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Correlation of the Coniacian and Santonian stages of the Upper Cretaceous in the Anglo-Paris Basin

ANDREW SCOTT GALE[1, 2]

[1] *School of the Environment, Geography and Geosciences, University of Portsmouth, Burnaby Building, Burnaby Road, Portsmouth PO13QL, UK; e-mail: andy.gale@port.ac.uk*
[2] *Department of Earth Sciences, The Natural History Museum, Cromwell Road, London SW75BD, UK*

ABSTRACT:

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The correlation of the Coniacian and Santonian chalks of the Anglo-Paris Basin is described on the basis of detailed lithological logs and extensive records of macrofossils and microcrinoids. In the almost complete absence of ammonites, inoceramid bivalves afford the highest resolution correlation of these stages in chalks, but their value here is limited by the absence of key genera and species, most notably in the Upper Coniacian and middle and Upper Santonian. Echinoids and other macrofossils (brachiopods, stalked crinoids, belemnites) have proved useful, but many are long-ranging or uncommon. Some marker beds, including flints and marl seams, provide useful correlations across the basin, but are locally absent. For the Upper Santonian, the stemless benthonic crinoids *Uintacrinus* and *Marsupites* provide high-resolution correlation, both within the basin and to other regions. The successions on the basin margins, in the far north of France (Nord, Pas de Calais) and the southwest (Touraine) are condensed and yield ammonites in association with important inoceramid species. The controls on sedimentation caused by sea-level changes are evaluated on a basinal and global scale, most especially for the Upper Santonian.

Key words: Coniacian; Santonian; Chalk; Southern England; Northern France.

INTRODUCTION

The past three decades have seen revitalised interest in chalk stratigraphy. Whereas this was seen for much of the 20th century as being primarily about zonation using macrofossils, studies on marker bed correlations (e.g., Mortimore 1986, 2011; Mortimore and Pomerol 1987), carbon and oxygen isotope stratigraphy (Jenkyns *et al.* 1994; Jarvis *et al.* 2006), volcanogenic marl beds (Wray 1999), sequence stratigraphy (Gale 1996; Robaszynski *et al.* 1998) and Milankovitch climate forcing (Thibault *et al.* 2016) have greatly broadened the scope of studies. The renewed interest has been paralleled in both France and the UK.

Robaszynski and Amédro (1986), Amédro and Robaszynski (2000a, b), and Amédro *et al.* (2006) have made detailed comparisons between the Coniacian and Turonian chalk successions in the Pas de Calais, northern France, and those in southeast England. Mortimore and Pomerol (1987) published an account of the correlation of Turonian to Campanian chalks of both northern France and southern England, across the Anglo-Paris Basin. These studies demonstrated that basically similar successions are present on both sides of the English Channel.

The present study grew out of a longstanding interest in chalk correlation and is largely the result of innumerable field excursions in both France and England. Firstly, I briefly describe the present status of Coniacian and Santonian stage and substage boundaries, then discuss, in some detail, the use of chalk macrofossils in high resolution correlation. There follows an evaluation of lithostratigraphic marker beds and their correlation across the basin, and a synthesis of biostratigraphical and lithostratigraphical correlations is described and illustrated. The important marginal successions of the Coniacian to Santonian in the Anglo-Paris Basin are reviewed, and a new synthesis of the Coniacian and Santonian sedimentary history of the basin is presented. Finally, the succession in the Upper Santonian of the Anglo-Paris Basin is compared to that developed in other parts of the world.

THE ANGLO-PARIS BASIN

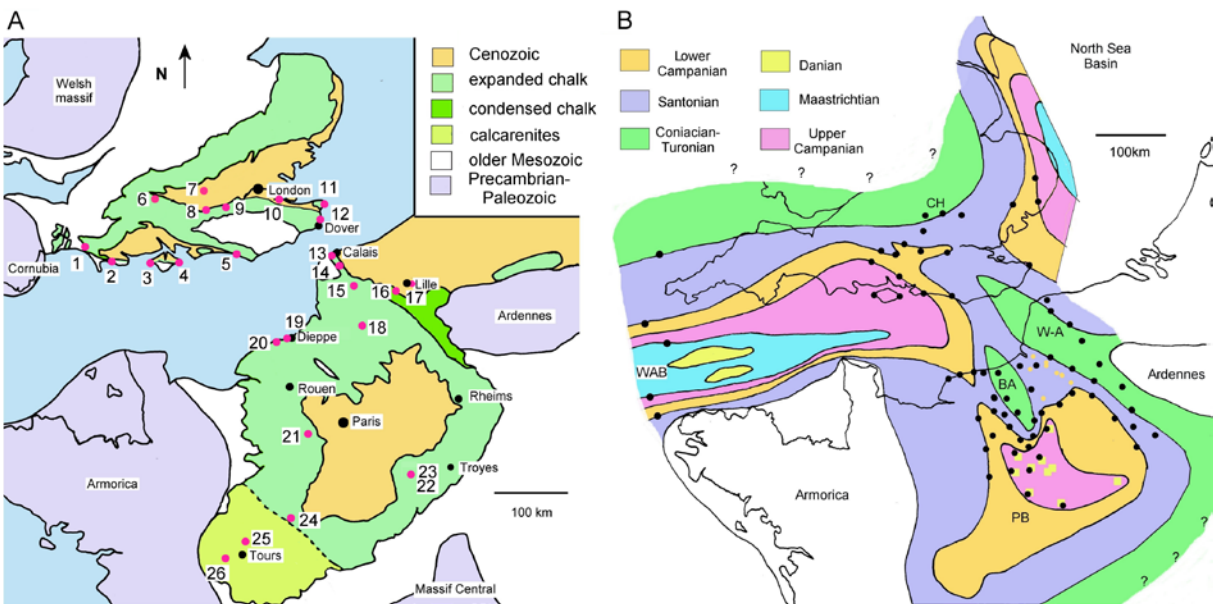
The Anglo-Paris Basin is a post-Variscan intracratonic flexural basin (Guillocheau *et al.* 2000; Amédro *et al.* 2024) in which sediment accumulation commenced during the Permian. It is surrounded by Variscan massifs; to the west, the Armorican Massif, to the northwest, the Cornubian Massif, to the south the Massif Central, and to the northeast by the Ardennes and Anglo-Brabant Massif (Text-fig. 1). Upper Cretaceous sedimentation is dominated by chalks, which reach a maximum thickness of 600–700 m (proved by boreholes) to the southeast of Paris (Robaszynski *et al.* 2000, 2005). However, the higher part of the Campanian and the entire Maastrichtian have been removed from the basin by Early Paleogene inversion and subsequent erosion, possibly caused by the effects of mantle plumes (Gale and Lovell 2017, 2020; Text-fig. 1B). The extent of Cretaceous sedimentation on the bordering massifs is uncertain because of subsequent erosion, but low-temperature thermochronology indicates that it is likely that the Upper Cretaceous extended onto part of the Massif Central (Morvern; Barbarand *et al.* 2013). In the southwest of the Paris Basin, on the southern part of the Armorican Massif, Coniacian and Santonian chalks pass laterally into a thin succession of calcarenites and hardgrounds (Text-fig. 1A).

Localities

Text-fig. 1A shows the main localities described and discussed in this paper, the details of which are provided in Table 1.

Methods of study

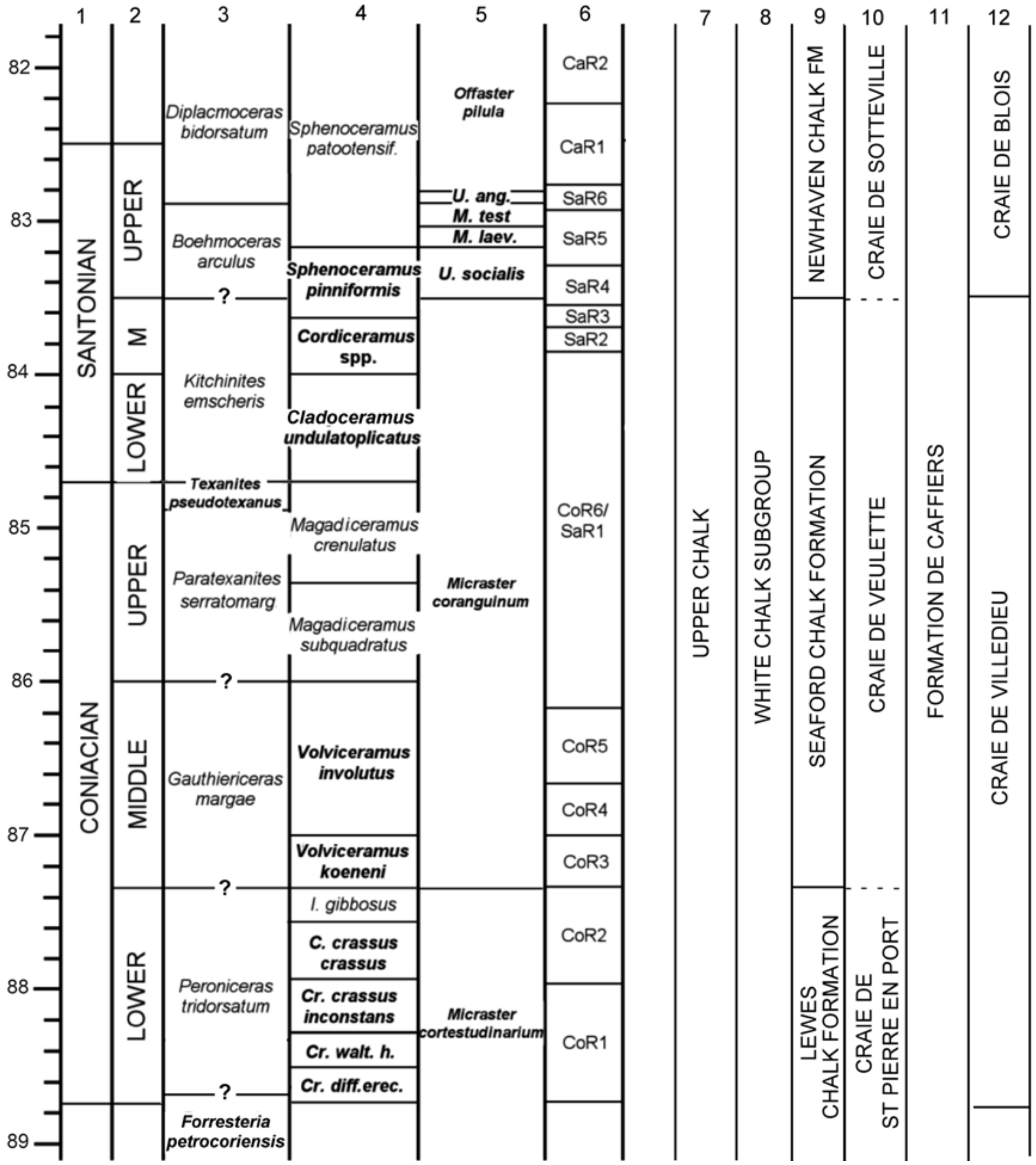
Available sections were logged in detail, macrofossils collected and samples (approximately 5 kg) were taken from some localities for microcrinoid analysis. These were prepared using 95% acetic acid following the method described in Gale (2019a). Authors of species and genera are not included in the paper and can be obtained by the reader from the numerous references to each group. Text-fig. 2 provides a Coniacian-Santonian timescale, macro- and microfossil zonations, and the names of formations in the Anglo-Paris Basin.



Text-fig. 1. Location of the study area. A – Cretaceous outcrop of the Anglo-Paris Basin, showing the distribution of Coniacian–Santonian facies and localities studied (for explanation see Table 1). B – palaeogeology of the sub-Paleogene surface, to show where the Santonian has been removed by erosion; CH – in the Chilterns; BA – over the Pays de Bray Anticline; W–A – over the Anglo-Brabant Massif. The absence in the Weald is conjectural. PB – Paris Basin, WAB – Western Approaches Basin. After Gale and Lovell (2020).

No. in Text-fig. 1A	Name, location	Co-ordinates	Nature of exposure	Unit exposed	References
1	North Barn, Long Bredy, Dorset	50°43’20.27”N, 2°36’55.07”W	Old chalkpit	Seaford Chalk Fm.	
2	Middle Bottom, Dorset	50°37’26.65”N, 2°17’54.59”W	Sea cliffs	Lewes, Seaford, Newhaven fms.	Gale (2018)
3	Freshwater, Isle of Wight Scratchell’s Bay, Isle of Wight	50°40’08.07”N, 1°34’46.85”W 50°39’40.62”N 1°34’46.85”W	Sea cliffs	Lewes, Seaford fms.	Gale (2019b)
4	Culver Cliff, Isle of Wight	50°39’57.29”N, 1°05’49.32”W	Sea cliffs	Lewes, Seaford fms.	Gale (2018)
5	Seaford Head, East Sussex	50°45’41.63”N, 0°06’48.77”E	Sea cliffs	Lewes, Seaford, Newhaven fms.	Mortimore (1986)
6	Boxford, Berkshire	51°26’40.91”N, 1°22’55.33”W	Old chalkpit	Seaford Fm.	Jarvis and Woodroof (1981)
7	Taplow, Berkshire	51°31’54.62”N, 0°41’23.02”W	Old chalkpit	Seaford Fm.	Jarvis (1980, 1992)
8	Clandon, Surrey	51°15’08.79”N, 0°28’52.54”W	Old chalkpit	Seaford Fm.	Robinson (1986)
9	Leatherhead, Surrey	51°17’48.56”N, 0°28’08.77”W	Old chalkpit	Seaford Fm.	
10	Cliffe, Kent	51°28’04.44”N, 0°28’03.02”E	Old chalkpit	Seaford Fm.	Robinson (1986)
11	Broadstairs, Thanet, Kent	51°22’45.35”N, 1°26’44.61”E	Sea cliffs	Seaford Fm.	Jenkyns *et al*. (1984)
12	Dover, Kent	51°07’53.75”N, 1°20’34.16”E	Sea cliffs	Lewes, Seaford fms.	Jenkyns *et al.* (1984)
13	Coquelles, Pas de Calais	50°55’49.77”N, 144’19.91”E	Old chalkpit	Craie de Caffiers	Amédro and Robaszynski (2000a, b)
14	Caffiers, Pas de Calais	50°50’45.19”N, 1°48’45.56”E	Railway cutting	Craie de Caffiers	Amédro and Robaszynski (2000a, b)
15	Cléty, Pas de Calais	50°38’45.15”N, 2°24’38.20”E	Old quarry	Craie de Caffiers	Amédro *et al.* (2023)
16	Haubourdin, Nord	50°36’04.84”N, 3°00’21.15”E	Disused quarry		Amédro *et al.* (2023)
17	Villeneuve d’Ascq, Nord	50°37’22.59”N, 3°8’39.15”E	Cored borehole		Amédro *et al.* (2023)
18	Beauval, Picardie	50°05’57.92”N, 2°20’17.17”E	Old quarry		Jarvis (1980, 1986, 2006)
19	Dieppe, Seine Maritime	49°56’31.45”N, 1°07’05.61”E	Sea cliffs		Hoyez (2008); Gale (2019a)
20	Veules-les-Roses, Seine Maritime	49°52’47.67”N, 0°48’22.47”E	Sea cliffs		Hoyez (2008); Gale (2019b)
21	Cherisy, Eure-et-Loir	48°44’42.23”N, 1°25’52.10”E	Old chalkpit		Robaszynski *et al.* (2023)
22	Paron, Yonne	48°10’28.69”N, 3°15’34.45”E	Road cuttings		Mortimore and Pomerol (1987)
23	St-Martin-du-Tetre, Yonne	48°12’48.92”N, 3°15’49.89”E	Road cuttings		Gale (2019a)
24	Châteaudun, Eure-et-Loir	48°05’10.06”N, 1°21’00.86”E	River cliff		De Grossouvre (1901)
25	Villedieu le Château, Loir-et-Cher	47°43’08.92”N, 0°39’02.80”E	Old quarries	Craie de Villedieu	Jarvis and Gale (1984)
26	Langeais, Indre-et-Loire	47°19’38.67”N, 0°24’38.20”E	Old quarry	Craie de Villedieu	Jarvis and Gale (1984)

Table 1. The main localities discussed in the paper. For location see Text-fig. 1.



Text-fig. 2. Stratigraphy of the Coniacian–Santonian stages, modified after Gale (2020, fig. 27.9). 1 – stages; 2 – substages; 3 – ammonite zones; 4 – inoceramid zones; 5 – traditional macrofossil zones; 6 – microcrinoid zones, after Gale (2019); 7 – traditional UK stratigraphy; 8 – subgroup; 9 – formations, southern England; 10 – formations, Seine Maritime (after Lasseur 2007); 11 – formations, Nord – Pas de Calais; formations, Touraine, after Jarvis and Gale (1984). Note that ammonites and inoceramids recorded from the chalks of the Anglo-Paris Basin are shown in bold.

STAGE AND SUBSTAGE BOUNDARIES

Coniacian

The GSSP for the base of the Coniacian is now defined by the lowest occurrence of the inoceramid *Cremnoceramus deformis erectus* at Salzgitter Salder in northern Germany (Walaszczyk *et al.* 2022). Kennedy and Walaszczyk (2004 and 2023, text-fig. 3) have shown this level as falling within the *Forresteria petrocoriensis* ammonite Zone. The remainder of the lower Coniacian corresponds with the *Peroniceras tridorsatum* Zone.

Middle Coniacian

The base of the middle Coniacian is placed at the lowest occurrence of the inoceramid *Volviceramus koeneni* (Kauffman *et al.* 1996). No boundary stratotypes have been proposed. Kennedy and Walaszczyk (2023, text-fig. 3) demonstrate that the middle Coniacian corresponds to the *Gauthiericeras margae* ammonite Zone.

Upper Coniacian

The base of the upper Coniacian is taken at the lowest occurrence of the inoceramid *Magadiceramus subquadratus* (Kaufmann *et al.* 1996) and there are no proposals for a locality recording this event. In the absence of this genus, the base of the substage is impossible to identify, because *Volviceramus* co-occurs with *Magadiceramus* over most of its range. Kennedy and Walaszczyk (2023, text-fig. 3) show the upper Coniacian as equivalent to the *Paratexanites serratomarginatus* and *Texanites pseudotexanus* ammonite zones.

Santonian

The base of the Santonian is marked by the lowest occurrence of *Cladoceramus undulatoplicatus* in the GSSP located at Olazagutia in Navarra, northern Spain (Lamolda *et al.* 2014).

Middle Santonian

Although widely used, the base of this substage has never been defined, although the top of the range of *C. undulatoplicatus* is a possible marker (Gale *et al.* 2020), although this is very difficult to pinpoint.

Upper Santonian

The base of the upper Santonian has been widely taken at the lowest occurrence of *Uintacrinus socialis* (Gale *et al.* 2020), but no formal proposals have been made.

Campanian

The GSSP for the base of the Campanian Stage is at Gubbio, Umbria, Italy and is defined by the base of magnetochron 33r (Gale *et al.* 2023). A proxy for this level in the Boreal chalk facies is the lowest occurrence of the echinoid *Offaster pilula* although this is often difficult to determine.

BIOSTRATIGRAPHY

Ammonites

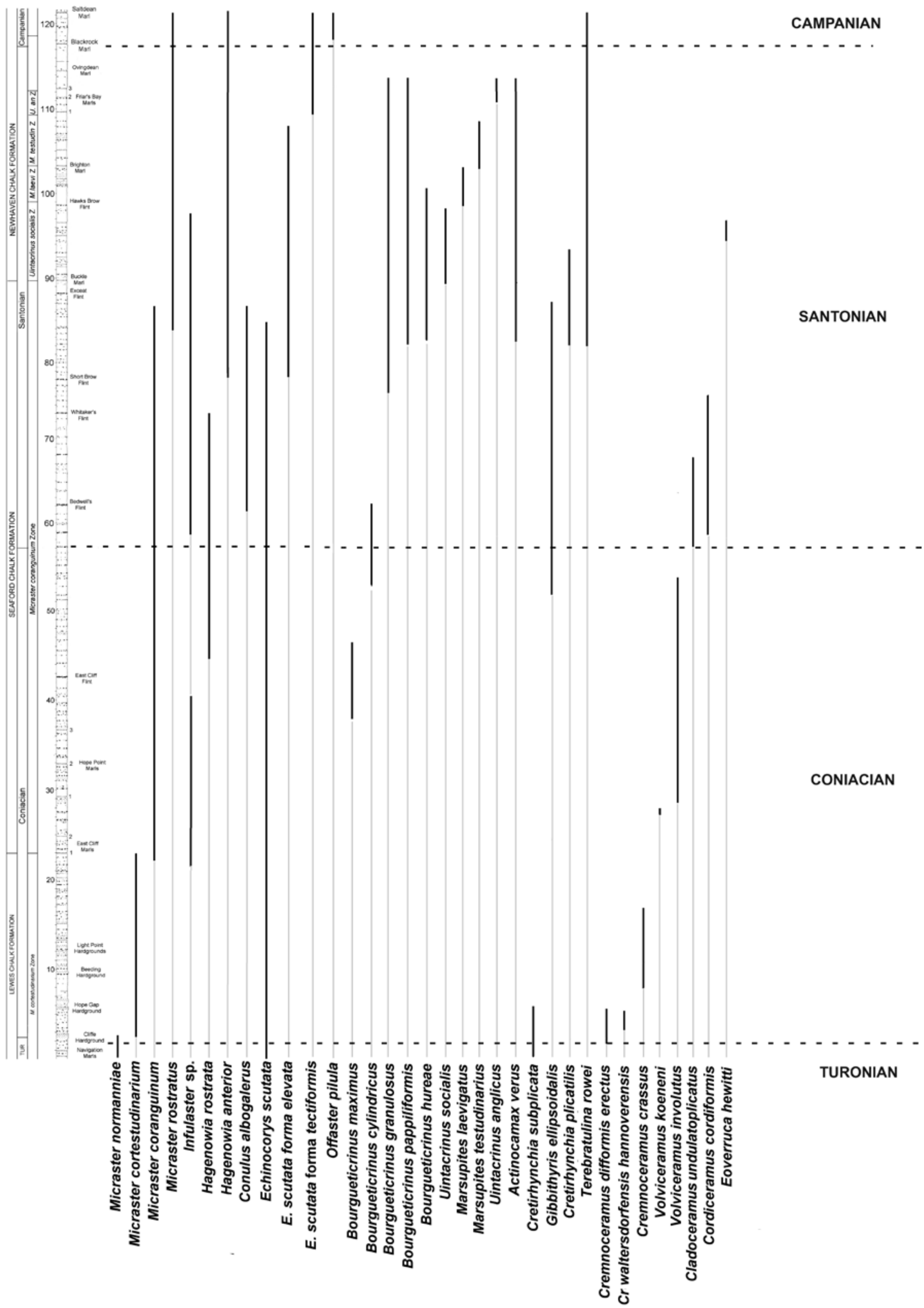
Ammonites are virtually absent in the basinal chalk facies of the Coniacian and Santonian, with the exception of giant specimens of the long-ranging *Parapuzosia leptophylla* (Kennedy 2019, 2020). However, towards the basin margins, in northwest France and more especially in the Craie de Villedieu in Touraine, ammonites are present and are found in association with inoceramid species which occur in the basinal chalks (Jarvis and Gale 1984). The ammonites of the Craie de Villedieu were described by Kennedy (1984).

Inoceramid bivalves

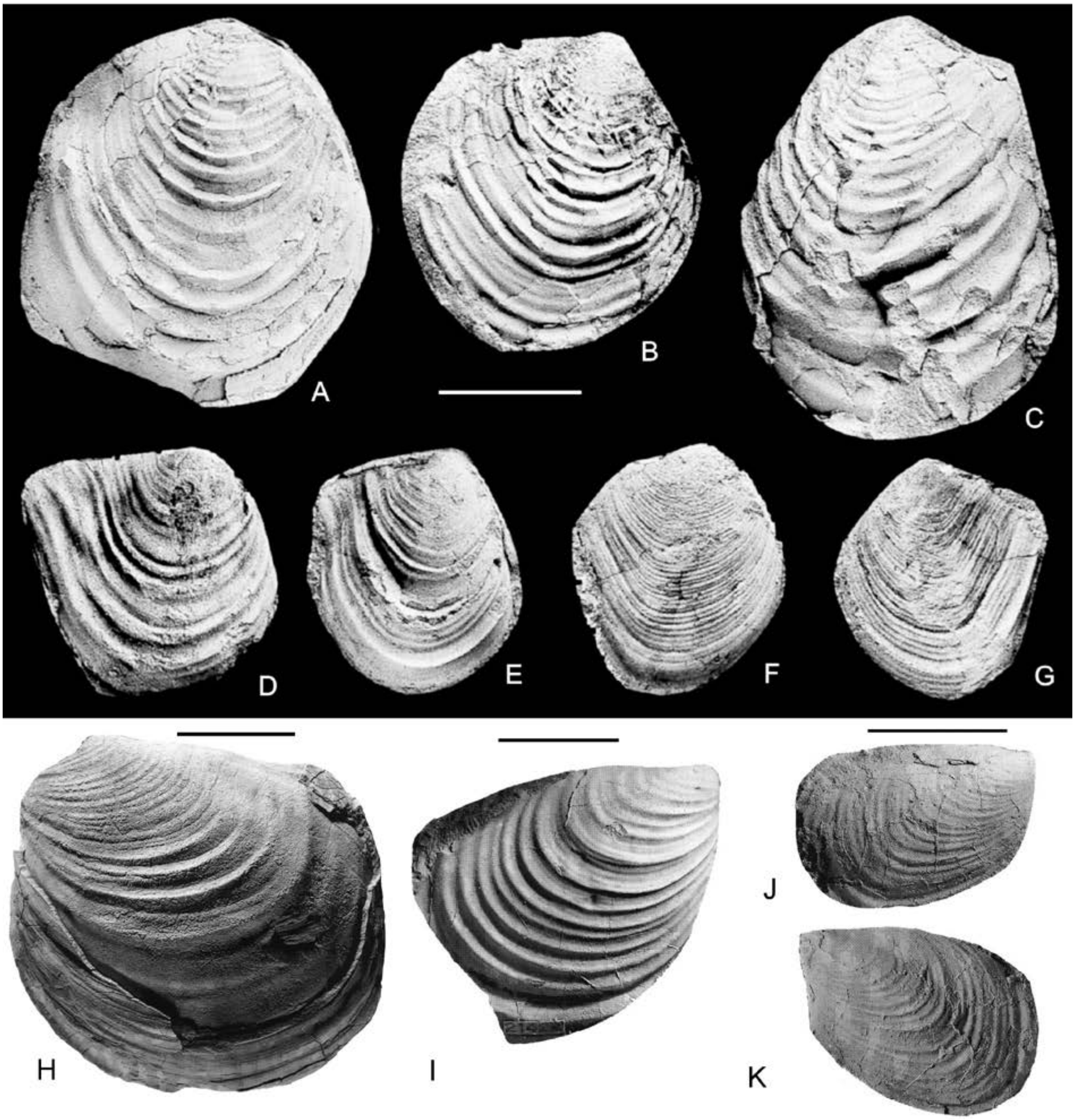
Over the past few decades, inoceramids have proved to be exceptionally useful for international correlation. A standard zonation for the Coniacian and Santonian of the Euramerican Biogeographic Region (*sensu* Kauffman 1973) has been provided, based most importantly upon material collected during construction of mineshafts in northern Germany (Niebuhr *et al.* 1998; Walaszczyk and Wood 1998, 2018) and from exposures in the Western Interior Basin of the USA (Walaszczyk and Wood 1998, 2018; Walaszczyk and Cobban 2000, 2006, 2007). However, in the soft, fine chalks of the Anglo-Paris Basin inoceramids are generally fragmentary and poorly preserved as a result of early diagenetic dissolution of the aragonitic inner shell layer, combined with sea floor current activity and intensive bioturbation. Additionally, for reasons unknown, even fragmentary material is very rare at some levels. Even given these restrictions, an outline inoceramid biostratigraphy for the Coniacian and Santonian can be established (Mortimore *et al.* 2001).

Coniacian

A lower Coniacian inoceramid stratigraphy for southern England was compiled by Mortimore *et al.* (2001, figs 2.21) and additional information was provided by Wood *et al.* (2004). The information is provided in Text-fig. 3. *Cremnoceramus deformis erectus*, the marker species for the base of the Coniacian (Walaszczyk *et al.* 2022; Text-fig. 4A–C herein) is recorded from the interval between the Navigation Marls and the Cliffe Hardground in West Sussex (Wood *et al.* 2004) and the next zonal index, *C. waltersdorfensis hannovrensis* from between the Cliffe and Hope Gap hardgrounds at the same locality (Text-fig. 4D–G).



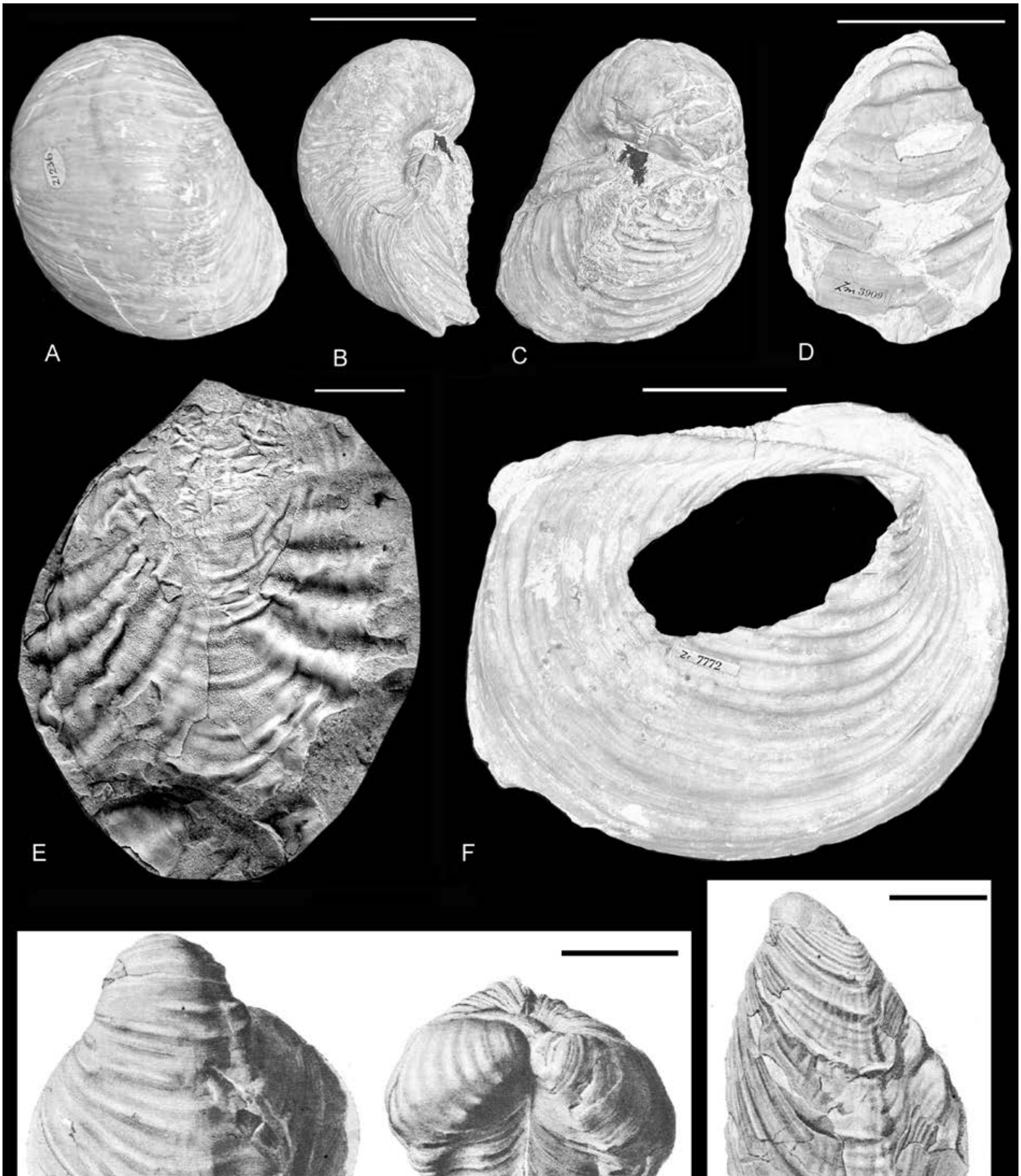
Text-fig. 3. Distributions of key macrofossils in the Coniacian–Santonian Chalk of the Anglo-Paris Basin. The column on the left is taken from the succession at Seaford Head, East Sussex, UK, with marker beds indicated.



Text-fig. 4. Zonal Coniacian inoceramids. A–C – *Cremnoceramus deformis erectus*; D–G – *Cremnoceramus waltersdorfensis hannovrensis*. H, I – *Cremnoceramus crassus crassus*; J, K – *Cremnoceramus crassus inconstans*. A–G after Walaszczyk *et al.* (2022, fig. 6); H–K after Walaszczyk and Cobban (2000, text-figs 25, 28). Scale bars: for A–G, I–K = 2 cm; for H = 5 cm.

Cremnoceramus crassus inconstans is recorded from the Hope Gap Hardground (Mortimore *et al.* 2001, fig. 2.21; Text-fig. 4J, K), and *C. crassus crassus* from the overlying Beeding Hardgrounds (Text-fig. 4H, I). However, many of these records lack detailed locality and stratigraphic information, and only material of *C. deformis erectus* and C. *waltersdorfensis hannovrensis* have been illustrated (Wood *et al.* 2004). Intensive search for determinable *Cremnoceramus* from Dover, Kent, and Dieppe, Normandy has produced very little material.

Although fragmentary material assigned to *Cremnoceramus* has been identified from Kent as high as the level above East Cliff Marl 2 (Bailey *et al.* 1983,



Text-fig. 5. Zonal Coniacian and Santonian inoceramids. A–C, F – *Volviceramus involutus*; E – *Cladoceramus undulatoplicatus*; G, H – *Cordiceramus cordiformis*; I – *Sphenoceramus pachti*. E after Gale *et al.* (2007, fig. 10.2); G, H, I after Woods (1912). Scale bars: for A–D, F = 5 cm; for E, G–I = 2 cm.

fig. 2), there appears to be a gap in the inoceramid record in the Anglo-Paris Basin, because *Inoceramus gibbosus* has not been found. In the Canadian Western Interior and continental Europe this species first appears in the topmost part of the range of the genus *Cremnoceramus*, and the top of the eponymous zone is marked by the lowest records of *V. koeneni* (Plint *et al.* 2017; Walaszczyk *et al.* 2017; Walaszczyk and Wood 1998, 2018) [although the species itself ranges higher into the middle Coniacian]. *Volviceramus koeneni* (Text-fig. 5D) is recorded from the same level in Sussex (Mortimore 1986, fig. 16) and Kent (Bailey *et al.* 1983, fig. 2), approximately 3 m above East Cliff Marl 2. It has recently been collected at an equivalent level at Lille, Nord (Amédro *et al.* 2023).

Volviceramus involutus is a highly distinctive, very widespread species in which the left valve is smooth and inrolled, and the right valve is ribbed and flat (Text-fig. 5A–C, F). The fragments of valves are distinctive, and the species occurs throughout the studied sections of the Anglo-Paris Basin. It occurs most commonly in the few metres underlying the East Cliff Flint, but very rarely specimens occur up to about 5 m beneath the basal Santonian marker (see below). The interval from about 5 m above the East Cliff Flint to the base of the Santonian contains very few inoceramids, and species of the genus *Magadiceramus*, which define the upper Coniacian zones of *M. subquadratus* and *M. crenelatus* (extensively developed in Germany and the USA; Walaszczyk and Cobban 2006) have never been found in the Anglo-Paris Basin.

Santonian

The basal marker for the Santonian GSSP is the lowest occurrence of the large, flat, divaricately ribbed species *Cladoceramus undulatoplicatus* at Olazagutia, northern Spain (Lamolda *et al.* 2014). This species (Text-fig. 5E) occurs extensively at a series of levels in the Seaford Chalk, *Micraster coranguinum* Zone, across the entire Anglo-Paris Basin. The lowest two of these are decametric beds packed with fragments and occasional entire specimens, at the levels of the Michel Dean and Bedwell flints (Bailey *et al.* 1983; Mortimore 1986; Mortimore *et al.* 2001). The same levels extend to the Seine Maritime coast (Dieppe-Pourville) and Paron in the Yonne valley (Mortimore and Pomerol 1987, fig. 20). *Cladoceramus undulatoplicatus* ranges for several metres above Bedwell's Flint in southern England and northern France, and is replaced by abundant, flat *Platyceramus* sp. which extend up to Whitaker's Flint and for several metres above this level. Rarer specimens of *Cordiceramus cordiformis* (Text-fig. 5G, H) and *Sphenoceramus pachti* (Text-fig. 5I) co-occur with *C. undulatoplicatus* (Bailey *et al.* 1983, fig. 2; Mortimore 1986, fig. 16) and the former species is found as high as the lower *Uintacrinus socialis* Zone.

The detailed inoceramid stratigraphy of the upper Santonian of the Anglo-Paris Basin remains elusive, as specimens are rare and fragmentary. Mortimore (2011, fig. 20) illustrated a specimen of *Sphenoceramus pinniformis* from the base of the *U. socialis* Zone at Sotteville, Seine Maritime, and unhorizoned specimens of this species are present in museum collections.

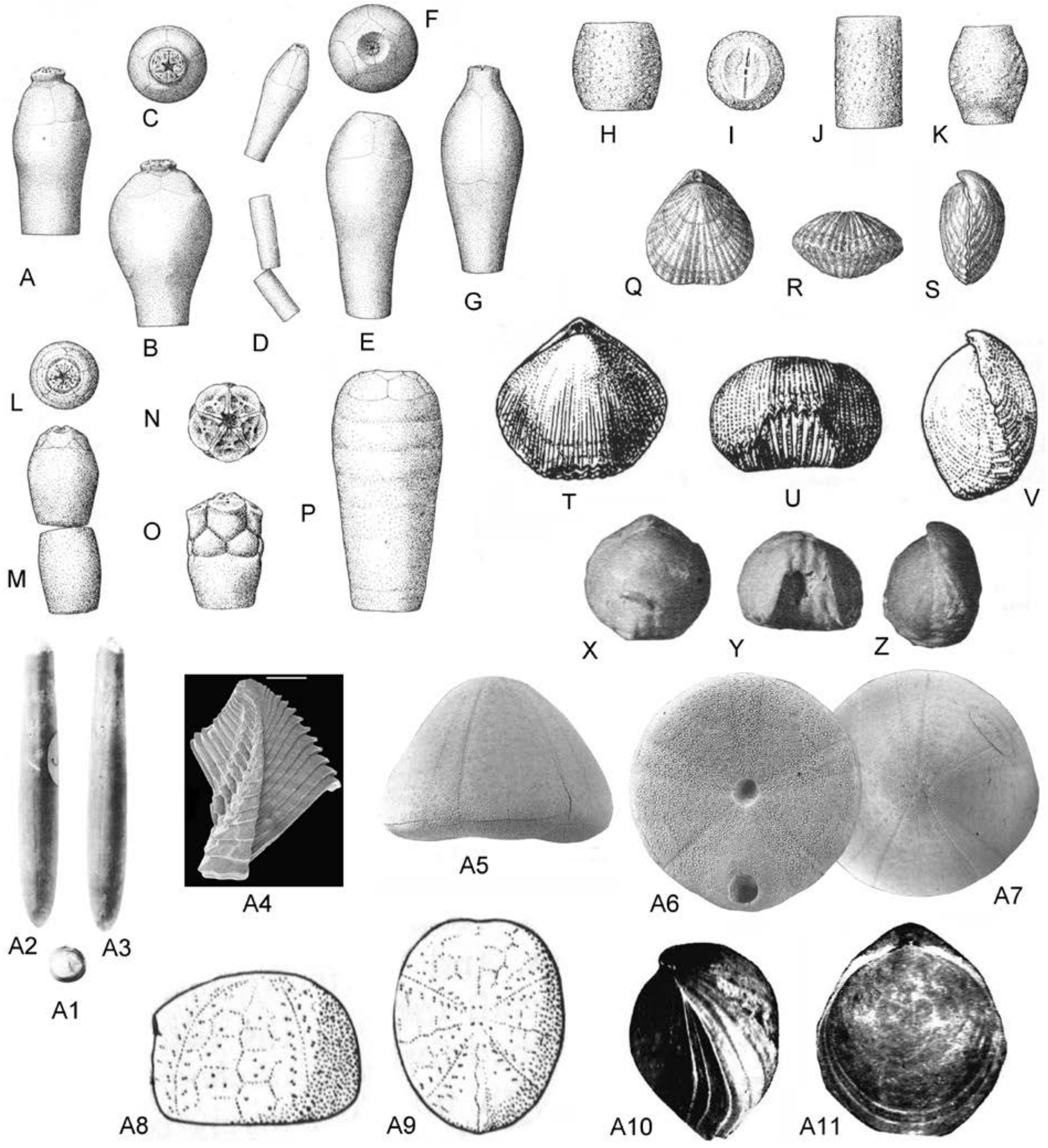
Brachiopods

Brachiopods have a limited biostratigraphical value in the Coniacian and Santonian chalks of the Anglo-Paris Basin because most are long ranging species, and there is significant lateral variation in the abundance of many taxa. The small rhynchonellid *Cretirhynchia subplicata* (Text-fig. 6X–Z) has a limited range, occurring in the uppermost part of the *Plesiocorys plana* Zone and extending up to the level of the Hope Gap Hardground in Sussex (Mortimore 1986, fig. 12) and an equivalent level in Kent (Bailey *et al.* 1983, fig. 2) and at Dieppe, France. *Cretirhynchia plicatilis* (Text-fig. 6T–V) has a short range (5 m) in east Kent, occurring at the level of Barrois' Sponge Bed (Bailey *et al.* 1983, fig. 2) and occurs at an equivalent level in Sussex and at Veules-les-Roses, Seine Maritime. However, Pettit (1950) separated *Cretirhynchia exsculpta* from the *Uintacrinus* and *Marsupites* zones as a discrete species which is abundant in Sussex but rare elsewhere, and it is uncertain which species is referred to in the older literature. The terebratulid brachiopod *Gibbithyris ellipsoidalis* (Text-fig. 6A10, A11) has a level of abundance between the Chartham and Bedwell's flints in Kent (Bailey *et al.* 1983, fig. 2), at Paron and Coquelles, France and in Sussex (Mortimore 1986, fig. 16). Finally, the small species *Terebratulina rowei* (Text-fig. 6Q–S) occurs commonly in the *Uintacrinus* and *Marsupites* zones across the Anglo-Paris Basin and extends up into the lower Campanian (Gale 2018).

Crinoids

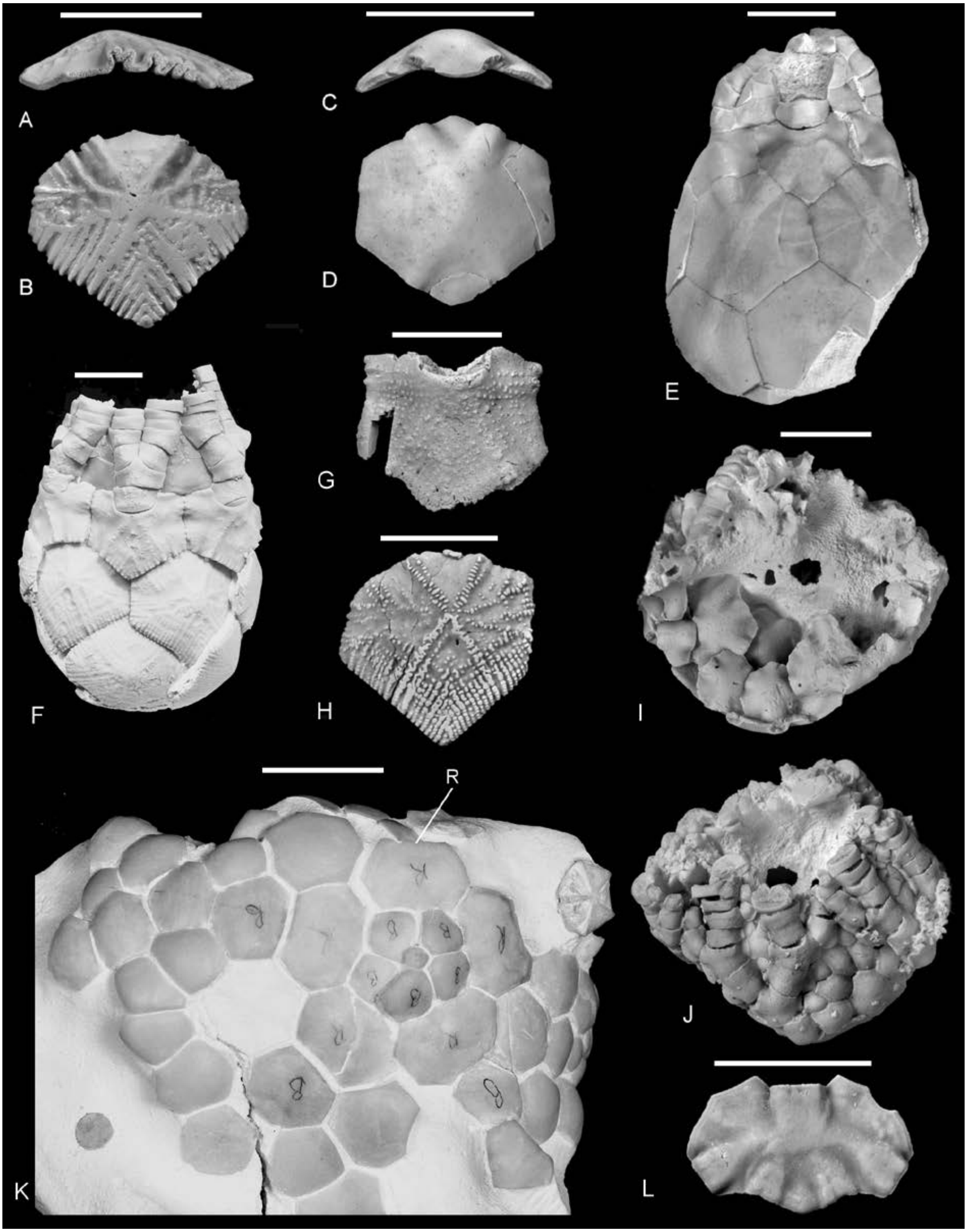
Bourgueticrinids

Cups and columnals of the bourgueticrinid genus *Bourgueticrinus* are common fossils in Coniacian and Santonian chalks and have been used in biostra-



Text-fig. 6. Selected fossils from the Chalk. A–G – *Bourgueticrinus papilliformis*, upper Santonian; H–K – *Bourgueticrinus granulosus*, middle to upper Santonian; L, M – *Bourgueticrinus maximus*, middle Coniacian; N – *Bourgueticrinus hureae*, upper Santonian; O – *Bourgueticrinus cylindricus*, lower Santonian; P – *Bourgueticrinus cylindricus*, lower Santonian; Q–S – *Terebratulina rowei*, upper Santonian; T–V – *Cretirhynchia plicatilis*, upper Santonian; X–Z – *Cretirhynchia subplicata*, lower Coniacian; A1–A3 – *Actinocamax verus*, upper Santonian; A4 – *Eoverruca hewitti*, *U. socialis* Zone; A5–A7 – *Conulus albogalerus*, lower–middle Santonian; A8–A9 – *Offaster pilula*, lower Campanian; A10–A11 – *Gibbithyris* sp., lower–middle Santonian. Precise ranges of the taxa are given in Text-fig. 3. Not to scale.

tigraphy since Rowe's observation (1902) that the 'nipple-shaped head' (cup of *Bourgueticrinus papilliformis*) was a characteristic fossil of the *Uintacrinus* Band. The taxonomy of *Bourgueticrinus* was revised by Rasmussen (1961) and a selection of stratigraphically restricted taxa is illustrated here (Text-fig. 6A–P):



Text-fig. 7. The benthonic crinoids *Uintacrinus* and *Marsupites* from the upper Santonian. A, B, F–H – *Marsupites testudinarius*, A, B – isolated basal plate in adoral and lateral views; F – cup in lateral view; G – radial plate in lateral view; H – basal plate in lateral view; C–E – *Marsupites laevigatus*, C, D – basal plate in adoral and lateral views; E – cup in lateral view; I, J, L – *Uintacrinus anglicus*, I, J – cup in aboral and adoral views; L – radial in lateral view to show crenulate form; K – *Uintacrinus socialis*, aboral view of cup to show smooth, polygonal radials (R). Scale bars = 1 cm.

- *Bourgueticrinus maximus*. The cup is barrel shaped, tapering adorally and the basals are small and triangular (Text-fig. 6L, M). The articular surfaces between columnals have irregular ridges. The species is restricted to the middle Coniacian in chalk facies (Text-fig. 3).
- *Bourgueticrinus cylindricus*. The cup is robust, elongated and the radials are small (Text-fig. 6P). The species is restricted to the uppermost Coniacian and lowest Santonian.
- *Bourgueticrinus granulosus*. The columnals and cup bear scattered fine granules (Text-fig. 6H–K). The species appears a few metres above Whitaker's Flint and extends up into the highest Santonian.
- *Bourgueticrinus papilliformis*. The cup tapers rapidly adorally and the articular surfaces of the radials form a narrow process (Text-fig. 6A–G). The species appears in the lower *U. socialis* Zone and persists into the *M. testudinarius* Zone.
- *Bourgueticrinus hureae*. In this species, the contacts between the radials, basals and proximale are deeply incised (Text-fig. 6N, O). The species occurs in the uppermost *M. coranguinum* and *U. socialis* zones.

Marsupitids

The stemless, benthonic crinoids of the genera *Uintacrinus* and *Marsupites* are highly modified comatulids (Milsom *et al.* 1994) and have been utilised stratigraphically since the late 19th century. They have a global distribution in upper Santonian sediments (Gale *et al.* 1996, 2008, 2023). However, they are virtually restricted to the chalk facies, and only *M. testudinarius* extends into clastic facies. The four recognised species are briefly described in ascending order; distal brachials are not determinable:

- *Uintacrinus socialis*. The radials and proximal brachials are flat or gently convex and smooth (Text-fig. 7K).
- *Marsupites laevigatus*. The cup plates are smooth with a pair of cross shaped rounded ridges, and the articulation between the basals and radials has two discrete articulation surfaces at the upper termination of the ridges (Text-fig. 7C–E).
- *Marsupites testudinarius*. The cup plates are sculptured with ridges or granules and the articulation surfaces between the basals and radials are crenulate (Text-fig. 7A, B, F, H).
- *Uintacrinus anglicus*. The radials and proximal brachials bear flat or slightly convex radially arranged ridges (Text-fig. 7I, J, L).

Roveacrinids

Tiny, pelagic microcrinoids are abundant in Coniacian and Santonian chalks of the Anglo-Paris Basin and were revised taxonomically by Gale (2016, 2019). They form the basis of a detailed zonation (CaR1-6, SaR1-6) which can be applied across the basin and in part to the Gulf Coast states of the USA (Gale *et al.* 2021). The microcrinoids are most useful in the lower and middle Coniacian and the upper Santonian where they can be used to define short zones (Text-fig. 8). The diversity and abundance are low in the highest Coniacian and lower Santonian.

Saccocomids

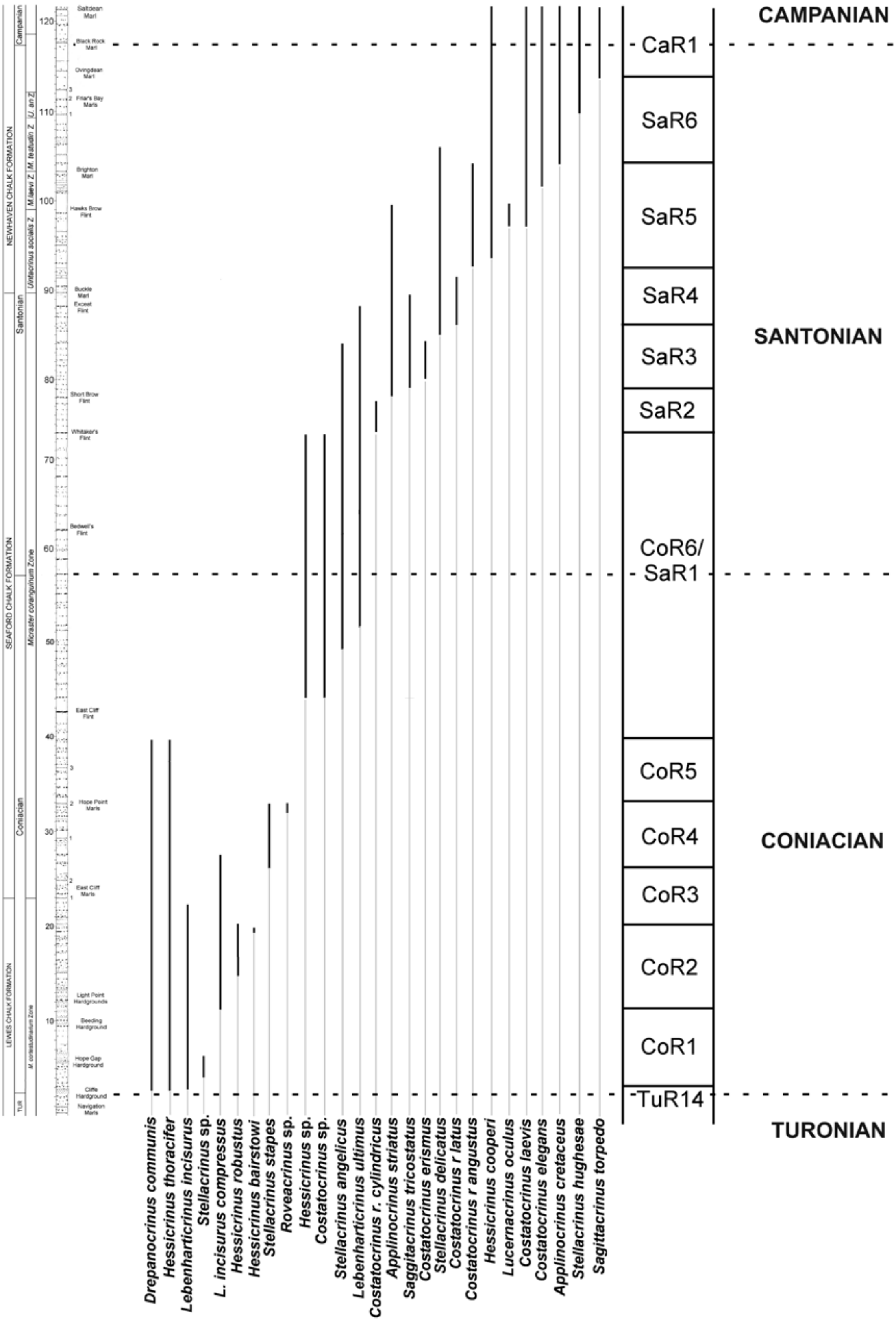
Three genera of saccocomids are present in the Santonian of the Anglo-Paris Basin, *Applinocrinus*, *Costatocrinus* and *Sagittacrinus*. *Costatocrinus* appears in the middle Santonian, and a succession of species and subspecies allow distinction of a series of zones, characterised successively by *Costatocrinus rostratus* forma *cylindricus* (zone SaR2; Text-fig. 9K), *Costatocrinus rostratus* forma *latus* (SaR3; Text-fig. 9F, G) and *Costatocrinus rostratus* forma *angustus* (SaR5; Text-fig. 9A, B). The lowest occurrence of *Sagittacrinus tricostatus* (Text-fig. 9C) defines the base of SaR3 (Text-fig. 8). The base of CaR1 is defined by the lowest occurrence of *Sagittacrinus torpedo* (Text-fig. 9D, E). *Applinocrinus cretaceus* first appears in the middle of SaR6 and ranges up into the upper Campanian.

Roveacrininae

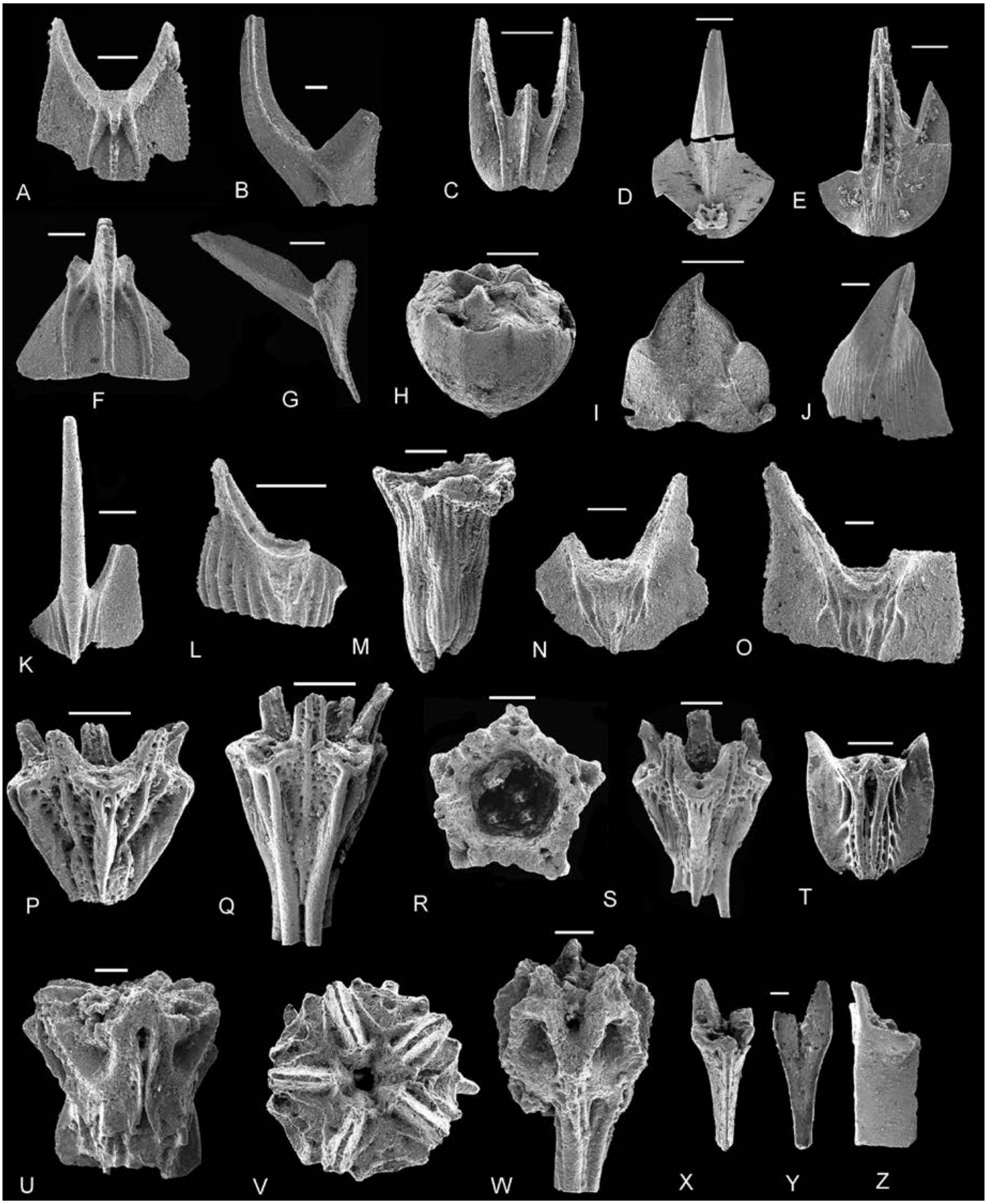
Roveacrinines (Text-fig. 9P–T) have robust, adorally expanding cups and flat, broad proximal brachials. *Drepanocrinus communis* is common in the lower Coniacian, but the genus disappears a few metres beneath the East Cliff Flint in all sections studied, a probable extinction (Text-fig. 8).

Orthogonocrininae

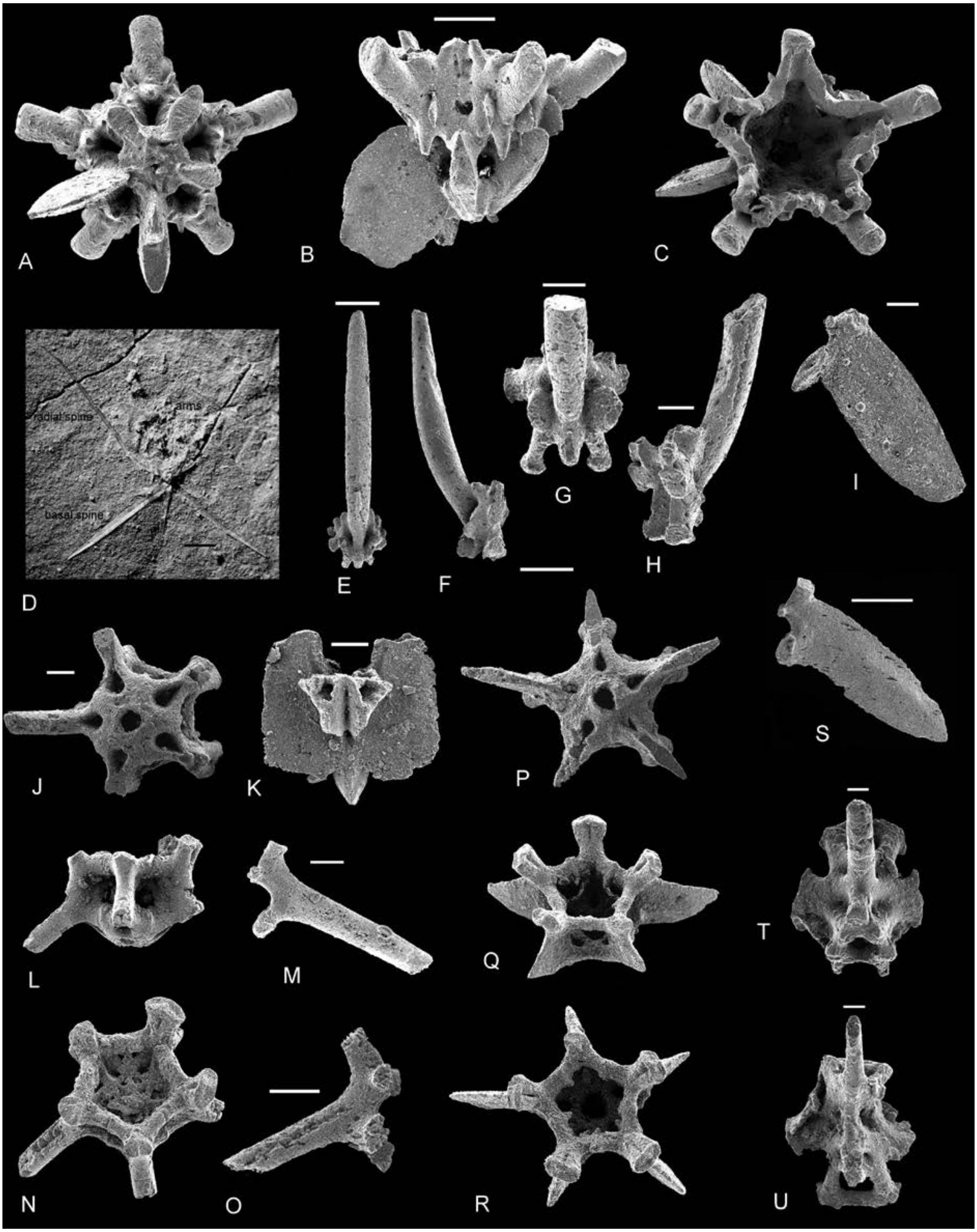
They are characterised by the robust, cylindrical cup with lateral openings (Text-fig. 9U–Z) and elongated proximal brachials. A form with laterally compressed brachials, *Lebenharticrinus incisurus* forma *compressus* (Text-fig. 9X–Z) appears in abundance at the level of the Light Point Hardground (lower Coniacian) and forms a widely correlatable marker and defining the base of CoR2.



Text-fig. 8. Ranges of microcrinoid species in the Coniacian and Santonian Chalks of the Anglo-Paris Basin, against a log of Seaford Head with marker beds. The column on the right represents the positions of the microcrinoid zonal boundaries, after Gale (2019a).



Text-fig. 9. Microcrinoids, Saccocomidae and Roveacrininae. A, B – *Costatocrinus rostratus* forma *angustus*, radial plate in external and lateral views; C – *Sagittacrinus tricostatus*, external view of proximal brachial; D, E – *Sagittacrinus torpedo*, proximal brachials in internal and external views; F, G – *Costatocrinus rostratus* forma *latus*, radial plate in external and lateral views; H, I – *Applinocrinus cretaceous*, H – cup in oblique adoral view, I – external view of brachial; J – *Applinocrinus striatus*, external view of brachial; K – *Costatocrinus rostratus* forma *cylindricus*, external view of brachial; L, M – *Costatocrinus elegans*, lateral views of radial and basal cone; N, O – *Costatocrinus erismus*, external views of radials; P–T – *Drepanocrinus communis*, P, Q, S – cups in lateral view, R – cup in adoral view, T – proximal brachial; U, V – *Lebenharticrinus incisurus*, lateral and apical views of cup; W – *Lebenharticrinus ultimus*, lateral view of cup; X–Z – *Lebenharticrinus incisurus* forma *compressus*, proximal brachial. Images are taken from Gale (2019a), which should be referred to for details of specimens. All ranges are shown in Text-fig. 8. Scale bars: for D, E, P–T = 0.5 mm, for all others = 0.2 mm.



Text-fig. 10. Microcrinoids, Hessicrininae. A–C, E–I – *Stellacrinus hughesae*, A–C – cup in aboral, lateral, and aboral views, E–H – radial plates, I – basal plate; D – *Stellacrinus lineatus*, entire individual with elongated radial and basal spines; P, S, Q, R – *Stellacrinus delicates*, P, Q, R – basal circlet in aboral, oblique, and adoral views, S – lateral view of basal spine; J–O – *Stellacrinus angelicus*, J, L, N – basal circlet in aboral, lateral, and adoral views, M, O – lateral views of basal spines; T, U – *Stellacrinus stapes*, lateral views of radials. Images are taken from Gale (2019a), which should be referred to for details of specimens. All ranges are shown in Text-fig. 8. Scale bars: for A–C = 0.1 mm; for E, F = 0.5 mm; for all others = 0.2 mm.

Hessicrininae

Hessicrinus is characterised by its low, conical cup and elongated radial spines (Text-fig. 10A–K). An evolutionary succession of species (Gale 2019) provide useful markers. *Hessicrinus thoracifer* disappears at the same level in the middle Coniacian as *Drepanocrinus communis* (Text-fig. 8) and *H. cooperi* is a characteristic of the uppermost Santonian (zones SaR5, 6).

Lucernacrinus is a relatively uncommon genus characterised by the lantern-like form of the cup (Text-fig. 11L–P) and species have short ranges in the upper Santonian (Text-fig. 8).

Stellacrinus is a highly derived hessicrinine in which the radial and basal spines are greatly elongated (Text-fig. 10D). A succession of species of *Stellacrinus,* characterised particularly by the form of the basal spines are stratigraphically useful in the Coniacian to Campanian stages. *Stellacrinus stapes* (Text-fig. 10T, U) has a short range in the middle Coniacian, defining zone CoR4 (Text-fig. 8). In the Santonian a succession of species with very limited ranges are present. These are *S. angelicus* (Text-fig. 10J–O), *S. delicatus* (Text-fig. 10P–S) and *S. hughesae* (Text-fig. 10A–C, E–I).

Microcrinoid zones

A succession of zones based on the ranges of roveacrinids (CaR1-6, SaR1-6) was established for the Coniacian and Santonian of the Anglo-Paris Basin (Gale 2019a; Text-fig. 8 herein) based on studies of sections in southern England (Kent, Sussex) and northern France (Dieppe, Veules-les-Roses in Seine Maritime). Although these have not been studied in all sections, they provide a very fine subdivision of the upper Santonian in particular where they can be identified as far away as the Yonne. Definitions of the zones are provided by Gale (2019).

Echinoids

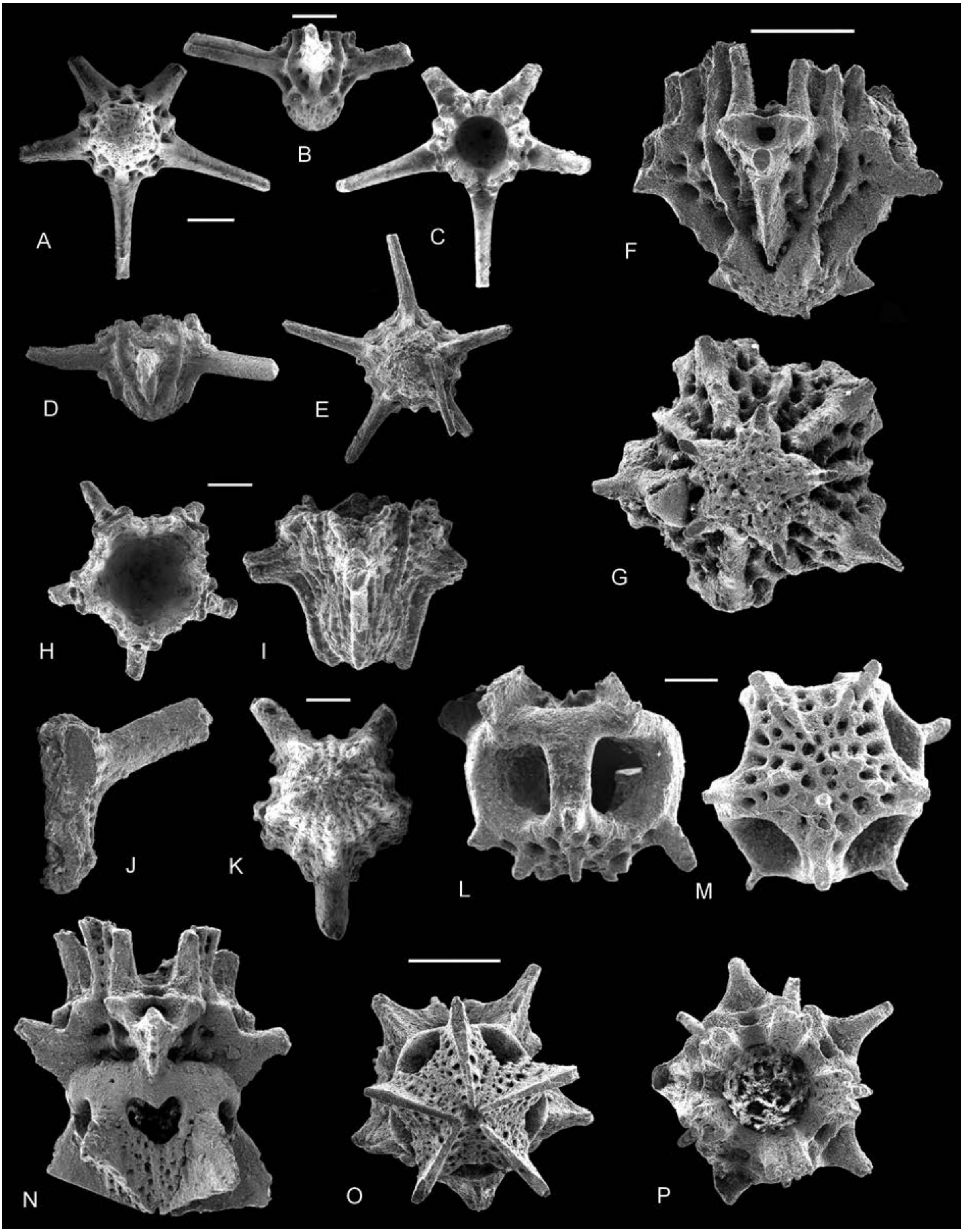
Spatangoids

The spatangoid genus *Micraster* has been employed biostratigraphically since the late 19th century, when the classical evolutionary study of Rowe (1899) demonstrated a succession of gradualistic changes in shape and details of test morphology through the English Turonian to Santonian chalk. The nomenclature applied to *Micraster* species has varied over the past 130 years but was stabilised by Smith and Wright (2012) on the basis of English material. David and Fouray (1984) described Turonian and Coniacian *Micraster* from the north coast of France.

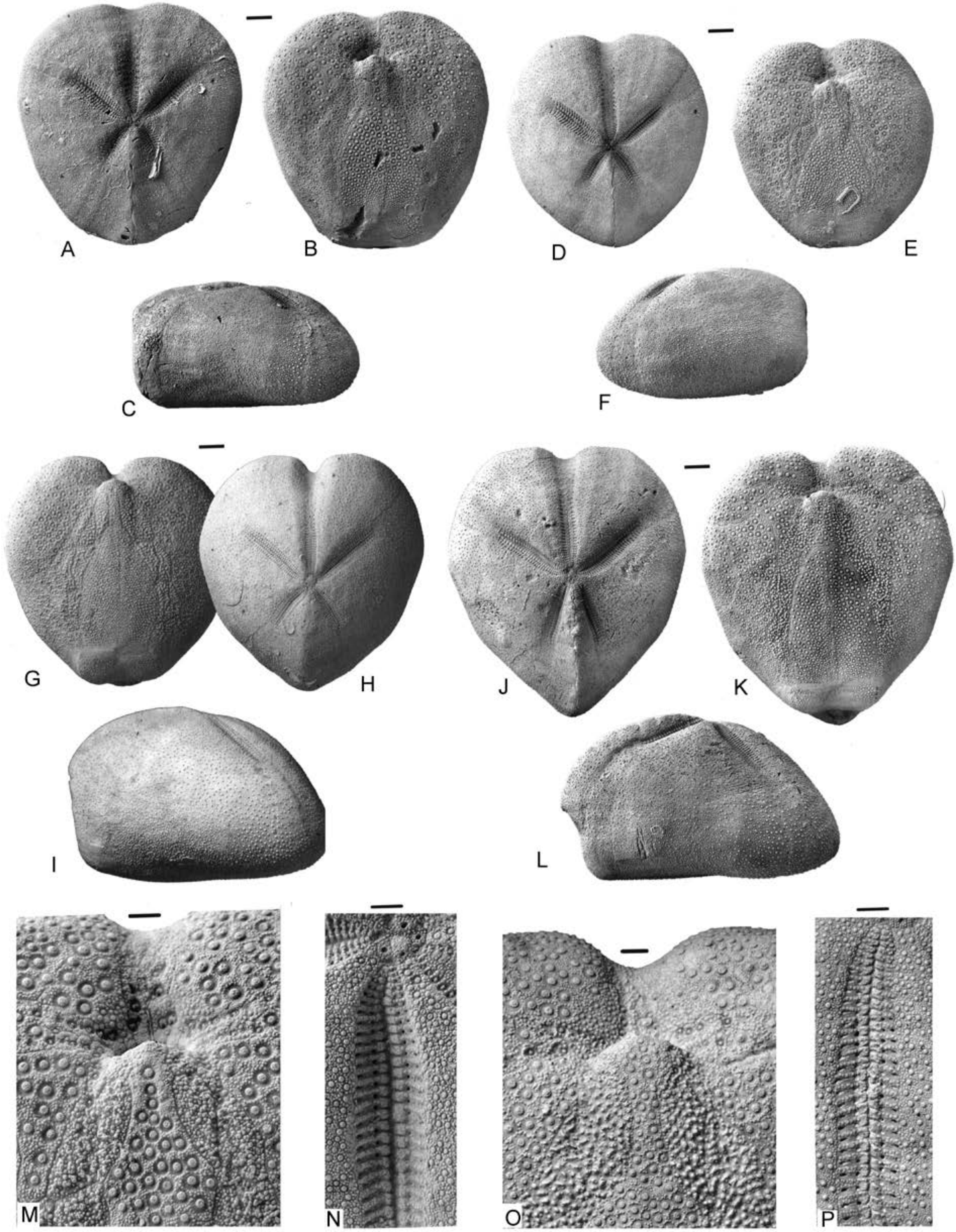
– *Micraster normanniae* (Text-figs 12A–C, 13A). This species is characterised by the narrow, parallel sided, fully tuberculate labral plate which extends only part of the way along ambulacral plate 2 (Text-fig. 13A; Smith and Wright 2012) and by the trapezoidal outline – *M. cortestudinarium* has a more rounded, heart-shaped outline. The species extends from the upper Turonian up to the level of the Cliffe Hardground.
– *Micraster cortestudinarium* (Text-figs 12D–F, 13B). The peristome is removed from the anterior border and is not overlapped by the fully tuberculate labrum. The shape of the labral plate and the symmetry of the sternal plates is variable (Smith and Wright 2012, p. 659).
– *Micraster coranguinum* (Text-figs 12G–I, 13D). This species is most especially differentiated from *M. cortestudinarium* by the position of the peristome and labral plate, which are closer to the anterior border, and the labral plate is parallel sided (Smith and Wright 2012, p. 670). The limits of distribution of *M. cortestudinarium* and *M. coranguinum* are close to the traditional zonal boundary, at the level of the East Cliff marls in southern England. Mortimore (1986, fig. 16) and Mortimore *et al.* (2001, fig. 2.21) record *Micraster bucailli* from the middle Coniacian Chalk in Sussex, a species which is typically found in the lower Coniacian of the Northern Province (Yorkshire; Smith and Wright 2012). Mortimore (1986, fig. 16) and Mortimore *et al.* (2001, fig. 2.21) record *M. turonensis* from the upper *cortestudinarium* and lower *coranguinum* zones in Sussex (a species described from the Craie de Villedieu in Touraine), but this was not recognised by Smith and Wright (2012) in their revision of the genus *Micraster.* Recently, Schlüter *et al.* (2023) redescribed *M. turonensis* from the middle Santonian of northern Spain.
– *Micraster rostratus* (Text-figs 12J–L, 13E). This species has a posterior aboral keel which is uniformly curved to the overhung periproct, such that the periproct is visible in the oral view (Text-fig. 13D). The species appears in the uppermost *M. coranguinum* Zone, and its abundance increases upwards to the *Marsupites testudinarius* Zone (Text-fig. 3).

Holasteroids

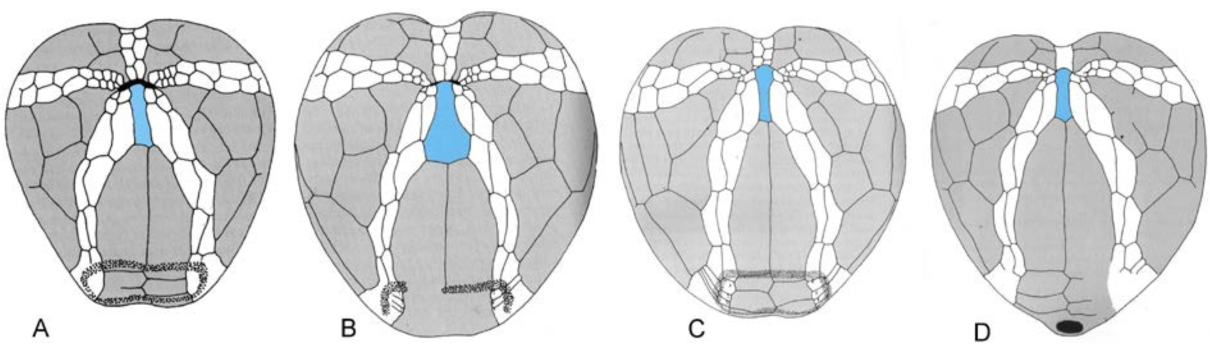
The holasteroid evolutionary lineage leading from *Infulaster* to *Hagenowia* displays dramatic changes



Text-fig. 11. Microcrinoids, Hessicrininae. A–C – *Hessicrinus bairstowi*, cup in aboral, lateral and adoral views; D, E – *Hessicrinus thoracifer*, cup in lateral and aboral views; F, G – *Hessicrinus cooperi*, cup in lateral and aboral views; H–K – *Hessicrinus robustus*, H, I – cup in adoral and lateral views, K – cup in aboral view; L, M – *Lucernacrinus oculus*, cup in lateral and aboral views; N–P – *Lucernacrinus woodi*, cup in lateral, aboral, and adoral views. Images are taken from Gale (2019a), which should be referred to for details of specimens. All ranges are shown in Text-fig. 8. Scale bars: for A–C, F, G, N–P = 0.5 mm, for all others = 0.2 mm.



Text-fig. 12. Echinoids. A–C – *Micraster normanniae*, in aboral, oral, and lateral views; D–F, M, N – *Micraster cortestudinarium*, D–F, test in aboral, oral, and lateral views, M – enlargement of peristome, N – enlargement of petal; G–I, O, P – *Micraster coranguinum* in oral, aboral, and lateral views, O – enlargement of peristome, P – enlargement of petal; J–L – *Micraster rostratus*, in aboral, oral, and lateral views. Ranges of species shown in Text-fig. 3. Modified after Smith and Wright (2012). Scale bars: for A–L = 5 mm; for M–P = 2 mm.



Text-fig. 13. Oral views of plating in *Micraster* spp. A – *M. normanniae*; B – *M. cortestudinarium*; C – *M. coranguinum*; D – *M. rostratus*. Blue – labral plate, grey – interambulacrals, white – ambulacrals, stippled – fasciole. See text for discussion.

in test morphology, with the apex of the test progressively drawn out into an elongated process (Gale and Smith 1982; Gale 2018). Much of the evolutionary change takes place in the Coniacian and Santonian (Text-fig. 14) and species have discrete ranges which do not overlap. The elongated rostra of *Hagenowia* are relatively common fossils on air weathered surfaces and in washed chalk residues.

– *Infulaster excentricus* (Text-fig. 15M–O). Large, laterally compressed holasterids with a tall apex and a deeply incised anterior sulcus occur uncommonly in the upper *M. cortestudinarium* Zone at Dover, Kent (Gale and Smith 1982) and at Senneville-sur-Fécamp on the Normandy coast.
– *Infulaster tuberculatus* (Text-fig. 15P, Q). Small *Infulaster*, questionably referred to this species by Smith and Wright (2003) occur commonly between the East Cliff marls and the East Cliff Flint (Text-fig. 3).
– *Hagenowia rostrata* (Text-fig. 15G–I). This distinctive echinoid appears a short distance above the East Cliff Flint and ranges up to the level of Whitaker's Flint. It has a level of particular abundance at Bedwell's Flint (Gale and Smith 1982, text-fig. 1).
– *Hagenowia anterior* (Text-fig. 15J–L). This species is characterised by its elongated, narrow, rostrum which still retains small plate rows of ambulacrals IIa and IVb (Text-fig. 14). The first species appears 4–6 m above Whitaker's Flint in Kent, Sussex and Veules-les-Roses, Normandy, and ranges up into the Santonian. Gale and Smith (1982, text-fig. 1) indicate a level of abundance in the middle of the *Uintacrinus socialis* Zone in Kent.

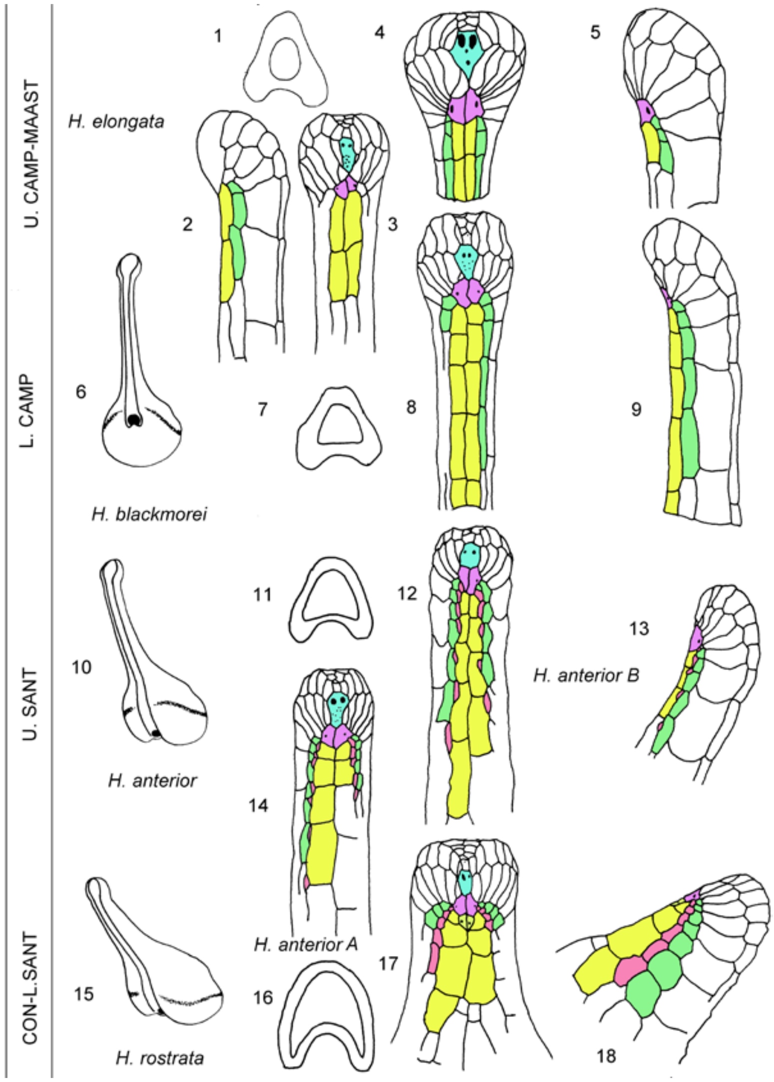
The large holasterid *Echinocorys* is a common Upper Cretaceous and lower Paleogene (Danian) fossil which is largely restricted to chalk facies. Numerous species have been described in the older literature, but most are now considered to be formae of *E. scutata* (Smith and Wright 2003). The neotype specimen of *E. scutata* (Text-fig. 15A–C) has an evenly convex aboral profile and originates from the *M. coranguinum* Zone (upper Coniacian or lower Santonian), although similar forms range through the Coniacian and Santonian (e.g., Text-fig. 15D, lower Coniacian). Inflated forms with a rounded ambitus and small base, referred to *E. scutata* forma *gravesii* (Smith and Wright 2003, pl. 171, figs 1–3) are common in the lower Coniacian. In the mid Santonian (levels 3–6 m above Whitaker's Flint, Text-fig. 3) a significant morphological change takes place, and oval, pyramidal forms, here referred to forma *elevata* (Text-fig. 15E) become common and persist up into the *M. testudinarius* Zone. In the highest Santonian, they are replaced by a variety with a trapezoidal lateral profile, forma *tectiformis* (Text-fig. 15F).

Holectypoids

The conical holectypoid *Conulus albogalerus* (Text-fig. 6A5–A7) appears at the level of the Chartham Flint in east Kent (Bailey *et al.* 1983, fig. 2), at Paron, France, and a slightly higher level in Sussex (Mortimore 1986, fig. 16). The first occurrence is therefore close to the base of the Santonian and the species can serve as an approximate proxy for the base of the stage. The abundance of *C. albogalerus* generally increases up the succession to the low *Uintacrinus socialis* Zone where it becomes rare and has local levels of abundance which cannot be traced regionally, such as the '*Conulus* Band' on the Thanet (Kent) coast.

Cirripedes

Small cirripedes are common in chalk residues, and one species, *Eoverruca hewitti* (Text-fig. 6A4)

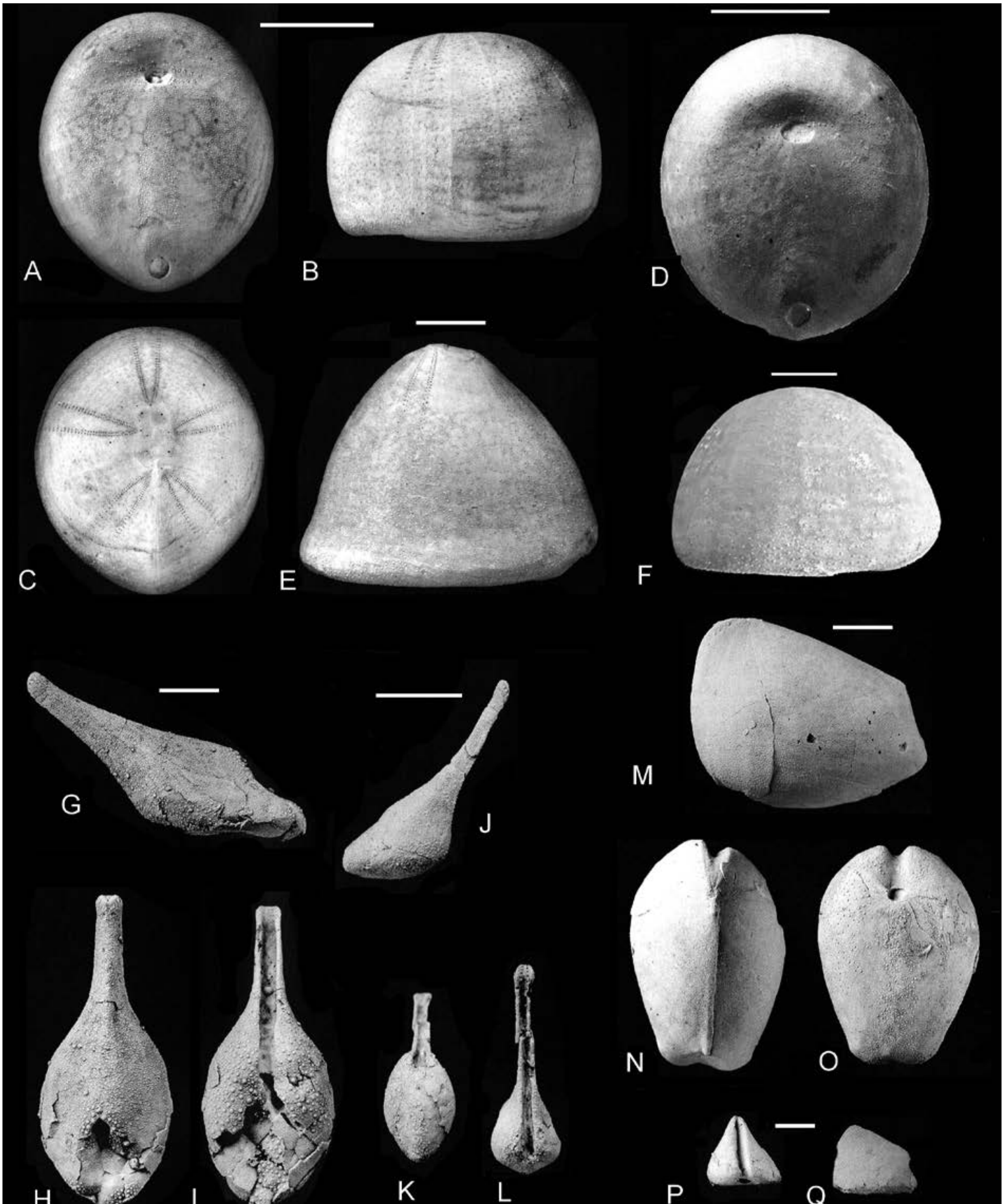


Text-fig. 14. Evolution of rostral structure in the holasteroid echinoid *Hagenowia*, modified after Gale (2018, fig. 7). The Coniacian to lower Santonian species *H. rostrata* (15–17; see also Text-fig. 15G–I) is characterised by its short, blunt rostrum and broad ambulacral plate rows II, IV (red, green) are relatively broad. In the middle–upper Santonian species *H. anterior* (10–13; see also Text-fig. 15J–L) the rostrum is long and narrow and the amb rows IIa and IVb are greatly reduced and lost in the succeeding Campanian and Maastrichtian species *H. blackmorei* (6–9) and *H. elongata* (1–5). The replacement of *H. rostrata* by *H. anterior* takes place several metres above Whitaker's Flint (Text-fig. 3). Yellow – interambulacral rows 1a, 4b; red – ambulacral rows IIa, IVb; green – ambulacral rows IIb, IVa; purple – oculars II, IV; blue – genital 2.

was found to have a very limited range in the lower part of the *Uintacrinus socialis* Zone (Gale and Vidovic 2023, fig. 17), extending through southern England, France and eastwards to Poland.

Integrated macrofossil and microcrinoid biostratigraphy

An integrated biostratigraphy for the Coniacian and Santonian of the Anglo-Paris Basin is provided in Text-fig. 3. Correlation to other regions is best afforded by the inoceramids and crinoids of the genera *Uintacrinus* and *Marsupites*. However, parts of the inoceramid record in the Anglo-Paris Basin are very incomplete. The succession of lower Coniacian *Cremnoceramus* species is only known in very few localities and cannot be used for intrabasinal correlation, and the marker species *Inoceramus gibbosus* is unknown, as is the upper Coniacian genus *Magadiceramus*. Some important, globally occurring inoceramid species are common, however, most notably the middle–upper Coniacian *Volviceramus*



Text-fig. 15. Biostratigraphically significant holasteroid echinoids from the Coniacian and Santonian chalks of the Anglo-Paris Basin. A–C – *Echinocorys scutata*, type forma from the uppermost Campanian or lower Santonian; D – *E. scutata* forma *gravesii* from the lower Coniacian; E – *E. scutata* forma *elevata* from the upper Santonian *M. testudinarius* Zone; F – *E. scutata* forma *tectiformis* from the upper Santonian *U. anglicus* Zone; G–I – *Hagenowia rostrata* in lateral, aboral, and oral views, from the middle Coniacian to middle Santonian; J–L – *Hagenowia anterior*, in lateral, oral, and anterior views, from the middle to upper Santonian; M–O – *Infulaster excentricus*, in lateral, apical, and oral views, from the lower Coniacian; P, Q – *Infulaster tuberculatus*, in anterior and lateral views, from the middle Coniacian. The ranges of these taxa are given in Text-fig. 3. Scale bars: for A–F = 5 cm; for M–O = 1 cm; for G–L, P, Q = 5 mm.

involutus and the lower Santonian *Cladoceramus undulatoplicatus*. Above the *Cladoceramus undulatoplicatus* level, Santonian inoceramid records are scanty and the zonation used in other regions cannot be applied. Similarly, the upper Santonian marsupitid crinoids have a global distribution (Gale *et al.* 2023). Ammonites of stratigraphical value are almost completely unknown in the Anglo-Paris Basin chalks; however, in the Craie de Villedieu in western France (Loire-et-Cher), ammonites co-occur with inoceramids and offer an approximate indication of the position of successive zones (Text-fig. 2, column 3).

The microcrinoids have considerable potential for interregional correlation and the succession of faunas in the Campanian of the Gulf Coast states of the USA is very similar to that in southern England (Gale *et al.* 2021). However, research on Coniacian and Santonian microcrinoids has yet been undertaken in other regions. The very rapid succession of species and formae in the mid- and upper Santonian affords real possibilities for their use in interregional correlation.

Benthonic foraminifera

The succession of benthonic foraminifera in the chalk of the Anglo-Paris Basin has been studied both in southern England and the Paris Basin. In the UK, the ranges of important taxa were established by Bailey *et al.* (1983) and a UKB zonation was produced by Hart *et al.* (1989). For the Coniacian–Santonian interval (Hart *et al.* 1989, fig. 7.24), this included UKB zones 11–15. Hampton *et al.* (2007) studied the micropalaeontological succession in the Seaford Head section and provided ranges for benthonic foram taxa. Equivalent studies in the Paris Basin, both on exposures and cores, were undertaken by Robaszynski *et al.* (1986, 2000, 2005). In the last of these studies a zonation comprising zones S/a, S/b, S/c lower, S/c upper, S/d and S/e was employed. Because the same species are present across the Anglo-Paris Basin, and their ranges are documented, it is possible to compare the two schemes directly (see below).

SEQUENCE STRATIGRAPHY

Grant *et al.* (1999), in a study of the Coniacian sequence stratigraphy of the Anglo-Paris Basin, used diverse criteria to identify individual sequences in basinal chalks. The lowstand systems tracts were identified from the presence of thin marl beds, nodular chalks and hardgrounds (Grant *et al.* 1999, fig. 1). The overlying transgressive systems tracts also contain hardgrounds and were characterised as white chalks with few flints; the highstand systems tracts contain regularly spaced layers of flints. Applying these criteria, Grant *et al.* (1999) identified eight 3rd order sequences within the Coniacian Chalk of the Anglo-Paris Basin.

A major problem with this approach is that the differences between the facies used are subtle and laterally very variable for individual units. For example, the marl bearing lowstands, identified as periods of increased clay input from the basin margins during a sea level low are levels in which a few thin (centimetric) marl beds are present, each containing less than 5% clay. Additionally, many of these marls are only developed very locally. The criteria used for the identification of systems tracts also overlap to a large extent; for example, hardgrounds are included as characteristic of lowstands, transgressive units and highstands. I conclude that it is impossible to identify and correlate the sequences described by Grant *et al.* (1999).

LITHOLOGICAL CORRELATION (Text-fig. 16)

flints

Some flint layers are of regional extent across the Anglo-Paris Basin and are isochronous on the basis of their position within the biostratigraphic framework described here. They thus record a regional event. The source of the silica is believed to be opaline silica in the form of sponge spicules. The surface of some flints preserve burrow systems in relief, and sections preserve traces of bioturbation fabric, indicating them to be in part at least replaced chalk, together with infilled porosity (Bromley and Ekdale 1984). In some cases, the morphology of flints is that of pre-existing *Thalassinoides* isp. burrow systems. It would appear that the regionally distributed flints may be related to minor omission surfaces-the silicification related to redistribution of silica into the higher porosity burrow infills, which in some cases become overgrown, so that the burrow morphology is lost (Wray and Gale 2006).

The correlative value of distinctive flint layers in East Kent, UK was proposed in the late 19th century by Bedwell (1874) and Whitaker (1865) who identified and named flints now called Bedwell's and Whitaker' Flint in the Santonian Chalk of Kent. Subsequently, flints in Kent were named by Smith and Gale (1982) and Bailey *et al.* (1983). Mortimore

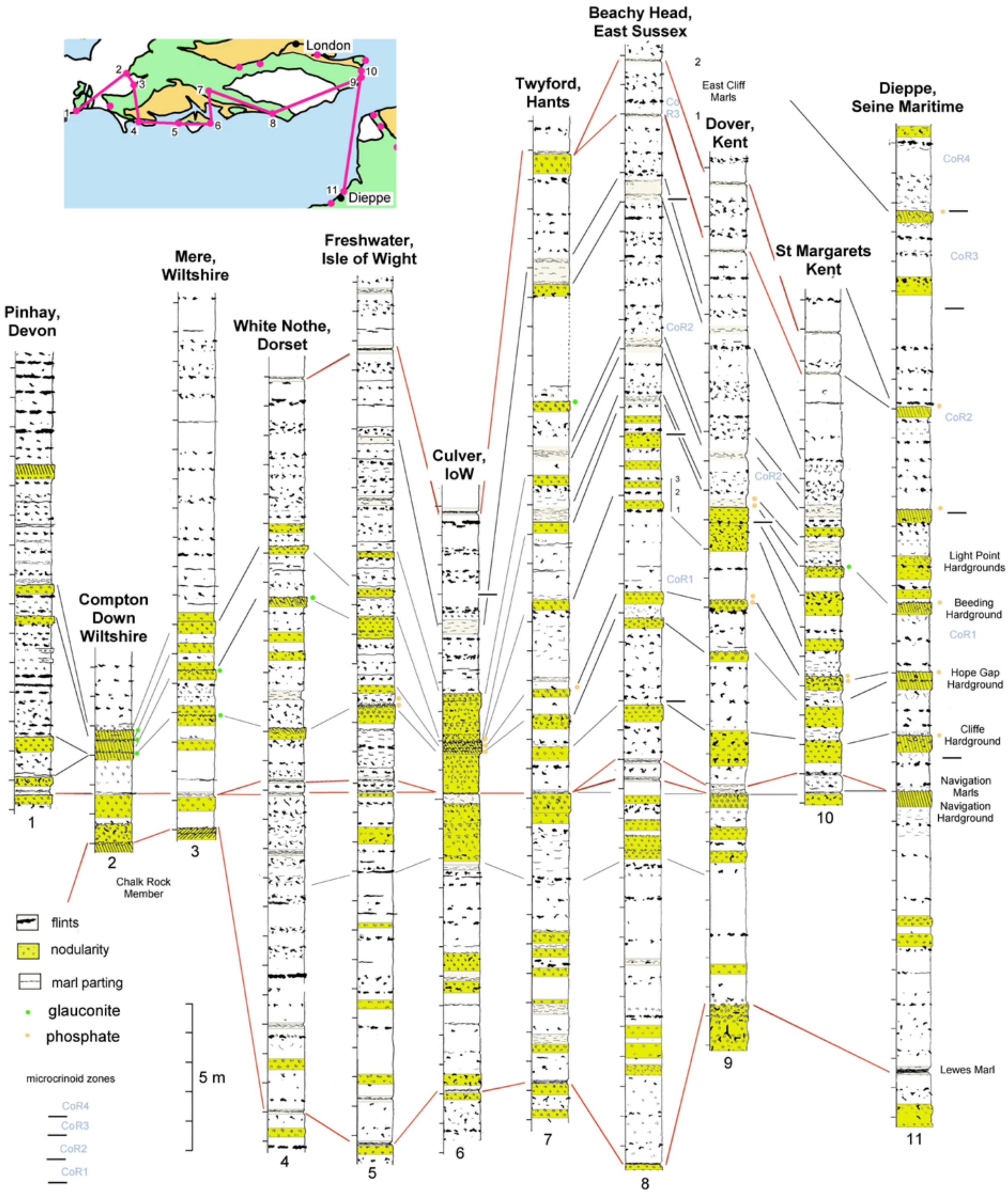
(1986) named numerous flint layers in the chalk of Sussex, sometimes replacing names which had been used previously. Individual flint layers which can be recognised across much of the Anglo-Paris Basin are:

– East Cliff Flint (= Seven Sisters Flint of Mortimore 1986). This comprises lenses up to 3 m in diameter and up to 20 cm thick, associated with abundant inoceramid debris, including *Volviceramus involutus.* This flint extends from Essex in the UK to the Yonne south of Paris (Text-fig. 17) in France and may be present as the Eppleworth Flint in Yorkshire (Mitchell 2018). At Dieppe, in Seine Maritime, Hoyez (2008) called this flint the Silex Mont Robin.
– Michel Dean Flint. This layer of compact nodular flints is intimately associated with the lower level of *Cladoceramus undulatoplicatus* in thinner successions (Text-figs 18 and 19; Sussex, Dieppe, Yonne), but lies 1–2 m lower in more expanded ones (Dorset, Isle of Wight, Coquelles, Nord Pas de Calais) where the inoceramids are associated with a slender *Thalassinoides* burrow flint (Text-fig. 19, columns 1–5, 7–11).
– Chartham Flint (= Baily's Hill Flint). This consists of widely spaced, broad (up to 2 m in diameter flints, which can be identified locally across the Anglo-Paris Basin (Text-figs 18 and 19).
– Bedwell's Flint (= Flat Hill Flint). This consists of densely spaced complex-shaped flints associated with an abundance of debris of *C. undulatoplicatus*; it is present in almost all sections in the Anglo-Paris Basin (Text-figs 18 and 19).
– Whitaker's Flint (= Rough Brow Flint). This semitabular flint consists of lenses which are locally conjoined and about 10–12 cm in thickness – hence Whitaker's designation as a '3-inch Band'. The immediately subjacent chalks contain abundant debris of *Platyceramus* sp. The flint is present across the Anglo-Paris Basin (Text-figs 18 and 20).
– Short Brow Flint. This is a lensoid flint which is locally developed.
– Exceat Flint. This is a thin semitabular flint present a short distance beneath the Buckle Marl, which marks the lowest occurrence of *Uintacrinus socialis.* It is present in Seine Maritime (Veules-les-Roses) and along the English coast from Dorset to Sussex (Text-fig. 21).
– Hawksbrow Flint. A distinctive flint consisting of large irregularly shaped nodules which is present along the coast of southern England from Dorset to Sussex but cannot be identified in Normandy. Its position is close to the top of the range of *U. socialis* (Text-fig. 21)

Marls

Thin (2–10 cm) layers of chalk containing up to 5% of clay are conspicuous in weathered exposures as shallow grooves and make distinctive negative excursions on electrical resistivity logs (Mortimore 1986). They are most useful for correlation, most notably in the Turonian, where a number have a volcanogenic origin and allowed the development of a tephrostratigraphy across the UK, France and northern Germany (Wray 1999). However, the lateral distribution of marls is highly variable and they are not present in all successions, even if these are expanded. Of the Coniacian and Santonian marls, only East Cliff 2 has a volcanic origin (Wray 1999).

– Navigation Marls. In southern England, a pair of marls, separated by 60–70 cm of chalk containing a large flint (Text-fig. 16, columns 4, 5, 8) were named by Mortimore (1986). In many localities, these are condensed to a single marl (Text-fig. 16, columns 1, 3, 6, 7, 9) or missing on the surface of the underlying Navigation Hardground.
– East Cliff Marls (= Shoreham Marls). A pair of marls, separated by several metres of chalk containing 3–4 nodular flint layers is present in more expanded basinal successions of southern England (Text-fig. 16, columns 8–10). The lower marl is more weakly developed and disappears locally, but the higher marl (East Cliff Marl 2) is more laterally persistent and has a volcanigenic origin (Wray 1999). In thinner successions (Text-fig. 16, columns 1, 11) the marls are occluded on a hardground surface which has been called the Chapel Rock Hardground in Devon (Jarvis and Tocher 1987), the Rochester Hardground in north Kent (Robinson 1986) and the Neuville Hardground at Dieppe, Seine Maritime (Hoyez 2008).
– Hope Point Marls (=Belle Tout Marls). A series of very thin, widely spaced marly partings in the Dover sections were called the Hope Point Marls by Bailey *et al.* (1983), and the Belle Tout Marls in Sussex by Mortimore (1986). These are laterally very variable in development.
– Horseshoe Bay Marl (new herein). In the expanded upper Coniacian sections of the Isle of Wight and Dorset a thin (2 cm) marl is present between the highest observable occurrences of *Volviceramus involutus* and the basal Santonian marker, the lowest bed of *Cladoceramus undulatoplicatus* (Text-fig. 17, columns 2–4). This is absent in the thinner successions of Kent and Sussex.
– Anglesqueville Marl. At Veules-les-Roses, Seine Maritime, Hoyez (2008) described a thin marl 7 m



Text-fig. 16. Correlation of uppermost Turonian and lower Coniacian chalks across the northern part of the Anglo-Paris Basin. Key lithostratigraphical markers are the Lewes Marl, the Navigation Marls and the East Cliff Marls. The succession contains numerous nodular chalk and incipient hardgrounds which are named after Mortimore (1986); however, in the absence of short-ranging fossils, the exact correlation of these is uncertain. The inoceramid marker for the base of the Coniacian, the lowest occurrence of *Cremnoceramus deformis erectus*, occurs at a level a short distance beneath the Cliff Hardground (see text). There is no detailed information as to the occurrences of the successive species of *Cremnoceramus* used to zone the lower Coniacian elsewhere (Text-fig. 2). Microcrinoids afford some useful correlations. Columns marked in metres.

beneath the correlative of the Exceat Flint (Text-fig. 21, column 3). This is also present at an equivalent level in Scratchell's Bay in the Isle of Wight.
- Buckle Marl. In the thicker basinal successions of the southern English and Normandy coasts (Text-fig. 21, columns 3–7), a thin marl (< 5 cm) is present, close to the lowest occurrence of *Uintacrinus socialis*.
- Brighton Marl. A thin marl is present at the boundary of the zones of *Marsupites laevigatus* and *M. testudinarius* on the Seine Maritime coast at Veules-les-Roses (Text-fig. 21, column 3) and in Sussex and the west of the Isle of Wight (Text-fig. 21, columns 5, 7).
- Friar's Bay Marls. Three marls, encompassing the range of *Uintacrinus anglicus,* are present in Sussex and the western Isle of Wight.

Nodular chalks and hardgrounds

Nodular chalks and hardgrounds, represent partially lithified sea floors formed during pauses in sedimentation (Garrison and Kennedy 1975) are characteristically stained by iron pyrites when fresh which weathers to an orange-brown hydroxide when exposed to meteoric water. Although they are called hardgrounds, many of the beds thus described in the lower Coniacian of the Anglo-Paris Basin are really just nodular chalks or incipient hardgrounds, as the surfaces are rarely lithified, mineralised, bored or encrusted. By comparison, the hardgrounds of the Turonian Chalk Rock Member are intensely lithified, mineralised by glauconite and phosphate and densely bored by sponges (Bromley and Gale 1982). Additionally, each Chalk Rock hardground surface has a distinctive topography and mineralisation which means that they can be correlated over considerable distances. Many of the lower Coniacian 'hardgrounds' named in Sussex by Mortimore (1986) are very difficult to correlate elsewhere, because they do not have distinctive surface characteristics, and the associated macrofossils are mostly long-ranging. Locally, as Culver Cliff in the Isle of Wight (Text-fig. 16, column 6) and widely across the north-western region where the Chalk Rock Member is present (e. g. Text-fig. 16, columns 2, 3), the lower Coniacian hardgrounds become intensely lithified and coalesce into a 1–2 m thick unit which is sometimes called the Top Rock Member (Hopson 2005).
- Navigation Hardground. This nodular chalk to incipient hardground can be most readily identified when the overlying Navigation Marls are present (e.g., Text-fig. 16, columns 4, 5, 8, 9, 10). At Puys, near Dieppe, it is a strongly lithified, mineralised hardground (Text-fig. 16, column 11).
- Cliffe Hardground. This is a rather weakly indurated nodular chalk in many localities, but is weakly phosphatised in some locations such as Puys, near Dieppe (Text-fig. 16, column 11).
- Hope Gap Hardground. The Hope Gap Hardground comprises two or more nodular chalks in Sussex and Kent (Text-fig. 16, columns 7–10), the higher of which is overlain by sparse phosphatised intraclasts. Its correlation further west on the southern English coast is very uncertain. At Puys near Dieppe, the two beds have become incorporated into a single, massively lithified hardground with a phosphatised surface (Text-fig. 16, column 11).
- Beeding Hardgrounds. These are a poorly characterised group of 3 weakly nodular chalks associated with 3 conspicuous flints at Seaford Head (Text-fig. 16, column 8). Its correlative levels elsewhere are uncertain.
- Light Point Hardground. A group of weakly nodular chalks at Seaford Head (Text-fig. 16, column 8). These tend to coalesce with the underlying Beeding Hardgrounds as at Dover (Text-fig. 16, column 9) and Puys near Dieppe (Text-fig. 16, column 11).
- Rochester Hardground. In north Kent, a massively lithified hardground is present at the top of the Lewes Chalk Formation, on the surface of which the East Cliff Marls are cut out (Robinson 1986). An equivalent hardground, also occluding these marls, is present at Dieppe, Seine Maritime (Hoyez 2008), and in Devon, where it was called the Chapel Rock Hardground (Jarvis and Tocher 1987).
- Clandon Hardground. A level containing nodular chalks occurs some metres above Whitaker's Flint in many sections in the Anglo-Paris Basin. Locally, towards the northern basin margins (Surrey, Hampshire, Berkshire, Dorset), these pass laterally into an intensively lithified hardground (Text-fig. 20, columns 1, 5, 6) which in some sections cuts down to just above Whitaker's Flint (Text-fig. 20, column 5). In Hampshire, the British Geological Survey has given this lithified chalk member status (Whitway Rock Member; Hopson 2005).

GEOCHEMICAL CORRELATION – $\delta^{13}C$

The presence of distinctive excursions in values of $\delta^{13}C$ in Coniacian and Santonian chalks was observed by Jenkyns *et al.* (1994) in the Kent succession. They noted the presence of a broad peak in values in the upper part of the Coniacian (Jenkyns *et al.* 1994, fig. 3) and a smaller peak in the uppermost Santonian. Jarvis *et al.* (2006) named numerous small excursions in $\delta^{13}C$ in the Coniacian and Santonian chalks of southern England, having analysed additional samples from Seaford Head, Sussex and Culver Cliff, Isle of Wight (Jarvis *et al.* 2006, figs 9, 11). A high-resolution $\delta^{13}C$ curve for the upper Coniacian-lower Campanian of the Seaford Head section was published by Thibault *et al.* (2016, fig. 2), which identified many of the events described by Jarvis *et al.* (2006) with greater precision. Gale *et al.* (2023) used the Seaford Head $\delta^{13}C$ data to show correlation with Lägerdorf in northern Germany and the GSSP at Gubbio, Italy. I do not include $\delta^{13}C$ data in this paper, as there are few published curves for the English Coniacian–Santonian and none for the French successions. Many of the published curves are of low resolution, and because much more detailed research is currently in progress (Ian Jarvis, pers. comm.). However, the use of $\delta^{13}C$ correlation in Coniacian and Santonian chalks will greatly help future studies.

CORRELATION OF THE BASINAL CHALK SUCCESSIONS

Lower Coniacian (Text-fig. 16)

The lower Coniacian in the Anglo-Paris Basin is represented by flinty chalks containing abundant bioclastic debris and more and less discrete, thin layers of orange-weathering nodular chalks which have been described as hardgrounds. In southern England, these constitute the upper part of the Lewes Nodular Chalk Formation which in Seine Maritime is called the Craie de St Pierre en Port (Lasseur 2007). In the Nord – Pas de Calais this interval falls within the Craie de Caffiers and the Membre du Pont de Caffiers (Amédro and Robaszynski 2000). This facies extends as far southeast as the Yonne (Mortimore and Pomerol 1987).

The lower Coniacian part of the Lewes Nodular Chalk Formation contains a succession of thin nodular chalks alternating with light grey, strongly bioturbated, weakly marly levels. Mortimore (1986) named the successive nodular beds in Sussex as the Navigation, Cliffe, Hope Gap, Beeding and Light Point hardgrounds (Text-fig. 16). Although these names have been applied to beds as far afield as the Lille region of the Pas de Calais (e.g., Amédro and Robaszynski 2000; Amédro *et al.* 2023) individual hardgrounds have only been identified from their relative positions, because they lack any distinctive lithological characters (see above) or fossil contents. Microcrinoids are of value in correlation of the lower Coniacian; in particular, the base of CoR2 coincides with the level of the Light Point Hardgrounds across the central Anglo-Paris Basin (Text-figs 8, 16).

The Navigation Marls are locally developed in the northern part of the Anglo-Paris Basin (Text-fig. 16, columns 4, 5, 8, 9, 10) but are commonly occluded on the surface of the underlying Navigation Hardground (Text-fig. 16, columns 6, 7, 11). The level of the Navigation Hardground has yielded upper Turonian *Inoceramus* aff. *glatziae* (Wood *et al.* 2004) and a single *Barroisiceras haberfellneri* (Gale and Woodroof 1981; Kennedy 2019) a species which occurs in the uppermost the Turonian (Walaszczyk *et al.* 2022; Kennedy and Walaszczyk 2023). Chalks immediately overlying the Navigation Marls at Downley, West Sussex, contain the earliest *Cremnoceramus* species, *C. waltersdorfensis waltersdorfensis*, which appears first in the uppermost Turonian. The base of the Coniacian, as determined by the lowest occurrence of the inoceramid *Cremnoceramus deformis erectus* (Walaszczyk *et al.* 2022) has only been precisely identified in a single locality, now lost, at Downley in West Sussex, where the species was found 5.5 m above the Navigation Marls (Wood *et al.* 2004) and overlain by a level containing abundant *Cremnoceramus waltersdorfensis hannovrensis* presumed to be above the Cliffe Hardground.

The occurrence of successive *Cremnoceramus* species in the lower Coniacian of southern England has never been documented in detail above the level described by Wood *et al.* (2004). A table in Mortimore *et al.* (2001, fig. 2.21) shows the distribution of species in relation to named hardgrounds, but no localities are provided and specimens are not illustrated. In fact, determinable *in situ* inoceramids are very uncommon in the upper part of the Lewes Chalk and therefore cannot be used for correlation. Very little information exists on the distribution of inoceramids in northern France.

The uppermost part of the lower Coniacian chalk includes a pair of distinctive, thin marl beds, the East Cliff Marls (= Shoreham Marls). The higher of these is volcanogenic (Wray 1999, see above) and both are locally cut out on the surface of a well lithified hardground (Text-fig. 16, columns 1, 7, 11). The higher East Cliff Marl is present at Fécamp on the Seine Maritime coast (Hoyez 2008). The lower Coniacian chalks are very variable in thickness (Text-fig. 16) depending on the extent of condensation on hardgrounds; the thickest successions known are in Sussex and Hampshire (Text-fig. 16, columns 7, 8). The lower Coniacian is considerably expanded to the northeast of Fécamp, Seine-Maritime, but is largely inaccessible in high cliffs.

Middle and upper Coniacian (Text-fig. 17)

The middle and upper Coniacian in the Anglo-Paris Basin comprises soft, fine white flinty chalks which form the lower part of the Seaford Chalk Formation in southern England (Hopson 2005) and the Craie de Veulette in Seine Maritime, France (Lasseur 2007; Text-fig. 2 herein). In southern England, the base of the Seaford Chalk is taken at East Cliff Marl 2 (= Shoreham Marl 2; Hopson 2005) which is taken to mark the transition between the coarser, sometimes nodular chalks of the underlying Lewes Nodular Chalk Formation. However, as noted by Hopson (2005) this boundary is frequently difficult to identify as there is a broad transitional interval and the lower part of the Seaford Formation is locally both sparsely nodular and coarse. East Cliff Marl 2 is present at Fécamp on the coast of Seine Maritime (Hoyez 2008).

The lower part of Seaford Chalk Formation contains thin marls in southern England which are variably developed across the region. In East Kent, there are 2 groups of marly partings of which the lower was called the Hope Point Marl (Gale and Smith 1982; Bailey *et al.* 1983), and in Sussex 3 Belle Tout marls are present (Mortimore 1986). At Culver Cliff, eastern Isle of Wight, a single thin marl is found in the equivalent interval, whereas at Freshwater, western Isle of Wight, more than 12 marl partings are present (Gale 2019, fig. 10.1).

There are records of the short-ranged but very widespread species *Volviceramus koeneni* a few metres above East Cliff Marl 2 in Kent (Bailey *et al.* 1983), Sussex (Mortimore 1986) and Lille (Nord, Amédro *et al.* 2023). Above this, large, flat thick shelled *Platyceramus* become abundant, associated with less common *Volviceramus involutus* (Text-fig. 5A–F). Small fossils are common on weathered surfaces, including *Infulaster tuberculatus*; Text-fig. 15P, Q). The level immediately above East Cliff Marl 2 contains the distinctive microcrinoid fauna of CoR4 (Text-fig. 8).

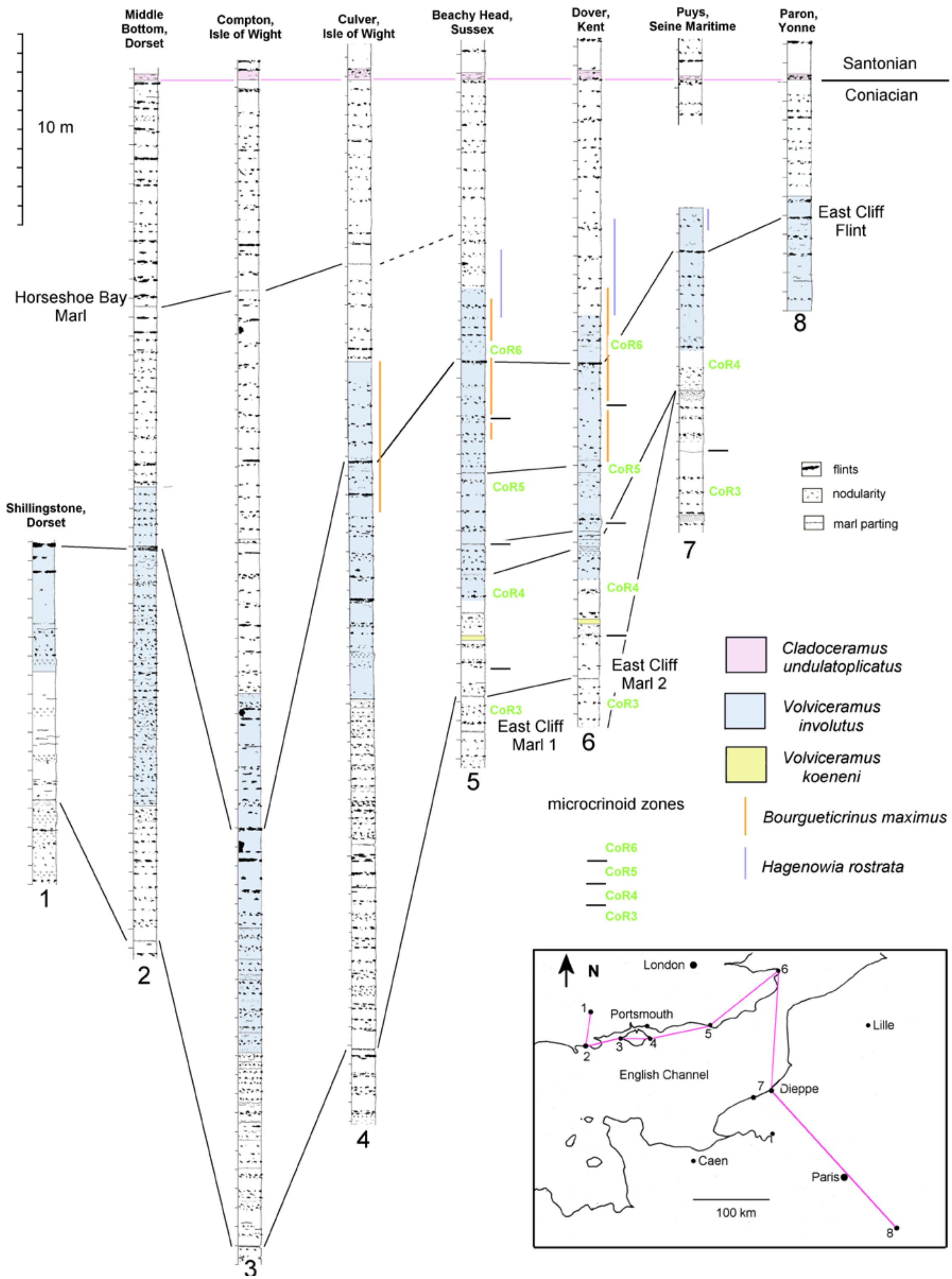
A conspicuous lensoid semitabular Flint, the East Cliff Flint (= Seven Sisters Flint) is present across the Anglo-Paris Basin from Dorset to the Yonne, within the upper part of the range of *V. involutus*. The flint may also extend to northeast England (Mitchell 2018). The flint provides an important marker within an interval of flinty chalk containing very few correlatable levels. Smaller fossils, such as the crinoid *Bourgueticrinus maximus* (Text-fig. 6L, M) and the echinoid *Hagenowia rostrata* (Text-fig. 15G–I) are common at the level of the East Cliff Flint (Text-fig. 17).

In the interval between the East Cliff Flint and the basal Santonian *C. undulatoplicatus* level inoceramid bivalves are virtually absent. A thin marl is present in the Isle of Wight and Dorset here called the Horseshoe Bay Marl (Text-fig. 17, columns 2 to 4). The middle and upper Coniacian chalk succession is expanded in the Isle of Wight (50–60 m) and relatively thin in Kent and Sussex (approximately 30 m). It is also expanded on the Seine Maritime coast but has not been studied in detail there. This interval is thin (10 m) at Paron in the Yonne but is expanded in the east of the Paris Basin in the boreholes at Poigny and St Colombe (50 m; Robaszynski *et al.* 2005).

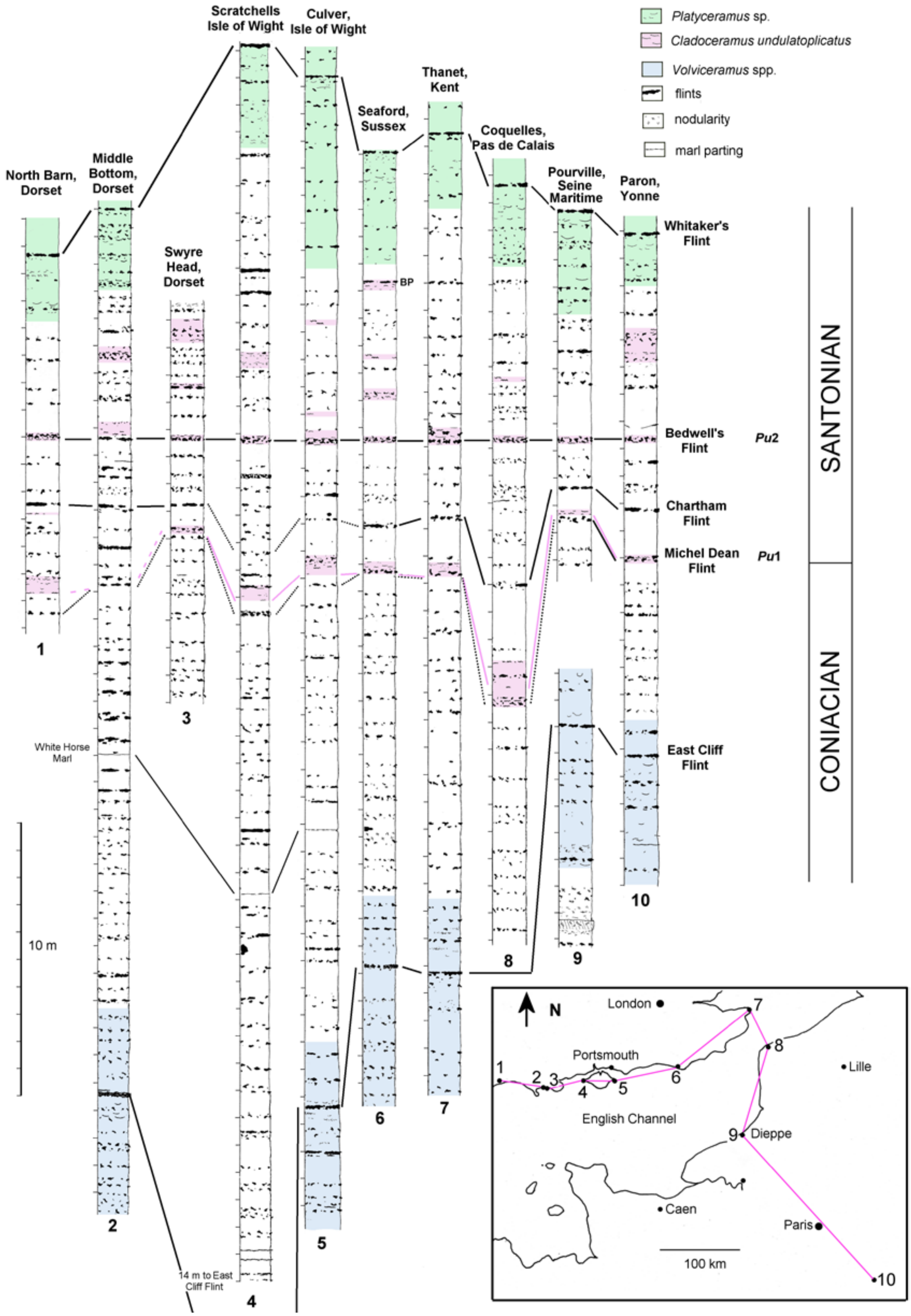
Lower and Middle Santonian (Text-figs 18–20)

In southern England, the lower and middle Santonian chalks are included in the Seaford Chalk Formation (Text-fig. 2), and comprise soft, fine, marl-free chalks containing numerous, rather evenly spaced layers of flint nodules. A similar succession, there called the Craie de Veulette, is present on the Normandy coast (Text-fig. 2; Lasseur 2007). In the Boulonnais, northern France, this unit falls within the upper part of the Craie de Caffiers (Amédro and Robaszynski 2000a, b).

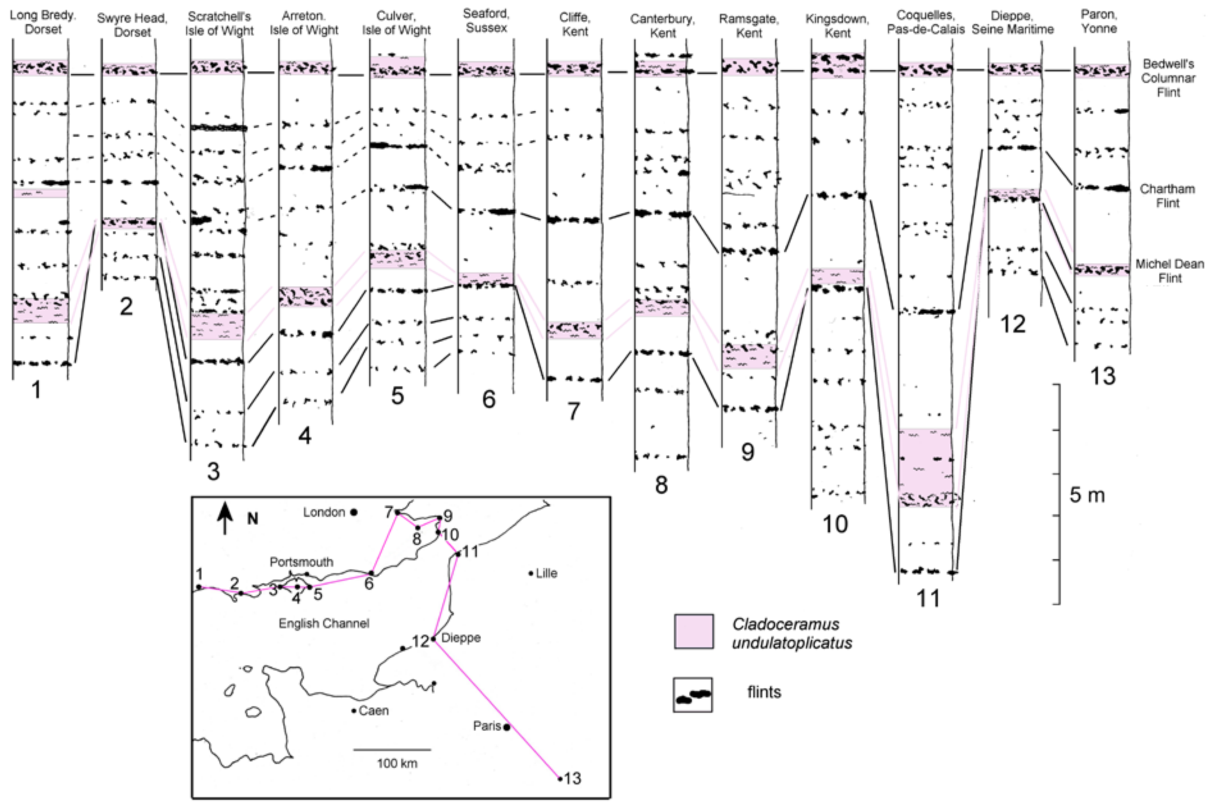
The base of the Santonian is marked everywhere in the basin by a layer of chalk, 0.5–2 m thick, which contains abundant fragments, and rarer whole specimens, of *Cladoceramus undulatoplicatus* (Text-figs 18 and 19). In thinner successions (e.g., Text-fig. 19, columns 2, 6, 10, 12, 13) the inoceramids overlie, or are present within, the Michel Dean Flint. In more expanded sections, they are within, or immediately underneath, an overlying burrow flint (Text-fig. 19, columns 1, 3–5, 7–9, 11). The formation of flint layers was perhaps controlled by the depth beneath the sediment-water interface at which the early diagenetic processes took place. Thus, with less sediment present, the Michel Dean Flint formed in the inoceramid bed. The interval between this, lowest, *C. undulatoplicatus* level and the next one up, associated with Bedwell's Flint, has only yielded the taxon at a single locality, north Barn in Dorset (Text-fig. 19, column 1). The large, lensoid Chartham Flint is present at many, but not all, localities (Text-fig. 19). *Conulus albogalerus* first appears at this level and becomes increasingly common upwards.



Text-fig. 17. Correlation of the middle and upper parts of the Coniacian chalk succession of the Anglo-Paris Basin. The East Cliff Marls and East Cliff flints provide important markers which can be recognised across the region, as do the inoceramids *Volviceramus koeneni* and *V. involutus*. The base of the middle Coniacian is taken at the level of occurrence of *V. koeneni*, and in the absence of *Magadiceramus*, the base of the upper Coniacian is unknown. The succession in the western Isle of Wight (column 3; Compton-Freshwater-Scratchell's) is very expanded. All logs by ASG. Columns marked in metres.



Text-fig. 18. Correlation of the higher Coniacian and lower Santonian chalk successions across the Anglo-Paris Basin. The East Cliff, Bedwell's and Whitaker's flints are important markers across the region as are the 2 lower levels with *C. undulatoplicatus* (*Pu*1, *Pu*2). The upper limit of the range of *Volviceramus involutus* is difficult to determine as the species is very rare in the upper part of its range and probably extends up to 5 m beneath the base of the Santonian. All logs by ASG. Columns marked in metres.



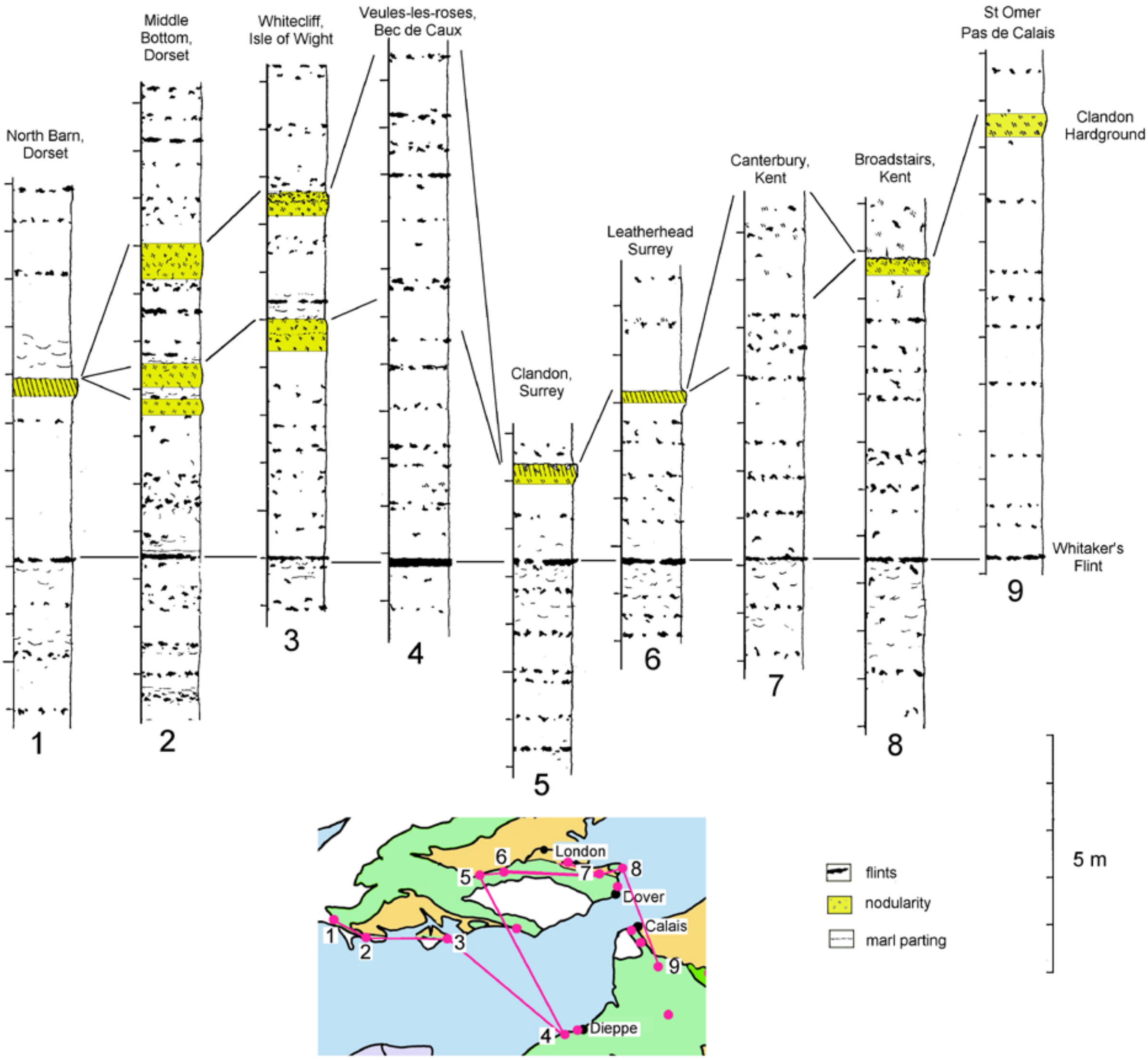
Text-fig. 19. Detailed correlation of the uppermost Coniacian and lowermost Santonian chalk succession across the Anglo-Paris Basin to show lateral variation in flint occurrence. Note the consistent presence of 2 layers containing abundant *P. undulatioplicatus*; the species is only present between these 2 levels at Long Bredy (column 1). In more expanded successions (columns 1, 3–5, 7–9, 11) the lower *P. undulatoplicatus* level is associated with a *Thalassinoides* burrow flint, but in more condensed localities (columns 2, 6, 10, 12, 13) it rests on of falls within the Michel Dean Flint. The lensoid Chartham Flint is consistently present in eastern and southern successions, but absent or difficult to identify to the west (columns 2–5). All logs by ASG.

Bedwell's Flint, comprising closely spaced, often digitate flints, contains abundant debris of *C. undulatoplicatus* at all localities studied. Above this level, the species occurs sporadically, and at different levels from place to place. The highest occurrence of the species is very difficult to determine, as all specimens are fragmentary. However, it is clear that *C. undulatoplicatus* is replaced by a large, flat, thick-shelled *Platyceramus* (Text-fig. 18) which increases in abundance up to Whitaker's Flint. This semitabular flint is a conspicuous marker in all the successions (Text-fig. 18).

Above Whitaker's Flint, several faunal changes are seen (Text-fig. 3) including the lowest occurrences of *Bourgueticrinus granulosus*, pyramidate *Echinocorys scutata*, *Actinocamax verus*, *Cretirhynchia plicatilis* and *Hagenowia anterior*. The development of weakly nodular chalks is seen in basinal settings several metres above Whitaker's Flint (Text-fig. 20, columns 2, 3) although these are locally absent (Text-fig. 20, column 4). Towards the basin margins, the nodular developments pass into a strongly lithified hardground (the Clandon Hardground) which locally (Text-fig. 20, column 5) lithifies an erosion surface which has cut down to just above Whitaker's Flint.

Upper Santonian (Text-fig. 21)

Across the Anglo-Paris Basin, the upper Santonian is represented by soft, fine, white nannofossil chalks. Across the central part of the basin the upper Santonian succession contains thin marl partings and has been called the Newhaven Chalk Formation in southern England (Mortimore 1986; Rawson *et al.* 2000; Mortimore *et al.* 2001; Hopson 2005) and the Craie de Sotteville on the Normandy coast (Lasseur 2007). However, the distribution of marls is very variable laterally; at Middle Bottom on the Dorset coast the succession virtually lacks marl beds (Text-fig. 21, column 4), and these are also absent along

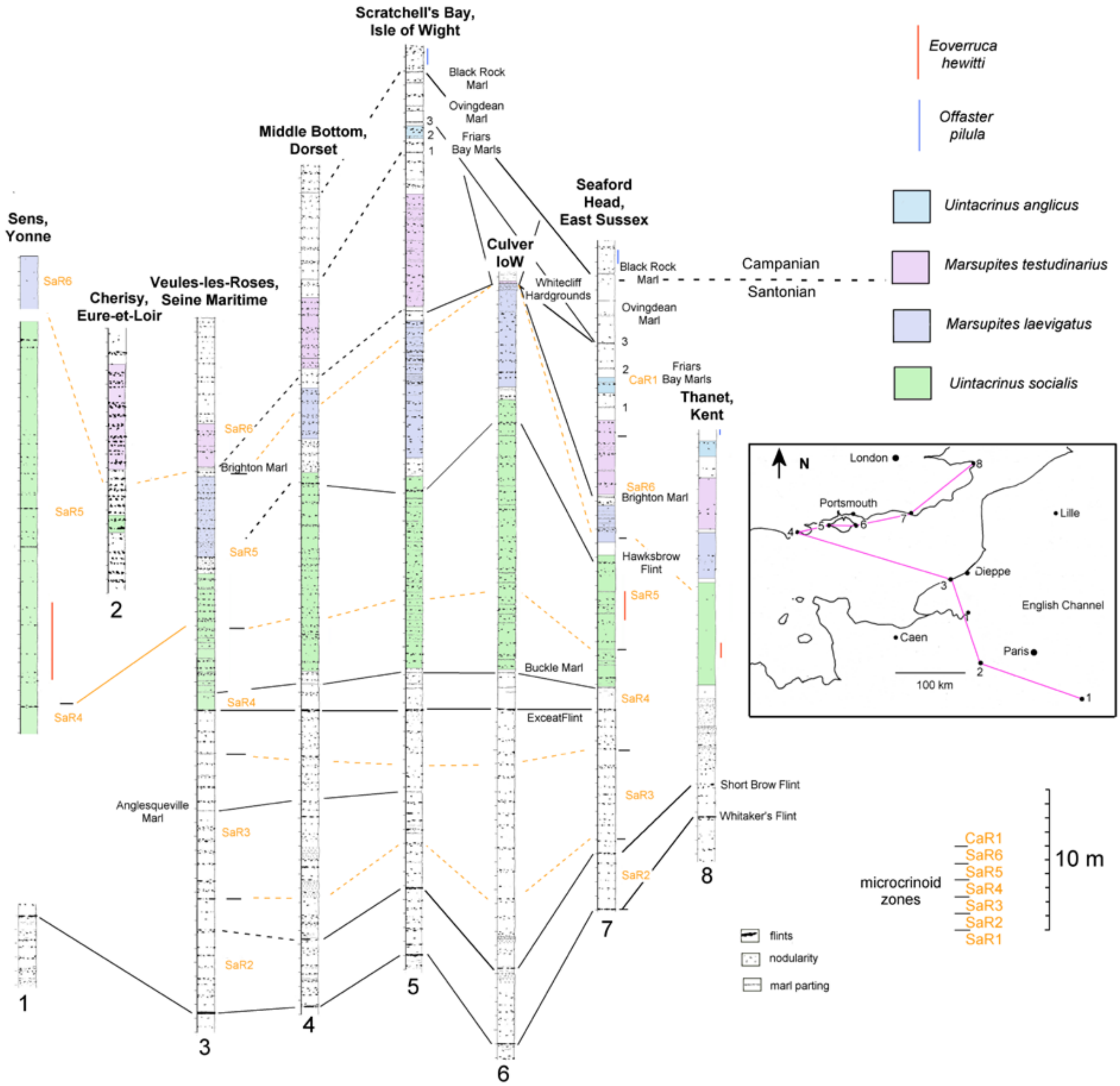


Text-fig. 20. Correlation of the middle Santonian chalks of southern England and northern France. Whitaker's Flint provides an important marker, and hardgrounds and nodular chalks (Clandon Hardground) are widely developed at the same level in various localities. At Clandon, surrey (column 5) the hardground lithifies an erosion surface which cuts down nearly to the level of Whitaker's Flint. Sections logged by ASG except St Omer, which is taken from Amédro *et al.* (2006). Columns marked in metres.

the outcrop of the North Downs in southern England (Surrey, Kent; Robinson 1986; Gale 2017). Marls are also absent at Cherisy (Eure et Loir) and at St Martin du Tetre in the Yonne (Text-fig. 21, columns 1, 2). Locally, as at Scratchells Bay on the Isle of Wight, the upper Santonian contains over 40 thin marl partings.

A succession of marls (Buckle, Brighton, Friar's Bay, Saltdean, Black Rock) were named by Mortimore (1986) on the Sussex coast (Text-fig. 21, column 7) and the Buckle and Brighton marls can be traced throughout the central part of the basin, westwards to the Isle of Wight (Text-fig. 21, columns 4, 5) and southwards to Veulettes-les-Roses in Seine Maritime (Text-fig. 21, column 3; Gale 2019; Hoyez 2008 and http://craies.crihan.fr). The Friar's Bay Marls can be identified from the occurrence of *Uintacrinus anglicus* between marls 1 and 3; they are not seen in northern France where the species has not been found. The proposed correlations are supported by the distribution of the zonal crinoids and microcrinoids (Gale 2019; Text-figs 3, 8).

Flints are very variably developed in the upper Santonian Chalks. In Kent and Surrey they are virtually absent, but the number and density of flint layers broadly increases to the south and west. At Cherisy



Text-fig. 21. Correlation of upper Santonian Chalk in the Anglo-Paris Basin, showing marker beds, microcrinoid zones, the ranges of *Uintacrinus* and *Marsupites* species and other taxa. All sections logged by ASG, except Cherisy which is taken from Robaszynski *et al.* (2023). Note the considerable expansion of the chalk succession in the Isle of Wight which is comparable to that developed in boreholes to the southeast of Paris (see Text-fig. 22). Columns marked in metres.

(Loir-et-Cher) the upper Santonian contains abundant, closely spaced layers of flint nodules (Text-fig. 21, column 3; Robaszynski *et al.* 2023), and the correlative level in the Craie de Blois of Touraine is densely flinty and contains spiculites (see below). Individual flint layers have been named in Sussex by Mortimore (1986) and include the thin, semitabular Exceat Flint which extends from Sussex westwards to Dorset and is also present on the Seine Maritime coast (Text-fig. 21, columns 3–7; Hoyez 2008). This occurs shortly beneath the lowest occurrence of *Uintacrinus socialis*. The Hawks Brow Flint, positioned close to the top of the range of *U. socialis,* is a nodular flint layer which extends along the south English coast but cannot be identified in Seine Maritime (Text-fig. 21, column 3). It is possibly present in the Yonne (Text-fig. 21, column 1).

The succession at Sens in the Yonne is incompletely exposed, but the accessible *U. socialis* chalk includes 25 m of poorly flinty chalk. The basal 2 m yielded microcrinoids of the SaR4 zone (Gale 2019) and the range of the cirripede *Eoverruca hewitti* here is 6 m, as compared to 2 m in Sussex. The thickness of microcrinoid zone SaR5 is approximately 23 m, as compared with 8 m in Sussex and 10.5 m at Veules-les-Roses, and it therefore appears that the *U. socialis* Zone in the Yonne is highly expanded.

At Whitecliff, Isle of Wight, the *U. socialis* Zone is very expanded, but the uppermost part of the Santonian is condensed at this locality, where the lower Whitecliff Hardgrounds lithify chalks containing *Marsupites laevigatus*, and *M. testudinarius* is present immediately above the lowest hardground (Text-fig. 21, column 6; Gale *et al.* 2013). The condensed upper Santonian is present within small erosional basins called cuvettes which contain granular phosphorite and are concentrated in Picardie, northern France (Jarvis 1980, 1982, 2006).

In summary, the upper Santonian Chalk of the Anglo-Paris Basin can be correlated in some detail using the four successive species of *Uintacrinus* and *Marsupites* and microcrinoids. In the central part of the basin (Dorset, Isle of Wight, Sussex, Normandy) a succession of marls and flints provide an independent correlation framework, but these are not present in thinner successions towards the basin margins. The most expanded successions are present in the Isle of Wight and Dorset on the southern English coast and were probably deposited on the downthrown sides of the Purbeck-Isle of Wight faults during extensional periods. The upper Santonian of the Yonne is incompletely known, but also very expanded.

Correlation with benthonic foraminiferans (Text-fig. 22)

The distribution of benthonic foraminiferan species in various successions in northern France and southern England is plotted in Text-fig. 22, using data derived from Bailey *et al.* (1983), Hart *et al.* (1989), Amédro *et al.* (2006), Hampton *et al.* (2007), and Robaszynski *et al.* (2005). The distribution of the S zones in France and the UKB zones in the UK is shown against correlations made using macrofossil levels and flints (Text-fig. 22). The benthonic foraminiferan zones all occur in the correct order, but the positions of the zonal boundaries are at different levels in individual sections relative to flints macrofossils and carbon isotope events (data from Jarvis *et al.* 2006 and Pearce *et al.* 2022). For example, the base of zone S/c (upper) is above the *C. undulatoplicatus* 1 level in East Kent (Text-fig. 22, column 3), significantly higher than in any other locality. The base of S/d is lower in the Pas de Calais (Text-fig. 22, column 4) than elsewhere, and the zone is surprisingly thin at Seaford Head in East Sussex (Text-fig. 22, column 2). The foraminiferal and carbon isotope data from the deep boreholes at Poigny, Seine-et-Marne (Robaszynski *et al.* 2005; Text-fig. 22, columns 6, 7) indicate that the upper part of the Coniacian and the Santonian are highly expanded in this region, in comparison with the thinner succession at Paron in the Yonne (Text-fig. 18, column 10).

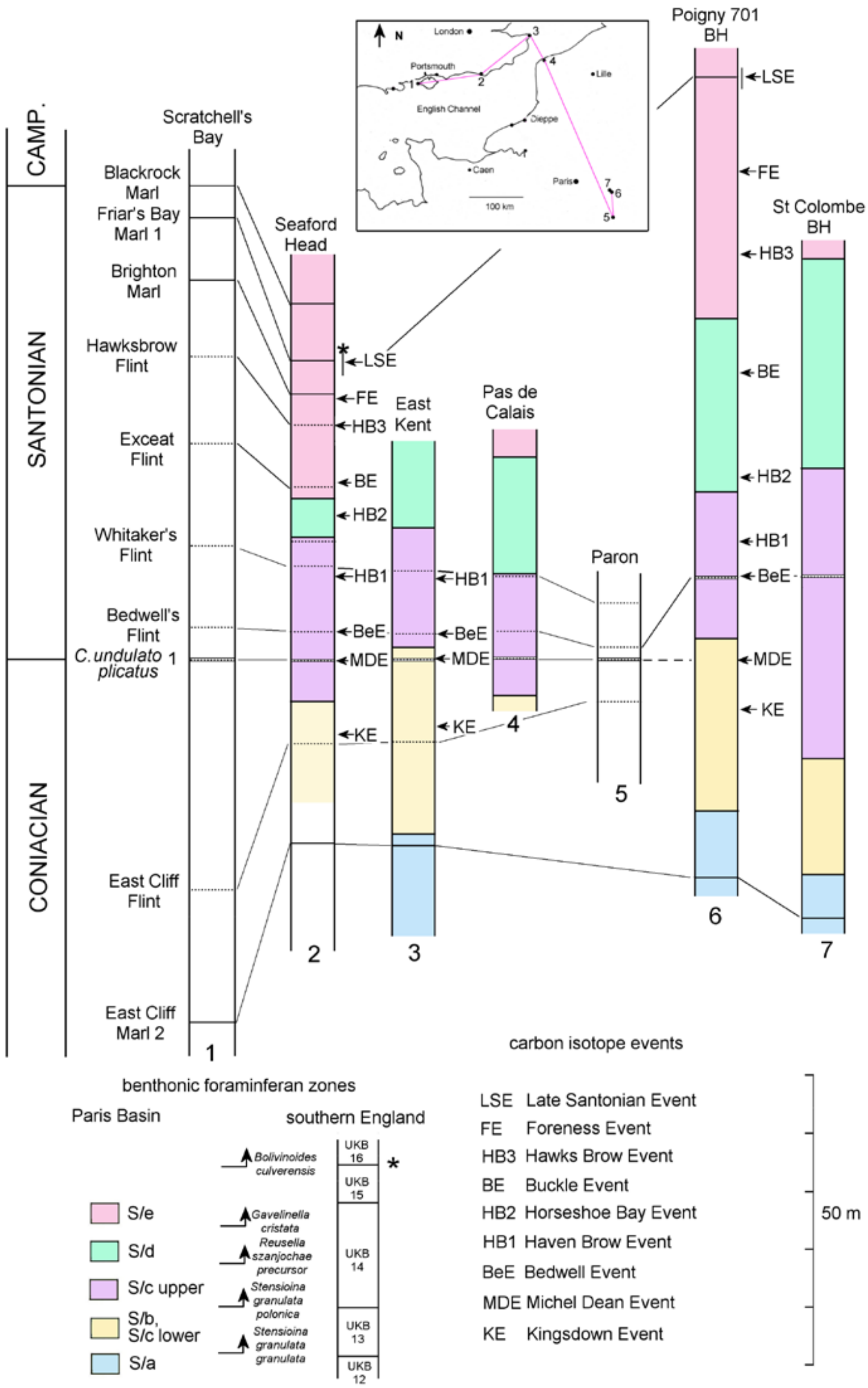
CONIACIAN AND SANTONIAN OF THE BASIN MARGINS

In Touraine, in the southwest of the basin adjacent to the Armorican Massif, Coniacian and Santonian successions thin significantly and the chalk passes laterally into a calcarentic facies containing a shallow water benthonic fauna (de Grossouvre 1901; Jarvis and Gale 1984). In the north of the basin, in the region of Lille, the Coniacian chalk succession thins northwards onto the Anglo-Brabant Massif, hardgrounds coalesce and finally passes into a thin succession of coarse glauconitic chalk (Amédro *et al.* 2023). The Santonian is not preserved in this region and the middle Coniacian is overlain by Paleogene sediments (Text-fig. 1B).

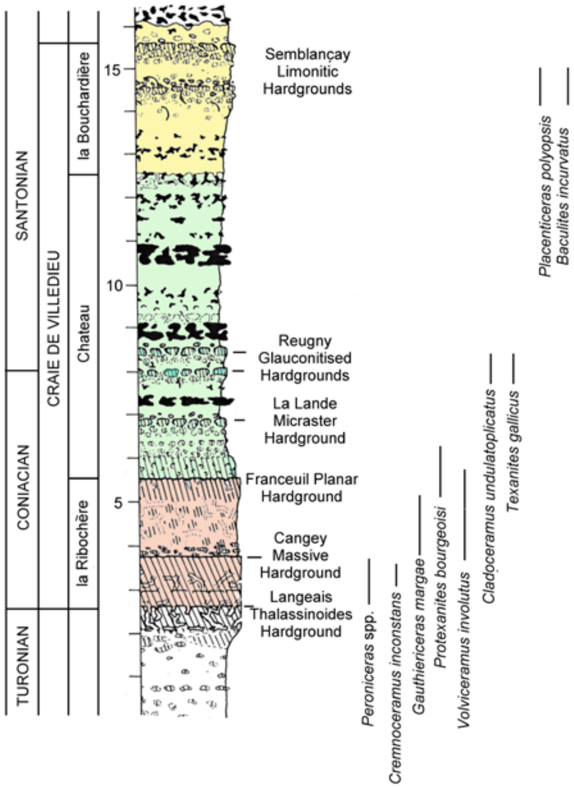
Touraine (Text-figs 23, 24)

In Touraine, adjacent to the southern part of the Armorican Massif, the Coniacian and Santonian are represented by a thin succession of silty, sometimes glauconitic calcarenites containing numerous hardgrounds which rest disconformably on the upper Turonian Tuffeau Jaune de Touraine. The summit of the Tuffeau Jaune is the massive, regionally developed Langeais Hardground (Jarvis and Gale 1984) which is overlain by the lower Coniacian to middle Santonian Craie de Villedieu (10–15 m). This in turn is overlain by the upper Santonian to lower Campanian Craie de Blois, a siliceous chalk containing abundant flints and spiculites and marl layers (Lasseur 2007). The region of transition from the chalks of the Paris Basin to these marginal sediments is poorly exposed and little understood (de Grossouvre 1901) who described major changes in lithology and faunas close to Châteaudun, Eure-et-Loir (locality 24 in Text-fig. 1A).

The Late Turonian age of the highest Tuffeau Jaune is confirmed by the presence of the ammonite *Subprionocyclus neptuni* immediately beneath the



Text-fig. 22. The distribution of benthonic foraminiferal zones plotted against marker beds, macrofossil levels and carbon isotope events for the upper Coniacian and Santonian of the Anglo-Paris Basin. There is no foraminiferal data for the uncoloured sections. The zonal schemes of Robaszynski *et al.* 2005 (S-zones) are correlated with the UKB zones of Hart *et al*. (1989) using the lowest occurrences of the marker species. Data from Bailey *et al.* (1983; East Kent), Hampton *et al.* (2007; Seaford Head East Sussex), and the Poigny 701 and St Colombe boreholes (Robaszynski *et al.* 2005). The correlations made using marker beds, benthonic zones and carbon isotope events works well for zones S/a to S/c (upper) but above this the ranges of species in southern England and in the Paris Basin differ significantly. Benthonic foraminiferal zone UKB16 is marked by the lowest occurrence of *Bolivinoides culverensis* in Sussex at the level of Friar's Bay Marl 3 (Hampton *et al.* 2007); this species is not recorded from the French boreholes. Note that the successions in the Provins boreholes are very expanded and of greater thickness than the succession at Scratchell's Bay, Isle of Wight. Carbon isotope events taken from Jarvis *et al.* (2006), Thibault *et al.* (2016) and Pearce *et al.* (2022).



Text-fig. 23. Succession in the Craie de Villedieu Formation at Villedieu, Loir-et-Cher, France. Modified after Jarvis and Gale (1984).

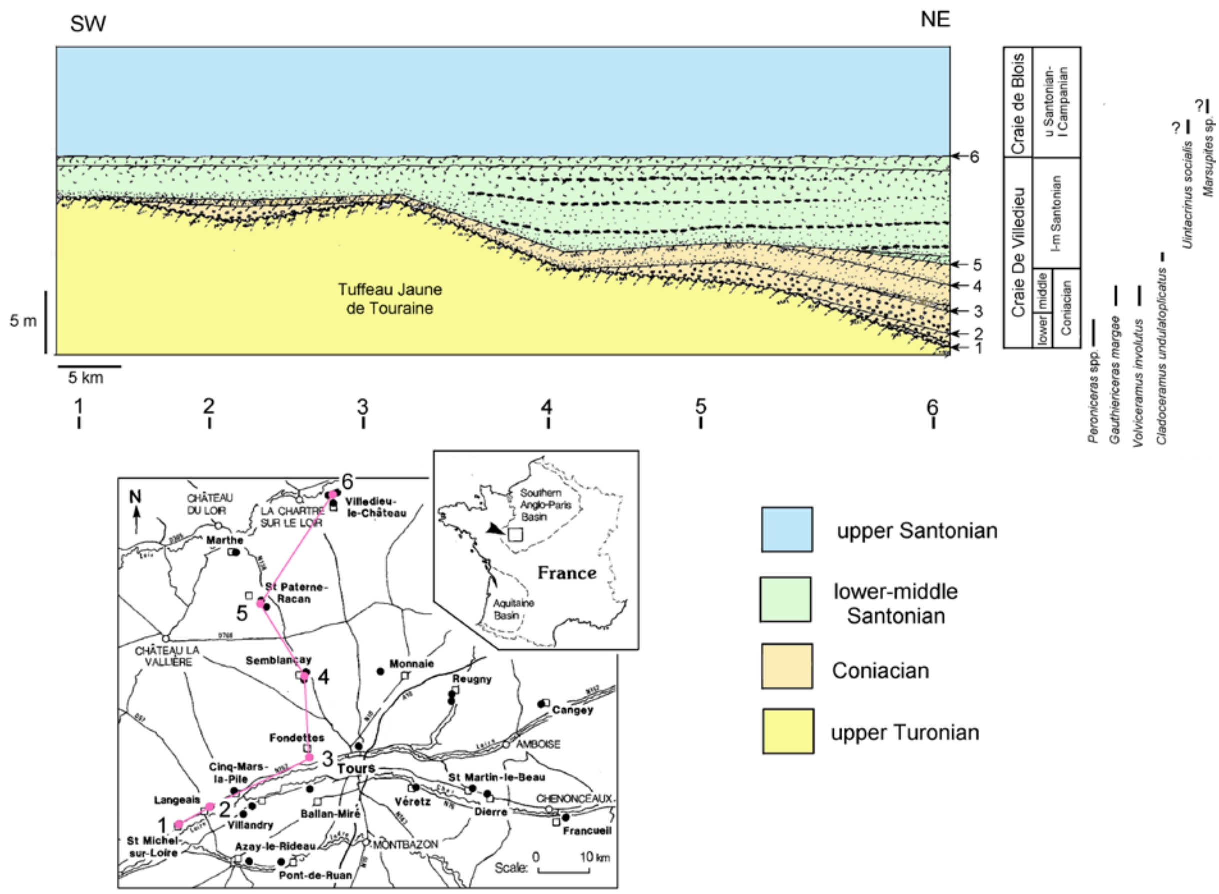
Langeais Hardground at Villedieu (Jarvis and Gale 1984; Kennedy 1984; Text-fig. 23). The uppermost Turonian zone of *Prionocyclus germari* (e.g., Kennedy and Kaplan 2019) is absent indicating a significant hiatus on the surface of the Langeais Hardground. The basal Craie de Villedieu member, the Calcaires dur de la Ribochère, comprises 2–7 m of bryozoan biosparites including 3 hardgrounds (Limeray, Cangey, Franceuil) with sharply demarcated upper surfaces. The lower two of these have yielded a diverse ammonite fauna ascribed to the *Forresteria* (*Harleites*) *petrocoriensis* and *Peroniceras tridorsatum* zones (Kennedy 1984) and a specimen of *Cremnoceramus* cf. *inconstans* (Jarvis and Gale 1984). The third, highest Franceuil Hardground contains the zonal index species *Gauthiericeras margae* in the lower part, and *Protexanites bourgeoisi*, indicative of the *Paratexanites serratomarginatus* Zone in the top 10 cm. The Franceuil Hardground also contains numerous fragmentary specimens of *Volviceramus involutus* which afford correlation with the basinal chalks of the Anglo-Paris Basin.

The overlying 7 m comprise sandy, glauconitic calcarenites of the Marnes Glauconieuses du Chateau Member (Text-fig. 23). The basal Oyster Hardground has yielded ammonites of the *Paratexanites serratomarginatus* Zone (Kennedy 1984), and the Reugny Hardgrounds contain abundant fragments of *Cladoceramus undulatoplicatus*, indicative of the lowest Santonian. The Santonian ammonites *Placenticeras polyposis* and *Baculites incurvatus* occur in the overlying Bouchardière Member, in a pair of nodular hardgrounds (Semblançay Hardgrounds) which mark the summit of the Craie de Villedieu. The overlying intensely siliceous chalks of the Craie de Blois are poorly exposed and little studied. They exceed 20 m in thickness (Lasseur 2007) and have in the past yielded both *Uintacrinus socialis* and *Marsupites* (Filliozat 1910), although the precise levels of these occurrences are not documented. The densely flinty chalks of the upper Santonian of Cherisy, Eure-et-Loir (Text-fig. 21, column 2; Robaszynski *et al.* 2023) are starting to resemble the siliceous facies of the Craie de Blois developed to the southwest.

In a NE-SW transect (Text-fig. 24) progressive onlap onto the surface of the Tuffeau Jaune takes place, as the Franceuil Hardground onlaps the underlying units of the Ribochère Member and is itself onlapped by the overlying Chateau Member. The events parallel depth-controlled facies shifts in the basinal chalks (see below).

Anglo-Brabant Massif (Text-fig. 25)

In the north of France (Pas de Calais), the Coniacian Chalk thins significantly eastwards towards the margin of the Anglo-Brabant Massif, and the hardgrounds present at Dover (Kent) and Caffiers (Pas de Calais) strengthen and converge (Amédro *et al.* 2023, fig. 7). The upper Turonian is largely condensed into a major hardground complex (‘Gros Tun’) which is equivalent to the Hitch Wood Hardground of the Chalk Rock Member in England (Bromley and Gale 1982) and, similarly, yields ammonites of the *Subprionocyclus neptuni* Zone. At Haubourdin, near Lille (Text-fig. 25, column 4) the lower Coniacian is reduced to about 7 m thickness and the various hardgrounds (‘Petit Tuns’) have yielded the lower Coniacian ammonite *Peroniceras* (Amédro et al. 2023, fig. 8). The East Cliff Marls are present at Haubourdin, and the overlying chalk yields, successively, *Volviceramus koeneni* and *V. involutus*. To the west of Lille (Text-fig. 25, column 5; Villeneuve d’Ascq), the lower Coniacian passes laterally into a strongly glauconitic, silty chalk, 4–5 m in thickness, the Craie glauconieuse de Lezennes (Amédro *et al.* 2023). The higher Coniacian, and all the Santonian



Text-fig. 24. Transect through the Craie de Villedieu from the northeast to the southwest. 1 – Langeais Hardground; 2 – Cangey Hardground; 3, 4 – Franceuil Hardground; 5 – Reugny Hardgrounds; 6 – Semblançay Hardgrounds. Modified after Jarvis and Gale (1984, fig. 6). Note the progressive onlap onto the southeastern margin of the Armorican Massif through the Coniacian and Santonian. The presence of *Uintacrinus* and *Marsupites* in the Craie de Blois is taken from Filliozat (2010), but the precise horizons of occurrence cannot be confirmed.

are missing beneath the Paleogene unconformity in the Lille district (Text-fig. 1B).

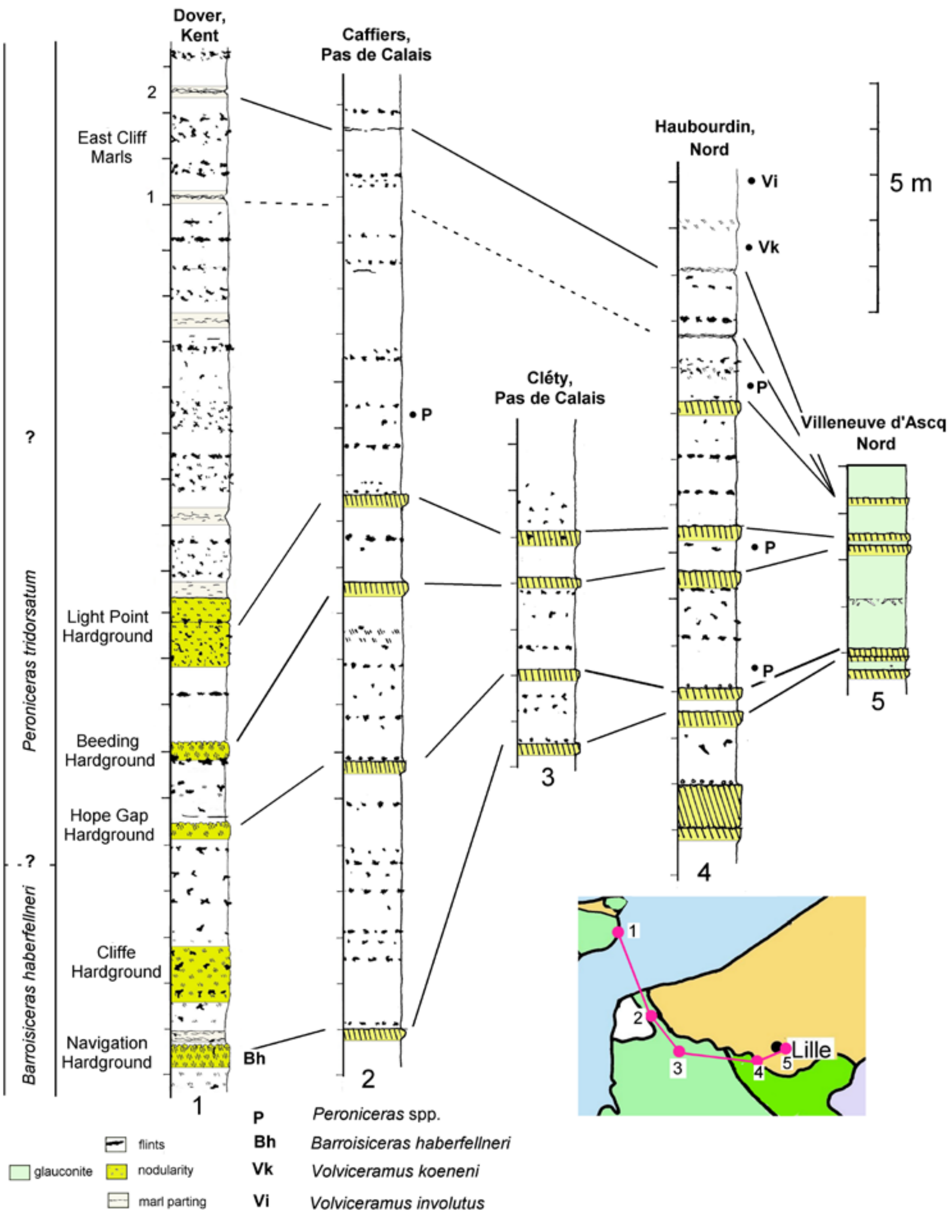
PATTERNS OF SEDIMENTATION, CONDENSATION, SEA LEVEL EVENTS

A summary diagram of the distribution of hardgrounds and hiatuses in the Coniacian and Santonian of the Anglo-Paris Basin is provided in Text-fig. 26. The main events shown are:

1. A significant hiatus, developed on the surface of a hardground, separates upper Turonian and lower Coniacian sediments on the margins of the Anglo-Paris Basin. In Touraine (Text-figs 23 and 24) this lies on the surface of the Langeais Hardground, which is of Late Turonian age (*S. neptuni* Zone), and a higher Turonian zone (*P. gemarii*) is missing. In southern England (Hertfordshire, Berkshire) an equivalent gap is found within the lower part of the Top Rock Member, probably equivalent to a condensation at the level of the Navigation Hardground and beds beneath it on the southern English coast (Text-fig. 16).

2. The highest part of the lower Coniacian is locally missing immediately above the level of a major hardground, which is called the Cangey Hardground in Touraine (Text-figs 23 and 24). Its equivalent is locally developed in the chalks of the northern Anglo-Paris Basin as a surface on which the East Cliff Marls are absent; the Rochester Hardground in Kent, the Chapel Rock Hardground in Devon, and the Neuville Hardground at Dieppe, Seine Maritime. At all these localities, middle Coniacian sediments containing *Volviceramus involutus* rest disconformably on the lower Coniacian.

3. The top of the *Volviceramus involutus* Zone is overlain by a strongly lithified hardground in Touraine (Franceuil Hardground) and an erosional

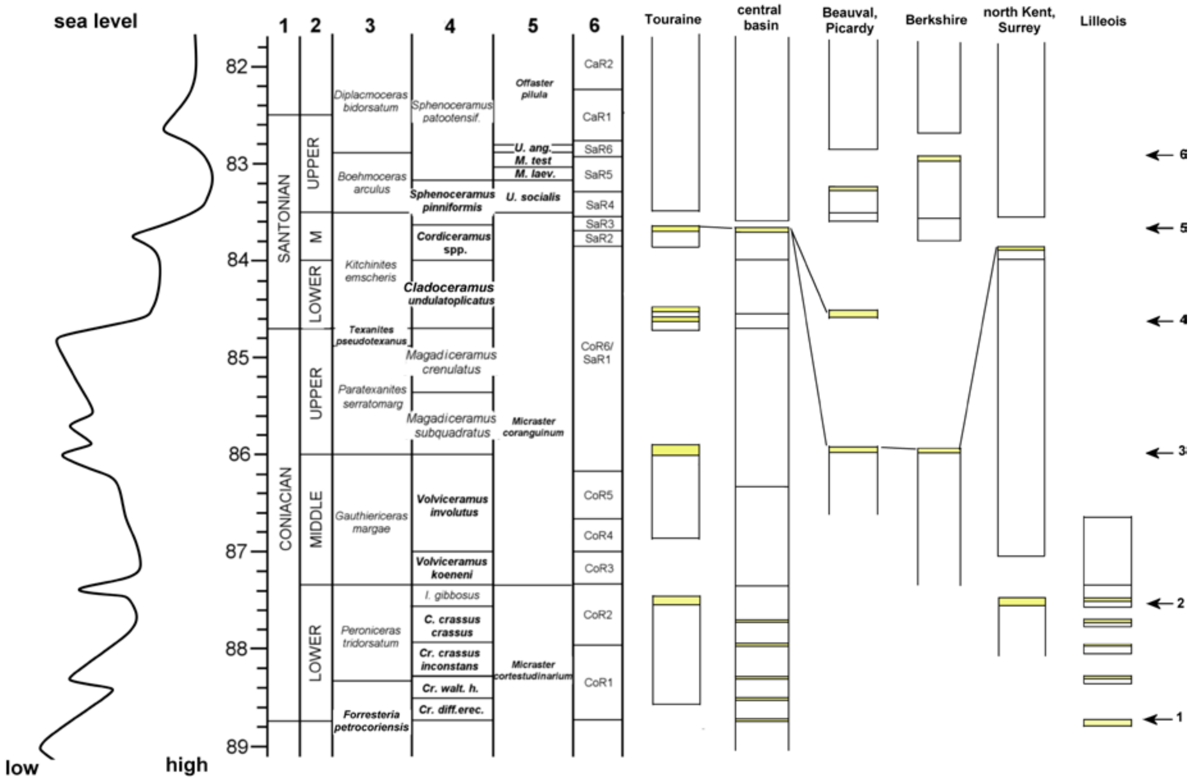


Text-fig. 25. Correlation of upper Turonian–Coniacian chalks onto the Anglo-Brabant Massif. Partly modified from Amédro *et al.* (2023). There is a progressive condensation eastwards to Haubourdin (column 4) as hardgrounds strengthen and converge. To the east of Lille, the lower Coniacian passes laterally into a glauconitic marl with hardgrounds (column 5). The presence of the lower Coniacian ammonite *Peroniceras* provides evidence of the presence of the *P. tridorsatum* Zone.

surface at the same level is locally developed towards the northern margins of the Anglo-Paris Basin, at Beauval in Picardie (Jarvis 2006) and at Boxford in Berkshire (Jarvis and Woodroof 1981; Gale 1990).

4. The base of the Santonian (level with *Cladoceramus undulatoplicatus*) is marked by 2 hardgrounds in Touraine (Reugny Hardgrounds; Text-fig. 23), and a condensed level containing this species is locally found in phosphate basins in Picardy (Jarvis 2006) resting on a hardground.

5. Hardgrounds are widely developed in the higher part of the middle Santonian; in Touraine, these are called the Semblançay Hardgrounds (Text-fig. 23) and an equivalent level in the chalk of southern England and northern France (Text-fig. 20) has been variously called 'Barrois' Sponge Bed', the Whitway Rock Member and the Clandon Hardground.

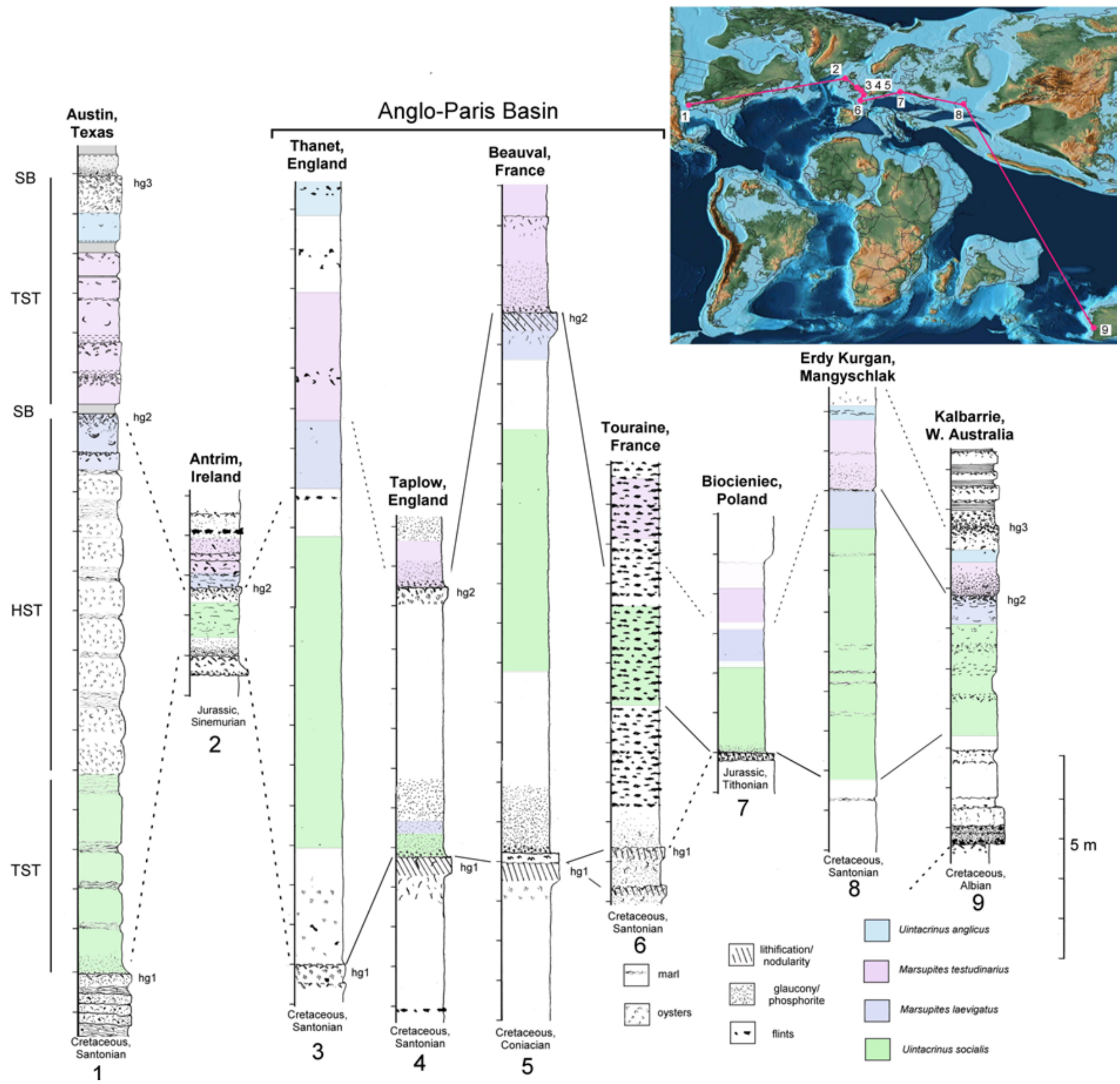


Text-fig. 26. Gaps in the Coniacian–Santonian succession of the Anglo-Paris Basin, plotted against a sea level curve (far left), the Coniacian part of which is taken from Landmann *et al.* (2017). The columns are: 1 – stages; 2 – substages; 3 – ammonite zones; 4 – inoceramid zones; 5 – traditional macrofossil zones; 6 – microcrinoid zones, after Gale (2019). Breaks in the succession, usually represented by hardgrounds, occur at the same levels: 1 – Turonian–Coniacian boundary, sometimes missing the highest part of the Turonian; 2 – around the top of the lower Coniacian; 3 – at the top of the middle Coniacian; 4 – at the base of the Santonian; 5 – high in the middle Santonian, beneath the lowest occurrence of *Uintacrinus socialis*; 6 – at the top of the *Marsupites laevigatus* Zone within the upper Santonian.

6. Hardgrounds are locally developed within the upper Santonian in the condensed successions found in phosphate basins in the chalk of northern France and southern England (Jarvis 2006, fig. 3). These are most frequently found at the top of the *Uintacrinus socialis* Zone, or between the ranges of *Marsupites laevigatus* and *M. testudinarius*.

It seems probable that these events are a consequence of eustatic sea level change. The overall pattern of sea level change through the Coniacian and lower Santonian of the Western Foreland Basin in Canada was documented by Plint *et al.* (2017, fig. 2) who provided a detailed curve for the Coniacian, based on outcrops and well logs. Their overall curve for the Coniacian and basal Santonian is reproduced here on the left hand side of Text-fig. 26. The major low shown in the upper Turonian–lower Coniacian interval corresponds to event 1 above, a significant break marked by hardgrounds on the margins of the Anglo-Paris Basin. The sea-level low within the lower Coniacian perhaps corresponds with one of the hardgrounds developed within the upper Lewes Chalk of southern England, possibly the Hope Gap Hardground (Text-fig. 16). The low at the top of the lower Coniacian, in the *Inoceramus gibbosus* Zone of Western Canada is coincident with a locally developed hardground in the chalk of the Anglo-Paris Basin (event 2 – variously called the Rochester Hardground, Chapel Rock Hardground and Neuville Hardground, Text-fig. 16). The sea level fall close to the top of the *Volviceramus involutus* Zone is represented in Touraine by the Franceuil Hardground (event 3; see Text-figs 23 and 24). Finally, the brief sea level fall in the latest Coniacian and subsequent Early Santonian transgression is marked in Touraine by the Reugny Hardgrounds which are overlain by the lowest *Cladoceramus undulatoplicatus* Zone (event 4, Text-fig. 23).

The overall Coniacian–Santonian sea level rise is clearly documented by the profile through the succes-



Text-fig. 27. Global occurrence of *Uintacrinus* and *Marsupites* in chalks. The lowest occurrence of *U. socialis* lies either immediately above, or some distance above a hardground (hg 1) and is found in glauconitic or granular phosphatic chalks in many localities (columns 1, 2, 4, 5, 7). The lower part of the range of *U. socialis* is interpreted as a transgressive systems tract (TST) which onlaps onto Jurassic basement at Antrim, Ireland and Biocieniec, Poland (columns 2, 7) and Lower Cretaceous at Kalbarrie, Western Australia (column 9) and represents a significant eustatic sea level rise of perhaps 30–40 m. Hg 2 represents a break (sequence boundary) within the upper part of the range of *Marsupites laevigatus*, and the base of the overlying *M. testudinarius* Zone marks the base of a transgression. Hg 3, only developed at Austin (column 1) and Kalbarrie (column 9) lies above the top of the range of *Uintacrinus anglicus*.

sion in Touraine (Text-fig. 24) where progressive onlap to the southwest of Coniacian and Santonian marginal marine facies is documented. Here, Santonian sediments of the La Ribochère Member onlap onto the Turonian. However, there is also significant offlap, probably recording brief sea level falls, such as that recorded between levels 4 and 5.

Global correlation of the upper Santonian (Text-fig. 27)

The upper Santonian represents the most widespread development of the Upper Cretaceous chalk facies globally, at least on continental shelves and in epicontinental basins (Gale *et al.* 1996). Chalks and marls of this age are found widely across Europe and in central Asia, in the Gulf Coast states of the USA, in the Western Interior Basin of the USA and in Western Australia. Remarkably, almost all of these regions also yield the benthonic crinoids *Uintacrinus* and *Marsupites*, often with a succession of all of the 4 species, illustrated in Text-fig. 27. These data provides an opportunity to evaluate possible eustatic controls on sedimentation on a global scale.

1. *Uintacrinus socialis* appears at the level of, or somewhat above, a group of hardgrounds (event 5 of the preceding section, Text-fig. 25). The sediment immediately overlying the hardgrounds contains glauconite, or locally pelletal phosphate, and marks a significant transgressive pulse and is interpreted to represent the base of a Transgressive Systems Tract (TST). In some regions (UK, Poland) the sediment containing *U. socialis* locally onlaps onto underlying Jurassic or is situated some distance above the underlying unconformity with the lower Cretaceous (Albian, Western Australia).

2. A hardground, or burrowed omission surface, is widely developed at the top of the range of *Marsupites laevigatus* and is immediately overlain by a coarse bioclastic lag containing *M. testudinarius* (Texas, locally in UK and northern France, Western Australia).

3. A hardground is present immediately overlying the range of *Uintacrinus anglicus* in Austin, Texas and Kalbarrie, Western Australia.

It is thus possible to demonstrate that these events were controlled by eustatic sea level change because they are globally synchronous. It is, however, difficult to accurately quantify the magnitude of the sea level changes involved. However, the TST which commenced immediately beneath the lowest occurrence of *Uintacrinus socialis* resulted in the deposition of fine nannofossil chalks which overlie glauconitic calcarenites. These chalks and marls onlapped onto the basement at some localities (Ireland and Poland – Jurassic; Western Australia – lower Cretaceous) and the sea level rise must have been in the order of 30–40 m. The duration of this transgression can be estimated using the orbitally tuned $\delta^{13}C$ curve provided by Thibault *et al.* (2016, fig. 4) to be approximately 200 kyr. This places the sea level rise within the field of likely glacioeustatic events in the study of Davies and Simmons (2023, fig. 11). The presence of a significant Late Santonian sea level rise was shown by Miller *et al.* (2004) and Kominz *et al.* (2008), but the magnitude they suggested (15 m) is too small.

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