MARINE-BRACKISH BANDS AND THEIR MICROFAUNA FROM THE LOWER PART OF THE WEALD CLAY OF SUSSEX AND SURREY

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ABSTRACT. A brackish-marine microfauna is described from the lower part of the Weald Clay (*Cypridea tuberculata* Zone) of Sussex. The fauna is dominated by ostracods; eight species are described, one subgenus and three species are new. One species of arenaceous foraminifera, and cirripedes, have also been found. The salinity range of the various species is critically examined and the fauna is compared with other Lower Cretaceous microfaunas outside the Weald.

THE molluscan faunas of the Weald Clay fall into two groups; those dominated by *Viviparus*, normally considered freshwater, and a less common fauna believed to show marine influence. Records of the occurrence of certain brackish/marine molluscs, including *Filosina gregaria* Casey (Worssam 1963, p. 14), *Melanopsis attenuatus* J. de C. Sowerby, *Cassiope* cf. *lujani* (de Verneuil) (Dines and Edmunds 1933, pp. 37–38), *Corbula*, *Nemocardium*, *Ostrea* (Gallois 1965, p. 29) and *Ostrea distorta* (J. de C. Sowerby), indicate that the Weald Clay is not purely freshwater in origin. It has long been suspected that the uppermost Weald Clay represents 'a temporary incursion of the sea before the true Lower Greensand transgression' (Arkell 1947, p. 151) and the occurrence of foraminifera and echinoid spines together with marine molluscs (Casey 1961) indicates that conditions at that time were probably marine.

In 1957 Anderson and Casey, besides demonstrating the brackish origin of the highest Weald Clay, indicated that there is a 'marine band, the mid-Weald Clay brackish/marine band, some 400 ft. below the top of the formation' (Anderson and Casey 1957, p. 51) with brackish/marine molluscs, foraminifera, and marine ostracods. In 1963 Anderson (in Worssam 1963, pp. 16–19) gave a list of the ostracods he considered to be 'marine or quasi-marine' and stated that they occur at numerous horizons within the Weald Clay. Allen and Keith (1965) using carbon isotope ratios demonstrated the fluctuations of palaeosalinities in Purbeck and Wealden carbonates.

Worssam (1965, pp. 46–47) indicated that two marine bands had been located in the Weald Clay cores of the Survey's Warlingham borehole, the higher of the two (approx. 1424 ft.) being the mid-Weald Clay marine band and the other (approx. 1446 ft.) 20–25 ft. below it marked by a mudstone with *Cassiope*, *Gervillia*, and *Ostrea*.

In the course of a study of Weald Clay microfaunas, the authors have located certain clay bands crowded with *Cassiope*, *Filosina* and oysters, containing brackish/marine ostracods, foraminifera, and cirripedes. These bands have been found at the Newdigate brick pit (Grid Ref., TQ 205245), the Clock House brick pit near Capel (TQ 176384) and in boreholes from the Warnham brick pit and vicinity (TQ 173345) (text-fig. 1).

The marine horizon at Warnham can be matched quite well with that at Capel both lithologically and palaeontologically. At both places it consists of two beds with *Cassiope* separated by 2 ft. of clay with few ostracods and much lignite (text-fig. 8). We

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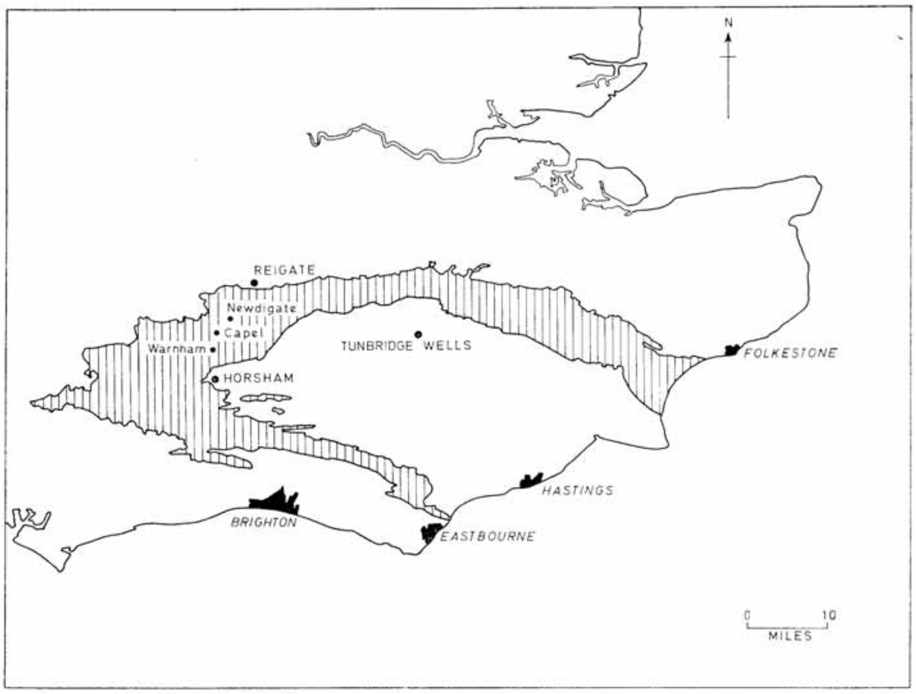
believe that this Warnham/Capel band is the equivalent of the two marine bands of the Warlingham borehole, with the mid-Weald Clay brackish/marine band (of Anderson and Casey 1957, p. 51) being represented by the upper of the two separate *Cassiope* bands. The *Cassiope* band at Newdigate lies above a red clay and therefore cannot be correlated with the Warnham/Capel band. Worssam and Thurrell (1967) suggest that it may represent the upper of the two bands in the Warlingham borehole, i.e. the mid-Weald Clay brackish/marine band. We suggest it is some distance above this band, thus



TEXT-FIG. 1. The outcrop of the Wealden in south-east England with localities worked.

much nearer to the top of the Weald Clay, and that it is not represented in the Warlingham borehole. According to MacDougall (personal communication) the Warnham/Capel band is 280 ft., the Newdigate band 320 ft. above the top of the Horsham Stone.

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(Croydon) Ltd. to their pit at Newdigate. N. W. A. acknowledges a research grant from the Natural Environments Research Council.

Abbreviations. In giving dimensions, which are given in millimetres, the following abbreviations are used: L, length; H, height; W, width. The holotypes are deposited in the British Museum (Natural History). Paratypes and the rest of the material are in the collection of the Geology Department, Sir John Cass College, London, and these specimen numbers are prefixed by the index letters SJCC.

SYSTEMATIC DESCRIPTIONS

Subclass OSTRACODA Latreille 1806
Order PODOCOPIDA Müller 1894
Superfamily CYPRIDACEA Baird 1845
Family ILYOCYPRIDIDAE Kaufmann 1900

Rhinocypris jurassica jurassica (Martin 1940)

Plate 29, figs. 6–7

1940 *Ilyocypris jurassica jurassica* n. ssp. Martin, p. 313, pl. 4, figs. 51–55.
1953 *Ilyocypris jurassica* Martin; Grekoff, p. 376.
1955 *Ilyocypris jurassica jurassica* Martin; Schmidt, p. 52.
1960 *Ilyocypris jurassica jurassica* Martin; Donze, p. 12, pl. 1, figs. 8–11.
1962 *Ilyocypris jurassica jurassica* Martin; Klingler, Malz, and Martin, p. 171, pl. 25, fig. 10.
1963 *Rhinocypris jurassica jurassica* (Martin); Oertli (1963*a*), p. 18, pl. 5, figs. 25–27.
1963 *Rhinocypris jurassica* (Martin); Anderson, p. 16.

Material. Eleven valves and carapaces (SJCC 66/1.1–11).

Dimensions

	L	H	W
Left valve	0·58	0·31	0·14
Right valve	0·54	0·27	0·13

Description. The left valve is larger than the right with slight overlap on all margins. Anterior margin broadly rounded, the posterior margin less so. Dorsal margin straight with a weakly marked anterior cardinal angle, the ventral margin is concave. The ventral and dorsal margins diverge anteriorly, so the carapace is higher anteriorly. The greatest width of the carapace occurs in the inflated posterior region.

The surface of the valve is heavily punctate and finely spinose. From the dorsal margin two narrow sulci extend to the centre of each valve, one of them arises mid-dorsally and produces a deeper, rounded sulcus in the centre of the valve. The other lateral sulcus is in the anterior of the valve and is less extended ventrally. On the anterior margin of each sulcus is a rounded tubercle. Internal view of the valve shows the tubercles to be hollow and the sulci appear as ridges.

Hinge structure could not be seen as the carapaces were partially pyritized, and the muscle scars were obliterated by mineralization. Probably the central sulcus acted as a boss for muscle attachment.

The inner lamella is rather wide anteriorly and postero-ventrally. Selvage is poorly developed and there are several weak lists developed. A narrow vestibulum occurs anteriorly.

Occurrence. From Newdigate in and vicinity of the 'marine band'.

Family CYPRIDIDAE Baird 1845

'*Cypris*' *henfieldensis* Anderson 1939

Plate 29, figs. 11–12

1885 ? *Cypris purbeckensis* Jones (part.), pl. 9, fig. 2.
1939 *Cypris henfieldensis* Anderson, pp. 307–8, pl. 12, figs. 9*a–b*.
1953 *Neocytheridea henfieldensis* (Anderson); Grekoff, p. 377.
1956 '*Cythereis*' *henfieldensis* (Anderson); Anderson, p. 54.
1963 '*Cypris*' *henfieldensis* (Anderson); Anderson, pp. 16–19.

Material. 2029 valves (SJCC 66/2.1–2029).

Average dimensions		L	H	W
	Left valve	0·86	0·48	0·16
	Right valve	0·83	0·46	0·15

Diagnosis. A smooth valved, sub-reniform ostracod of the subfamily *Cypridinae*. Posterior margin is broadly pointed ventrally. Left valve slightly larger than right, overlapping it slightly along the ventral margin and at the anterior cardinal angle. Hinge simple, a fine ridge on the right valve fits into a corresponding groove on the left. Inner lamella wide, with a narrow fused portion and a wide free portion and conspicuous vestibulum at both ends. Muscle scars typical of *Cypridinae*, six scars arranged in two groups.

Remarks. Occurs commonly throughout the Weald Clay but is reduced in numbers in the vicinity of the 'marine bands'.

Superfamily DARWINULACEA Brady and Norman 1889
Family DARWINULIDAE Brady and Norman 1889

Darwinula leguminella (Forbes 1855)

Plate 29, fig. 8

EXPLANATION OF PLATE 29

All figures × 50.

Figs. 1–2. *Cypridea marina* Anderson, M. S., Newdigate, Surrey. 1, Right valve, external view, SJCC 66/9.1. 2, Left valve, external view, SJCC 66/9.2.

Fig. 3. *Cypridea tuberculata* (J. de C. Sowerby), Capel. Right valve, external view, SJCC 66/10.1.

Figs. 4–5. *Cypridea pumila* Anderson, M. S., Clock House pit, Capel. 4, Right valve, external view, SJCC 66/11.1. 5, Left valve, external view, SJCC 66/11.2.

Figs. 6–7. *Rhinocypris jurassica jurassica* Martin, Newdigate, Surrey. 6, Right valve, external view, SJCC 66/1.1. 7, Left valve, external view, SJCC 66/1.2.

Fig. 8. *Darwinula leguminella* (Forbes), Warnham, Sussex. Left valve, external view, SJCC 66/3.1.

Figs. 9–10. *Darwinula oblonga* (Roemer), Newdigate, Surrey. 9, Left valve, external view, SJCC 66/4.1. 10, Right valve, external view, SJCC 66/4.2.

Figs. 11–12. '*Cypris*' *henfieldensis* Anderson, Newdigate, Surrey. 11, Right valve, external view, SJCC 66/2.1. 12, Left valve, external view, SJCC 66/2.2.

Figs. 13–21. *Fabanella bononiensis* (Jones), Newdigate, Surrey, and Warnham, Sussex. 13, Female right valve, external view, SJCC 66/5.1. 14, Female left valve, external view, SJCC 66/5.2. 15, Female left valve, internal view, SJCC 66/5.2. 16, Female right valve, internal view, SJCC 66/5.1. 17, Male right valve, external view, SJCC 66/5.3. 18, Female carapace, dorsal view, SJCC 66/5.4. 19, Female carapace, ventral view, SJCC 66/5.6. 20, Female left valve, dorsal view, SJCC 66/5.2. 21, Female right valve, dorsal view, SJCC 66/5.1.

1855 *Cypris leguminella* Forbes in Lyell, p. 294, fig. 334*c*.
1855 *Darwinula leguminella* (Forbes) Jones, pp. 346–7, pl. 8, figs. 30–31.
1886 *Darwinula leguminella* (Forbes); Jones, p. 147, pl. 4, figs. 4*a–c*.
1888 *Darwinula leguminella* (Forbes); Jones, p. 538.
1940 *Darwinula leguminella* (Forbes); Martin, p. 317, pl. 4, figs. 58–61.
1940 *Darwinula* (450) *leguminella* (Forbes); Wicher, p. 268, pl. 2, fig. 8.
1953 *Darwinula leguminella* (Forbes); Grekoff, p. 376.
1959 ? *Darwinula leguminella* (Forbes); Zalányi, pp. 425–8, text-figs. 12*a–d*, 12/*a*, 13*a–c*.
1961 *Darwinula leguminella* (Forbes); Martin (1961*b*), p. 119, pl. 14, fig. 19.
1962 *Darwinula leguminella* (Forbes); Klingler, Malz, and Martin, pp. 187–8, pl. 25, fig. 14.
1963 *Darwinula leguminella* (Forbes); Christensen, pp. 21–23, pl. 2, figs. 2*a–c*; text-figs. 3, 4*b*.
1963 *Darwinula leguminella* (Forbes); Oertli (1963*a*), p. 20, pl. 6, fig. 40.

Material. 107 valves and carapaces (SJCC 66/3.1–107).

Average dimensions	L	H	W
Carapace	0·77	0·31	0·29

Description. Small, sub-cylindrical carapace. Dorsal margin only very slightly arched, ventral margin slightly concave in anterior half and diverging posteriorly, greatest height in the posterior half of the carapace. Posterior margin smoothly and broadly rounded, anterior more sharply pointed ventrally. In dorsal view the carapace is lanceolate, the posterior region is inflated. The left valve is larger than the right with overlap at all margins, especially ventrally, where there is a knurl in the left valve margin coinciding with the position of greatest concavity. Hinge margin is straight.

Carapace is thin, the surface smooth, often shiny. Muscle scars in the usual rosette arrangement, typical of all species of the genus. Hinge is peculiar in that the smaller (right) valve bears a median groove. It appears that the larger left valve has a median ridge with shallow, elongated sockets anterior and posterior to it. There seem to be no corresponding teeth present on the right valve and it is very likely that the margin of this valve fits into these sockets. The structure of the inner lamella could not be observed.

Occurrence. Common at all three localities, and right through the Weald Clay, much reduced or in cases completely missing in the 'marine bands'.

Remarks. There seems to be some disagreement in the hinge structure as described by Christensen (1963) according to whom the hinge comprises two elements only.

Darwinula oblonga (Roemer 1839)

Plate 29, figs. 9–10

1839 *Cypris oblonga* Roemer, p. 52, pl. 20, fig. 21.
1843 *Cypris oblonga* Roemer; Dunker, p. 39.
1846 *Cypris oblonga* Roemer; Dunker, p. 60, pl. 13, figs. 26*a–b*.
1862 *Cypridea oblonga* (Roemer); Jones, p. 128, pl. 5.
1940 *Cyprione* (628) *bristovii* Jones; Wicher, p. 268, pl. 2, fig. 7.
1940 *Cyprione oblonga* (Roemer); Martin, pp. 319–22, pl. 4, figs. 62–63.
1949 *Cyprione oblonga* (Roemer); Wolburg, p. 353.
1951 *Cyprione oblonga* (Roemer); Steghaus, p. 209, pl. 14, fig. 8.
1953 *Darwinula oblonga* (Roemer); Grekoff, p. 376.
1955 *Cyprione oblonga* (Roemer); Schmidt, p. 53.
non 1960 *Cyprione oblonga* (Roemer); Neale, p. 214, pl. 1, figs. 6, 8, pl. 3; figs. 9*a–b*, 11*a–b*, pl. 4, figs. 1–4.

1962 *Darwinula oblonga* (Roemer); Klingler, Malz, and Martin, p. 188, pl. 27, fig. 18.
1963 *Darwinula oblonga* (Roemer); Christensen, pp. 23–25, pl. 2, figs. 5*a–c*, text-fig. 4*a*.
1963 *Darwinula oblonga* (Roemer); Oertli (1963 *a*), pp. 20–21.

Material. 149 valves and carapaces (SJCC 66/4.1–149).

Average dimensions		L	H	W
	Carapace	1·11	0·57	0·50

Description. Carapace ovate, oblong to somewhat trapezoidal in shape. Dorsal margin is long and lowly arched; ventral margin slightly concave, the two margins diverge posteriorly. Anterior margin is bluntly pointed ventrally; posterior margin is more broadly rounded with larger angle ventrally than dorsally. Greatest height of carapace is in the posterior region. Carapace is slightly wider in posterior half with posterior end less pointed than the anterior. Left valve is larger than the right with overlap on all margins, but less pronounced at the hinge.

Shell is thin, smooth, and often shiny and transparent with large, prominent, sub-central muscle scars arranged in the pattern of a rosette, with a small antennal scar in front of and ventral to the main group. The faintly visible normal pore canals are widely spaced.

The hinge consists in the left valve of a long narrow groove with an anterior shallow socket. The margin of the right valve fits into the groove and a low tooth is produced anteriorly. The hinge line is very long with the anterior elements occurring about 10% of the valve length from the anterior.

The inner lamella is very narrow, noticeable only at the anterior and posterior margins and completely fused with the outer lamella. About fifteen thin, short, and straight radial pore canals occur anteriorly, and about twenty-five at the posterior.

Occurrence. Occurs throughout the Weald Clay following in its distribution various species of *Cypridea*. Only rarely found with *D. leguminella* and like it its numbers drop markedly in the 'marine bands'.

Superfamily CYTHERACEA Baird 1850
Family CYTHERIDEIDAE Sars 1925

Fabanella bononiensis (Jones 1880)

Plate 29, figs. 13–21; text-figs. 2*a–g*

1880 *Cythere boloniensis* Jones, pp. 615–16.
1885 *Candona bononiensis* (Jones); Jones, pp. 348–9, pl. 9, figs. 7–8.
1940 *Cyprideis polita* Martin, pp. 350–3, pl. 7, figs. 110–13, pl. 9, figs. 149–51.
1951 '*Candona*' *bononiensis* (Jones); Anderson, pp. 209–11.
1953 *Neocytheridea bononiensis* (Jones) Grekoff, p. 377.
1961 *Fabanella polita polita* (Martin); Wolburg, p. 199, pl. 1, fig. 3, text-figs. 1–2.
1961 *Fabanella polita polita* (Martin); Martin (1961*a*), p. 113, pl. 14, fig. 9.
1961 *Fabanella polita polita* (Martin); Martin (1961*b*), p. 186, pl. 1, figs. 1–4, 10–12.
1962 *Neocytheridea bononiensis bononiensis* (Jones); Wick and Wolburg, pp. 218–19, pl. 32*b*, figs. 1–2.
1963 *Neocytheridea bononiensis bononiensis* (Jones); Christensen, pp. 36–38, pl. 3, figs. 2*a–e*, text-fig. 11.
1963 *Fabanella boloniensis* (Jones); Anderson, p. 16.

Material. 385 valves and carapaces (SJCC 66/5.1–385).

Average dimensions		L	H	W
	♀ carapace	0·83	0·45	0·45
	♂ carapace	1·00	0·48	0·47

Description. Carapace exhibits sexual dimorphism. Males are about 15% longer than females. Anterior and posterior margins are broadly and equally rounded. The ventral margin shows an anterior concavity and is extended below posteriorly. There is a well-marked anterior, but hardly noticeable posterior cardinal angle. A swelling at the anterior cardinal angle marks the ocular region. The greatest height of the valve falls in the posterior half. The carapace is moderately inflated with the greatest width at mid-point. The valves are equal in size and no overlap occurs apart from that at the hinge.

The carapace is heavily calcified. Its surface is covered with punctae, the size of which increases towards the centre of the valve. There is sometimes a suggestion of a concentric pattern of punctae on the valves.

The hinge is lophodont. In the right valve two terminal teeth are found and a median groove, which may not extend from tooth to tooth but only occupy the anterior half of that distance. The anterior tooth occupies roughly 20% of the hinge length and is slightly larger than the posterior one. The median groove appears to slope down from the top of the anterior tooth across the median part of the hinge. In the left valve are corresponding anterior and posterior sockets and a median ridge.

The inner lamella is narrow with a well-developed selvage. The inner margin and line of concrescence do not coincide; there is a narrow anterior vestibulum. Radial pore canals are spindle-shaped, thick in the middle and thinning at each end. There are about twenty anteriorly and ten posteriorly.

The muscle scar pattern consists of a sub-vertical row of four and two separate scars in front of the row, one in line with the first and second (from the dorsal side) and the other below the fourth.

Occurrence. In the 'marine bands' at Warnham, Capel, and Newdigate.

Remarks. There seems to be great confusion as regards the specific status of *F. bononiensis*. Originally described by Jones in 1880 as *Cythere boloniensis*, he amended it (1885) to *Candona bononiensis*. *Cyprideis polita* Martin 1940 is a junior synonym of *C. bononiensis* Jones 1880. In the German literature several subspecies of *F. polita* have been described, all based on the varying degree of punctuation of the valves (Martin 1961), and on the degree of inflation of the posterior half of the carapace (Wolburg 1961). Our specimens are closest to those described by Martin as *F. polita polita* although the surface of the valves is not entirely smooth. It is very likely that we are faced with one species only and the variation in ornamentation is of phenotypic nature.

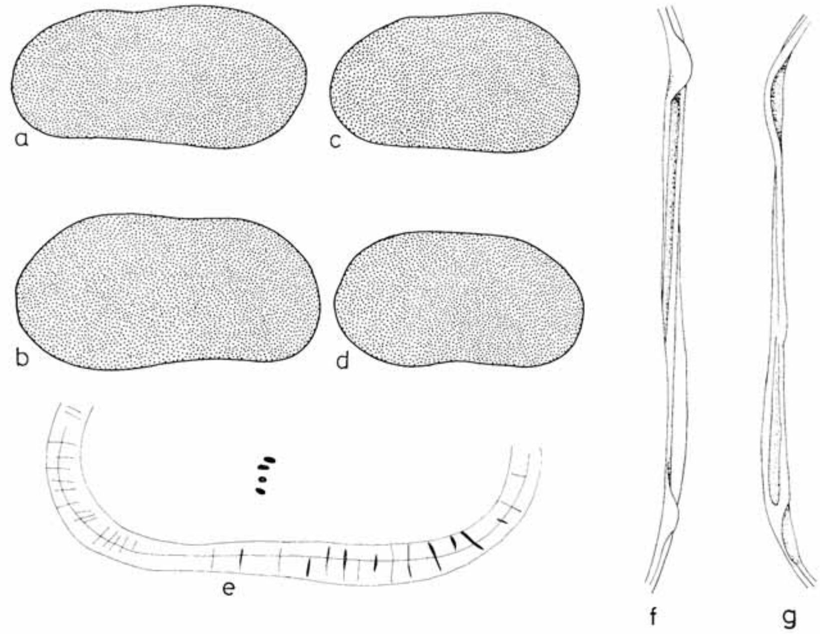
Subgenus *Sternbergella* (*Parasternbergella*) subgen. nov.

Type species. Sternbergella (*Parasternbergella*) *wolburgi* sp. nov.

Diagnosis. A subgenus of *Sternbergella* with lophodont hinge.

Remarks. In all respects *S.* (*Parasternbergella*) subgen. nov. agrees with *Sternbergella* but the strikingly different hinge warrants the establishment of a new subgenus.

Wolburg (personal communication) observed a gradual reduction of the hinge of *Sternbergella* from the antimerodont towards lophodont in the higher German Wealden. *Cypris cornigera* Jones 1888 on the basis of its lophodont hinge should also be considered belonging to this new subgenus. *Dolocytheridea* Triebel 1938 seems to be closely allied to *Sternbergella* and Dr. Wolburg (personal communication) drew our attention to the



TEXT-FIG. 2. *Fabanella bononiensis* (Jones 1880). *a*, Left valve, male, outline, ×50. *b*, Right valve, male, outline, ×50. *c*, Left valve, female, outline, ×50. *d*, Right valve, female, outline, ×50. *e*, Free margin, right valve, female, ×100. *f*, Right valve hinge, ×150. *g*, Left valve hinge, ×150.

strikingly similar parallel evolution of the two genera. A suggested tentative evolutionary relationship is shown on text-fig. 3.

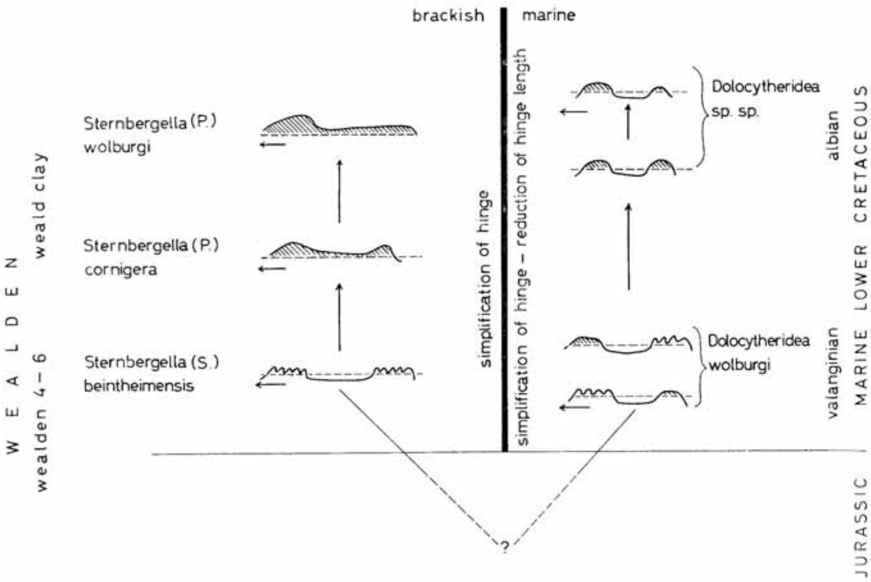
Sternbergella (*Parasternbergella*) *wolburgi* sp. nov.

Plate 30, figs. 7–12; text-figs. 4*a*–*b*, 5*a*–*f*

Holotype. A female carapace, Io. 3949. *Paratypes*, 286 valves and carapaces (SJCC 66/7.1–286).

Locus typicus Clock House brick pit, Capel, Surrey; 'marine band', lower part of Weald Clay.

Diagnosis. A species of *Sternbergella* (*Parasternbergella*) with a trapezoid (♀♀) or oval (♂♂) carapace. The greatest height of the valves is at the posterior cardinal angle. Fused part of the inner lamella uniformly narrow along the free margin with a broad inner lamella anteriorly. Hinge unusual; all positive elements are in the right valve consisting of a sharp long anterior tooth and a very poorly developed posterior tooth, the two being connected by a sharp but low median ridge. The left valve carries a corresponding structure, but only the deep anterior socket is conspicuous.



TEXT-FIG. 3. Suggested evolutionary relationship between *Dolocytheridea*, *Sternbergella* s. str. and *S.* (*Parasternbergella*).

Dimensions		L	H	W
	Holotype	1·08	0·65	0·47
Average dimensions of paratypes				
	♀ Left valve	0·99	0·59	0·24
	♀ Right valve	0·96	0·58	0·20
	♂ Left valve	1·20	0·65	0·29
	♂ Right valve	1·18	0·62	0·25

Description. Carapace shows strong sexual dimorphism; females are shorter, higher, and more trapezoid shaped, males about 15% longer and more oval in outline. Both sexes are characterized by the position of the greatest height in the carapace which is at the posterior cardinal angle. The left valve is larger than the right and the overlap is especially marked ventrally and at the hinge. The carapace is not much inflated, the greatest width occurs in the median to posterior regions.

The anterior margin is broadly rounded, the posterior broadly pointed at mid-height in males and more ventrally in females. The ventral margin is almost straight but in the male right valves there is a short concave portion anteriorly. The hinge margin is straight in both of the female valves, sloping towards the anterior at a slightly greater angle in the right valve. In males the hinge margin is gently arched. The cardinal angles are rounded and inconspicuous with the exception of the posterior cardinal angle in females which is well developed, situated about two-thirds of the length from the anterior. It also marks the highest point of the valve.

The surface of the valve is smooth and often translucent; there are few, well spaced large normal pore canals. The fused portion of the inner lamella is relatively narrow and of almost uniform length along the length of the free margin. At the anterior the inner margin and the line of concrescence do not coincide and there is a wide free portion of the inner lamella present forming a wide vestibule. Elsewhere the line of concrescence and inner margin coincide. The well-developed selvage is prominent right round. Radial pore canals are trumpet shaped, widening towards the surface, numbering about twenty-four anteriorly and eighteen posteriorly. They are rather irregular mainly in length and width.

The central muscle scar pattern consists of a slightly backwardly arched row of four scars, the second of which (from top) is often attenuated. Two scars occur in front of the main group, one in line with the top or second one in the row, and the other one well below the bottom scar of the row. Often two more groups of scars can be observed, one group consisting of two scars is situated anteroventrally from the main group and represents probably the mandibular muscles; the other group of scars is above the vertical row and consists of a large and a small scar.

The hinge is rather unusual and it is difficult to fit it into any of the established hinge types. It is probably closest to the lophodont hinge, but all the positive hinge elements are carried by the right valve so it cannot be definitely identified with the lophodont type where the median element of the right valve is negative. The right valve hinge consists of a large peg like tooth at the anterior which projects well above the margin of the valve in side view. The posterior element is a weakly developed narrow ridge connected to the anterior element by a very ill-defined smooth ridge. The left valve carries the corresponding negative hinge features, only the anterior deep socket being conspicuous.

Occurrence. In great numbers in the 'marine band' at Capel and less common in the 'marine bands' at Warnham and Newdigate.

EXPLANATION OF PLATE 30

All figures × 50 unless otherwise stated.

Figs. 1–6. *Hutsonia capelensis* sp. nov., Capel, Surrey. 1, Carapace, female, from right, holotype, Io 3948. 2, Carapace, female, from left, holotype, Io 3948. 3, Carapace, male, from right, SJCC 66/6.1. 4, Carapace, male, from left, SJCC 66/6.1. 5, Carapace, female, dorsal view, holotype, Io 3948. 6, Carapace, male, dorsal view, SJCC 66/6.1.

Figs. 7–12. *Sternbergella* (*Parasternbergella*) *wolburgi* sp. nov., Capel, Surrey. 7, Carapace, female, from right, holotype, Io 3949. 8, Carapace, female, from left, holotype, Io 3949. 9, Carapace, male, from right, SJCC 66/7.1. 10, Carapace, male, from left, SJCC 66/7.1. 11, Carapace, female, dorsal view, holotype, Io 3949. 12, Right valve, female, dorsal view to show hinge, × 150, SJCC 66/7.2.

Figs. 13–17. *Schuleridea* (*Eoschuleridea*) *wealdensis* sp. nov., Newdigate, Surrey and Warnham, Sussex. 13, Carapace, female, from right, holotype, Io 3950. 14, Carapace, female, from left, holotype, Io 3950. 15, Right valve, male, external view, SJCC 66/8.1. 16, Left valve, male, external view, SJCC 66/8.2. 17, Carapace, male, dorsal view, SJCC 66/8.3.

Figs. 18–21. *Ammobaculites* sp., Capel, Surrey.

Remarks. *S.* (*P.*) *wolburgi* sp. nov. differs from *S.* (*P.*) *cornigera* (Jones 1888) in its forwardly sloping hinge margin, stronger hinge, and lack of well-developed posterior spines.

TEXT-FIG. 4. *Sternbergella* (*Parasternbergella*) *wolburgi* sp. nov. *a*, Female left valve, internal view, ×90. *b*, Female right valve, internal view, ×90.

Family SCHULERIDEIDAE Mandelstam 1959

Schuleridea (*Eoschuleridea*) *wealdensis* sp. nov.

Plate 30, figs. 13–17; text-figs. 5*a–c*

Holotype. A female carapace, Io 3950. *Paratypes*, 524 valves and carapaces (SJCC 66/7.1–524).

Locus typicus 'Marine band', lower part of Weald Clay; Newdigate, Surrey.

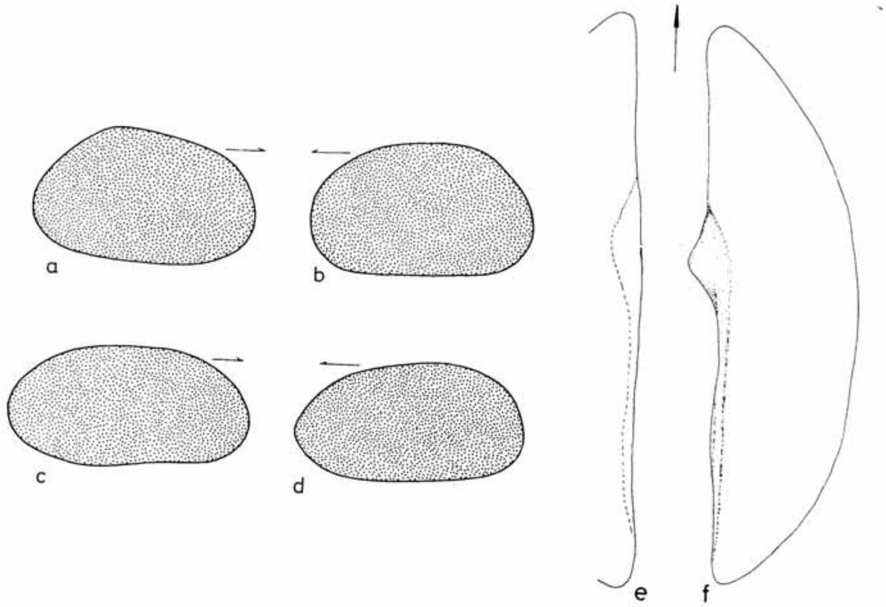
Diagnosis. A species of *Schuleridea* (*Eoschuleridea*) with a relatively narrow duplicature and only about fifteen radial pore canals on the anterior margin. Carapace is small with very strong sexual dimorphism.

Dimensions of holotype. L, 0·47; H, 0·34; W, 0·27

Average dimensions of paratypes

	L	H	W
♀ Left valve	0·50	0·37	0·17
♀ Right valve	0·45	0·31	0·12
♂ Left valve	0·63	0·37	0·17
♂ Right valve	0·59	0·31	0·12

Description. The carapace is ovoid (♀♀) or more elongated (♂♂). The left valve is larger than the right and overlaps it along the entire margin. The degree of overlap is strongest



TEXT-FIG. 5. *Sternbergella* (*Parasternbergella*) *wolburgi* sp. nov. *a*, Outline of female right valve, ×35. *b*, Outline of female left valve, ×35. *c*, Outline of male right valve, ×35. *d*, Outline of male left valve, ×35. *e*, Left valve hinge, female, ×90. *f*, Right valve hinge, female, ×90.

ventrally and dorsally, least noticeable along the posterior end. The right valve is smaller, on the average by 7–10% (length). The sexual dimorphism is very strong, the males being about 25% longer than the females.

In side view the two valves are very different in shape. The left valve in both sexes has a convex dorsal margin, rounded anterior and slightly pointed posterior end. The ventral part of the valve shows a slight swelling, more pronounced in the females. In the females the posterior cardinal angle is more conspicuous, the anterior being more rounded; in males the opposite is the case. The maximum height of the valve is at the anterior cardinal angle which is about one-third of the length from the anterior in females and one-quarter in males. The right valve is much more angular in both sexes, both cardinal angles being conspicuous. The dorsal and ventral margins are almost straight. The posterior end is more pointed than in the left valve.

The surface of the valve is smooth with large but few normal pore canals. The shell is thick and heavy, often transparent. A slight ocular depression is present.

The hinge conforms to the usual paleomerodont type found in *Schuleridea* but is less strongly developed than in most Jurassic or Cretaceous species. The hinge in the left valve consists of two crescentic loculate terminal sockets connected by a locellate median groove. The anterior socket is the larger of the two and it contains eight loculi, the posterior having only six or seven. The median groove is situated on top of a bar that is derived from the upper lip of the terminal sockets. The groove is finely locellate with sixteen to eighteen fine locellae. A deep spindle-shaped accommodation groove is found above the median element. The corresponding hinge structure in the right valve comprises three positive elements, two terminal dentate ridges with a finely denticulate bar in between. The average length of the hinge is 0·28 mm. in females and 0·38 mm. in males.

The anterior duplicature is narrow. The inner margin and line of concrescence seem to coincide although in some specimens a very narrow vestibule was observed. The radial pore canals are rather thick, getting rapidly narrow towards both ends. The typical fan-shaped arrangement of the radial pore canals, characteristic of *Schuleridea*, is hardly recognizable; only the last two or three pore canals on each side turn slightly outwards. The number of radial pore canals is between fifteen and seventeen on the anterior margin, same in both males and females.

The muscle scar pattern consists of four scars in a nearly vertical row with two anterior scars in line with the top and bottom scars of the vertical row.

Occurrence. In 'marine bands' from Warnham, Capel, and Newdigate.

Remarks. Species of *Schuleridea* (*Eoschuleridea*) have been described so far only from the Bathonian Estuarine Series of Eastern England (Bate 1967).

Family PROTOCYTHERIDAE Ljubimova 1955

Hutsonia capelensis sp. nov.

Plate 30, figs. 1–6; text-fig. 7*a–d*

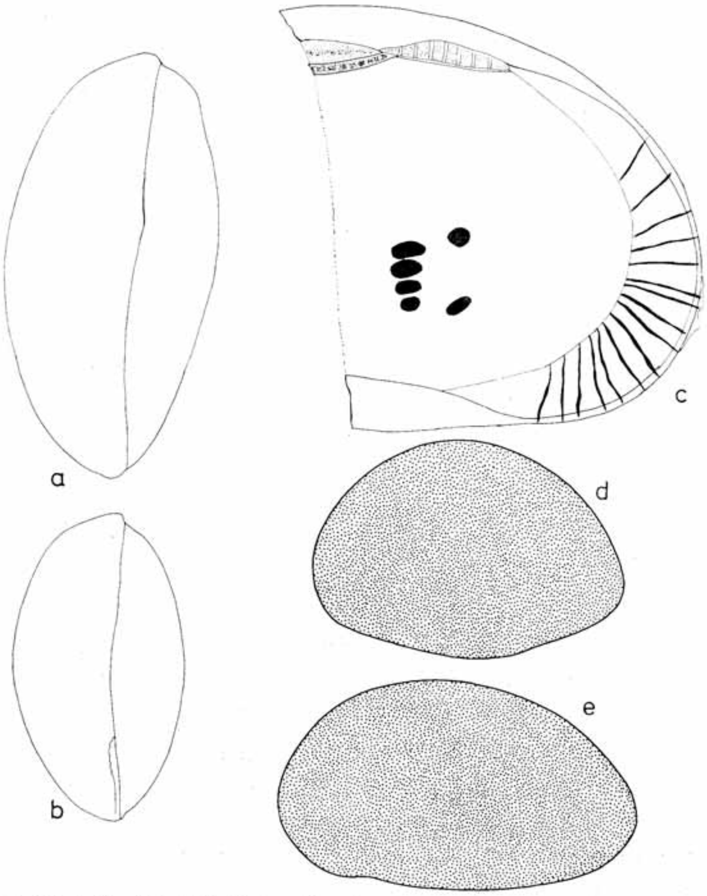
Holotype. A female carapace, Io 3948. *Paratypes*, 32 valves and carapaces (SJCC 66/6.1–32).

Locus typicus 'Marine band', Lower Weald Clay; Capel, Surrey.

Diagnosis. A species of *Hutsonia* with well-developed bisulcate anterior ornamental complex. Sulci are deep, crescent-shaped, inclined forward, with an elongated median lobe running full length between the sulci. Under this complex, slightly posteriorly, two pits occur in a horizontal row. The central and posterior part of the valve is ornamented by three quasi-horizontal ribs. Sexual dimorphism is very pronounced.

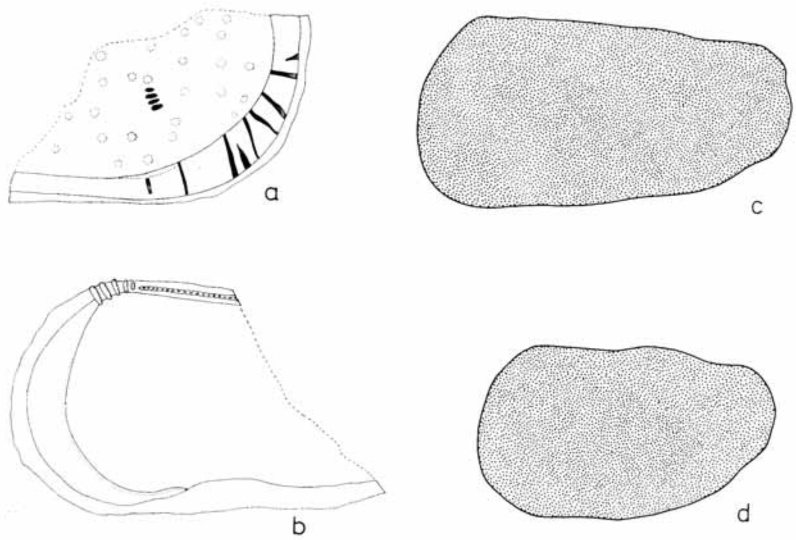
Dimensions of holotype. L, 0·60; H, 0·36; W, 0·31.

Average dimensions of paratypes		L	H	W
	♀ Left valve	0·60	0·36	0·19
	♀ Right valve	0·58	0·34	0·13
	♂ Left valve	0·79	0·40	0·19
	♂ Right valve	0·76	0·37	0·13



TEXT-FIG. 6. *Schuleridea* (*Eoschuleridea*) *wealdensis* sp. nov. *a*, Carapace, male, dorsal view, ×100. *b*, Carapace, female, dorsal view, ×100. *c*, Female left valve, anterior margin and muscle scars, ×200. *d*, Outline of female left valve, ×100. *e*, Outline of male left valve (? juvenile), ×100.

Description. Carapace sub-pyriform in side view. The left valve is larger, overlapping the right slightly along the ventral margin. In males the overlap is more pronounced and extends to the anterior and posterior margins. Sexual dimorphism is extremely strong, males being about 25% longer than females. The two valves are almost identical in shape. The dorsal margin is straight with a slight convexity which is anteriorly in males and at about mid-length in females. The two cardinal angles are well marked. Anterior margin is broadly rounded, the posterior ends in a blunt point well above the mid-height. The ventral margin rises slightly sinuously towards the posterior end. At about three-eighths length from the anterior there is a short concave portion in the ventral margin; this is much more in evidence in males. The greatest height of the valve is at the anterior cardinal angle, about one-eighth distance from the anterior. In dorsal view carapaces of the two sexes are considerably different in shape, males being almost elliptical with the greatest width only slightly posterior to mid-length; in females, however, the position of the greatest width falls in the posterior third of the carapace. Females are also much more pointed towards the posterior in this view.



TEXT-FIG. 7. *Hutsonia capelensis* sp. nov. *a*, Female left valve, anterior margin and muscle scars, × 110. *b*, Female right valve, anterior margin and anterior portion of hinge, × 110. *c*, Outline of male left valve, × 75. *d*, Outline of female left valve, × 75.

The surface ornamentation consists of an anterior complex of two sulci separated by a lobe and a central and posterior system of ribs. The anterior sulci are crescent-shaped, slightly oblique forwards. The median lobe extends the full length of the sulci and it is thickest at its middle. Two pits occur antero-ventrally arranged parallel to the ventral margin, the first of these two lying just under the ventral end of the posterior sulcus, the second a short distance behind.

A near horizontal system of sharp crested ribs form the rest of the ornamentation. Three of these ribs form a constant feature, running on the lateral side of the valve starting from below the lobe and converging slightly towards the posterior. The upper two of these ribs are deflexed ventrally at their anterior end. On male valves an additional but much shorter rib is situated above. Several very fine ribs run on the ventral side of the valve. The whole surface seems to be finely punctate.

The internal characteristics could be only partially observed as most of the material is in the form of closed carapaces. The hinge is antimerodont with five to seven crenulations on the anterior element and a locellate median groove in the right valve. Normal pore canals are large and numerous. Radial pore canals appear to be thick and few, about eight on the anterior margin. The duplicature is heavily calcified, and a narrow vestibulum may be present anteriorly.

Remarks. Species of *Hutsonia* have been described from Upper Jurassic–Lower Cretaceous brackish/marine deposits, mainly from North America. *Hutsonia capelensis* sp. nov. appears to be closest to the type species *H. vulgaris* Swain 1946, but differs from it by the presence of well-defined longitudinal ribbing and the lack of reticulation.

Class CIRRIPEDIA

Plates of a lepadomorph cirripede assigned to *Zeugmatolepas hausmanni* Dunker and Koch, by Anderson (1963, p. 63) are abundant in the lower of the two *Cassiope* bands at the Clock House brick pit, Capel. Carinae, scuta and terga are found in association with *Sternbergella* (*Parasternbergella*) *wolburgi* sp. nov. and *Hutsonia capelensis* sp. nov. Scutal plates are the most common at Capel but carinal plates form the bulk of the cirripede fauna at Warnham. There is rather wide variation in the size and shape of the carinae which suggests that there may be more than one species present. The abundant lignite associated with the 'marine bands' may indicate that the cirripedes were probably attached to floating plant debris.

Order FORAMINIFERIDA Eichwald 1830
Family LITUOLIDAE de Blainville 1825

Ammobaculites sp.

Plate 30, figs. 18–21

Material. Several hundred specimens.

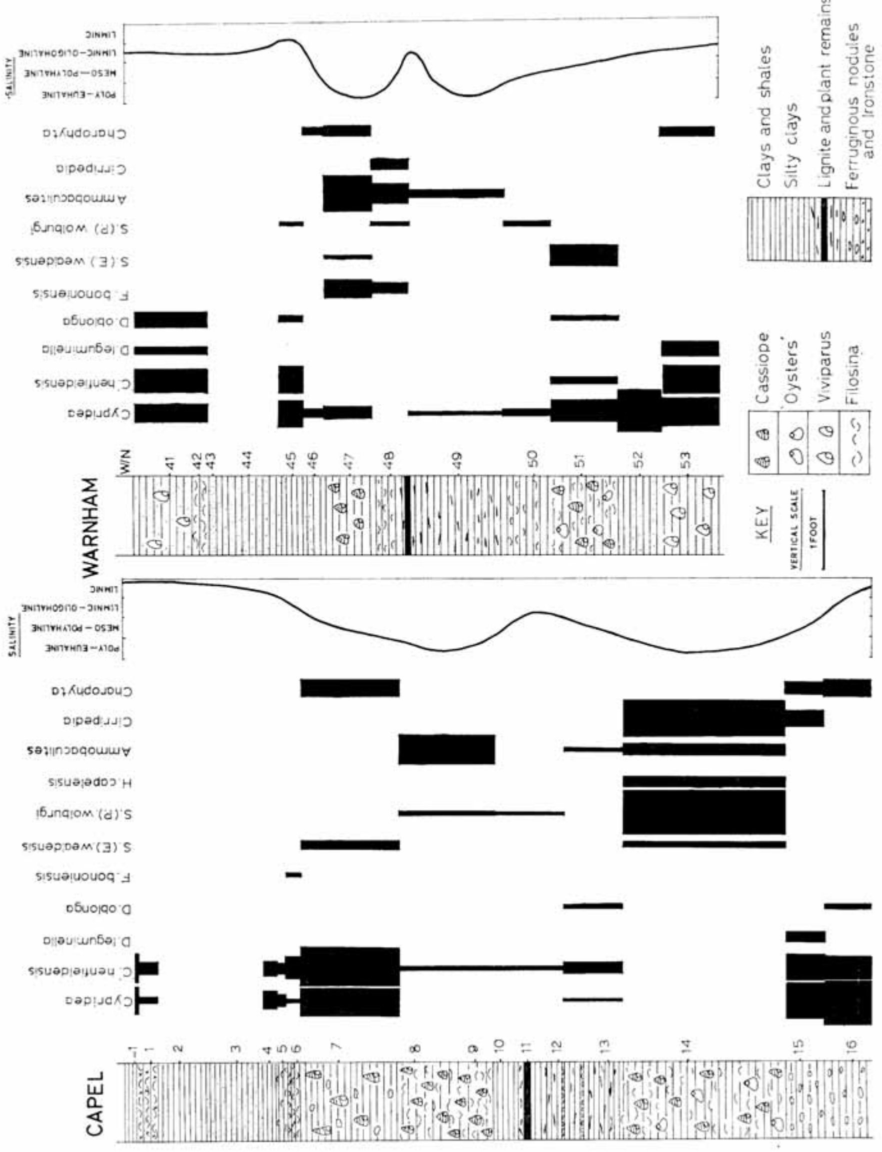
Average dimensions. Length: 0·6–0·8 mm.; Diameter of coil: 0·3–0·5 mm.; Breadth of last chamber: 0·2–0·25 mm.

Remarks. The material is rather poorly preserved, all chambers are usually flattened and therefore specific identification is not attempted. Fairly extensive variation can be observed in the examined population but it appears nevertheless monospecific. The material of the tests consists of fine uniform grade quartz grains.

Occurrence. From the 'marine bands' at Newdigate, Capel, and Warnham.

INTERPRETATION OF ENVIRONMENTS

It is generally accepted that some species of ostracods are accurate indicators of various environmental parameters, including salinity. Two methods of approach can be used in determining the original salinity: (*a*) Comparison with the living representatives of the genus, if any. This is, at least theoretically, the most reliable approach, but serious errors may be introduced by not differentiating between biocenosis and thanatocenosis in the study of modern ostracod faunas. Wagner (1964) pointed out that this is especially important in the study of estuarine or delta environments where considerable transportation of empty shells takes place. (*b*) Shell characteristics can be indicative of the degree of salinity. Weakly calcified valves, weak hinge structure and narrow fused



TEXT-FIG. 8. Stratigraphical distribution of microfossils in and in the vicinity of the marine bands at Capel and Warnham. (The relative abundance of various microfossils is expressed by the width of the columns.)

zone are typical of freshwater forms. On the other hand, strongly calcified, heavy shelled forms with strongly developed hinges are more characteristic of marine (mainly benthonic) forms (Hartman 1964). In brackish water species the overall size and degree of calcification decreases with salinity. The inferred salinity range of various micro-fossils found in or near the 'marine bands' is examined below. On this basis four distinct micro-fossil assemblages are recognized.

A. *Freshwater assemblage*

Genus *Cypridea* Bosquet 1852

Many species of *Cypridea* are abundant throughout the Weald Clay. A sharp fall in their numbers heralds the establishment of brackish conditions and they are absent from some parts of the 'marine bands'. At Warnham and Capel the dominant species in the vicinity of the 'marine band' are a form close to *Cypridea pumila* Anderson, M. S. (Pl. 29, figs. 4–5) and the heavily ornamented *C. tuberculata* (J. de C. Sowerby) (Pl. 29, fig. 3) in which the size and shape of the tubercles vary while the pattern remains the same. At Newdigate the dominant species is *Cypridea marina* Anderson, M. S., a large form with a number of stout rounded tubercles (Pl. 29, figs. 1–2). We consider all species of *Cypridea* in the 'marine bands' to be transported specimens and therefore we are not concerned with them in this study.

Genus *Theriosynoecum* Branson 1936

Theriosynoecum fittoni (Mantell 1844) occurs in large numbers in the freshwater deposits of the Weald Clay but is exceedingly rare in the 'marine bands'. *T. fittoni* follows the distribution of the various species of *Cypridea* and is considered to be a completely freshwater genus.

B. *Limnic-oligohaline assemblage*

This assemblage includes forms that are assumed to be generally freshwater dwellers with some tolerance of brackish conditions. The evidence of recent species of *Darwinula* and *Ilyocypris* from slightly brackish environments (Wagner 1957, Neale 1964, and Hartman 1964) is supported by the presence of small numbers of their fossil representatives from beds immediately adjacent to the 'marine bands'.

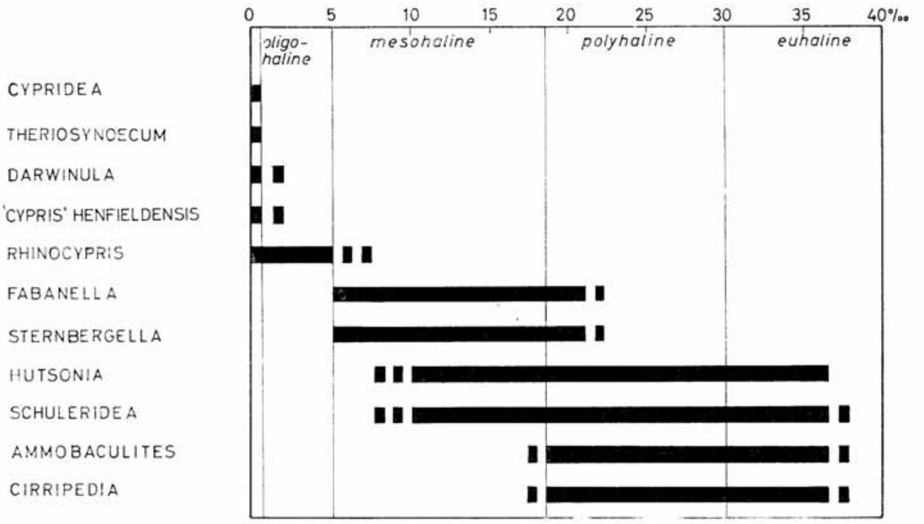
Rhinocypris. Recent species of *Ilyocypris*, a very closely allied, if not the same genus, are freshwater dwellers but with a certain tolerance of brackish conditions. Hartman (1964, p. 490 in discussion) mentions its occurrence in the brackish environments of the Baltic, with salinities of $5^0/_{00}$ or more, although the same species is usually found in fresh or nearly freshwater. In the Weald Clay *Rhinocypris* occurs with *Cypridea* suggesting a limnic biotope generally but on the evidence of modern species from the Baltic we envisage a slight tolerance of brackish conditions.

Darwinula. Recent species of *Darwinula* live in waters with salinities of $0–1^0/_{00}$ (Wagner 1957, Neale 1964).

'*Cypris*' *henfieldensis*. Very little can be said about this genus as it is certainly new and as yet undescribed. Anderson (1963) states this to be a 'marine or quasimarine' species. It occurs, however, right through the Weald Clay in large numbers with the usual 'freshwater' fauna. The presence of numerous valves of '*Cypris*' *henfieldensis* in certain samples from the 'marine bands' may be explained by current transportation of the thin but large valves. Tentatively a slight tolerance of brackish conditions may, however, be assumed.

C. *Meso-polyhaline assemblage*

Fabanella is not known from fully marine deposits. Oertli (1963*b*) estimates its range between 5–18°/₀₀, possibly higher.



TEXT-FIG. 9. Presumed salinity tolerances of microfossils from the 'marine bands'. (Classification of brackish waters according to the 'Venice System'.)

Sternbergella (*Parasternbergella*) occurs with *Fabanella*, for this reason it is considered here brackish. Both genera are common in the brackish horizons of the German Wealden (Wolburg 1962, Martin 1961*a*, 1961*b*).

D. *Poly-euhaline assemblage*

Schuleridea (*Eoschuleridea*). Species of this subgenus have been described only from the Bathonian Upper Estuarine Series of Eastern England (Bate 1967). According to Bate (personal communication) these species come from a shallow marine environment with *Ostrea*, although the salinity may have been less than standard. *Schuleridea* s. str. has a wide tolerance of brackish conditions (Oertli 1963*b*, Donze 1960) although it is found predominantly in marine deposits (Morkhoven 1962).

Hutsonia is generally considered a marine/brackish form with most species described from marine deposits (Swain 1946). On the basis of its occurrence in the Weald Clay 'marine bands' we tentatively suggest the same salinity tolerance for *Hutsonia* as for *Schuleridea*. *Ammobaculites* is a typical brackish/marine arenaceous foraminifer found in modern delta and lagoonal environments with salinities between 20–30$^0/_{00}$ (Phleger 1960) but fossil species probably have wider tolerance.

Cirripedia. Modern barnacles are usually marine but tolerate somewhat reduced salinity.

THE AGE OF THE 'MARINE BANDS'

The described marine/brackish microfauna of the 'marine bands' gives little in the way of correlation with other Lower Cretaceous deposits outside the Weald. There is a close affinity with marine/brackish microfaunas from the higher German Wealden (4–6) but the similarity is due to the presence of such long ranging forms as *Fabanella bononiensis*, *Ammobaculites sp.*, etc. Species of more marine character are, however, totally different, *Schuleridea* (*Eoschuleridea*) *wealdensis* sp. nov., *Hutsonia capelensis* sp. nov., and *Cirripedia* in the Weald Clay and species of *Pachycytheridea*, *Galliaecytheridea*, *Protocythere*, *Parexophtalmocythere*, *Schuleridea*, *Cytheropteron*, and *Haplocytheridea* in the Wealden of north-west Germany (Martin 1961*a*).

There is a complete lack of Boreal Lower Cretaceous marine microfauna (Neale 1960, Kaye 1963) in the 'marine bands' of the Weald Clay, indicating the presence of an effective barrier between the marine environment of Northern England and the Weald during the deposition of the 'marine bands'.

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ADDENDUM

F. W. Anderson in two recent papers (1967*a*, *b*) describing ostracods from the Weald and Wadhurst Clays mentions a large number of 'marine' bands from these formations. These marine bands are based on the presence of the so-called 'S-phase species' (e.g. non-*Cypridea* species) and he states that the 'S' and 'C' (*Cypridea*) faunas are antipathetic in vertical distribution. In our opinion only certain genera in the 'S-phase faunas' can be considered as marine-brackish indicators. These are *Fabanella*, *Orthonotacythere*, *Eoschuleridea* (= *Haplocytheridea* of Anderson) and *Sternbergella*. Species of these genera occur together with foraminifera and cirripedes, and are antipathetic to species of *Cypridea*. The rest of the 'S-phase' species in borehole material we examined occur in varying quantities together with species of *Cypridea*, and the variation in the ratio of the *Cypridea* and non-*Cypridea* species may be a function of some other factor than salinity. Some of these 'S-phase' species have living equivalents and the salinity tolerance of these is discussed on pp. 158–9 above. Among the others *Miocytheridea henfieldensis* in our view is a cypridinid ostracod and *Mantelliana mantelli* shows affinity to *Candona* on the basis of its muscle scars. *Theriosynoecum fittoni* is in our view a non-marine ostracod. Allen and Keith (1965) indicated extremely low salinities ($\delta^{13}C = -15{\cdot}33$) from near the top of the Weald Clay (sub-sample 66–382). Professor Allen kindly sent us a piece of this sample; the ostracod fauna consisted almost entirely of *T. fittoni*.

According to our interpretation of the salinity ranges of Wealden ostracod species only three brackish-marine horizons exist in the Weald Clay of Sussex and Surrey. The lowest, in the *dorsispinata* Zone, is doubtful as it only contains *Fabanella bononiensis* but no foraminifera, cirripedes or *Cassiope*, and therefore was not included in our paper. The second in the *tuberculata* Zone is described in detail above while the third horizon, not encountered in the borehole material is found in the *valdensis* Zone near the top of the Weald Clay.

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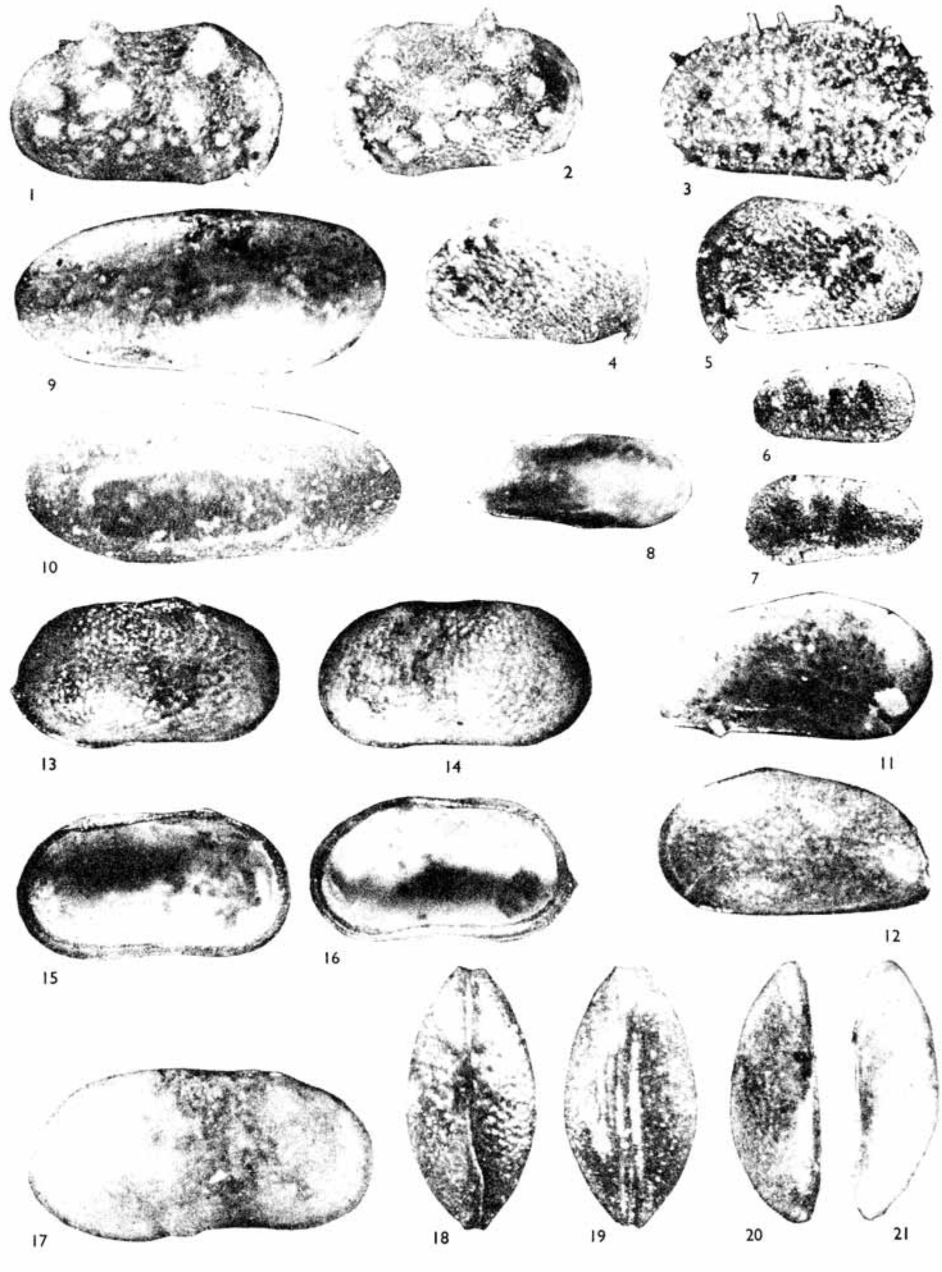

KILENYI and ALLEN, Wealden ostracods

KILENYI and ALLEN, Wealden microfossils