (1983, fig. 4). The lowest of these straddles the junction of the Lower Turonian *Watinoceras devonense* and the *Mammites nodosoides* zones somewhat above the stratigraphical level assigned to the Mytiloides Band in England. Similarly, in the Söhlde Formation at its type locality (Söhlde, Braunschweig area), the earliest of the *Mytiloides* Events is placed in the lowest part of the *Mammites nodosoides* Zone (Wiese 2009, fig. 5).

FURTHER STRATIGRAPHICAL REFINEMENT

The extent to which this folgen-based scheme can be refined by marrying it with the cyclostratigraphy of Gale (1990, 1995, 1999), making use of the 21 ka Milankovitch chalk-marl couplets, is uncertain. The marker bands would define the geological time whereas the chalk-marl couplets the ticking of the second hand. In the interval between the base of the Middle Cenomanian *Acanthoceras rhotomagense* Zone and the base of the Late Cenomanian *Neocardioceras judii* Zone there is reasonable corroboration between the cyclicity in Western Europe and North America where radiometric dates suggest an interval of 2.2 Ma compared to 2.24 Ma determined by couplet counts (Gale 1995). On a grander scale, the match is poor between the Cenomanian based on radiometric dates (6.6 Ma) from North America and that based on cyclostratigraphy (4.45 Ma) from Europe. Where are the lost cycles representing the missing 2.15 Ma? This suggests that part of the cyclicity preserved in the Lower Cenomanian chalk of western Europe is either (1) unrelated to the 21 ka Milankovitch chalk-marl couplets, but to cycles of longer periodicities of different origin, or (2) there are large gaps in the sequence that have not been recognized.

The time scale of some of the marker bands are probably little different from those of two or three chalk-marl couplets (e.g., Lower Orbirhynchia mantelliana Band, Arlesiensis Band, Primus Band, Pycnodonte Band), although others (e.g., Gryphaeoides/Ultimus Band, Jefferies Boreal Fossil Band) may represent ten or more couplets. Geographic differences have been reported (see above) between the number of couplets associated with particular marker bands and these may reflect incomplete collecting, the slow lateral migration of marker band populations, or the absence of individual chalk-marl cycles.

Where parts of the Cenomanian sequence are not represented by chalk-marl Milankovitch cyclicity, or have been partially or wholly obliterated by diagenesis, reliance has to be based on marker bands. Any improvement in refining the stratigraphical framework is therefore by the recognition of additional primary marker bands. At Speeton, where attempts have been made to match the heavily diagenetically affected Cenomanian chalk section of the Northern Province with well-developed chalk-marl sections in the Southern Province, they have met with difficulties. Mitchell (1995, 1996) and Paul *et al.* (1994, fig. 11) assigned an uninterrupted sequence of couplets from B13 at the base of the Six-Band Group of Jeans (1980) in the Dalby Folge, including the overlying Bigby and Candlesby folgen, to D8 at the top of the Nettleton Folge (Text-fig. 22). The Grey Bed, marking the base of the Candlesby Folge, is clearly seen but its contact with the underlying Bigby Folge has been variously interpreted. Jeans (1980), Mortimore *et al.* (2001), and Wilmsen and Wood (2004, pp. 221, 222) all recognize a sharp erosional base (there are traces of glauconite at the base) associated with extensive burrowing into the underlying chalk. Mitchell (1995, 1995) does not recognize any possible interruption to the sequence. This has allowed Paul *et al.* (1994, fig. 11) to fit the appropriate fossil marker bands of the Candlesby Member into a sequence of Middle Cenomanian chalks and marls and their supposed couplets. Text-fig. 22 contrasts the assignment of couplets by these authors, the presence of marker beds, an original photographic record of the sequence taken in the mid-1960s and the section as envisaged by Jeans (1980, fig. 16). Evidence suggests that the assignment of "couplets" to the lower part of this poorly preserved sequence cannot be substantiated. There is evidence of loss of part of the sequence beneath the Grey Bed. At Folkestone, where the Middle Orbirhynchia mantelliana Band is best developed, it occurs through couplets B35 to B41 and it contains the Arlesiensis marker Band in the uppermost couplet. At Speeton, the Middle Orbirhynchia mantelliana Band is represented by a single specimen of *Orbirhynchia* from near or at the base of the Grey Bed (couplet 41 of Paul *et al*. 1994), in spite of extensive collecting on these cliff. There is no evidence that *Orbirhynchia* is represented in the chalks assigned to couplets B35 to B40 (Mitchell 1995, 1996; Paul *et al*. 1994). Wilmsen and Wood (2004) suggest that the erosion surface cuts down to a level in the Early Cenomanian *M. dixoni* Zone but some distance above the Lower Orbirhynchia mantelliana Band.

Such difficulties are not surprising considering the high degree of diagenetic alteration that may have been involved. Assuming the chalk-marl couplets started with a bulk specific gravity of 1.64 (**Standard Louth Chalk** of Jeans *et al.* 2014, text-fig. 10), the present representatives of these couplets – nodular and very nodular chalk – are associated with a great variety of marl bands, some parallel to the general bedding, most clearly angled to it, nearly all of them displaying evidence of being of pressure dissolution origin and considerably affected by their tectonic setting (Jeans 1980). The bulk specific gravity of these different varieties of chalk is in the range 2.27–2.52 (Jeans 1980, table 9). The pore-filling calcite cement was generated internally within the chalk by pressure dissolution as the overpressure was released by faulting (Jeans *et al*. 2014, p. 446). The conversion of a typical soft chalk with a bulk specific gravity of 1.64 to a dense chalk of 2.39 involves a volume reduction of 30 % or more and when combined with tectonic effects were probably responsible for the destruction or obscuration of any chalk – marl alternations beyond recognition.

CONCLUSIONS

The eight folge-based subdivision of the Cenomanian chalk of England and its extension into northern Germany and France provides an additional and alternative approach for correlation as it relies on common fossil assemblages that are readily preserved in contrast to the vagrancies of ammonite assemblages. Many of the defining marker bands are more refined chronologically than either the ammonite zones or subzones and avoid the diagenetic effects that can render isotope stratigraphy difficult to resolve. The folge-based scheme provides a spatial and time framework in which the effects of migrating pore fluids on their host strata can be studied It does not replace other approaches to Cenomanian chalk stratigraphy but is an additional tool in providing a time-related framework in which interactions between migrating fluids and the sediments and strata through which they pass can be identified. Consequently, this approach has been used widely in oil exploration to predict and trace the pattern of migration of hydrocarbons and their associated porefluid to their trapping in potential reservoirs. It has become clear in the Chalk from detailed studies of the patterns of calcite cementation (Hu *et al*. 2012, fig. 26) and the development of clay mineral assemblages (Hu *et al*. 2014; Jeans *et al.* 2014) that, during their post-depositional history, the original pore waters have been partially or wholly replaced from external sources, either from different lithofacies of the Chalk itself or perhaps farther afield. This folge-based scheme, masquerading as a "members-based scheme" for many decades, has considerably forwarded the understanding of the Chalk and its diagenesis. There is need to unravel the diagenetic complexities of the Cenomanian Chalk of Europe before we can hope for a better understanding of the changing conditions leading up to the Cenomanian–Turonian Oceanic Event.

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