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# The *Aucellina* biostratigraphy of the Upper Albian (Early Cretaceous) of the Kirchrode I cored borehole, Hannover-Kirchrode, northern Germany

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ABSTRACT:

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The *Aucellina* biostratigraphy of the Upper Albian Kirchrode Marls Member succession in the Kirchrode I (1/91) cored borehole is described and the fauna illustrated. The borehole commenced at an unknown depth below the Early Cenomanian marls of the Bemerode Member, but higher beds of the Kirchrode Marls and the basal beds of the Bemerode Member were exposed in the Mittellandkanal and its Stichkanal extension at Misburg. The borehole and surface exposures permit a virtually complete Late Albian succession of *Aucellina* species to be observed. Published *Aucellina* range data from the borehole are reassessed and it is suggested that the lower part of the recorded range is based partly on misidentifications of fragments of thin-shelled bivalves such as *Syncyclonema* and *Amussium*. *Aucellina* appears in the borehole succession within the upper part of the *Callihoplites auritus* ammonite Subzone (*Mortoniceras inflatum* Zone) and continues to the top of the borehole succession within the *Preaeschloenbachia briacensis* ammonite Subzone (*Stoliczkaia* spp. Zone). *Aucellina* from higher in the *briacensis* Subzone collected from the Misburg Mittellandkanal section are also discussed and illustrated.

There is some evidence that *Aucellina* occurs typically at levels in the borehole containing predominantly Boreal European Province ammonites, supporting the general inference that *Aucellina* lived in cooler northern waters. In contrast, *Aucellina* is poorly represented in intervals with Tethyan ammonites and thin-shelled inoceramids (e.g. the *Mortoniceras* (*Durnovarites*) *perinflatum* Subzone, *Stoliczkaia* spp. Zone). The *briacensis* Subzone, with an admixture of Tethyan (*Stoliczkaia*) and Boreal ammonites contains a distinctive, taxonomically highly diverse *Aucellina* assemblage.

Relevant taxonomic research on European Late Albian and Early Cenomanian *Aucellina* faunas is reviewed. The Late Albian *Aucellina* succession in the borehole differs from that established from partially correlative successions in England.

**Key words:** Early Cretaceous; Late Albian; *Aucellina*; Kirchrode Marls; Boreal marine environments.

## INTRODUCTION

Species of the thin-shelled bivalve *Aucellina* provide an important element in Cretaceous biostratigraphy. The genus is typically Boreal in occurrence and thus enables an indication of the ingress of cooler northern waters into the European Province. Two evolutionary phases in *Aucellina* can be identified in the Early Cretaceous. The first extends from the Barremian or Early Aptian and ends in the Early Albian. In Europe, there is an *Aucellina*-free interval between the Early and Late Albian. The second phase (Frieg and Kemper 1990, p.

130), which is the subject of this paper, commences in the Late Albian *Callihoplites auritus* Subzone of the *Mortoniceras inflatum* ammonite Zone and extends throughout the later Albian into the Early Cenomanian. Like the first phase, this second phase is marked by intervals and horizons of mass occurrences of *Aucellina* but, in this second phase, the bivalve faunal diversity is extremely low and the *Aucellina* are associated with thin-shelled pectinaceans such as *Syncyclonema*. The intervals between the occurrences of *Aucellina* contain only small thin-shelled inoceramids which, with very few exceptions, are not associated with *Aucellina*. Whether there is a corresponding preponderance of European Province ammonite species associated with the *Aucellina* intervals, and a preponderance of Tethyan Province forms with the intervening inoceramid intervals, cannot be determined on the available evidence although there is a strong suggestion that this is the case.

The Kirchrode I (1/91) cored borehole, drilled in 1991 for the German contribution to the international ALBICORE Programme, commenced below the base of the Cenomanian Bemerode Member and traversed some 245 m of Late Albian marls belonging to the Kirchrode Mergel Member of the Gault Formation, for which it is the stratotype (Fenner 2001a; Wiedmann and Owen 2001). The borehole, situated in Hannover-Kirchrode (Fenner 2001b, fig. 1), is structurally located in a subbasin of the Lower Saxony Basin, between the Benthe and Lehrte salt diapirs (Fenner 2001a, figs 7, 8) (Text-fig. 1 herein). A second cored borehole, Kirchrode II, drilled in 1994, 880 m from Kirchrode I, commenced at a level some distance below the top of the Kirchrode I succession, and extended the succession below the Kirchrode Mergel into the underlying Middle Albian Minimus Ton Member and the Early Albian Schwicheldt Ton Member.

The sediments of the Kirchrode I borehole are all of Late Albian age ranging, in terms of the ammonite zonal scheme (Owen 2012), from the *Dipoloceras cristatum* Zone up to the *Praeschloenbachia briacensis* Subzone (*Stoliczkaia* spp. Zone) (Text-fig. 2). Compared with Upper Albian successions elsewhere in Europe, the *Callihoplites auritus* Subzone (*Mortoniceras inflatum* Zone) in the borehole is unusually thick (164 m) and was divided by Wiedmann and Owen (2001, p. 165; table 2) into earlier and later parts on the basis of ammonite occurrences. The *auritus* Subzone (lower part) is additionally characterized by shell fragments of the thick-shelled inoceramid bivalve *Inoceramus lissus* (Seeley), whereas the *auritus* Subzone (upper part) is characterized by the occurrence of *Aucellina* and by the absence of inoceramids. A succession of *Aucellina* species ranges through some 80 m of sediment from a level within the upper part of the *Callihoplites auritus* Subzone up to 3 m below the top of the core, within sediments of the *briacensis* Subzone. Sediments of latest Albian age, also belonging to the *briacensis* Subzone, are known to occur above the level of the top of the Kirchrode I core and were exposed in the Mittellandkanal and its Stichkanal at Misburg (Kemper 1990; Owen 1990; Fenner 2001b, fig. 1; Owen 2007, fig. 2). The succession exposed along the Stichkanal extends from the Kirchrode Mergel into the Early Cenomanian Bemerode Member and also contains *Aucellina* (Kemper 1990), but has not been investigated in detail.

The correlation of the *Aucellina* and ammonite successions in the Kirchrode Mergel is important in the interpretation of Upper Albian successions with *Aucellina* in boreholes throughout north Germany (Kemper 1978, 1979, 1984; Elstner and Kemper 1990; Frieg and Kemper 1990). Frieg and Kemper (1990) used the relatively abrupt and, presumed by them to be isochronous, entry of *Aucellina* in washed residues in these boreholes to place a boundary between their 'Oberes Ober-Alb'(with *Aucellina*) and 'Unteres Ober-Alb' subdivisions. Based on the published record of the downward limit of *Aucellina* (Wiedmann and Owen 2001, table 2), this boundary would appear to coincide with the boundary between the lower and upper part of the *auritus* Subzone in the Kirchrode I borehole (Text-fig. 2).

The *Aucellina* and other thin-shelled bivalves were collected by Dr. J. Fenner of the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, from the core of the Kirchrode I borehole. This material was studied at the Natural History Museum London in the context of parallel work carried out on the ammonite biostratigraphy of both the Kirchrode I and II borehole successions (Wiedmann and Owen 2001; Owen 2007). The aim of the present paper is to document the *Aucellina* biostratigraphy of the upper part of the Kirchrode Marls in the Kirchrode I borehole, based solely on the BGR specimens collected from the core and not on published records from lower levels. *Aucellina* material collected from an even higher level in the *briacensis* Subzone exposed in the banks of the Mittellandkanal near Kanalstrasse, Hannover-Misburg, 2 km NNE of the borehole (Kanalstrasse section herein; Text-fig. 1) is also discussed and illustrated.

There is no intention at this point to investigate the taxonomy of the Kirchrode *Aucellina* in a continuation of the earlier work on the *Aucellina* from cored boreholes through Late Albian–Early Cenomanian successions in England (Morter and Wood 1983). Neither this latter material nor the material illustrated from the Bemerode Member (Bemerode-Schichten) of the Misburg Stichkanal and boreholes in the Hannover area by Kemper (1990, pl. 2) has been re-examined in the current investigation. The Upper Albian *Aucellina* biostratigraphy established in England, although relevant to this study, is significantly different from that in the Kirchrode borehole succession. This problem will need to be resolved by a wider systematic taxonomic study of the English and German Late Albian and Early Cenomanian *Aucellina*, which is outside the scope of the present paper and may well necessitate a total reassessment of the taxonomy currently applied.

A significant proportion of the *Aucellina* merited illustration following preparation from the matrix. Like the figured ammonite material from the Kirchrode boreholes (Wiedmann and Owen 2001; Owen 2007), all the figured specimens are referred to herein by their depth in metres in the Kirchrode I borehole or by their height in metres above water level in the Misburg Kanalstrasse section. The specimens are preserved in the BGR collections in Berlin.

## REVIEW OF RELEVANT TAXONOMIC RESEARCH ON LATE ALBIAN AND EARLY CENOMANIAN *AUCELLINA* FAUNAS

Although a systematic taxonomic study of *Aucellina* will not be given here, it is necessary to discuss certain aspects of previous work which affect the interpretation of the Kirchrode Marl succession.

### Polutoff (1933)

Polutoff (1933) provided a comprehensive review of previous work on *Aucellina*, particularly by Pompeckj (1901), Pavlow (1907) and Sokolov (1923). He documented *Aucellina* occurrences from the supposed Upper Albian sediments of the Sieletz [Polish: Sielec] borehole, near Żnin, ca. 35 km SSW of Bromberg [Polish: Bydgoszcz] in northern Poland (Polutoff 1933, fig. 4), and recognised *A*. *gryphaeoides*, *A*. *quaasi* Wollemann, *A*. *krasnopolskii* (Pavlow) and *A*. cf. *parva* Stoliczka. In addition, he established two new taxa. *A*. *gryphaeoides* n. var. *cycloides* was based on two large (25 mm height, 27 mm length), near-circular right valves (Polutoff 1933, fig. 1) from a single depth in the borehole; some specimens from other depths that differed slightly in shape from the two specimens illustrated were questionably also referred to this new variety. *A*. *uerpmanni* sp. nov. was based on a single small (8.5 × 8.5 mm) distinctively shaped right valve, with a disproportionately large anterior auricle relative to the remainder of the valve (Polutoff 1933, fig. 3), which was collected some 12 m higher in the borehole.

It must be emphasised that part, if not all, of the succession attributed by Polutoff to the Upper Albian should probably be assigned to the basal Cenomanian, in that the entry in flood abundance of *Inoceramus crippsi* Mantell used by him to mark the base of the Cenomanian actually indicates the base of the second ammonite subzone (*Mantelliceras mantelli* Zone, *Sharpeiceras schlueteri* Subzone) of the Cenomanian. Furthermore, not only is *Aucellina* relatively common in the underlying *Neostlingoceras carcitanense* Subzone elsewhere, but some of the other macrofossils recorded from the ‘Upper Albian’ of the borehole – notably the belemnite *Neohibolites* sp. juv. cf. *ultimus* d’Orbigny – are much more suggestive of the Cenomanian than the Albian.

### Morter and Wood (1983)

Morter and Wood (1983) reviewed the previous history of research and the existing Upper Albian–Cenomanian *Aucellina* taxa in their study of the *Aucellina* biostratigraphy of Upper Gault (Upper Albian) mudstone and basal Chalk (Cenomanian) successions of southern and eastern England. Their material came largely from the Cambridge Greensand at the base of the Chalk, and from cored boreholes with excellent ammonite- and inoceramid bivalve-based biostratigraphical control. The lower part of the Cambridge Greensand is rich in phosphorites and contains reworked *Aucellina* that are partly phosphatized, uncrushed and preserved in three dimensions, with the valves still associated. The best specimens retain extensive areas of the shell. The neotype of *Aucellina gryphaeoides* (Morter and Wood 1983, fig. 3a, pl. 1, fig. 5) is preserved in this manner and is inferred to come from this level. The higher part of the Cambridge Greensand lacks the phosphorites and contains indigenous, unphosphatized *Aucellina*. It should be noted that although the Cambridge Greensand yields reworked phosphatized ammonites derived from Upper Albian ammonite zones ranging from the earlier *auritus* to *rostratum* Subzones (Gallois, Morter and Owen in prep.), the phosphatized and indigenous *Aucellina* from this bed could be either Upper Albian or basal Cenomanian.

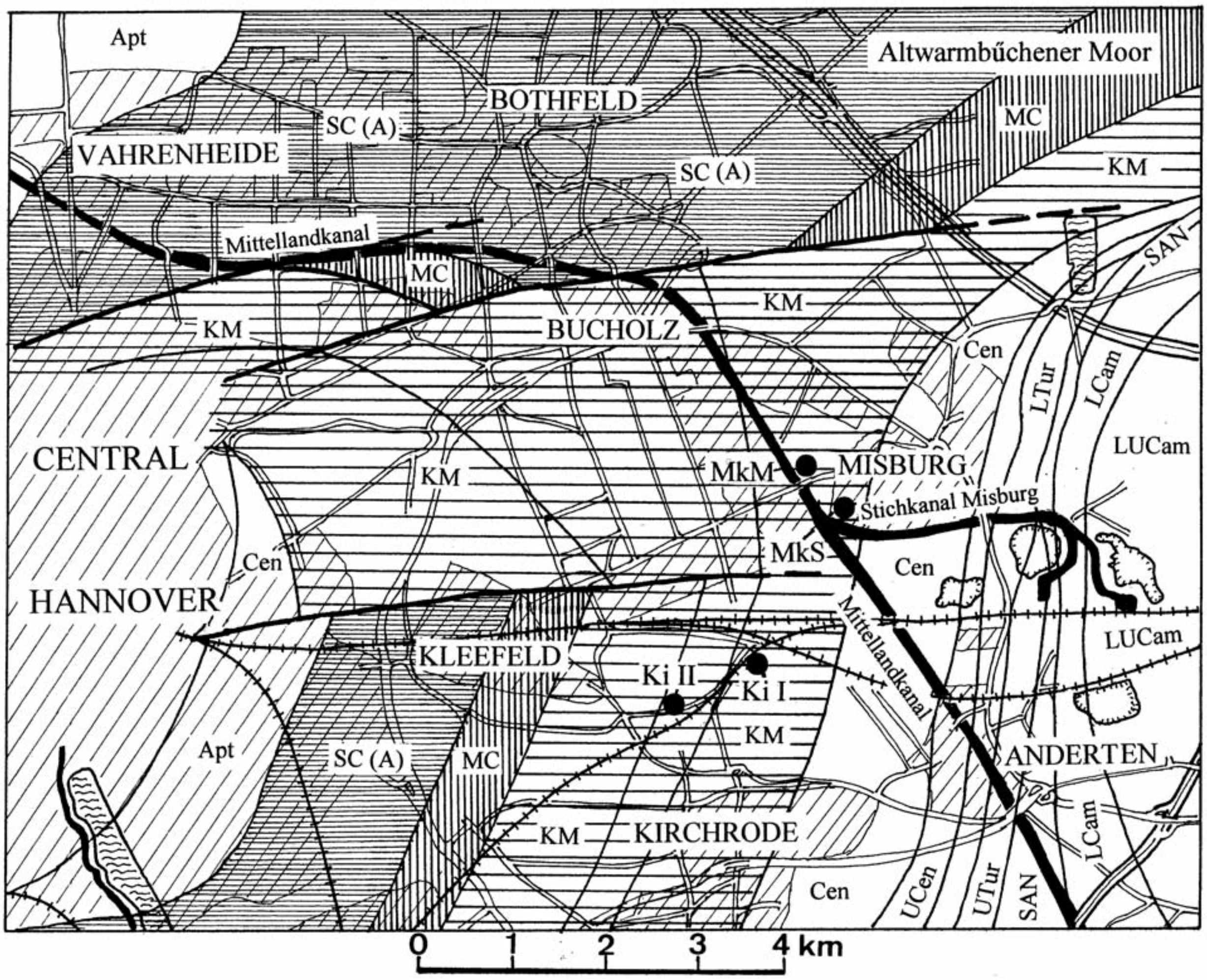
In addition to *A. gryphaeoides*, Morter and Wood (1983) also recognised small forms in the Cambridge Greensand that they attributed to *A. krasnopolskii*, as well as larger, elongate *Buchia*-like narrow forms similar to *A. coquandiana* (d’Orbigny, 1846), a taxon originally described from the ‘Vraconian’ (Upper Albian) of Escragnolles in the south of France, and commonly considered to be conspecific with *A.*

*gryphaeoides.* Like Polutoff (1933) in his study of the Sieletz borehole, Morter and Wood (1983) recognised in their material *A. gryphaeoides* var. *cycloides* and *A. uerpmanni*, the two latter taxa for the first time outside eastern Europe. They recorded the former taxon from *rostratum* Subzone sediments of boreholes in eastern England. In particular, by finding the two valves in association in basal Cenomanian sediments in both southern and eastern England (cf. Morter and Wood 1983, fig. 3b, pl. 1, fig. 15), they were able to identify the left valve of *A. uerpmanni,* which is significantly different from that of *A. gryphaeoides.* A left valve of *A. uerpmanni* from the basal Cenomanian 'Tourtia' of Lüneburg in Germany had, in fact, previously been illustrated by Wollemann (1902, pl. 3, fig. 2a) as *A. gryphaeoides.*

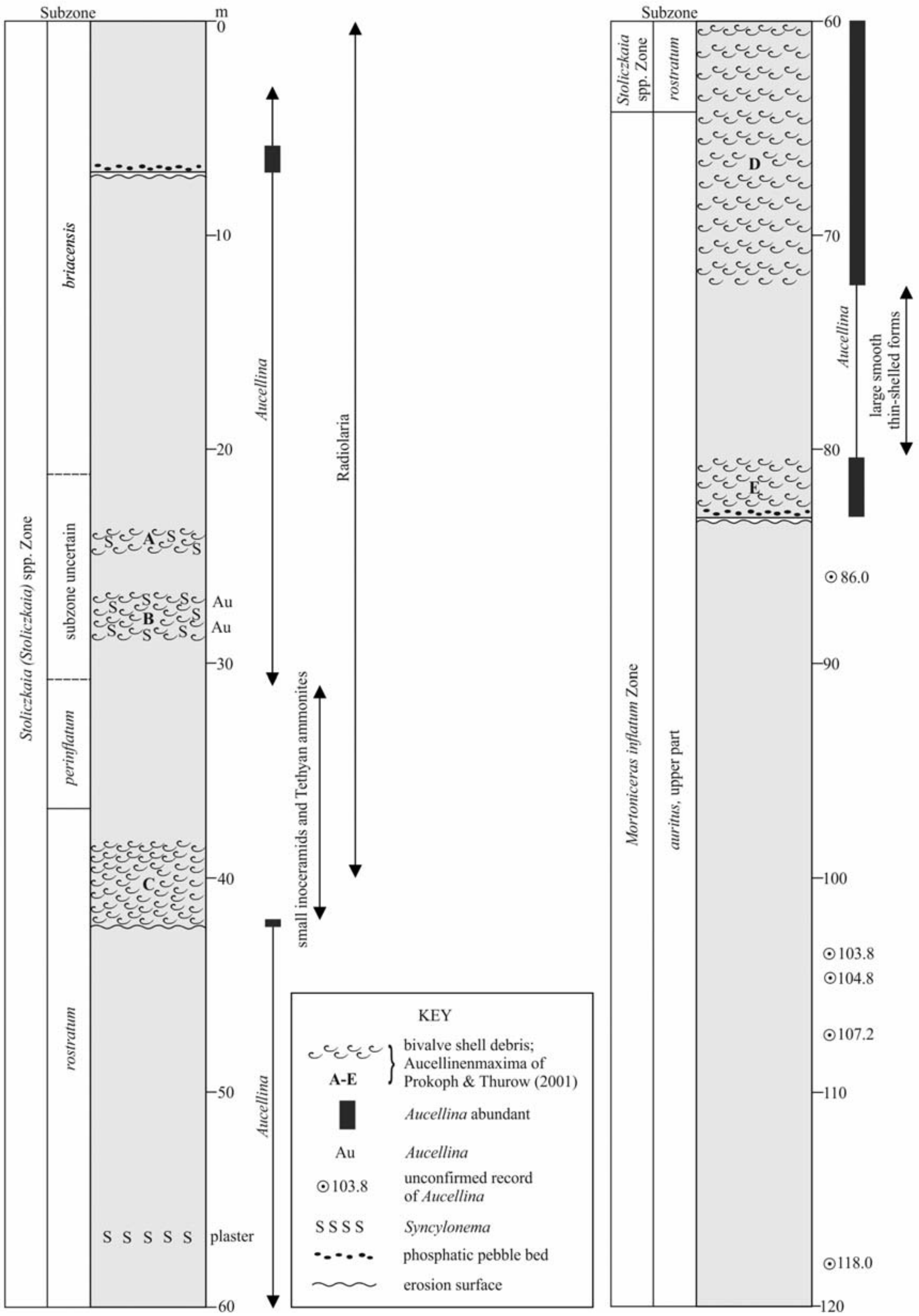
*The* gryphaeoides *and* uerpmanni *morphotypes*

Morter and Wood (1983, fig. 3) showed additionally that two distinct *Aucellina* morphotypes, named by them the *gryphaeoides* and the *uerpmanni* morphotypes, could be recognized in the Upper Albian–basal Cenomanian successions of southern and eastern England. The two morphotypes appeared to co-occur throughout the succession yielding *Aucellina,* in an analogous, and similarly inexplicable, manner to the broad (*pachti*) and narrow (*cardissoides*) morphotypes of the inoceramid bivalve genus *Sphenoceramus* in the Santonian and basal Campanian of northern Europe.

The left valve of the *gryphaeoides* morphotype is generally much more obliquely (postero-ventrally) elongate and thinner shelled than that of the *uerpmanni*




Text-fig. 1. Locality map of the Hannover area with superimposed solid geology and positions of the Kirchrode I and II borehole sites, the Mittellandkanal Stichkanal at Misburg MkS and the Mittellandkanal section at Misburg MkM (from Owen 2007). Built up areas are shown in faint inclined hatching. Sub-Tertiary/Quaternary outcrop is shown east of central Hannover – Albian sediments are shown ruled. Sedimentary unit identifications are as follows: Apt – Aptian; SC(A) – Schwicheldt Ton Member (close horizontal ruled); MC – Minimus Ton Member (close vertical ruled); KM – Kirchrode Mergel Member (open horizontal ruled). Upper Cretaceous sediments shown un-ruled: Cen – Lower and Middle Cenomanian; UCen – Upper Cenomanian; LTur – Lower Turonian; UTur – Upper Turonian; SAN – Santonian; LCam – Lower Campanian; LUCam – lower Upper Campanian




Text-fig. 2. Outline section of the upper part of Kirchrode I borehole to show ammonite biozonation, range of radiolaria in the sediment and the ranges and abundance of *Aucellina*. A to E are the *Aucellina* Maxima recognised in the original log of the borehole by Prokoph and in Prokoph and Thurow (2001). Note that in terms of actual specimens collected, Maxima A and B correspond to abundance levels of *Syncyclonema,* with only a single thin abundance level of *Aucellina* near the top of Maximum B morphotype. The flange-like concentric ornament weakens and tends to disappear almost completely as it crosses the valve from the anterior margin, to be replaced by predominantly radial sculptural elements, only to reappear at the posterior margin. The top of the anterior ear turns down at an oblique angle from the anterior margin. The obliquely elongate right valve possesses a narrow, diminutive anterior auricle.

The left valve of the *uerpmanni* morphotype is characterised by a thicker shell than that of the *gryphaeoides* morphotype, with a more strongly developed flange-like concentric ornament that is continuous in strength from the anterior to the posterior margin of the left valve. The valve is typically triangular, reminiscent of the Triassic taxon *Pseudomonotis speluncaria* Schlotheim, with a marked posterior sulcus and an anterior ear that protrudes at right angles from the anterior margin. The anterior auricle of the right valve is much larger relative to the remainder of the valve than that of the *gryphaeoides* morphotype and the valve tends to be posteriorly truncated.

### *Microsculpture*

In their generally well preserved material in mudstones and chalks, Morter and Wood (1983) additionally recognised a stratigraphical succession of distinctive types of microsculpture of the shell of the left valve, particularly in the umbonal region, which they illustrated by SEM photographs (Morter and Wood 1983, pl. 2). The microsculpture was observed in both morphotypes, but developed to a different extent. *Aucellina* from the base of the *auritus* Subzone (lower part) possessed a microsculpture consisting of coarse concentric flanges crossed by radial elements to produce a reticulate pattern; in addition, the otherwise weakly ornamented umbonal region showed widely spaced raised ribs (Morter and Wood 1983, pl. 2, fig. 8). In contrast, *Aucellina* from the top beds of the higher part of the *auritus* Subzone, and from the base of the overlying *Stoliczkaia* spp. Zone, lacked this microsculpture and possessed a shell that they described as ‘smooth’. In the higher part of the *rostratum* Subzone, the *Aucellina* left valves showed a reticulate microsculpture of prominent, irregular, widely spaced concentric flanges, traversed by widely spaced radial raised elements (Morter and Wood 1983, pl. 2, figs 3, 4). Possession by an *Aucellina* of any one of these three types of microsculpture allows unequivocal assignment to the Albian, rather than to the Cenomanian.

In marked contrast, the undated (Upper Albian–basal Cenomanian) neotype of *A. gryphaeoides* from the phosphorite-rich part of the Cambridge Greensand showed a microsculpture of fine, closely spaced incised radial striae (Morter and Wood 1983, pl. 2, figs 1a, b). In indigenous *Aucellina* from the higher part of the Cambridge Greensand and particularly from the basal part of the Chalk in eastern England, this fine radial microsculpture was much more strongly developed and was traversed by relatively closely-spaced concentric elements to produce a reticulate pattern (Morter and Wood 1983, pl. 2, figs 5, 6a, b). This latter type of microsculpture was also seen in material from the basal Cenomanian ‘Tourtia’ at Lüneburg-Zeltberg quarry in northern Germany (Morter and Wood 1983, pl. 2, fig. 7).

### **Bertram and Kemper (1971)**

Bertram and Kemper (1971, pl. 3, figs 7–14) published photomicrographs of *Aucellina* fragments from washed residues taken from the Upper Albian sediments of boreholes in the Hannover area in northern Germany. With the exception of one figure, these were all of right valves and showed the distinctive comb-like row of small tubercles (ctenolium) on either side of the byssus groove between the anterior auricle and the remainder of the valve. Kemper (1989, pl. 2) published SEM photographs of exceptionally well preserved left and right valves of extreme juvenile *Aucellina* in washed residues from the top of the Upper Albian and basal Cenomanian sediments of Lüneburg. He also illustrated a probable adult bivalved specimen (pl. 2, figs 8) from the Upper Albian (*Stoliczkaia* spp. Zone) marls of the Mittellandkanal near Misburg, as well as a right valve (pl. 2, fig. 9) suggestive of *A. uerpmanni*.

## DEVELOPING TECHNIQUES

All the specimens and the surrounding matrix had been hardened with the proprietary product CAPAPLEX in the BGR prior to being received in the NHM. This comprises an artificial resin suspended in an aqueous medium. This treatment produces a shiny protective layer that is not possible to remove using solvents. *Aucellina* treated in this way generally proved difficult or impossible to develop. The majority of specimens illustrated in this paper were originally exposed only to a limited extent and were developed by cutting away the hardened matrix with a scalpel, followed by carefully and repeatedly dampening the matrix with a drop of water. This allowed the matrix to partially disaggregate, after which it was removed using a fine brush and fine needles. Care needed to be taken not to allow water to pass between the matrix of the internal mould and the shell, as this tended to enhance any fine, albeit invisible, existing micro-cracks in the shell. No treatment of the

*Aucellina* and other fossils subsequent to development has taken place.

The *Aucellina* in the *briacensis* and *perinflatum* subzones, and in the highest three metres of the *rostratum* Subzone, are preserved in a relatively indurated marlstone which is particularly difficult to develop. At circa 40 m depth, close to the top of the *rostratum* Subzone, there is a noticeable change, in that the matrix suddenly becomes much less intractable. This is attributable to the fact that the sediment above this level contains a significant proportion of radiolaria, preserved either as calcium carbonate or pyrite casts of the tests, indicating an increase in marine plankton productivity. At and above 7 m depth, the siliceous skeletons of radiolaria and diatoms become increasingly abundant and better preserved, indicating a further increase in productivity (Fenner 2001b).

## PRESERVATION AND TAPHONOMY

The *Aucellina* occur either as isolated individuals, scattered individuals in relatively close proximity, or as plasters. Some plasters may consist of a predominance of right valves (e.g. Pl. 5, Fig. F). At levels with concentrations of *Aucellina*, there is no evidence of any preferred orientation or of way-up ('convex-up' versus 'convex-down') preservation in the sediment.

The left and right valves are commonly separated, particularly in the case of the plasters, but there are many horizons at which the two valves are in association. In many cases this is not immediately apparent, but becomes first revealed on removing the matrix from the exposed valve. The disc-like right valves are generally undistorted through compaction and much better preserved than the more inflated, gryphaeate left valves. The left valves are commonly either more or less flattened through compression, or even additionally sheared over onto the anterior margin. In only very few specimens was it possible to reveal the distinctive anterior auricle morphologies characteristic of the *gryphaeoides* and *uerpmanni* morphotypes respectively.

Compared with the well preserved English material, the Kirchrode I *Aucellina* are less well preserved and very few specimens show any indication of microsculpture of the umbonal region of the left valve. In general, with the exception of material from the *briacensis* Subzone, the ornament on the left valve is weak and the surface of the shell shows signs of corrosion. This feature coincides with associated corrosion of aragonitic ammonite shells or their complete removal being replaced by pyritic films on mudstone casts. The tendency for the matrix to crack on drying has led to fragmentation of some of the *Aucellina.* In some cases, the highest part of the internal mould of the right valves has become detached from the remainder of the mould along a conchoidal fracture surface. In addition, diminutive cones of mineral matter (presumably salt) have formed both on the surface of the matrix surrounding the shells and on the internal and external moulds. Both of these features are shown by the right valve illustrated in Pl. 6, Fig. K. These microscopic salt crystals suggest increased saline concentrations in the sediments during diagenesis.

## STRATIGRAPHICAL RANGE OF *AUCELLINA* IN THE KIRCHRODE I BOREHOLE

Wiedmann and Owen (2001) divided the *Callihoplites auritus* Subzone succession into lower and upper intervals based upon ammonite occurrences. Their boundary between the early and late *auritus* Subzone sediments was placed between 126.22 m and 129.24 m depths. There is a problem in the recorded range of *Aucellina* in the Kirchrode I core. Wiedmann and Owen (2001) followed the determinations of *Aucellina* from the original British Plaster Board Co. log of this borehole taken by Prokoph (Prokoph and Thurow 2001) and recorded the range from 0 to 130 m depth, the latter depth being within the topmost early *auritus* Subzone sediments. Owen (2007) recorded the range from 0–80 m depth in the Kirchrode II core, a position well within early *auritus* sediments. Fenner (2001 b, c) divided the higher part of the Kirchrode I borehole succession of the Kirchrode Mergel into three facies units. In descending order, these comprised (i) a unit with large radiolaria down to 40 m depth; (ii) a unit from 40 m to ca. 85 m depth in which *Aucellina* was of common occurrence; (iii) a unit from ca. 85 m to ca. 170 m depth in which *Aucellina* was rare. Wiedmann and Owen (2001) also recorded an *Aucellina* with an ammonite at 104.78 m, but this was based on a mis-identification of a *Syncyclonema.* The range of *Aucellina* in the Kirchrode I core determined by the author based on actual specimens collected does not extend below a depth of 83.18 m i.e. within the upper part of the *auritus* ammonite Subzone. This interval corresponds to the common occurrence of *Aucellina* recorded by Fenner (2001 b, c). The present study shows that records of *Aucellina* in the earlier part of the *auritus* Subzone are based on specimens of *Syncyclonema* and *Amussium* incorrectly identified as *Aucellina* species by these authors. All of the other thin-shelled bivalves below 83.18 m depth belong to *Amussium* (135.17 m, 144.63 m, 151.11 m, 155.16 m, 163.32 m, 168.67 m, 180.02 m depths), *Syncyclonema* or related pectinacean (104.15 m, 104.78 m, 105.05 m, 121.44 m, 129.50 m, 145.96 m, 160.14 m depth) or to small, extremely thin-shelled inoceramids (158.12 m, 158.19 m, 158.56 m depth) (Appendix 1). No specimens correspond to the records of *Aucellina* in the early part of the *auritus* Subzone at ca. 120 m and ca.190 m depth given by Prokoph and Thurow (2001, fig. 2).

The proven range of *Aucellina* in the Kirchrode cores has important implications for the dating of Upper Albian sequences elsewhere in Germany. If the range of *Aucellina* established here for the succession in Kirchrode I applies equally to other areas of north-west Germany, the boundary between the Unteres Ober-Alb and Oberes Ober-Alb of Kemper (e.g. 1978) must be placed within the late *auritus* Subzone sediments, not earlier as suggested by Wiedmann and Owen (2001), Prokoph and Thurow (2001) and Fenner (2001b). In East Anglia (eastern England), within the early part of the *auritus* Subzone, *Inoceramus lissus* (Seeley) is a characteristic large bivalve, this is followed by an interval devoid of either *lissus* or *Aucellina* but with other thin-shelled bivalve genera. Above, common *Aucellina* specimens occur in sediments of later late *auritus* and *Mortoniceras rostratum* age. This is very similar to the situation seen in the Kirchrode cores where Wiedmann and Owen (2001) indicate the range of *I. lissus* within the early *auritus* Subzone. This range taken together with the proven range of *Aucellina* determined here shows a close comparison between East Anglia and northern Germany.

## *AUCELLINA* MAXIMA AND GAPS WITH NO *AUCELLINA* RECORDS

Four acme-occurrence intervals (Aucellinenmaxima), designated A to E in descending stratigraphical order, were recognised by Prokoph in the original log and by Prokoph and Thurow (2001). Maxima A and B are in the subzonally uncertain interval between proven *Praeschloenbachia briacensis* Subzone at 21.10 m and proven *Mortoniceras rostratum* Subzone at 36.90 m; maximum C is in the *rostratum* Subzone; maximum D spans the lowest ca. 4 m of the *rostratum* Subzone and the top ca. 8 m of the *Callihoplites auritus* Subzone (upper part); maximum E lies within the upper part of the *auritus* Subzone (upper part). In the published paper (Prokoph and Thurow 2001), these four *Aucellina* maxima, and three inoceramid bivalve maxima (F, G, H) lower in the succession, were collectively termed bivalve maxima. The original *Aucellina* maxima were linked by Prokoph and Thurow (2001, p. 93, fig. 17 to condensation horizons associated with the bases of 200 ka cyclostratigraphic cycles.

Although this was not made entirely clear by those authors, it is presumed here that the four *Aucellina* maxima relate to numbers of *Aucellina* shell fragments per gram of sediment rather than to levels containing relatively complete shells. This is suggested by the fact that no *Aucellina* from the highest maximum (A) are represented in the material investigated. It is also probable that shell debris belonging to other thin-shelled bivalves (notably *Syncyclonema*, *Amussium* and inoceramids) has been included in the *Aucellina* count.

Analysis of these maxima based on the material actually collected (see below), rather than on shell fragments in washed residues, suggests that maxima B and C are maxima of thin shelled bivalves (including *Aucellina*), and that only relatively restricted intervals within these maxima correspond to true *Aucellina* maxima. On the other hand, maximum D clearly corresponds to an *Aucellina* maximum, and the same applies to the upper part of maximum E. *Aucellina* is also well represented between maxima C and D, and between maxima D and E.

Maximum A (c. 1 m, from c. 23.8 m depth to c. 24.8 m depth): no specimens of *Aucellina* apparently collected; *Syncyclonema* at 24.82 m depth.

The 1.9 m interval between maxima A and B

25.21 m depth: *Aucellina* RV juv. interior
25.32 m depth *Syncyclonema*
26.02 m depth: *Aucellina*, *gryphaeoides* morphotype LV (Text-fig. 2B); echinoid fragment
26.36 m depth: *Syncyclonema*

Maximum B (c. 2.2 m, from 26.7 m to 28.9 m depth): *Aucellina* at 27.48 m and 27.53 m depth; then at 28.91 m depth; common *Syncyclonema* at 27.71 m, 27.91 m (plaster), 28.05 m and 28.51 m depths.

At the top of the interval (28.9 m to c. 38.3 m depth) between maxima B and C, specimens of *Aucellina* were collected down to 31.06 m depth.. A record of *Mortoniceras* (*Cantabrigites*) sp. at 30.72 m (Wiedmann and Owen 2001) is inferred to correspond to a Tethyan incursion near the base of this interval. Below 31.06 m depth there is a 10.95 m interval virtually without *Aucellina* down to the next horizon with common *Aucellina* at 42.01 m depth, near the base of maximum C. It is noteworthy that this latter virtually *Aucellina*-free interval includes six records of Tethyan ammonites (32.52 m, 35.60 m, 36.41 m, 36.87 m, 39.13 m and 40.15 m depths; Wiedmann and Owen 2001) and that (with the exception of an *Aucellina* left valve shell fragment at 32.02 m depth ) the only bivalves collected are thin-shelled inoceramids which are similar to, or conspecific with, the forms described from the expanded Upper Albian succession in the Vocontian Trough in southern France (cf. Gale in Gale *et al*. 1996, pp. 527, 529, figs 21f, j; 31g, h).

Maximum C (c. 4 m, from c. 38.3 m to 42.3 m depth): *Aucellina* only in the basal 30 cm, at 42.01–42.03 m, 42.15 m, 42.29 m and 42.30 m depths; small thin-shelled inoceramids at 38.95 m, 39.02 m, 39.05 m, 39.41 m and 39.63 m depths. Note that no *Aucellina* are represented in the collection from the interval with thin-shelled inoceramid bivalves.

Maximum D (12. 6 m, from 60 m to 72.6 m depth): *Aucellina* very well represented).

Maximum E (5.5 m, from 80.2 m to 85.7 m depth): *Aucellina* at 80.38–39 m, 80.63–80.65 m; 81.45 m, 81.80 m and 83.18 m (plaster); no *Aucellina* or any other bivalves appear to have been collected from the lowest circa 2.5 m of the interval.

Based on specimens collected, there are also intervals with no *Aucellina* record, but with thin-shelled inoceramids only (top two-thirds of maximum C in the *rostratum* Subzone) or *Syncyclonema* only (maximum A and centre of maximum B in the subzonally uncertain interval between the *briacensis* and *perinflatum* Subzones). With very few exceptions (with *Amussium* at 51.04 m depth; with *Syncyclonema* at 56.98 m depth, both in the *rostratum* Subzone), *Aucellina* appears not to co-occur with other bivalves in these low-diversity faunas.

From 39 m depth to 1.5 m depth (including maxima C, B and A in one 200 ka cycle), there is an increase in bioturbation and carbonate content, redeposition (see Prokoph and Thurow 2001, fig. 2), condensed horizons and a high content of radiolarians; this is related to an inferred regressive facies and a relative sea level fall (Prokoph and Thurow (2001, pp. 94, 95). The interval from 132 m to 39 m depth, on the other hand is inferred to represent relatively deep water.

## ANALYSIS OF *AUCELLINA* IN THE KIRCHRODE I BOREHOLE

### Size

With the exception of some large, thin-shelled, bivalved specimens from close to the bottom of the succession with *Aucellina*, most of the *Aucellina* in the Kirchrode I borehole core are relatively small sized. It is unclear whether the small size is attributable to the differential preservation of early ontogenetic stages and juvenile individuals only, or whether environmental conditions limited growth beyond a certain size. Not only are the individuals generally small sized, but even in the case of the larger (and presumably more mature) individuals, distortion through compaction and lateral shearing has rendered the majority of specimens difficult to investigate in terms of their original morphology.

### Morphotypes

Both the *uerpmanni* and *gryphaeoides* morphotypes established by Morter and Wood (1983) in the English Albian–Cenomanian successions are present in the Kirchrode I material and in the material from the Kanalstrasse section on the Mittellandkanal. However, the two morphotypes in the material investigated can only be distinguished by the distinctive features of the left valves. Although several different types of right valves which might be attributable to one or the other morphotype are present (see discussion below), the well preserved specimens are invariably isolated. Where an exposed right valve is actually associated with a left valve of a bivalved specimen still buried in the matrix, in no case has it proved possible to develop the left valve in order to identify the morphotype. This is because of the extreme fragility of the specimens concerned and the fact that no hardening agent was used. The same problem applies to exposed left valves of bivalved specimens with a buried right valve. It is noteworthy that the bivalved specimens appear to belong almost exclusively to the *gryphaeoides* morphotype

The *uerpmanni* morphotype in the Kirchrode I material can be determined in the left valves from the overall triangular morphology, the development of a strong posterior sulcus and the continuous concentric ornament (cf. Pl. 2, Fig. I). Generally, it is the presence of a posterior sulcus that enables the immediate identification of this morphotype, for the continuous concentric ornament is not always clear on the shell and is indistinct on the internal mould, whereas the sulcus is always conspicuous on the internal mould, (e.g. Pl. 4, Fig. D). In a few cases, it has proved possible to observe the distinctive anterior auricle (Pl. 2, Fig. M; Pl. 4, Fig. G)

The *gryphaeoides* morphotype can also be distinguished in the left valves from the obliquely, posteroventrally elongated shape, the irregular development of the concentric ornament, the clearly defined posterior auricle and the non-sulcate (or only extremely weakly sulcate) posterior margin. The *gryphaeoides* morphotypes are generally significantly larger and thinner shelled than the *uerpmanni* morphotypes. In many cases they are bivalved, whereas the *uerpmanni* morphotype seems to be represented by isolated valves. In only very few cases has it been possible to observe the distinctive downturned anterior auricle (Pl. 4, Figs F, L, O). The contrast between the early ontogenetic or juvenile stage of *the gryphaeoides* morphotype left valve (Pl. 4, Fig. F) and the equivalent *uerpmanni* morphotype left valve (Pl. 4. Fig. G) is particularly instructive.

Although the two morphotypes co-occur throughout the succession (e.g., Pl. 1, Fig. N from the *briacensis* Subzone; Pl. 2, Figs H–J, L–O from the *rostratum* Subzone; Pl. 4, Figs B, D from the *auritus* Subzone, upper part), there are some horizons with a predominance of small-sized left valves of the *uerpmanni* morphotype that could almost be described as *uerpmanni* bioevents.

**Assemblages**

There is a clear separation between the *Aucellina* of the *briacensis* Subzone (Pl. 1) and those from the rest of the succession. The *briacensis* subzonal assemblage, down to circa 7 m depth, is characterised by much more strongly ornamented shells, notably the left valve with widely spaced concentric flanges (top left specimen in Pl. 1, Fig. J). The assemblage is additionally characterised by a distinctive narrow, obliquely elongate right valve with a small, strongly upturned anterior auricle (Pl. 1, Figs F–H). This type of right valve is reminiscent of *Buchia* rather than *Aucellina* and is also found in the higher part of the same subzone in the Kanalstrasse section on the Mittellandkanal (Pl. 6, Fig. M).

The assemblage at 7.17 m depth in the borehole (*briacensis* Subzone) is remarkable in view of the diversity of morphotypes in association (Pl. 1, Fig. I). This horizon is located just above a surface with phosphate and glauconite that marks an uphole increase in the proportion of radiolaria in the sediment (Fenner 2001b). In addition to a specimen of the *Buchia*-like right valve (Pl. 1, Fig. H), and two strongly ornamented, inflated, left valves (Pl. 1, Fig. J), tentatively attributed to the *gryphaeoides* and *uerpmanni* morphotypes respectively, there is also an obliquely elongate left valve of the *gryphaeoides* morphotype, (Pl. 1, Fig. L) with an extremely fine concentric microsculpture on the tip of the umbo (Pl. 1, Fig. M). The *uerpmanni* morphotype left valve (bottom right in Pl. 1, Fig. J) is similar to the left valve from the Kanalstrasse section (Pl. 6, Fig. A).

Large, thin-shelled *Aucellina* occur in the *auritus* Subzone (upper part) at 73.38 m (Pl. 3, Fig. I), 76.32 m (Pl. 3, Fig. M), 76.45 m (Pl. 3, Fig. N) 78.64 m (Pl. 3, Fig. O), 80.38–80.39 m (Pl. 3, Fig. P) and 80.63–80.65 m depths (Pl. 4, Fig. C). Essentially, these occurrences are in the interval between maxima D and E of Prokoph and Thurow 2001). The specimen from 78.64 m shows all the features (loss of ornament) associated with the inferred cool phase in England at the base of the *Stoliczkaia* spp. Zone. This is a large individual; the specimen from 80.38–80.39 m depth is even larger. Such large forms are not known from the *auritus* Subzone in England.

The left valves from the late *auritus* Subzone appear to include more quadrate forms of the *gryphaeoides* morphotype (e.g. Pl. 3, Fig. J) in addition to the more usual posteroventrally elongated valves. It is unclear whether or not this is a distortion effect resulting from compaction. There is also a left valve with exceptionally fine concentric microsculpture on the anterior margin (Pl. 3, Fig. K)

**Right valves**

There is a considerable diversity of right valve morphology among the *Aucellina* investigated. Unfortunately, the majority of right valves are isolated and detached from the corresponding left valves. This means that in no case has it proved possible to attribute right valves unequivocally to one or the other (*gryphaeoides* or *uerpmanni*) morphotype. Nevertheless, there are posteroventrally elongated valves that are suggestive of the *gryphaeoides* morphotype and smaller, posteriorly truncated valves, that are likewise suggestive of the *uerpmanni* morphotype. However, there is no evidence of the clear distinction between valves with small, narrow anterior auricles (*gryphaeoides* morphotype) and those with an upturned, disproportionately large anterior auricle (*uerpmanni* morphotype) found in the English material (cf. Morter and Wood 1983, fig. 3). It is possible, however, that this clear distinction, particularly in the case of the *uerpmanni* morphotype, applies to stratigraphically younger material than any investigated from the Kirchrode I borehole. The isolated right valve of *Aucellina uerpmanni* described from the Sieletz borehole, Poland, by Polutoff (1933) is probably from the basal Cenomanian and that is certainly true of the right valve of the bivalved specimen illustrated by Morter and Wood (1983, fig 3b, pl. 1, fig. 15).

A right valve that shows all the features of the *gryphaeoides* morphotype is illustrated in Pl. 5, Fig. A. Note the oblique growth axis, the posteroventral elongation and the fact that the anterior auricle is small, narrow and does not extend to the anterior margin of the valve. The right valve shown in Pl. 5, Fig. E is also of this type. These valves, in particular that shown in Pl. 5, Fig. A, can be contrasted with the valve illustrated in Pl. 5, Fig. C, which is subrectangular in outline, with a markedly truncate posterior margin and an anterior auricle that extends to the anterior margin. This valve can perhaps be attributed to the *uerpmanni* morphotype, although as noted above, it does not compare particularly well with right valves from stratigraphically younger (Cenomanian?) levels. Two diminutive (extreme juvenile?) right valves from the same horizon (Pl. 5. Figs N, O) show the contrast between the posteriorly obliquely elongate and the posteriorly truncate outline respectively. The right valve interior views (Pl. 5, Figs J, K) are posteriorly markedly truncate, and are strongly suggestive of the *uerpmanni* morphotype. However, the distinction between the two morphotypes may be somewhat more complicated than that described above. For example, the right valve (Pl. 5, Fig. C) that is possibly attributable to the *uerpmanni* morphotype differs in outline from that shown in Pl. 5, Figs L, M. The former has a relatively small anterior auricle, no posterior auricle and a truncated posterior margin. The latter, on the other hand, combines a disproportionately large anterior auricle with a well separated posterior auricle and a slightly oblique growth axis. Unfortunately, in no case has it proved possible to separate right valves from the matrix so that both the exterior and interior views of the same valve could be illustrated.

## KANALSTRASSE SECTION, MITTELLANDKANAL

Two km NNE of the Kirchrode I borehole (Owen 2007, fig. 2), specimens of *Aucellina* were collected from mudstones close to the top of the Kirchrode Marl Member exposed in the banks of the Mittellandkanal at the corner of Mühlenweg and Kanalstrasse. The section at this locality is inferred to lie not far below the base of the Cenomanian Bemerode Beds. Collections were made from three levels: at water level; two metres above water level; and from more than two metres above water level (see skeletal section measured from the top downwards in Owen 2007, fig. 4). Some of the *Aucellina* from these surface exposures are surprisingly well preserved. *Aucellina* preserved in hard sediment, particularly from the horizon at water level, have wafer-thin, transparent shells; material from more friable sediment is much less well preserved. Both the *gryphaeoides* and *uerpmanni* morphotypes are represented. In the *gryphaeoides* morphotype, the ornament consists of medium-spaced, thin concentric flanges that weaken towards the centre of the valve, where they are crossed by strong radial elements. The umbonal region of a small left valve in the highest sample shows a fine concentric microsculpture (Pl. 7, Fig. H).

The size, wafer-thin shell, ornament and microsculptural details of the *Aucellina* left valves do not match particularly well any encountered in the material from the highest part of the Kirchrode I borehole. However, the highest circa 3 m of the borehole succession is not represented in the *Aucellina* material investigated in this study. Even the highest part of the borehole succession with *Aucellina* yields only either extremely small individuals or isolated earliest ontogenetic stages, in either case with a different microsculpture from any seen in the Kanalstrasse section. The first medium-sized *Aucellina* in the borehole appear in the plaster at 7.17 m depth and include a form with widely spaced concentric flanges that is not represented in the Kanalstrasse assemblage

In addition to the forms described above, the *Buchia*-like form recorded from the assemblage at ca. 7 m depth in the *briacensis* Subzone in the Kirchrode I borehole is present (Pl. 6, Fig. M), as is the diminutive coarsely ornamented early ontogenetic stage (Pl. 7, Fig. H) found even higher in the borehole.

It is clear that the Kanalstrasse section, with its distinctive *Aucellina* assemblage, must lie stratigraphically above the highest levels in the borehole yielding *Aucellina.* This interpretation is supported by the occurrence in this section, but not so far found in the borehole, of the subzonal index ammonite *Praeschloenbachia briacensis* (see Owen 2007), indicative of the higher part of the *briacensi*s Subzone.

It must be emphasised that there is no evidence in the *Aucellina* material from the *briacensis* Subzone of the Kanalstrasse section of the fine striate microsculpture found in derived topmost Albian and/or basal Cenomanian *Aucellina* from the Cambridge Greensand in England or of the advanced striate reticulate microsculpture shown by *Aucellina* from the basal Cenomanian marlstones at Lüneburg in northern Germany (see Morter and Wood 1983)

## DISCUSSION

The preservation of the *Aucellina* material in the borehole is significantly poorer than that of the material investigated earlier by Morter and Wood (1983) from cored boreholes through the Upper Albian Gault mudstones and basal Cenomanian Chalk in eastern and southern England.

Although the two basic (*gryphaeoides* and *uerpmanni*) morphotypes can be recognised in both the Kirchrode I and Kanalstrasse material, the sequence of ornament and microsculptural details of the left valves of the *Aucellina* from the English boreholes cannot readily be identified. In particular, the form with coarse, widely-spaced flange-like concentric ornament on the left valve (Pl. 1, Fig. J) that is found in the assemblage at 7.17 m in the borehole (*briacensis* Subzone) finds its closest parallel in England in a specimen of the *gryphaeoides* morphotype (Morter and Wood 1983, pl.

2, fig. 3) from the higher part of the *rostratum* Subzone (Bed 18 of Gallois and Morter 1982) in East Anglia.

In contrast to the English Upper Albian borehole successions investigated by Morter and Wood (1983) in East Anglia, in which the *briacensis* Subzone is not represented, and the highest preserved sediments below the basal Cenomanian erosion surface belonged to the *Mortoniceras rostratum* Subzone (Gallois and Morter 1983), some 21 m of the *Praeschloenbachia briacensis* Subzone and some 15 m of the underlying *Mortoniceras* (*Durnovarites*) *perinflatum* Subzone are preserved at the top of the Kirchrode I borehole. Furthermore, the late *Callihoplites auritus* Subzone in the English boreholes is relatively thin, whereas this subzone in the Kirchrode I borehole is enormously expanded. It is also noteworthy that, in the English boreholes, *Aucellina* occurrences in the *auritus* Subzone are restricted to the base of the Subzone (lower part) and to the top of the Subzone (upper part), whereas *Aucellina* in the Kirchrode I borehole occur throughout some 20 m of the Subzone (upper part) and there is no unequivocal evidence (based on specimens collected) of the occurrence of *Aucellina* below this level. The *Aucellina* from the base of the late *auritus* Subzone in England have a distinctive left valve umbonal microsculpture ('raised ribbed reticulate' of Morter and Wood 1983), which is not represented in any part of the Subzone in the Kirchrode succession. The *Aucellina* from the top of the *auritus* Subzone in both the English and Kirchrode borehole successions are characterized by a loss of ornament that is also seen in forms from the base of the overlying *Stoliczkaia* spp. Zone and is generally associated with inferred cooler water conditions. However, the exceptionally large, thin-shelled, poorly ornamented forms from the top of the *auritus* Subzone (upper part) in the Kirchrode borehole succession are not represented at a correlative level in England. The specimen from 78.64 m depth (Pl. 3, Fig. O) near the base of the interval between *Aucellina* maxima D and E is a particularly large individual; the specimen from 80.38–80.39 m depth (Pl. 3, Fig. P) at the top of *Aucellina* maximum E is even larger.

## *AUCELLINA* AS ENVIRONMENTAL INDICATORS IN THE KIRCHRODE I BOREHOLE

*Aucellina* appears to occur typically in those parts of the Kirchrode I succession in which the ammonite fauna consists predominantly of European Province (Boreal) forms (see Wiedmann and Owen 2001, table 2 for details) and the associated bivalve faunas are of extremely low diversity. This supports the generally accepted inference that *Aucellina* lived in cooler northern waters. For example, the large, thin-shelled *Aucellina* from the *auritus* Subzone (upper part), essentially in the interval between *Aucellina* maxima D and E (particularly the specimens from 78.64 m and 80.38–80.39 m depth), show the loss of ornament that is associated with the inferred cool phase at the base of the *Stolizkaia* spp. Zone in the English successions (Morter and Wood 1983). In contrast, it is noteworthy that, based on specimens collected, *Aucellina* is virtually unrepresented in the *perinflatum* Subzone, which is essentially characterised by Tethyan ammonites (*Cantabrigites*, *Durnovarites*) and small thin-shelled inoceramid bivalves.

On the other hand, the *Aucellina* from the overlying *briacensis* Subzone, which contains a mixture of Tethyan (e.g. *Stoliczkaia*) and Boreal (e.g. *Arrhaphoceras*) ammonites in the Kanalstrasse sections (Owen 2007), are represented by an assemblage of high taxonomic diversity that differs from any other in the borehole. The sediments of this Subzone are rich in radiolarians. Both the *gryphaeoides* and *uerpmanni* morphotypes in this assemblage are characterized by left valves with strongly developed ornament and the preservation of microsculpture on the umbonal region. The *briacensis* subzonal *Aucellina* assemblage also includes small *Buchia*-like right valves which are found in both the borehole and Kanalstrasse successions.

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## Appendix 1: Associated low diversity faunas

***Stoliczkaia* spp. Zone, *Praeschloenbachia briacensis* Subzone (**Maxima A and B)

*Syncyclonema* at 19.58–19.59 m , 22.12 m, 24.82 m, 25.32 m, 26.36 m (plaster), 27.71 m, 27.91 m (plaster) and 28.51 m depths

Echinoid fragment at 26.02 m depth

Diminutive *Terebratulina* at 27.48 m and 27.53 m depths

***Stoliczkaia* spp. Zone, *Mortoniceras* (*Durnovarites*) *perinflatum* Subzone**

Thin-shelled inoceramids at 31.80 m and 35.87 m depths

***Stoliczkaia* spp. Zone, *Mortoniceras* (*Mortoniceras) rostratum* Subzone** (maximum C)

*Syncyclonema* at 56.43 m and 56.98-99 m depths

Thin-shelled inoceramids at 38.95 m, 39.02 m, 39.05 m, 39.41 m and 39.63 m depths

*Amussium* at 51.04 m depth

Crab *Etyus martini* MANTELL at 61.52 m depth

***Mortoniceras inflatum Zone, Callihoplites auritus Subzone* (upper part)** (maximum E)

*Syncyclonema* at 104.15 m and 105.05 m depths

***Mortoniceras inflatum Zone, Callihoplites auritus Subzone* (lower part)**

*Amussium* at 135.17 m, 151.11 m, 155.16 m, 163.32 m, 168.67 m and 180.02 m depths

*Terebratulina* "*martiniana*" sensu germanico at 162.51 m depth; then at 202.39 m, 208.92 m, 211.78 m and 212.27 m depths

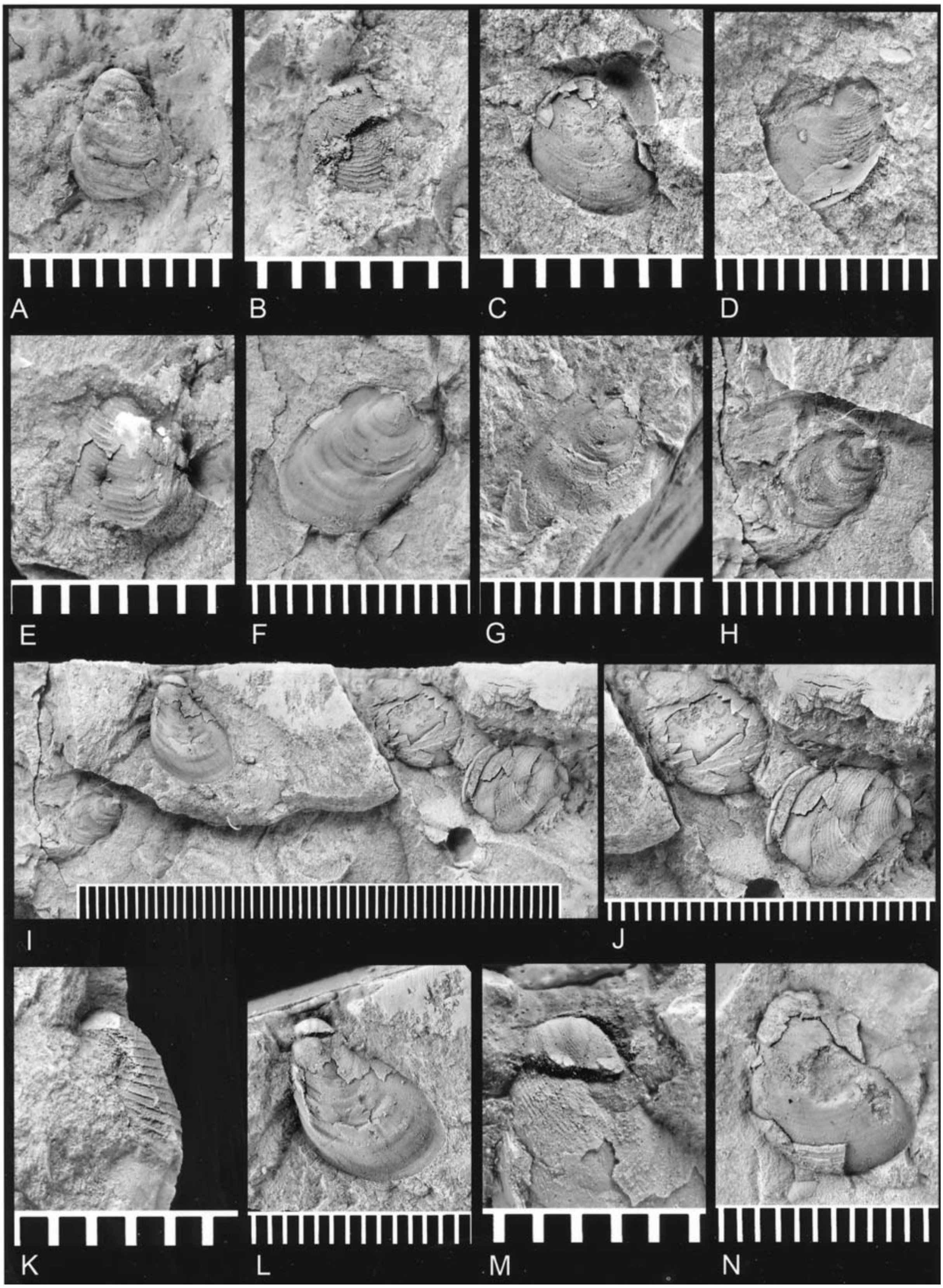
PLATES 1–7

# PLATE 1

*Aucellina* from *Praeschloenbachia briacensis* Subzone, Kirchrode I borehole

**A –** 3.42 m, small LV, note closely-spaced radial microsculpture at apex; compare Fig. B. [cf. Pl. 7 fig. H].
**B –** 6.87–6.89 m, small LV, morphotype uncertain, with well developed concentric ornament.
**C –** 7.10 m, small LV, internal mould with some shell, morphotype uncertain.
**D** – 7.10 m, [same block as Fig. C] small LV external mould with some shell, *gryphaeoides* morphotype?
**E –** 7.17 m, small LV internal mould with some shell, *uerpmanni* morphotype?
**F –** 4.20 m, *Buchia*-like RV.
**G –** 7.10 m [same block as Figs C, D], *Buchia*-like RV.
**H –** 7.17 m, *Buchia*-like RV (enlargement of specimen on left-hand side of Fig. I).
**I –** 7.17 m, association of one RV (see Fig. H) several different LVs, including one definite *gryphaeoides* morphotype.
**J –** 7.17 m, enlargement of the two LVs on left-hand side of Fig. I; note the widely-spaced and closely-spaced concentric ornament respectively; the right-hand specimen is similar to the *uerpmanni* morphotype in Pl. 6, Fig. N from the Kanalstrasse section.
**K –** 7.10 m, LV, to show flange-like concentric ornament at anterior margin.
**L –** 7.17 m, *Aucellina* LV (*gryphaeoides* morphotype) shown in Fig. I.
**M –** 7.17 m, enlargement of umbonal region of above, to show fine, closely-spaced, concentric microsculpture.
**N –** 7.19 m, LV internal mould with some shell, *uerpmanni* morphotype.

Scale in millimetres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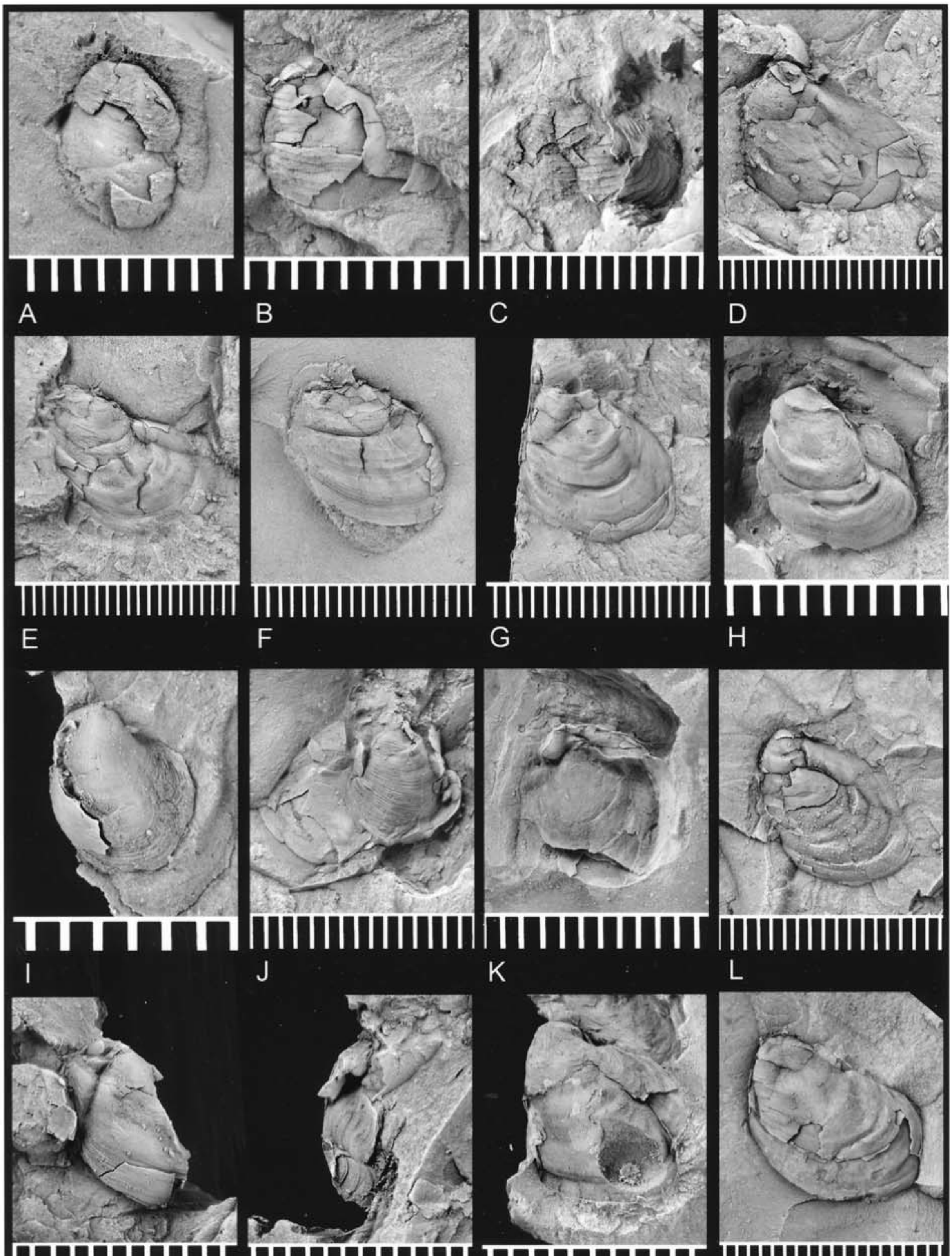
# PLATE 2

*Aucellina* LVs, Kirchrode I borehole
A: *Praeschloenbachia briacensis* Subzone; B–E: subzone uncertain; F: *Mortoniceras* (*Durnovarites*) *perinflatum* Subzone; G–P: *Mortoniceras* (*M.*) *rostratum* Subzone

**A** – 17.05 m: reworked specimen, morphotype uncertain, slightly phosphatized.
**B** – 26.02 m, *gryphaeoides* morphotype (note irregular, slightly oblique concentric ornament weakening towards centre of valve).
**C** – 27.48 m, LV distorted through compaction, interruption of concentric flanges suggests *gryphaeoides* morphotype.
**D** – 27.53 m, *gryphaeoides* morphotype.
**E** – 28.31 m, *gryphaeoides* morphotype.
**F** – 31.06 m, *gryphaeoides* morphotype.
**G** – 42.15 m, *gryphaeoides* morphotype, shell more or less smooth.
**H** – 42.45 m, *uerpmanni* morphotype; note well developed posterior sulcus.
**I** – 42.71 m, *uerpmanni* morphotype, to show strongly developed scale-like ornament and marked posterior sulcus.
**J** – 43.10 m, *uerpmanni* morphotype associated with an unidentified RV.
**K** – 45.03m, bivalved specimen to show RV inside LV, RV with corroded shell surface; morphotype uncertain, possibly *uerpmanni*.
**L** – 49.42 m, *gryphaeoides* morphotype, internal mould with some shell; shell more or less smooth.
**M** – 60.29 m, *uerpmanni* morphotype, anterior view to show anterior auricle.
**N** – 60.29 m, *uerpmanni* morphotype, posterior view to show posterior sulcus.
**O** – 60.39 m, *uerpmanni* morphotype, shell sheared over onto anterior margin, posterior auricle and sulcus clearly visible.
**P** – 60.54 m, *gryphaeoides* morphotype.

Scale in millimetres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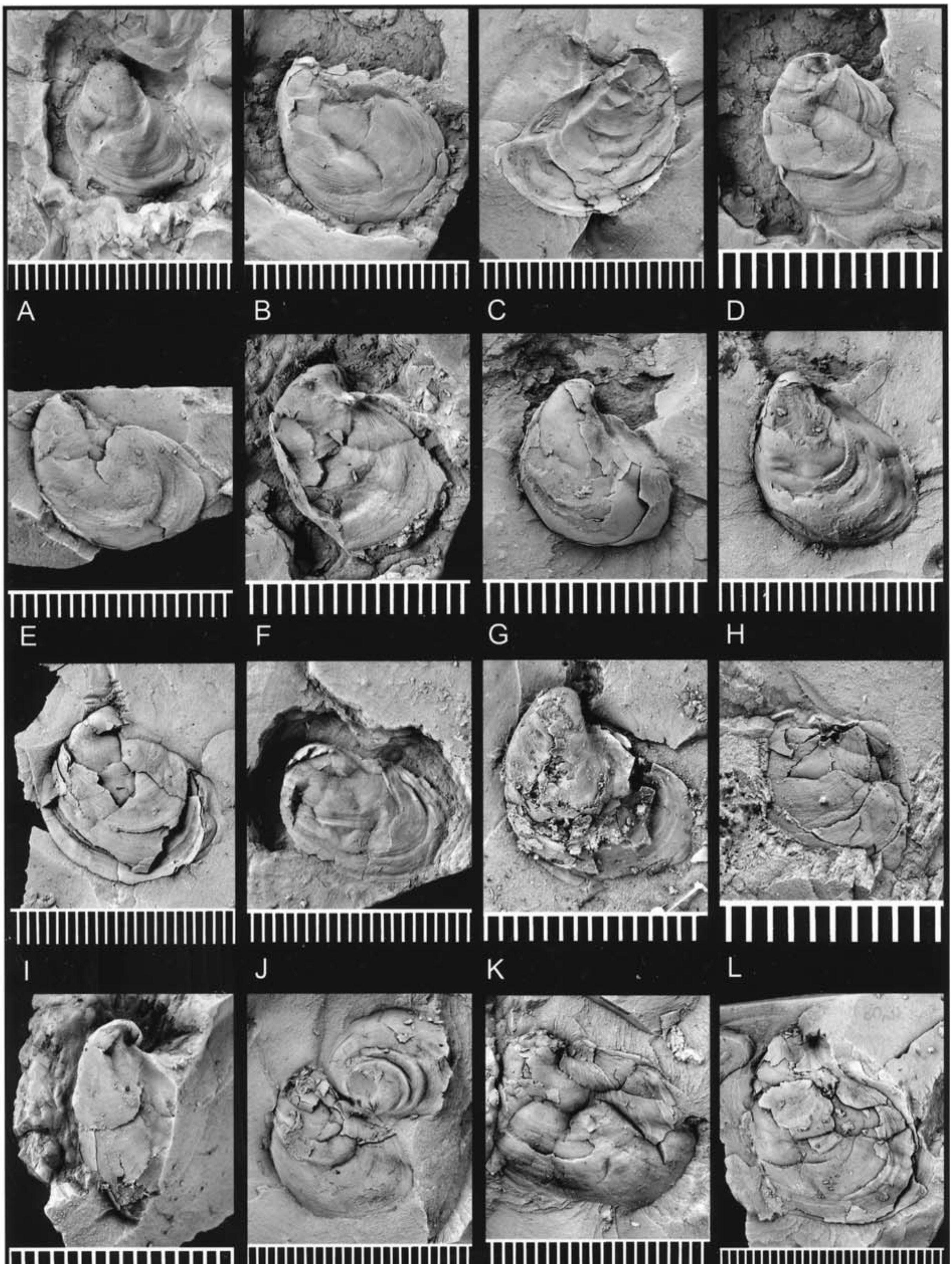
# PLATE 3

*Aucellina* LVs, Kirchrode I borehole A: basal part of *rostratum* Subzone; B–P *Callihoplites auritus* Subzone (upper part)

**A –** 61.80-61.86 m, morphotype uncertain;strongly rugate concentric ornament, not interrupted; weakly sulcate possible *uerpmanni morphotype*.
**B –** 64.42 m, *gryphaeoides* morphotype, bivalved specimen (note fine concentric ornament towards anterior margin).
**C –** 66.35 m, *gryphaeoides* morphotype, interior view.
**D –** 66.90 m, *uerpmanni* morphotype, shell sheared over onto anterior margin; to show posterior sulcus.
**E –** 67.40 m *gryphaeoides* morphotype, rather wide anterior flanges, contrast fine flanges in Fig. 3B {this specimen is missing following photography].
**F –** 68.69 m, *gryphaeoides* morphotype, sheared over onto anterior margin, weak radial ornament not seen in photo.
**G –** 71.12 m, *gryphaeoides* morphotype, three-dimensional, with minimal compaction except for compressed anterior margin; fine anterior flanges.
**H –** 72.88 m, *gryphaeoides* morphotype, internal mould (note irregular development of concentric ornament and weak posterior sulcus).
**I –** 73.38 m, *gryphaeoides* morphotype, weak radial microsculpture on umbo, reticulate in very oblique illumination; as Plate 6**J.**
**J –** 73.93 m, *gryphaeoides* morphotype other side of block containing RVs in Pl. 6, Fig. J.
**K –** 74.38 m, *gryphaeoides* morphotype, bivalved specimen, (note fine concentric ornament on anterior margin).
**L –** 75.21 m, morphotype uncertain, bivalved specimen to show both concentric and radial ornament.
**M –** 76.32 m, morphotype uncertain, distorted LV, sheared over onto flattened anterior margin.
**N –** 76.45 m, *gryphaeoides* morphotype LV and RV internal moulds, not necessarily belonging to same individual.
**O –** 78.64 m, *gryphaeoides* morphotype, large, very thin-shelled, bivalved specimen.
**P –** 80.38 m, *gryphaeoides* morphotype, large, very thin-shelled, bivalved specimen.

Scale in millimetres

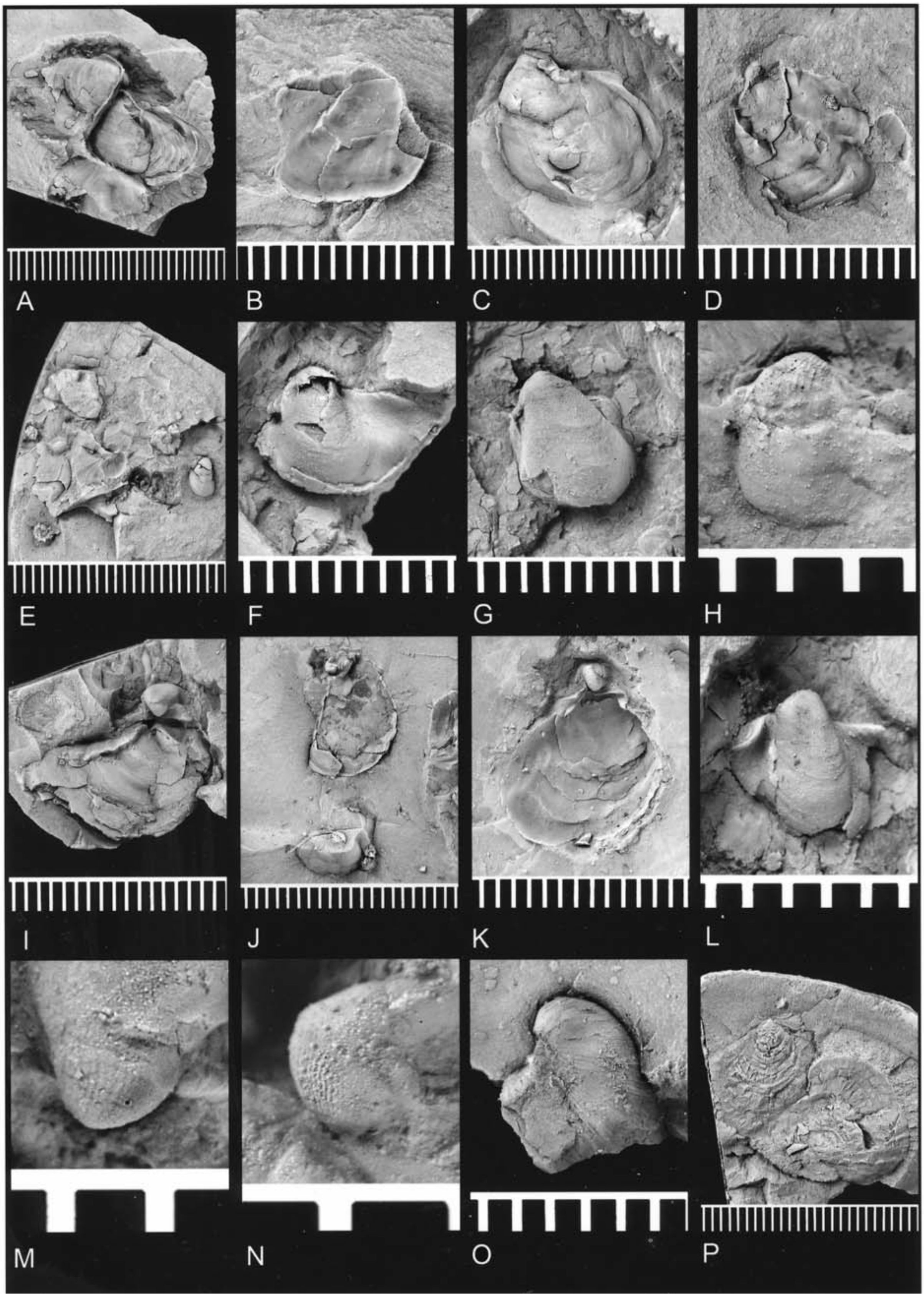


# PLATE 4

*Aucellina* and *Syncyclonema,* Kirchrode I borehole
A–E, H–O: *Callihoplites auritus* Subzone (upper part); F, G, P: *Mortoniceras* (*M.*) *rostratum* Subzone

**A** – 80.38 m, *gryphaeoides* morphotype, two bivalved specimens
**B** – [another block] 80.63–80.65 m,: *uerpmanni* morphotype, interior of LV**.**
**C** – 80.63–80.65 m, *gryphaeoides* morphotype, bivalved specimen.
**D** – 80.63-–80.65 m, *uerpmanni* morphotype, internal mould of LV with some shell, posterior sulcus clearly visible.
**E** – 83.18 m, phosphate-strewn surface with *Aucellina*: diminutive LV, morphotype uncertain, external mould, probably of *gryphaeoides* morphotype; RV with large anterior auricle suggestive of *uerpmanni* morphotype.
**F** – 51.16 m, umbonal region of left valve of *gryphaeoides* morphotype to show downturned anterior auricle and straight posterior auricle.
**G** – 63.12 m, umbonal region of left valve of *uerpmanni* morphotype [?as Pl. 5, Fig. F another specimen].
**H** – 65.93 m, left valve, morphotype uncertain, to show radial microsculpture on umbo.
**I** – 69.01 m, *gryphaeoides* morphotype, bivalved specimen.
**J** – 60.80 m, *gryphaeoides* morphotype, bivalved specimen with unusually straight posterior margin; incomplete internal mould of left valve of *uerpmanni* morphotype.
**K** –71.08 m, *gryphaeoides* morphotype, interior of LV; other side of same block contains right valve in Pl. 6, Fig. B.
**L** – 72.92 m, umbonal region of *gryphaeoides* morphotype to show downturned anterior auricle and straight posterior auricle. See Pl. 6, Fig. G [on other side].
**M** – 69.01 m, tip of umbo of specimen illustrated in Pl. 4, Fig. I to show radial microsculpture.
**N** – 60.80 m, tip of umbo of specimen illustrated in Pl. 4, Fig. J to show radial microsculpture.
**O** – 75.09–75.10 m, *gryphaeoides* morphotype, anterior view of umbonal region of LV to show downturned anterior auricle.
**P** – 56.98 m, *Syncyclonema* plaster (note characteristic asymmetrical development of auricles).

Scale in millimetres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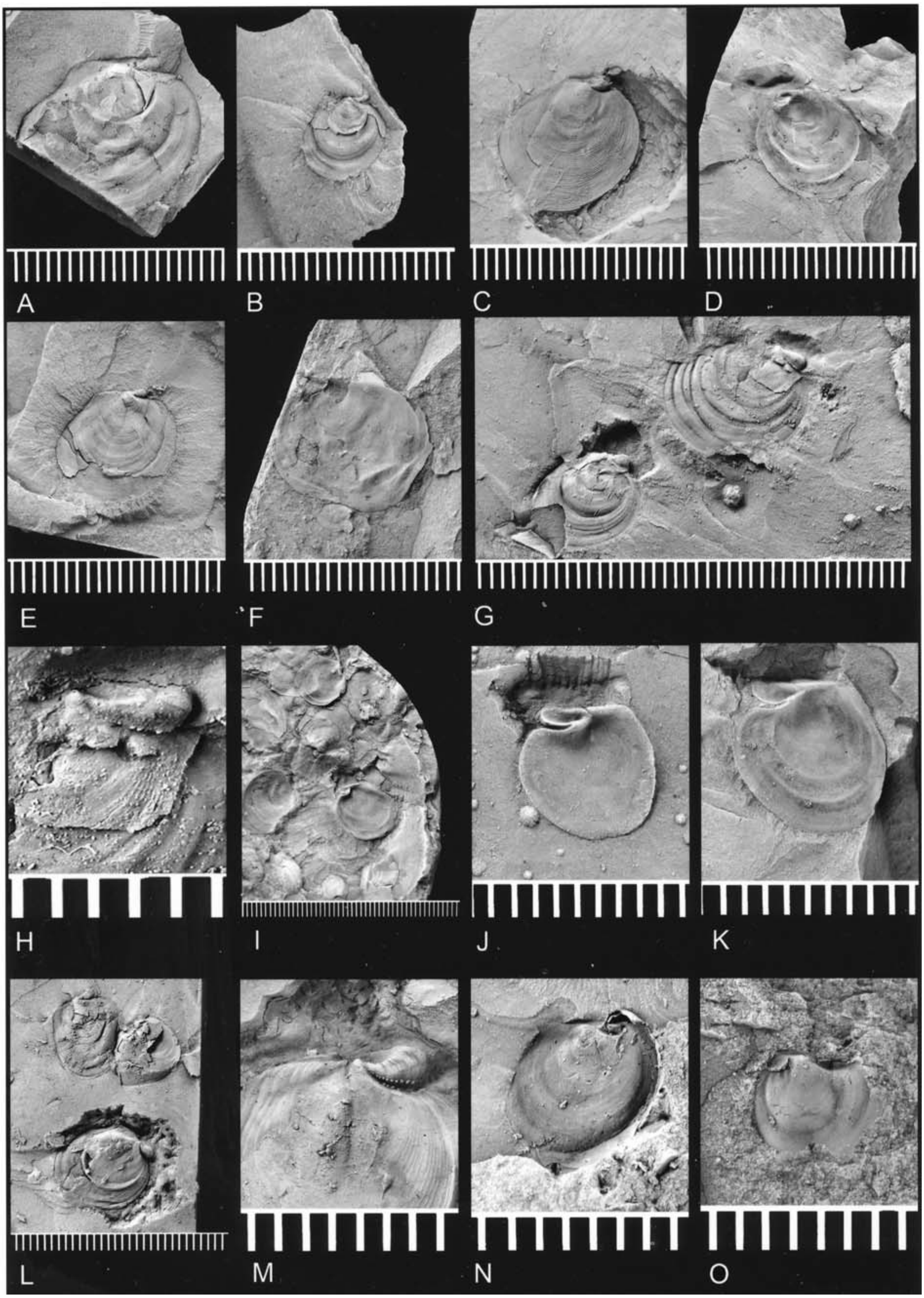
# PLATE 5

*Aucellina* RVs, Kirchrode I borehole
A–I: *Mortoniceras* (*M.*) *rostratum* Subzone; J–O: *Callihoplites auritus* Subzone (upper part)

**A –** 42.60 m, *gryphaeoides* morphotype? internal mould with some shell preserved in umbonal region (note clearly defined posterior auricle, postero-ventral elongation, and that that tip of narrow anterior auricle does not reach anterior margin; contrast RV in Pl. 5, Fig. C).
**B –** 42.60 m, internal mould with some shell; probably earlier ontogenetic stage of RV in Pl. 5, Fig. A.
**C –** 42.90 m, *uerpmanni* morphotype? (note quadrangular outline, absence of posterior auricle, truncated posterior margin, and that tip of wide anterior auricle reaches anterior margin; contrast RV in Pl. 5, Fig. 1).
**D –** 43.85 m, interior of RV.
**E** – 47.28 m, postero-ventrally elongated RV similar to RV in Pl. 5, Fig. A.
**F –** 51.04 m, interior of large RV.
**G –** 56.10 m, two strongly rugate RVs, with short, broad anterior auricles.
**H –** 56.10 m, detail of right-hand RV in Pl. 5, Fig. G (note ctenolium at base of anterior auricle).
**I –** 61.80–61.86 m, plaster with several RVs.
**J –** 67.45 m, interior of RV. Truncated posterior margin and broad anterior auricle suggests *uerpmanni* morphotype.
**K –** 68.18 m, interior of RV similar to Pl. 5, Fig. J.
**L –** 68.20 m, RV with broad anterior auricle; another similar RV adjacent to a *uerpmanni*? morphotype LV.
**M –** 68.20 m, detail of RV in Pl. 5, Fig. L (note well developed ctenolium; contrast RVs in Pl. 5, Figs A, C).
**N –** 70.01 m, juvenile LV, internal mould inside LV (note oblique posterior margin; contrast RV in Pl. 5, Fig. O).
**O –** 70.02 m, juvenile LV, internal mould (note truncated posterior margin and laterally extended anterior margin; contrast RV in Pl. 5, Fig. N)

Scale in millimetres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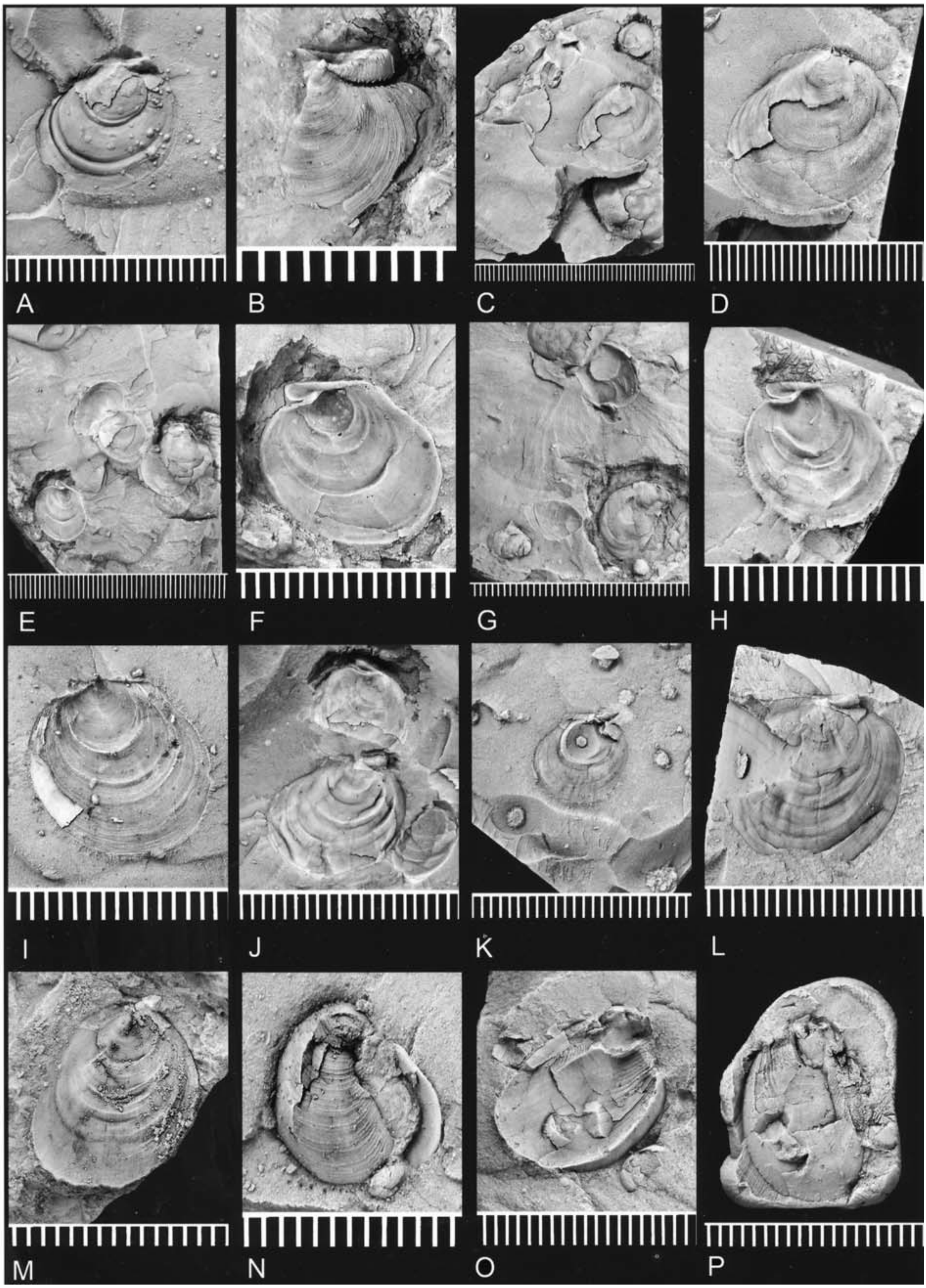
# PLATE 6

*Aucellina* RVs
A–L from the *Callihoplites auritus* Subzone (upper part) of the Kirchrode I borehole;
M–P from the *Praeschloenbachia briacensis* Subzone of the Mittellandkanal, section near Kanalstrasse

**A –** Kirchrode I borehole, 70.03 m, RV internal mould with shell preserved in umbonal region (compare RVs in Pl. 5, Figs E, L, M).
**B –** Kirchrode I borehole, 71.08 m, exceptionally well preserved fragment of RV to show ctenolium, radial and concentric ornament, details of ligament and the protuberant umbonal tip; *gryphaeoides* morphotype LV interior figured in Pl. 4, Fig. K on other side.
**C –** Kirchrode I borehole, 71.33 m, association of large RV above *gryphaeoides* morphotype LV, small RV at top of picture, external mould *uerpmanni* morphotype LV at top left of picture.
**D –** Kirchrode I borehole, 71.33 m, detail of large RV figured in Pl. 6, Fig. C (note extended posterior auricle and oblique growth suggestive of *gryphaeoides* morphotype but shape of valve not as RV in Pl. 5, Fig. A; weak radial ornament on internal mould not seen on photo). Weak posterior sulcus
**E –** Kirchrode I borehole, 71.74 m, association of LV and RV shells and external moulds, plus isolated RV.
**F –** Kirchrode I borehole, 71.74 m, detail of isolated RV figured in Pl. 6, Fig. E.
**G –** Kirchrode I borehole, 72.92 m, association of two RVS plus LV of *gryphaeoides* morphotype; small *Terebratulina* sp. at bottom right of picture. [As Plate 4, fig. L., opposite side of block.]
**H** – 72.05 m, detail of interior of RV.
**I** – Kirchrode I borehole, 72.99 m, external mould of RV with diminutive anterior auricle.
**J –** Kirchrode I borehole, 73.93, two RVs, other side of block in Pl. 3, Fig. J.
**K** – Kirchrode I borehole, 74.70 m, RV internal mould (note highest part of valve missing on a conchoidal fracture surface; pyramid-like crystal growth in centre of fracture surface and in matrix).
**L –** Kirchrode I borehole, 76.32 m, RV *gryphaeoides* morphotype (note diminutive anterior auricle, straight posterior auricle and oblique growth).
**M –** Mittellandkanal, section near Kanalstrasse, at water level, *Buchia*-like RV internal mould with oblique, protuberant anterior auricle (compare similar RVs from the *briacensis* Subzone of the Kirchrode I borehole in Pl. 1, Figs F–H).
**N –** Horizon as above, *uerpmanni* morphotype, well preserved bivalved specimen, showing scale-like concentric ornament continuing right across sulcate LV.
**O –** Horizon as above, *gryphaeoides* morphotype LV external mould to show interrupted concentric ornament.
**P –** Horizon as above, plasticine pull of *gryphaeoides* morphotype LV external mould in Pl. 6, Fig. O.

Scale in millimetres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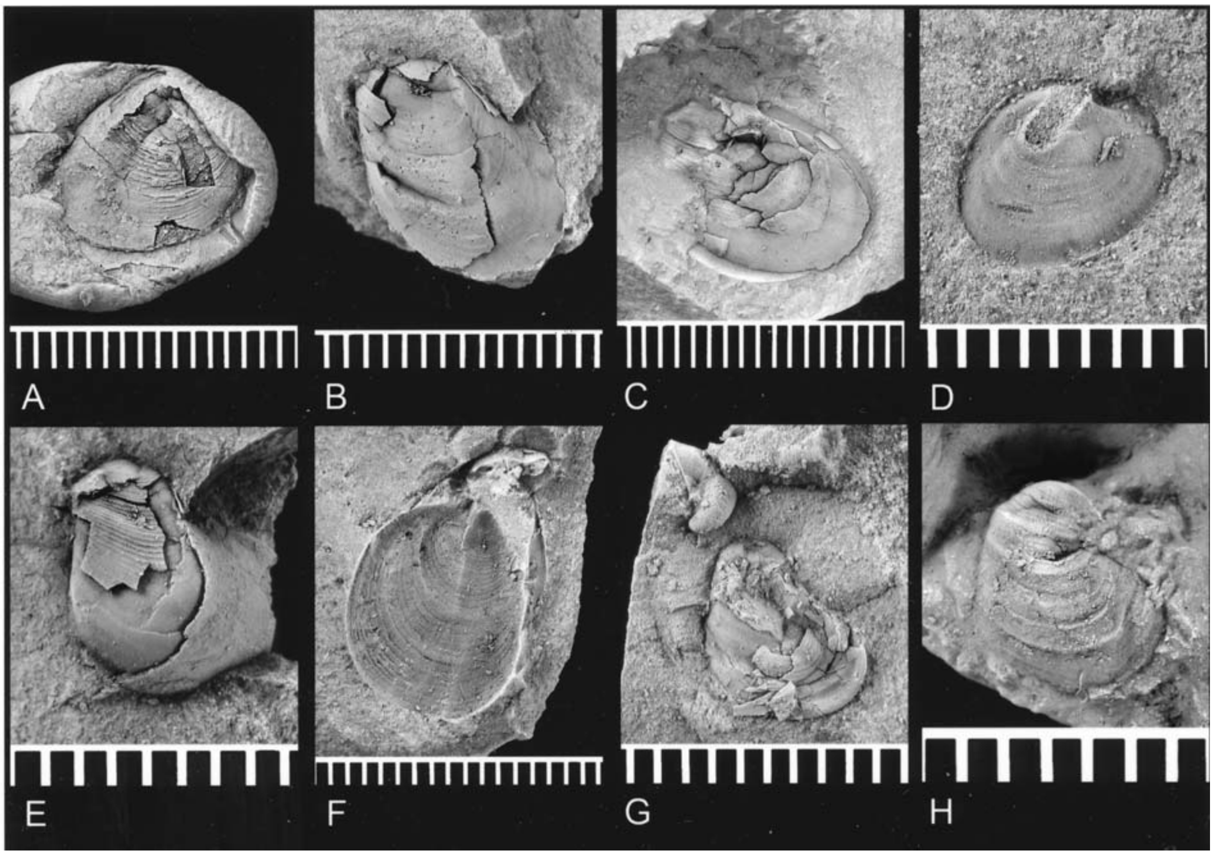
# PLATE 7

*Aucellina* from the *Praeschloenbachia briacensis* Subzone Mittellandkanal, section near Kanalstrasse

**A –** Horizon at water level, plasticine pull of *uerpmanni* morphotype LV external mould from same block as *gryphaeoides* morphotype LV external mould in Pl. 6, Fig. O.
**B –** Horizon 2 m above water level, *gryphaeoides* morphotype LV internal mould with weakly developed posterior sulcus.
**C –** Horizon as above, *gryphaeoides* LV internal mould with some shell preserved (note interruption of concentric ornament in centre of valve and weakly developed radial ornament on internal mould).
**D –** Horizon as above, small RV internal mould with truncated posterior margin and laterally extended anterior margin.
**E –** Horizon >2 m above water level, detail of umbonal region of LV (morphotype uncertain) to show fine, closely-spaced concentric microsculpture.
**F –** Horizon as above, *gryphaeoides* morphotype LV external mould.
**G –** Horizon as above, small LV (morphotype uncertain); at top left of picture umbonal region of (*gryphaeoides* morphotype?) with fine, closely-spaced microsculpture.
**H –** Horizon as above, LV (*uerpmanni* morphotype?) to show widely-spaced concentric ornament and finely-spaced reticulate microsculpture on umbo.

Scale in millimetres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