New records of ostracods and ammonites from the Aalenian (mainly Concavum Zone) of the Zollernalb (Swabian Alb, SW Germany)

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Abstract

The lithostratigraphy and ammonite/ostracod biostratigraphy and the accompanying fauna of several sections and outcrops around the Hohenzollern (Zollernalb, SW Germany), ranging from the topmost Opalinuston Formation (uppermost Lower Aalenian) to the basal Wedelsandstein Formation (lowest Lower Bajocian) are described and analyzed. The study of ostracods from 41 samples from the Aalenian and Lower Bajocian of the Heiligenbach, Hausterberg and Roschbach sections has yielded approximately 4,100 specimens. Significant changes in the ostracod assemblage occur at the base of the Lower Aalenian “Comptum” Subzone, at the Bradfordensis/Gigantea subzonal boundary, at the Bradfordensis/Concavum zonal boundary and at the Aalenian/Bajocian boundary (Concavum/Discites zones). A minor change occurs above the Calceola-Bank within the Concavum Zone. The following new ostracod species are described: Cytheropterina crassicostata sp. nov., Eucytherura eberti sp. nov. and Eucytherura foveolata sp. nov. In addition, 15 presumably new species are briefly described; 10 ‘incertae sedis’ taxa are figured, but left in open nomenclature. The ammonite faunas of the Inopernabank and Konglomeratbank beds (Upper Aalenian, Bradfordensis Zone, Gigantea Subzone) as well as the ammonite faunas from the Calceolabank and Rostroten Kalkbank beds (Upper Aalenian, Concavum Zone, Concavum Subzone, cavatum biohorizon) are described and correlated with those of other areas.

Zusammenfassung

Die Lithostratigraphie und die Ammoniten-/Ostracoden-Biostratigraphie sowie die Begleitfauna mehrerer Profile und Aufschlüsse in der Umgebung des Hohenzollern (Zollernalb, SW-Deutschland), von der obersten Opalinuston-Formation (oberstes Unter-Aalenium) bis zum basalen Wedelsandstein (unterstes Unter-Bajocium), werden beschrieben. Die Auswertung von 41 Proben (aus dem Aalenium bis zum Unter-Bajocium) vom Heiligenbach, Hausterberg und Roschbach hat ca. 4100 Ostracoden erbracht. Signifikante Änderungen in der Ostracoden-Gemeinschaft gibt es an der Basis der “Comptum”-Subzone (Unter-Aalenium), den Grenzen der Bradfordensis/Gigantea-Subzone, der Bradfordensis/Concavum-Zone sowie an der Aalenium/Bajocium Grenze (Concavum/Discites-Zone). Eine weniger stark ausgeprägte Änderung der Ostracoden-Gemeinschaft erfolgt innerhalb der Concavum-Zone, oberhalb der Calceola-Bank. Folgende neue Arten wurden beschrieben: Cytheropterina crassicostata sp. nov., Eucytherura eberti sp. nov. und Eucytherura foveolata sp. nov. Darüber hinaus werden 15 wahrscheinlich neue Arten kurz beschrieben; 10 “incertae sedis”-Taxa werden in offener Nomenklatur abgebildet. Die Ammonitenfaunen der Inopernabank und der Konglomeratbank (Ober-Aalenium, Bradfordensis-Zone, Gigantea Subzone) werden ebenso wie diejenige der Calceola-Bank und der Rostroten Kalkbank (Ober-Aalenium, Concavum-Zone, Concavum-Subzone, cavatum-Horizont) beschrieben und mit Ammonitenfaunen anderer Gebiete korreliert.

† deceased
Keywords
Upper Aalenian, Achdorf Formation, ammonites, ostracods, Zollernalb, SW Germany

Schlüsselworte
Ober-Aalenium, Achdorf-Formation, Ammoniten, Ostracoden, Zollernalb, SW-Deutschland

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1. Introduction and previous studies

In the context of the field works on the occasion of the investigation of the lithostratigraphy as well as the ammonite and ostracod biostratigraphy of the "Unterer Wedelssandstein" and "Sowerbyi-Oolith" members (Wedelsandstein Formation; Lower Bajocian) of the Zollernalb (Dietze et al. 2019), the survey of the sections was expanded to the underlying beds of the Achdorf Formation (uppermost Lower and Upper Aalenian). Surprisingly, some of these beds yielded a rich ammonite fauna. This was quite unexpected, since Hahn (1975) mentioned that ammonites are very rare in the Upper Aalenian of this area. The microfauna samples are very rich in ostracods. Therefore, we decided to publish the lithostratigraphical and biostratigraphical results regarding the Achdorf Formation and parts of the Opalinuston Formation in a separate publication, which is presented here.

Our knowledge on the Aalenian ostracod fauna from Germany is mainly based on studies from the 1930’s to 1960’s as summarized by Dietze et al. (2019). Ernst (1989), Ohmert (1996, 2004), Brand and Mönnig (2009), Franz et al. (2009, 2014), and Dietze et al. (2017a, 2019), provided more recent data. Publications on Aalenian ostracods from other European areas include Bate (1963a, b, 1968, 1978, 2009), Sheppard (1981), Morris (1983), Ainsworth (1986, 1990, 1991), Ainsworth et al. (1989), Whittaker and Hart (2009) [Great Britain, Ireland], Dépêche (1985), Bodergat (1997) [France], Arias et al. (2009) [Spain], Tröster (1987), Reisdorf et al. (2016), and Tesakova (2017) [Switzerland]. Aalenian ostracods have also been described from Argentina (Ballent 1991; Boomer and Ballent 1996; Ballent and Whatley 2000, 2009) and Iran (Kochhann et al. 2015).

There is only little information available on the ammonites of the uppermost Aalenian (Concavum Zone) in SW Germany. Stratigraphic data and numerous local details were provided by Beisswenger (1920), Rieber (1922), Schmierer (1925, 1926), Stahlecker (1926, 1934), Schmidt (1933), Erb (1938), Lörcher (1939), Boongaard (1948), Rieber (1961), Hahn (1975f), and Hiller and Kunze (1979). Rieber (1963) described and figured well-preserved ammonites from the Concavum Zone of the "Hofwald" section near Metzingen (Middle Swabian Alb). The so-called "Concava-Bank" of the Zollernalb in Rieber (1963: 16) corresponds to our "Konglomeratbank" (see also Rieber 1922: 46). Bayer (1969) described some hammatoceratid ammonites from the Concavum Zone of the Wutach area and the "Hofwald" section. Ohmert (1981) dealt as well with the outcrops in the "Hofwald”. Sanns and Schweizer (1987), among others, investigated the lithology and formation of the "concava-Bank" bed. Finally, Franz and Nitsch (2009) revised the lithostratigraphy of the Aalenian in Baden-Württemberg.

2. Description of the sections

All sections are described bottom-up.

2.1 Balingen-Zillhausen (Roschbach)

Opalinuston Formation (Zillhausen Member)

Bed no.

1. [Zopfplatten] (ca. 1.0 m [Rieber 1963]).
2. (ca. 8.0 m [Rieber 1963]): claystone with layers of siderite concretions (only the uppermost 2 m are exposed) at 0.4 m, 0.9 m and 1.5 m below the top.

**Achdorf Formation**

3. (0.15–0.2 m): grey, hard marly limestone, with bivalves and Leioceras crassicostatum.

4. (0.15 m): grey carbonaceous marlstone; in the upper part gritty, with siderite concretions.

5. (0.03 m): grey, very hard marly limestone nodules.

6. (0.2 m): grey marlstone with compressed Leioceras crassicostatum.

7. (0.05 m): light grey, pyritic marly limestone nodules with dark grey Chondrites burrows. Mainly small specimens of Leioceras “comptum”, irregularly embedded and partly accumulated.

8. (0.4 m): carbonaceous marlstone with higher clay content than in beds 4 and 6.

9. (0.03 m): grey marly limestone nodules.

10. (0.2 m): clay marlstone.

11. (0.18 m): marly limestone, partially splitting in the lower third. At the base with hazelnut-sized pebbles. Above very hard marly limestone concretions with shrinkage cracks (septaria) and fine shell debris.

12. (ca. 2.0 m): claystone, badly exposed.

13. (0.05 m): grey, hard marly limestone.

14. (ca. 5.5 m): claystone with layers of septaria and siderite concretions (section is divided by a wooden bridge at the "Geopfad" into a lower and an upper part) below: ca. 4.0 m claystone with a layer of septaria (0.05 m) ca. 1.8 m above the base above: ca. 1.5 m claystone (with layers of siderite concretions at 1.1 m, 0.8 m, 0.7 m and 0.4 m below the top; ca. 0.85 m below the top, a hard, sandy, micaceous marly limestone with ichnofossils; 0.25 m below the top another septaria layer).

15. (0.05 m): hard carbonaceous marlstone.

16. (0.2 m): greyish brown marly limestone with Ludwigia murchisonae (see Rieber 1963).

17. (0.4–0.45 m): grey carbonaceous marlstone.

18. (0.25 m): greyish brown, marly limestone.

19. (0.15 m): carbonaceous claystone.

20. (0.25 m): grey, hard marly limestone; with Staufenia staufensis and Brasilia bradfordensis (Rieber 1963).

21. (0–0.12 m): grey, very hard, loaf-shaped marly limestone nodules with Staufenia staufensis (SMNS 70519/1 [microconch]). From a corresponding nodule layer of the nearby Bezighofenbach section (Rieber 1963), a large S. cf. staufensis (SMNS 70519/55) with a relatively wide umbilicus was recorded.
22. (ca. 1.7 m): grey marlstone, mostly not exposed. (Rieber (1963) described 4 harder beds up to 1.65 m above bed 20, the uppermost one as an oolitic nodule layer with Staufenia staufenensis).

23. (ca. 6 m): claststone, not exposed; only the uppermost 0.3 m are visible.

24. (0.05–0.15 m): [Inopernabank] spotty-grey, tough, marly limestone with greyish brown bark and isolated small, rounded pebbles. At the base larger Thalassinooides burrows, in the lower part of the bed small, flattened marlstone pebbles (0.03–0.05 m). Few fossils: Gryphaea sp., Pinna sp., belemnites.

25. (6.0 m): dark claststone with several layers of siderite concretions in the upper 0.5 m.

26. (0.05–0.1 m) [Konglomeratbank (= bed 3 in Dietze et al. 2019)]: grey marly limestone with abundant pebbles. Ludwigella arcticens (Fig. 16: 3a, b).

27. (ca. 0.3 m): dark grey, laminated carbonaceous claststone, with fine shell debris and small nodules (up to 5 mm). Rare, compressed Graphoceras sp., a fragmentary Graphoceras sp. (SMNS 70519/2) at the top sample Ro19-1: 0–0.05 m above the Konglomeratbank sample Ro19-2. 0.25–0.3 m above the Konglomeratbank.

28. (max. 0.1 m) [Calceolabank (= bed 5 in Dietze et al. 2019)]: grey, marly limestone with many Gryphaea calceola in its lower part, in clay-rich parts predominantly in "convex upward" position. Some of the shells are stacked into each other. The layer is nodular in some places and then wedges out. At one point many large Trigonia alemannica and compressed ammonites (?Graphoceras) occur. At another place nearby well-preserved Graphoceras cf. concavum (Fig. 16: 1, 4) and Brasilia cf. decipiformis (Fig. 21: 2a, b, 5a, b).

29. (0.15 m): carbonaceous claststone with few small Gryphaea.

30. (0.1–0.15 m): carbonaceous claststone with masses of small Gryphaea (Gryphaea calceola) up to 2 cm in diameter and small phosphorite concretions. Sample Ro19-3.

31. (0.15 m): grey calcoolithic marlstone (reddish brown in weathered state), with single hard marly limestone nodules. Few bivalves and belemnites.

32. (0.15 m) [Rostrote Kalkbank (= bed 9 in Dietze et al. 2019)]: hard limestone, rusty red crust, inside greenish grey and brown-red marbled.

33. (0.95 m; see Ohmert 2004): carbonaceous claststone. Sample Ro19-4: 0–0.05 m above the Rostrote Kalkbank Sample Ro19-5: 0.05–0.15 m above the Rostrote Kalkbank.

**Wedelsandstein Formation**

34–36. [Sowerbyi-Oolith (= beds 11–13 in Dietze et al. 2019)] (see Franz 1986, Dietze et al. 2019).

34. (0.05–0.07 m): limestone nodules, calcitic ooids only in Chondrites burrows.

35. (0.06–0.1 m): dark grey, muscovite-bearing, laminated oolitic claststone with belemnites and Hyperlioceras.

36. (0.04–0.13 m): grey elongated limestone nodules with irregular surfaces, hard, calcitic oolites (0.1–0.2 mm diameter), with small pebbles, in places densely packed. Bivalves (Gryphaea, Entolium), belemnites, serpulids; strongly bioturbated (Chondrites). Ammonites: Hyperlioceras sp. and Euahoplus sp. (see Dietze et al. 2019).

Higher up **Unterer Wedelsandstein** (see Dietze et al. 2019).

**2.2 Hechingen-Boll (Hausterberg)**

Landslide above the former Friedrichstal castle near Hechingen-Boll

**Achdorf Formation**

**Bed no. / sample no.**

1. (min. 1.5 m): claststone, thickness unknown. Only uppermost part exposed.

2. (0–0.115 m): nodular bed of grey marly limestone, with small light grey, phosphoritic pebbles (0.2–1 cm) and marly limestone pebbles up to 3 cm, partly compressed. Graphoceras sp.

3. (1.5 m): dark grey claststone

4. (0.15 m): nodular bed, like bed 2, but continuously developed.

5. (ca. 4 m): grey claststone
   - not exposed
   - Slipped blocks from the Rostrote Kalkbank (0.15 m) and the Calceolabank (0.15 m) with Gryphaea calceola, Graphoceras sp. (SMNS 70519/3), Euahoplus sp. (SMNS 70519/4).

6. (ca 7–8 m): claststone, mostly badly exposed. The upper 3 m excavated for sampling. Layers of siderite concretions at 0.15 m, 0.2 m, 0.5 m and 1.5 m below top. 1.6 m below top 0.10–0.15 cm long and 0.03–0.04 m thick lenses of light grey, lenticularly bedded, fine-sandy limestones.
   - Ha19-1 (3.05–2.55 m below bed 7)
   - Ha19-2 (2.05–1.55 m below bed 7)
   - Ha19-3 (1.05–0.25 m below bed 7)
   - Ha19-4 (0.15–0.25 m below bed 7)

7. (0.15 m) [Sowerbyi-Oolith]: claststone, with occasional irregular-shaped, often flat nodules (up to 0.10 m long and 0.04 m thick) of greyish limestone with borings, the sediment infill of which is calcoolithic. The nodules are settled on all sides with bryozoans, oysters and serpulids and show in places a fine, dark brown coating. Small phosphoritic pebbles (up to 0.05 m) are not rare. Some of them show parallel scratch-like traces. In the pebbles occasionally casts of endobenthic bivalves occur. In the claststone fragments of Actinostreon, Ctenostreon and fragments of abraded belemnites.
with borings occur. One fragmentary *Hyperlioceras*
from the "Weinhalde" section, 700 m SE of the Haustereberg section.
- Ha19-5 / (above bed 7)
- Ha19-6

2.3 Jungingen (Mühlbächle and Starzel)

2.3.1 Mühlbächle

*Achdorf-Formation:*

**Bed no. / sample no.**

1. (min. 0.5 m): claystone
2. (0.1–0.12 m): pyrite-bearing grey, weathered rusty, hard marly limestone. Many tiny gryphaeids, rare belemnites and bivalves. Few, mostly very small ammonites. *Brasilia bradfordensis* (Fig. 19: 1a, b)
3. (0.45 m): claystone. In the upper part a single carbonaceous burrow (diameter up to 0.04 m) was observed.
4. (0.05–0.1 m): hard, grey marly limestone with many pebbles of different size and burrows at the base.
5. (1.8–2.0 m): claystone; only partly exposed.
6. (0.05–0.08 m): grey marly limestone with pebbles; accumulations of very small gryphaeids.
7. (1.6 m): claystone with several layers of siderite concretions (0.4, 0.6, 0.8, 0.9, 1.0, 1.15 and 1.3 m above base).
8. (0.05–0.08 m) flat to nodular, hard, grey marly limestone with occasional pebbles.
9. (0.01–0.05 m): marlstone.
10. (0.15–0.18 m): [inopernabank] greyish brown, hard marly limestone, easily splitting in weathered state. Numerous larger pebbles, especially in the lower part, where they can be flattened. Small, light grey pebbles give the rock a speckled appearance. Large burrows at the base. Bivalves are characteristic for the Inopernabank (big *Pholadomya*, *Inoperna sowerbyana*, *Gryphaea calceola* [smaller ones than those in the Calceolabank]). Some of the endobenthic bivalves are still in life position (see Quenstedt 1857: 357).
11. (ca. 3.5–4.0 m) claystone, not exposed.
12. (0.1–0.12 m) [konglomeratbank] hard, greyish brown marly limestone, with big pebbles. Large *Pholadomya* in life position.
13. (0.35 m): grey marl with abundant *Gryphaea calceola* (up to 0.03 m).
14. (0.15–0.18 m) [calceolabank] (= bed 12 in Dietze et al. 2019): Hard, grey, pyrite-bearing marly limestone. Partly easily splitting. Weathered brown and decomposing. At the base abundant *Gryphaea calceola* (up to 0.06 m large), only very rarely with right valves. The gryphaeids are embedded individually or in accumulations. Well-preserved ammonites are relatively common, predominantly in the lower third of the bed: *Brasilia cf. decipiens* (Fig. 19: 5a, b), *B. aff. decipiens* (Fig. 20: 3a, b), *Graphoceras aff. magnum* (Fig. 20: 1a, b), *G. cavatum* (Fig. 21: 2a, b), *G. cf. cavatum* (Fig. 20: 2a, b, Fig. 21: 1a, b), *G. pulchrum* (Fig. 22: 3a, b), *G. decorum* (Fig. 22: 1a, b), *G. formosum* (Fig. 22: 2a, b, 5a, b), *G. fallax* (Fig. 22: 4), *Ludwigella cornu* (Fig. 19: 2), *L. attracta* (Fig. 19: 3). *L. micra* (Fig. 19: 4), *Euapetoceras cf. euapetum* (Fig. 23: 1a–c), *E. cf. kochi* (Prinz) (The ammonite figured in Fig. 24 comes from an excavation pit in Jungingen 500 m west of the Mühlbächle stream).
15. (0.20 m): grey carbonaceous claystone.
16. (0.05 m): single hard marly limestone nodules (up to 0.05 m).
17. (0.20 m): grey carbonaceous claystone with small phosphoritic nodules. Masses of small gryphaeids (*Gryphaea calceola*).
18. (0.10 m): rough, phacoidal, reddish marlstone with occasional hard marly limestone nodules; pholadomyids. *Graphoceras concavum* is recorded from the Bachenaum section (Rieber 1922, 1963), which is situated about 50 m east of the Mühlbächle.
19. (0.08–0.1 m): light grey, very hard limestone with numerous dark grey burrows (*Chondrites* and cylindrical burrows up to 4 mm in diameter). Occasional compressed ammonites. Thin marly joint with bed 20.
20. (0.1–0.12 m) [rostrote Kalkbank] (= bed 15 in Dietze et al. 2019): On the outer surface weathered with a typical rusty red margin. In fresh state a hard, light grey, reddish and greenish grey marbled limestone. *Graphoceras* sp.
21. (8.0 m) (= bed 16 in Dietze et al. 2019): claystone (thickness according to A. Rieber 1922). Poorly exposed.
- Mue19-1

*Wedelsandstein-Formation:*

22. (0.15–0.2 m) [Sowerbyi-Oolith] (= bed 17 in Dietze et al. 2019): grey carbonaceous claystone with marly limestone nodules. Some nodules show concentric growth structures. Club-shaped borings are filled with calcitic oolites. The surface of rounded to flat nodules is densely covered on all sides with bryozoans, serpulids and sessile foraminifers. Some other nodules are grey inside, calcolitic, with scattered very small light grey pebbles. Rare serpulids, belemnites, bivalves and pebbles occur in the matrix. The very irregular-shaped, calcolitic limestone nodules are overgrown as well. In the claystone between the nodules occasional belemnites and endobenthic bivalves, *Entolium*.

Higher up follows the Unterer Wedelsandstein (see Dietze et al. 2019).
2.3.2 Starzel (river bed near the road Jungingen–Killer, see Lörcher (1939: 224):

**Achdorf-Formation: Bed no.**

1. (min. 0.4 m): claystone
2. (0.05 m): grey, flat nodular marly limestone.
3. (0.01–0.05 m): marly joint.

4. (0.15–0.2 m) [**Inopernabank**]: hard, grey limestone, in places speckled with small, light grey pebbles and large burrows at the base. Larger, mostly flattened pebbles occur predominantly in the lower part of the bed. The bed varies greatly in thickness and compactness. Large Pholadomya lirata, Inoperna soweryana, Goniomya literata, Gryphaea calceola (up to 0.03 m), Entolium sp., Propeamussium pumilum, and Oxytoma inaequivalvis. Small gastropods, belemnites and ammonites. Graphoceras cavatum (Fig. 13: 2a, b, 9a, b), G. aff. fallax (Fig. 13: 3), Brasilia decipiens (Fig. 13: 1a, b), Ludwigella attracta (Fig. 13: 7, 8), L. tenuis (Fig. 13: 4), L. aff. tenuis (Fig. 13: 5), L. attenuata (Fig. 13: 6), Planammatoceras sp. (Fig. 14: 1a–c). Lörcher (1939: 224) misidentified this bed as Calceolabank.

5. (min. 0.5 m): claystone.

6. Higher parts of the section are not exposed, except of the Rostrote Kalkbank bed above the railway bridge near the village Killer.

2.4 Hechingen-Beuren (Heiligenbach, Sießenwald, Hanneswiesle)

**2.4.1 Heiligenbach**

(the strata below bed 1 were not studied in detail)

**Bed no. / sample no.**

"Ob-1m" He19-1 1.0 m below Onkoidbank.

"Ob" (0.15–0.2 m) [**Onkoidbank**]: L. opalinum [m], about 11 m below "Wasserfallschichten". In its upper part a marly limestone, dark grey, upper and lower surface very irregular, with shrinkage cracks and oncocids (Fig. 3).

"x" (about 11 m): sandy, carbonaceous claystone, a single Lycoceras dilucidum.

- He19-2 0–0.1 m above Onkoidbank: numerous crinoids and bivalves.
- He19-3 1 m above Onkoidbank, numerous crinoids, Leioceras opaliniforme (body chamber).
- He19-4 2 m above Onkoidbank.
- He19-5 5 m below "Wasserfallschichten": Isolated lenticular, thin-layered, sandy-calcareous layers, micaceous, with crinoid debris (Pentacrinitenplatte with Chariocrinus wuerttembergicus), ichnofossils (Gyrochorte, Palaeophycus and others).
- He19-6 3 m below "Wasserfallschichten" of "WS" (about 14–15 m) [**Wasserfallschichten**] with several cascades in the river bed (Rieber 1922; Lörcher 1939; Kobler 1972: 14, pl. 2 [left column]).

1. (2.0 m): claystone, dark grey (at approx. 1.0 ca. 0.04 m irregular carbonaceous marlstone pebbles.
- He19-7 (middle)

2. (0.08–0.1 m) [**Belemnitenbreccie**]: hard, bluish-grey marly limestone, base very irregular, with a coquina of bivalves/echinoderms and grey pebbles, partially

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**Figure 2. Section Heiligenbach, lower part. Achd. Fm = Achdorf Formation; Ssz. = Subzone.**
with bivalve borings, irregularly bedded. Abundant belemnites, *Gryphaea calceola*, *Chlamys textoria*.

3. (7–8 m): claystone with layers of siderite concretions; only partly exposed.
   - 3a: 1.0 m above bed 2: layer of nodules (carbonaceus marlstone/siderite)
     - He19-8
     - He19-9 (3.0 m above bed 2): rare bivalves, *Bactrylium*, cylindrical burrows.
   - 3b: ca. 4.0 m above bed 2: noticeable nodule layer (brown marly limestone)
     - He19-10 (1.0 m below top): burrows
   In the upper 0.25 m single mica-bearing fine sandy limestone plates (up to approx. 0.03 m thick) with a rich ichnofauna, *Gyrochorte comosa*.

4. (0.7 m) [Zopfplatten]: fine sandy limestone, mica-bearing, splitting into thin plates; *Gyrochorte comosa*.

5. (ca. 3.5 m): very poorly exposed
   - 1.5 m above bed 4: claystone with siderite nodules.
     - He19-11 small gastropods.
     - He19-12 (directly below bed 6): very numerous agglutinating foraminifera.
   - 0.15–0.2 m: grey, marly limestone, small pebbles (up to nut-size). Lörcher (1939) described ammonites probably coming from this bed (or from bed 10).

6. (ca. 0.1 m): dark grey claystone.

7. (0.05 m): grey marly limestone, few small pebbles.

8. (ca. 3–4 m): dark grey claystone, very badly exposed
   - He19-13 (middle)
   - He19-14

9. (0.01 m): grey carbonaceous marl with a layer of pebbles.

10. (0.4 m): dark grey claystone.

11. (0.3 m): grey marlstone.

12. 0–10 cm grey, lenticular to nodular marly limestone; accumulations of remarkably small sized ammonites: *Leioceras "comptum", L. evolutum, L. striatum, L. paucicostatum* (from the corresponding layer of the Steinlach creek north of Mössingen-Talheim: *L. crassi-costatum, L. "comptum", L. striatum, L. paucicostatum, L. evolutum, L. sp. (with broad whorls)*) occasional bivalves; shrinkage cracks.

13. (0.03 m) dark grey marly claystone.

14. (0–0.1 m): carbonaceous marl nodules, in places a continuous, very hard carbonaceous marlstone bed with calcite-filled shrinkage cracks (Septarienbank). Occasional small ammonites (*Leioceras "comptum"*).

15. (0.02 m) (directly on top of bed 15): sandy carbonaceous marl tiles, trace fossils (not continuously present).

16. (0.35 m): dark grey marly claystone.

17. (0.08 m): grey sandy carbonaceous marlstone.

18. (0.65 m): dark grey claystone with siderite nodules.

19. (0.05–0.08 m): dark grey carbonaceous marl with small pebbles; thin marly claystone layer.

20. (1.1–0.12 m): grey carbonaceous marl with small pebbles [20 + 21: "Doppelbank"]

21. (0.1–0.12 m): grey carbonaceous marl with small pebbles [20 + 21: "Doppelbank"]

22. (ca. 2 m): dark grey claystone with grey limestone lenses.
23. (0.05–0.07 m): grey carbonaceous marl, irregular surface; abundant pyrite, pebbles up to 0.03 m.
24. (ca. 1 m): dark grey claystone, approx. 0.7 m above bed 23 with a layer of siderite nodules.
25. (0.05 m): grey marly limestone with small pebbles.
26. (1.3 m): dark grey claystone, layers of siderite nodules at 0.15, 0.65, and 1.15 m above bed 25.
• He19-16 (0.01 m above bed 25): crinoids
27. (0.08 –0.1 m): brown, coarsely conglomeratic marly limestone; bivalves and belemnites.
28. (3.5–4 m): dark grey claystone, only partly exposed.
• He19-17(0.25 m below bed 29)
29. (0.15 m): grey lenticular splitting carbonaceous marl.
30. (0.15 m): light grey marly limestone with dark grey spots.
31. (0.03 m): brownish grey carbonaceous marlstone with masses of small pebbles.
32. (0.15 m): brown marly limestone with bivalves [29–32: Staunfisbanshink]
33. (ca. 6 m): claystone, not exposed; according to Lörcher (1939) with several carbonaceous beds.
• He19-18 (0.5 m above bed 32)
• He19-19 (0.2 m below bed 34)
34. (0.1–0.15 m): grey marly limestone, thin bivalve shells; single small pebbles.
35. (2 m): claystone.
• He19-20 (0.4 m below bed 36)
36. (0.01 m): grey marly limestone, small pebbles up to 3 cm; shell debris. Belemnite, nautiloid (Cenoceras), Graphoceras.
37. (ca. 0.7 m): dark grey claystone.
38. (0.05 m): irregularly shaped bed of grey marly limestone.
39. (0.7 m): claystone; 0.4 m above bed 38 a layer of siderite nodules. Arthropod burrows at the top.
• He19-21 (0.4 m above bed 38)
40. (0.1 m) [Inoperanahbank]: grey, coarse conglomeratic limestone, with phosphoritic spots; Pholadomya irata, Gryphaea calceola, Inopera sowerbyana, ammonites: Graphoceras cf. caduciferum (Fig. 17: 1a, b), Brasilia sp. (SMNS 70519/54).
41. (4 m) (= bed 1 in Dietze et al. 2019): dark grey claystone, occasional flat siderite nodules at 0.6 m below top.
• He19-22 (41 middle)
• He19-23 (41, 0.5 m below bed 42)
42. (0.08–0.1 m) [Konglomeratbank] (= bed 2 in Dietze et al. 2019; starting from here this section had already been sampled in 1988): blueish grey limestone with pebbles. A fragment of Graphoceras sp. (Fig. 17: 2).
43. (0.02 m): calcioolitic marl.
• He19-24
44. (0.15–0.17 m): grey to brownish marly claystone.
• He19-25
45. (0.17 m) [Calceolabank], (= bed 5 in Dietze et al. 2019) grey marly limestone, lenticular splitting, on top 0.02 m oolitic marl. Thin-shelled bivalves, at the base (in places in marl lenses) abundant Gryphaea calceola. Ammonites: Brasilia decipiens (Fig. 18: 1), B. aff.
decipiens (Fig. 18: 4a, b). Graphoceras fallax (Fig. 18: 5), G. cavatum (Fig. 18: 2), G. cf. v-scriptum (Fig. 18: 3), Ludwigella arcitenens (Fig. 17: 3), L. sp. (Fig. 17: 5), Euaptetoceras infernense sensu Buckman (Fig. 17: 4).

46. (0.02 m): greyish beige claystone.
   • He19-26
47. (0.05 m): single grey limestone nodules up to 5 cm, partly with numerous small Gryphaea and serpulids.
48. (0.33 m): grey laminated claystone, with abundant small gryphaeids, single belemnite.
   • He19-27 (at the base)
   • He19-28 (0.1 m above bed 47)
49. (0.25–0.35 m) [Rostrote Kalkbank] (= bed 9 in Dietze et al. 2019): reddish brown carbonaceous marl with marly limestone nodules; 2 or 3 layers of flat siderite nodules. At the base 0.05 m greenish brown marly limestone.
   This outcrop is covered by terrace gravel of the Heiligengebirge.

2.4.2 Eastern tributary of the Heiligenbach coming from the Sießenwald, approx. 30 m east of the “Hunnengrab”

In the river bed there is a light grey, hard limestone bed (0.15 m) with a rust-coloured rim and many burrows. Its lithology resembles the lower bed of the Rostrote Kalkbank from the Mühlbächle section at Jungingen. An indeterminable ammonite fragment. A larger Euaptetoceras sp. (SMNS 70519/5) comes from a loose block of the Rostrote Kalkbank.

2.4.3 Hanneswiesle

This outcrop is located on a forest path in the Hanneswiesle district west of Beuren.

Bed no.
1. (0.08–0.1 m) [Konglomeratbank].
2. (0.2 m): carbonaceous claystone.
3. (0.03 m): firm marlstone with many Gryphaea calceola.
4. (0.15–0.2 m) [Calceolabank]: brownish marly limestone, splitting into plates in places, but in places solid grey marly limestone with a reddish brown rim also in weathered state. Small gryphaeids are firmly fixed in clusters on the bed surface (see Erb 1938).

Ammonites (Graphoceras pulchrum (Fig. 15: 5a, b), G. cf. pulchrum (Fig. 15: 4a, b), G. cf. concavum (Fig. 15: 1a, b), G. decorum (Fig. 15: 2), G. aff. apertum (Fig. 15: 3a, b), Ludwigella arcitenens (Fig. 15: 6a, b), Euaptetoceras infernense sensu Buckman (Fig. 14: 2a, b)) are mainly found in the lower part of the bed.
2.5 Bisingen-Thanheim (Heiligenkopf)

Since we did not find Aalenian ammonites in this outcrop, we here refer to Dietze et al. (2019) for the description of the section.

3. Description of the ostracod assemblages (M. Franz)

3.1 Methods

For the present study, a total of 41 samples were taken in September 2018 and September 2019. Individual samples, which were already taken in 1988 at the Heiligenbach, were included in the investigation.

Microfossils have been extracted by first drying the samples (0.5–1 kg), breaking them down with the aid of hydrogen peroxide (3% solution of $\text{H}_2\text{O}_2$) and then sieving them under water. The residues were then cleaned by boiling them for 15 minutes in a moderately concentrated sodium chloride solution (3 teaspoons NaCl / 0.25 l water). From the fractions > 0.5 mm and > 0.315 mm of the residues, 3–5 trays were examined. From the fractions > 0.2 mm and > 0.15 mm we examined 3 trays.

Photographs were taken using SEM in Stuttgart (SMNS).

3.2 Results

Introductionary remark:

The investigation of the Geisingen clay pit (Franz et al. 2018) has considerably increased the knowledge about the ostracod fauna of the Aalenian of SW Germany. The present investigation of approximately the same part of the section showed very good agreement in the Opalinum zone. However, several species are much rarer in the sections studied herein. In addition, strong changes in thicknesses and facies are noticeable. The vertical distribution of the species first described in Franz et al. (2018) – *Bellowella catena*, *Cardobairdia tesakovae*, *Cytheropterina alacostata*, *Eucytherura eberti*, *Euc. foveolata*, *Euc. sp. 3*, *Euc. sp. 5*, *Pleurocythere ohmerti*, *Progonocythere scutula* – is consistent in both sections.

The 41 samples yielded a total of 4,149 specimens, ranging from 0 to > 700 specimens per sample. For a semi-quantitative analysis of the composition of the ostracod assemblages the greater numbers of single (right or left) valves were counted as 1, resulting in a total of 2,758 individuals.

A total of 108 species were identified, 329 specimens remained undetermined. From 34 species of the Upper Opalinuston Formation, 22 do not cross the boundary to the overlying Achdorf Formation. The Achdorf Formation yielded a total of 62 species including the 12 already known from the Opalinuston Formation. In the Lower Wedelsandstein Formation 4 new species appear, 11 persist from the Aalenian.

At zone or subzone level, two relative maxima in the total number of species are recorded in the Opalinum Subzone and Concavum Zone (Table 4). The highest number of species in the Concavum Zone correlates with the highest number of newly reported species as well as the total number of genera and families.

Short descriptions of new species of cytherurids (*Eucytherura* sp. 3–11, *Procycytherura* sp. 2, P. sp. 5, *Procycytheropteron* sp. 1) in our material are excluded. Ten presumably new species were found only in numbers of one to five specimens and could not be assigned to any known genus. For this reason, these taxa were left in open nomenclature. In the samples of the fine sandy layers, the ostracods are partly covered by remnants of sediment (mainly quartz grains) and/or fragmentarily preserved.

Abbreviations:

| Acronym | Definition |
|---------|------------|
| LGRB    | Landesamt für Geologie, Rohstoffe und Bergbau im Regierungspräsidium Freiburg, Germany; |
| SMNS    | Staatliches Museum für Naturkunde Stuttgart, Germany; |
| C       | carapace; |
| RV      | right valve; |
| LV      | left valve; |
| HT      | Holotype. |

3.2.1 Systematic descriptions

In the following, the ostracod taxa that were found in the studied sections are listed in systematic order with information on their known occurrence. For detailed lists of synonyms, reference is made to Franz et al. (2018). Three new ostracod species are described. In addition, 15 presumably new species are briefly described in open nomenclature.

Order Myodocopida Sars, 1866

Family Polycopidae Sars, 1866

Genus *Polycope* Sars, 1866

*Polycope pelta* Fischer, 1961

Material. 2 V in sample He19-9 and Mü I.

Distribution. Upper Toarcian to Upper Bathonian.

*Polycope cf. riegrafii* Brand, 1990

Fig. 10: 1

Material. 2 C in sample He19-27

Distribution. Upper Aalenian, Concavum Zone; SW Germany.
**Polycope sp.**

**Material.** 1 C, 4 V in samples He19-15–21.

**Occurrence.** Upper Aalenian, Murchisonae Zone – Concavum Zone; SW Germany.

Remarks: The material comprises predominantly very small, smooth carapaces and valves with no visible ornamentation and therefore it is not determinable to species level under the microscope. It cannot be excluded that they belong to different species.

Order Podocopida Müller, 1894
Family Cytherellidae Sars, 1866
Genus Cytherella Jones, 1849

**Cytherella apostolescui** Ainsworth, 1986
Fig. 8: 1

**Material.** 30 C, 585 RV, 517 LV in samples He19-14–28, Mue19-1, Ha19-2–5 and Ro19-1–2.

**Distribution.** Upper Toarcian to Lower Oxfordian; SW Germany, Ireland.

**Cytherella apostolescui** ? ssp.

**Material.** 12 RV in samples He19-24 and Ro19-1–2.

**Distribution.** Upper Aalenian, Concavum Zone; SW Germany.

Remarks. This ?subspecies was first described and figured from Thanheim (Dietze et al. 2019).

Genus Cytherelloidea Alexander, 1929

**Cytherelloidea cf. cadomensis** (Bizon, 1960)

**Material.** 11 C, 18 RV, 28 LV in samples Ha19-4–6 and Ro19-1.

**Distribution.** Upper Aalenian to Lower Bajocian; England, France, SW Germany.

**Cytherelloidea cf. catenulata** (Jones & Sherborn, 1888)
Fig. 8: 2

**Material.** 2 RV, 1 LV in samples He19-17–18.

**Distribution.** Upper Aalenian to Bathonian; England, France, SW Germany.

**Paracypris sp.**

**Material.** 1 C in sample He19-1.
Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.

Remark. The specimen is very small and preserved in pyrite and could therefore not be assigned with certainty to any species.

Family Macrocyprididae Müller, 1912
Genus Macrocypris Brady, 1868
Macrocypris aequabilis Oertli, 1959
Fig. 9: 3

Material. 4 C samples in He19-19–21.

Distribution. Lower Aalenian to Lower Oxfordian; Germany, Scotland, N Switzerland, Russia.

Macrocypris ? liassica Bate & Coleman, 1975
Fig. 10: 4

Material. 4 C, 3 RV, 1 LV in sample He19-27 and Ro19-3.

Distribution. Toarcian to Upper Aalenian; England, SW Germany; Upper Bathonian; N Germany.

Macrocypris sp.

Material. 1 C, 1 R in samples He19-1 and He19-7.

Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.

Bythoceratina (Praebythoceratina) sp. 1

Material. 1 C, 8 RV, 9 LV in samples He19-16–27 and Ro19-4–5.

Occurrence. Upper Aalenian, Murchisonae to Concavum zones; SW Germany.

Description. A species of Praebythoceratina which is distinguished by the combination of the following features: an U-shaped lobe with an irregularly reticulate spine in the ventro-central area. Its anterior branch is strongly convex and irregularly reticulate, with dominant subvertical ridges. The posterior branch is broad and gently arched and covered with irregular pores. Along the anterior margin there is a pronounced bulge, which is also irregularly reticulate.

Genus Patellacythere Gründel & Kozur, 1971

Patellacythere paravulsa cf. tenuis Brand, 1990
Fig. 10: 5

Material. 2 C, 6 RV, 7 LV in samples He19-21–27 and Ro19-1–3.

Occurrence. Upper Aalenian, Concavum Zone; SW Germany.

Patellacythere cf. vulsa (Jones & Sherborn, 1888)
Fig. 6: 2

Material. 1 LV in sample He19-9.

Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.

Patellacythere unguulina (Triebel & Bartenstein, 1938)
Fig. 10: 6

Material. 3 RV, 1 LV in sample Mue19-1.

Occurrence. Upper Aalenian, Concavum Zone; Germany.

“Monoceratina” aff. posterocarinata Brand, 1990
Fig. 10: 7

Material. 2 C in sample He19-21 and Ro19-1.

Occurrence. Upper Aalenian, Concavum Zone; SW Germany.

Genus Tanycythere Cabral et al., 2014

Tanycythere posteroelongata Cabral et al., 2014
Fig. 10: 8

Material. 1 C in sample He19-27.

Distribution. Upper Toarcian to Upper Aalenian; SW Germany, Portugal.

Family Cytheruridae Müller, 1894
Genus Cytheropterina Mandelstam, 1956
Cytheropterina alacostata Franz et al., 2018
Fig. 10: 9

Material. 4 CV, 14 LV in samples He19-27, Mue19-1, Ha19-2 and Ro19-4–5.

Distribution. Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

Cytheropterina bicuneata (Braun) in Franz et al., 2018

Material. 53 RV, 50 LV in samples He19-16–27, Mue19-1, Ro19-1–5, Ha19-2.

Distribution. Lower Aalenian to Lower Bajocian; SW Germany.
**Cytheropterina crassicostata** sp. nov.

http://zoobank.org/6732D1E8-29AD-472F-B6F9-BCC64C020053

Fig. 10: 10–13

**Etymology.** crassus (lat.) = coarse, fat; costatus (lat.) = ribbed; referring to the broad rounded ribs.

**Holotype.** Right valve, figured on Fig. 10: 10, SMNS 70521/71.

**Paratypes.** two left valves, one right valve, figured on Fig. 10: 11–13, SMNS 70521/72–74.

**Type locality.** Heiligenbach valley near Hechingen-Beuren (SW Germany).

**Type horizon.** Achdorf Formation, claystone above the Calceolabank, bed no. 46 in Fig. 4; Concavum Zone.

**Material.** 11 RV, 11 LV in samples He19-26–27, Mue19-1 and Ro19-4–5.

**Diagnosis.** Medium size. Subtriangular outline, with broad, rounded irregular ribs; the underside of the alate extension being smooth except for its posterior part.

**Description.** Carapace medium-sized, subtriangular. Right and left valve (identical in outline and ornamentation): Anterior margin symmetrically rounded. The dorsal margin is straight, medianly slightly concave. The ventral margin converges, partly straight or in a slight curve, to the acuminate posterior end. The ventral margin is obscured by a broad triangular wing. The anterior and posterior marginal zones are covered with roundish pits. The anterior marginal zone is offset with a small, asymmetrically round-ed step against the lateral surface. A broadly rounded, mediodorsally-anteroventrally running rib forms a second step running diagonally over the anterior half of the valve. From this rib another broad rib branches off slightly below the middle, running subvertically towards the edge of the wing. The adjoining surface, which ends in the symmetrically rounded tip of the broad wing, is characterised by three wide, flat, bulbous elevations separated by wide furrows and pits. The furrows and pits as well as the ribs and depressions are covered with roundish secondary pits. Posteriorly, this area is bounded by a slightly curved, subvertical, rounded rib that tapers from dorsal to ventral. The posterior marginal zone is offset with a further, almost straight, subvertical step. Marginal zone wide anteriorly (Fig. 10: 13). The underside of the wing, which in ventral view forms a rectangular triangle, is smooth, except for its posterior third. A triangular area is covered by small grooves which are most prominent along the posterior margin of the wing. Hinge and other internal details are not observed.

**Comparisons.** *Cytheropterina crassicostata* resembles in outline *Cytheropterina bicuneata* (Braun) as reported by Franz et al. (2018) from the Aalenian and Lower Bajocian of SW Germany, and *Cytheropterina cribra* Fischer, 1962 (p. 339, Fig. 25: 8–11) from the Toarcian to Bajocian. The main differences are the coarse, softly rounded ornamentation, the smooth underside of the wing and the bigger size.

**Occurrence.** Upper Aalenian, Bradordensis Zone (Gigantea Subzone) to Concavum Zone, SW Germany.

**Cytheropterina cribra** (Fischer, 1962)

**Material.** 1 C, 4 LV in samples He19-7–12.

**Distribution.** Lower Toarcian to Upper Bajocian; France, Germany, Ireland, Spain, N Switzerland.

**Procytherura celtica** Ainsworth, 1986

Fig. 6: 3

**Material.** 2 RV in samples He19-12 and from the Geisingen clay pit.

**Distribution.** Upper Toarcian to Lower Bajocian; Germany, Ireland.

**Procytherura euglyphea** Ainsworth, 1986

Fig. 6: 4, 5

**Material.** 3 C, 4 RV, 6 LV in samples He19-5–26.

**Distribution.** Upper Toarcian to Lower Bajocian; SW Germany, Ireland.

**Procytherura multicostata** Ainsworth, 1986

Fig. 6: 6, 7

**Material.** 3 C, 4 RV, 6 LV in samples He19-5–26.

**Distribution.** Upper Toarcian to Lower Bajocian; SW Germany, Ireland.

**Procytherura aff. serangodes** Ballent & Whatley, 2000

Fig. 8: 4

**Material.** 1 C in sample He19-15.

**Distribution.** Lower Aalenian to Lower Bajocian; SW Germany; mid-Callovian; Argentina.

**Procytherura sp. 2** Franz et al., 2018

Fig. 6: 8

**Material.** 1 RV in sample He19-8, 1 C in the Geisingen clay pit.

**Occurrence.** Lower Aalenian, Opalinum Zone; SW Germany.

**Description.** Very small, subovoidal outline in lateral view. Lateral surface with five broadly rounded ribs, subhorizontal in the midventral to posteromedian area; in the anterior half of the valve bent anteroventrally. Roughly reticulated in the region of these ribs by subvertical transverse ribs.

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### Table 1. Dimensions of *Cytheropterina crassicostata* sp. nov.

|          | Length  | Height | Width  |
|----------|---------|--------|--------|
| Holotype | 0.516 mm| 0.338 mm|        |
| Paratype | 0.556 mm| 0.364 mm| 0.222 mm|
**Procytherura sp. 5**

Fig. 10: 14

**Material.** 1C, 1 RV in samples He19-24–25.

**Occurrence.** Upper Aalenian, Concavum Zone; SW Germany.

**Description.** Very small, subtriangular outline in lateral view. Lateral surface weakly ornamented by two fine longitudinal ribs delimiting a spindle-shaped field, posteriorly rounded and anteriorly pointed. Parallel to the anterior margin there is a third, also very fine rib. Another middorsal-midanteral rib halves the acute-angled triangular field between the frontal rib and the upper longitudinal rib.

**Genus Tethysia Donze, 1975**

? *Tethysia* sp.

**Material.** 1 LV in sample He19-8.

**Occurrence.** Lower Aalenian, Opalinum Zone; SW Germany.

**Genus Eucytherura Müller, 1894**

**Eucytherura eberti** sp. nov.

http://zoobank.org/12B4883C-8F55-481A-A41E-B2665DB8069F

Fig. 6: 9–11

2018 *Eucytherura* aff. *scottia* (Whatley, 1970). – Franz et al., p. 72, plate 3: 17.

2019 *Eucytherura* aff. *scottia* (Whatley). – Dietze et al., fig. 11.

**Etymology.** In honour of the German palaeontologist Martin Ebert, who initiated the investigation of the Geisingen clay pit with his extensive preliminary work.

**Holotype.** Carapace, figured on Fig. 6: 9, SMNS 70521/9.

**Paratypes.** Two carapaces, figured in Fig. 6: 10, 11, SMNS 70521/10–11.

**Type locality.** Heiligenbach valley near Hechingen-Beuren (SW Germany).

**Type horizon.** Opalinuston Formation, Zillhausen Subzone; SW Germany.

**Material.** 10 C, 28 RV, 34 LV from the Heiligenbach, Thanheim and Roschbach sections and the Geisingen clay pit.

**Diagnosis.** A new species of *Eucytherura* with broad, smooth posterodorsal, frontal and ventral ribs. Intercostate areas weakly reticulate.

**Description.** Very small, subrectangular. Left valve slightly larger than right with anterodorsal and postero-dorsal overlap. Anterior margin weakly rounded with extremity below mid-height; posterior margin pointed in right and bluntly rounded in left valve, apex above mid-height. Posterior cardinal angle pronounced in both valves; anterior cardinal angle more rounded in right than in left valve. Dorsal margin slightly convex to straight; ventral margin medianly slightly convex. Greatest height at anterior cardinal angle; greatest width antero-ventrally; greatest length above mid-height. Ornament consists of a series of broad longitudinal ribs and swellings, and with weakly reticulate intervening areas. A broad, posteriorly weakly alate rib extends from a postero-ventral position across the ventro-lateral surface of the valve, terminating antero-ventrally. A similar broad rib extends mid-posteriorly to mid-dorsally. The eye tubercule is well developed and is connected to a narrower frontal rib, which parallels the anterodorsal margin. A less prominent second rib or elongate swelling parallels the latter mid-anteriorly. Intercostate areas are weakly reticulate, with a characteristic row of small elongate pits above the muscle-scar field. 3–4 small marginal denticles occur anteriorly. Normal pores few and wide-spaced. Internal details not observed.

**Comparisons.** *Eucytherura eberti* closely resembles *Eucytherura scottia* Whatley, 1970 from the Callovian and Oxfordian of Scotland. It differs mainly in the length of the dorsal rib, the absence of the anterior tubercles, being replaced by two parallel ribs and the pits above the muscle-scar field.

**Distribution.** Lower Aalenian to Upper Aalenian, Opalinum to Bradfordensia zones (Gigantea Subzone); SW Germany.

**Eucytherura foveolata** sp. nov.

Fig. 6: 12–14

http://zoobank.org/7D6E8E7E-FA22-4597-837D-3E25EBF70FD7

2018 *Eucytherura* sp. 4. – Franz et al., p. 72, plate 3: 22

**Etymology.** From *fovea* (lat.) = pit; referring to the characteristic pits on the lateral surface.

**Holotype.** One carapace, figured in Fig. 6: 12, SMNS 70521/12.

**Paratypes.** Two carapaces, figured in Fig. 6: 13, 14, SMNS 70521/13–14.

**Type locality.** Drillcore KB 1/93 Geisingen (SW Germany).

**Type horizon.** Opalinuston Formation, Zillhausen Subformation, sample G08Fr, Lower Aalenian.

**Material.** 19 C, 2 RV, 2 LV from samples He 19-3–12 and from the Geisingen clay pit.

**Diagnosis.** A small-sized species of the genus *Eucytherura* with the following characteristics: pitted lateral surface with a fine median rib.

**Description.** Very small, subrectangular. Left valve slightly larger than right with dorsal overlap. Anterior margin rounded with extremity slightly below mid-height; posterior margin pointed in right and bluntly rounded in left valve, apex above mid-height. Posteri-
or cardinal angle rounded; anterior cardinal angle pronounced in both valves. Dorsal margin straight in left, slightly convex in right valve; ventral margin straight or slightly concave. Greatest height at anterior cardinal angle; greatest length above mid-height. Ornament consists of a fine median, horizontal or subdiagonal rib, accompanied on both sides by shallow, about 15 μm wide, round or subangular pits with a rough surface. A third row of such pits running antero-medianly – posteriorly; further pits in variable numbers and positions scattered on the lateral surface. Particularly striking are 4 rhomboidally grouped pits (Fig. 6: 12) in the mid-dorsal area. Eye-tubercle only weakly developed. Internal details not observed.

Comparisons. All other previously known species of *Eucytherura* have a well-developed ornamentation with sharp or broad ribs and/or reticulate surfaces.

Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.

### Eucytherura liassica Bate & Coleman, 1975

Fig. 6: 15

**Material.** 2C, 1 RV, 8 LV in samples He19-3–26 and Ro19-2.

**Distribution.** Toarcian to Upper Aalenian; England, SW Germany.

### Eucytherura michelseni (Finger, 1983)

Fig. 6: 16

**Material.** 2C, 2 RV, 8 LV in samples He19-3–18 and Ro19-4–5.

**Distribution.** Upper Pliensbachian to Lower Bajocian; Denmark, England, Sweden, Germany, Argentina, ? Australia.

### Eucytherura cf. parairregularis Brand, 1990

Fig. 9: 4

**Material.** 5 C, 2 LV in samples He19-19–25, Ha19-4–5.

**Distribution.** Upper Aalenian, Bradfordsensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

### Eucytherura plumhoffi Tesakova, 2017

Fig. 7: 1

**Material.** 1 C, 3 RV, in samples He19-1–7.

**Distribution.** Lower Aalenian, Opalinum Zone; SW Germany, N Switzerland.

### Eucytherura transversiplicata (Bate & Coleman, 1975)

Fig. 7: 2

**Material.** 13 C, 9 RV, 7 LV in samples He19-3–28, Ha19-4–5 and Ro19-3–5.

**Distribution.** Pliensbachian to Bajocian; Argentina, Egypt, England, Germany, Ireland, North Africa, Wales.

### Eucytherura cf. yunga Ballent & Whatley, 2009

Fig. 9: 5

2018 *Tethysia* sp. 1 Tesakova. – Franz et al., p. 71, plate 3: 12.

2019 ? *Eucytherura* sp. 10. – Dietze et al., plate 7: 21.

**Material.** 1 C, 10 RV, 6 LV in samples He19-19–27, Ro19-1, and from the Thanheim section and the Geisingen clay pit.

**Distribution.** Upper Aalenian to Lower Bajocian; Argentina, SW Germany.

### Eucytherura aff. yunga Ballent & Whatley, 2009

Fig. 10: 15

**Material.** 1 LV in sample He19-27.

**Distribution.** Upper Aalenian to Lower Bajocian; Argentina, SW Germany.

**Remark.** This specimen closely resembles plate 1: 7 in Ballent and Whatley (2009).

### Eucytherura aff. sp. B Boomer & Ballent, 1996

Fig. 10: 16

**Material.** 1 LV in sample He19-25.

**Occurrence.** Lower Aalenian, Opalinum Zone; SW Germany, N Switzerland.

### Eucytherura sp. 1, *Euc*. sp. 3 and *Euc*. sp. 5

These species were first named and figured by Franz et al. (2018) but without descriptions; in the following we add their descriptions:

### Eucytherura sp. 1 Franz et al., 2018

Fig. 7: 3

**Material.** 5 RV, 1 LV in samples He19-2–12; 17 C, 1 RV from the Geisingen clay pit; 1 C from the Benken borehole (Switzerland).

**Occurrence.** Lower Aalenian, Opalinum Zone; SW Germany, N Switzerland.

**Description.** Very small, subrectangular. Left valve slightly larger than right with dorsal overlap. Anterior margin rounded with extremity slightly below mid-height; posterior margin pointed in right and bluntly rounded in left valve, apex above mid-height. Posterior cardinal angle rounded; anterior cardinal angle pronounced in both valves, slightly more rounded in right valve. Dorsal and ventral margins slightly convex in both valves. Greatest height at

| Table 3. Dimensions of *Eucytherura foveolata* sp. nov. |
|--------------------------------------------------------|
| **Length** | **Height** |
| Holotype | 0.327 mm | 0.158 mm |
| Paratype | 0.318 mm | 0.162 mm |
Very small, subovoidal. Anterior mar

d

Eucytherura sp. 3 Franz et al., 2018
Fig. 7: 4

Material. 25 C, 4 RV, 4 LV in samples He19-6–18 and from
the Geisingen clay pit.

Occurrence. Lower to Upper Aalenian, Opalinum to
Bradfordensios zones; SW Germany.

Description. Very small, subrectangular. Left valve slight-
ly larger than right with dorsal overlap. Anterior margin
rounded with extremity slightly below mid-height; posterior
margin pointed in right and bluntly rounded in left valve,
 apex above mid-height. Posterior cardinal angle rounded;
anterior cardinal angle pronounced in both valves, slightly
more rounded in right valve. Dorsal margin straight in right
valve and slightly convex in left valve. Greatest height at an-
terior cardinal angle; greatest length above mid-height. Shell
surface regularly reticulate with rounded meshes of uniform
size. Hemispherical eye-tubercle well developed. Starting
from the eye-tubercle, a fine frontal rib, straight in the left
valve, convex in the right valve, runs parallel to the ante-
rodorsal margin. A second rib runs subvertically from the
eye-tubercle and then bends mid-anteriorly to the anterior
margin. A ventral rib starts posteroventrally and ends mid-
ventrally with its anterior end slightly ascending towards the
ventromedian side. A short subvertical ridge is located at the
posterior cardinal angle. Internal details not observed.

Eucytherura sp. 5 Franz et al., 2018
Fig. 9: 6

Material. 1 C in sample He19-19; 5 RV, 1 LV from the
Geisingen clay pit.

Occurrence. Lower to Upper Aalenian, Opalinum to
Bradfordensios zones; SW Germany.

Description. Very small, subovoidal. Anterior margin
asymmetrically rounded with extremity below mid-height;
posterior margin pointed, apex above mid-height. Posterior
cardinal angle rounded; anterior cardinal angle pronounced
in both valves. Dorsal margin slightly convex, ventral margin
convex. Greatest height at anterior cardinal angle; greatest
length above mid-height. Shell surface irregularly and
coarsely reticulated. The most striking feature is the gently
undulating surface with slight anterodorsal, middorsal and
anteroventral depressions. The eye-tubercle is fused with a
short, indistinct frontal rib. A short bulge-like rib is located at
the posterior cardinal angle. Internal details not observed.

Eucytherura sp. 11
Fig. 9: 7

Material. 1 RV, 2 LV in samples He19-18 and He19-24–25.

Occurrence. Upper Aalenian, Bradfordensios Zone; SW
Germany.

Description. Very small, subovoidal. Anterior mar-
gin asymmetrically rounded with extremity below mid-
height; posterior margin rounded, apex above mid-
height. Anterior and posterior cardinal angles rounded;
both slightly more pronounced in right valve. Dorsal
margin slightly concave in their right valve, slightly con-
 vex in the left one. Greatest height at anterior cardinal
angle; greatest length above mid-height. Shell surface
reticulate, with wide rectangular to polygonal meshes.
Eye-tubercle absent.

Right valve: A long, well-defined frontal rib runs from
the anterior cardinal angle to the anteroventral margin.
The lateral surface is characterized by three fine ribs, the
first of which starts in the median region, runs a short
distance towards the anterior cardinal angle, then bends
perpendicularly towards the anterior margin and after a
second 45° bend towards the anteroventral margin. The
median rib starts mid-posteriorly above mid-height and
ends anteromedianly below mid-height. A long, upwardly
curved ventral rib runs from the posteroventral margin to
the anteroventral region. One (or two) ribs parallel the ven-
tral rib on the ventral side of the valve.

Left valve: The frontal rib is slightly curved
(preservation?) and only weakly developed. The (dorso-
median – mid-anterior rib meets the ventral rib at an 60°
angle. The median rib starts mid-posteriorly above mid-
height and ends anteromedianly at mid-height. Two ribs
parallel the ventral rib on the ventral side of the valve.
Further, especially internal details were not observed,
partly for preservation reasons.

Eucytherura sp. 10
Fig. 10: 17, 18

Material. 1 RV, 1 LV in samples He19-24–25.
Genus *Balowella* Wienholz, 1967

*Balowella catena* (Franz et al., 2018)

Fig. 9: 8, Fig. 11: 1

2018 *Procytheropteron catena* sp. nov. – Franz et al., p. 73, plate 4: 4–6.

**Material.** 3 C, 22 RV, 26 LV in sample He19-18–28.

**Distribution.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

**? Balowella sp.**

**Material.** 1 RV in sample He19-18.

**Distribution.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone); SW Germany.

**Remark.** The single (juvenile ?) specimen is only tentatively placed in this genus due to its small size and poor preservation.

Genus *Cytheropteron* Sars, 1866

**? Cytheropteron sp. 1**

Fig. 11: 2, 3

**Material.** 3 RV, 4 LV in samples He19-25 – Ha19-3.

**Occurrence.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

**Description.** Very small, triangular. Anterior margin round-ed with extremity slightly below mid-height; posterior margin pointed, apex below mid-height. Cardinal angles rounded in left valve, cardinal angles pronounced in right valve.

**Right valve:** Dorsal margin straight, slightly convex, ventral margin slightly convex, medianly partly obscured by a median overhang of the lateral curvature. The punctate shell surface is longitudinally and vertically strongly curved with a ventral overhang. The curvature is concavely recessed in the uppermost area along a sharp oval bend, ending in a weak anteromedian lobe. A narrow anterodorsal depression parallel to the anterior margin is limited by a short, slightly curved frontal rib, ending above mid-height.

**Left valve:** Dorsal margin strongly convex, otherwise identical to the right valve.

Hinge due to poor preservation not clearly visible, possibly merodont; other internal details not observed.

Genus *Procytheropteron* Ljubimova, 1955

**Procytheropteron aff. gramanni** Brand, 1990

Fig. 11: 4, 5

**Material.** 3 RV, 2 LV in samples He19-22–24 and Ro19-1.

**Occurrence.** Upper Aalenian, Concavum Zone; SW Germany.

**Remarks.** Our specimens resemble *Procytheropteron grammanni* Brand, 1990 (plate 9: 10) from the Upper Bathonian of NW Germany; they differ in age and in the coarser ornamentation and reticulation.

**Procytheropteron sp. 1** Franz et al., 2018

Fig. 11: 6

**Material.** 2 LV in sample He19–24 and from the Geisingen clay pit.

**Distribution.** Upper Aalenian, Bradfordensis Zone; SW Germany.

**Description.** Very small, ovoidal. Anterior margin almost symmetrically rounded; posterior margin pointed, apex at mid-height. Cardinal angles rounded in the left valve.

Dorsal margin straight to slightly convex, ventral margin convex, medianly partly obscured by a median overhang of the lateral curvature. The complete lateral surface is decorated with vertical, broadly rounded ribs. The ribs in the median part of the valve are irregular, interrupted at about mid-height, and offset laterally against each other. The vertical ribs are framed by a curved ventral rib, which is also rounded, and a similar dorsal rib, which almost touch each-other mid-posteriorly.

Internal details not observed.

Genus *Metacytheropteron* Oertli, 1957

**Metacytheropteron opalinum** Plumhoff, 1963

**Material.** 3 C, 5 RV, 3 LV in samples He19-5–12.

**Distribution.** Upper Toarcian to Upper Aalenian; Germany.

Genus *Aphelocythere* Triebel & Klingler, 1959

**Aphelocythere dilgeri** Franz et al., 2018

Fig. 7: 5

**Material.** 2 RV, 3 LV in samples He19-1–22.

**Distribution.** Lower Aalenian to Lower Bajocian; SW Germany.

**Aphelocythere pygmaea** Plumhoff, 1963

Fig. 7: 6

**Material.** 7 C, 10 RV, 9 LV in samples He19-1–13.

**Occurrence.** Upper Aalenian, Murchisonae Zone; SW Germany.
**Aphelocythere recta** Ohmert, 2004
Fig. 11: 7

**Material.** 1 C in sample Ro19-4.

**Occurrence.** Upper Aalenian, Concavum Zone; SW Germany.

**Aphelocythere aff. recta** Ohmert, 2004
Fig. 11: 8

**Material.** 1 RV in sample Ro19-4.

**Occurrence.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

**Remark.** Ohmert (2004) mentioned this species as a probable ancestor of *Aphelocythere recta* from the top of the Concavabank.

? *Aphelocythere* sp. 1
Fig. 7: 7, Fig. 11: 9

**Material.** 2 C, 5 RV, 1 LV in samples G08Fr, G12Fr, G13Fr, He19-6, He19-26–28.

**Occurrence.** Lower to Upper Aalenian, Opalinum to Concavum zones; SW Germany.

**Description.** Very small, subrectangular. Anterior margin rounded with extremity slightly below mid-height; posterior margin rounded, apex above mid-height. Cardinal angles rounded in both valves, slightly more pronounced in left valve. Dorsal margin straight, ventral margin slightly convex. The shell surface is smooth, with a number of pits, which are difficult to recognize due to bad preservation. Internal details not observed.

**Family Cytherideidae** Sars, 1925

**Genus Vernoniella** Oertli, 1957

*Vernoniella? caytonensis* Bate, 1965
Fig. 12: 10

**Material.** 1 C in sample Ro19-5.

**Occurrence.** Upper Aalenian, Concavum Zone; SW Germany.

**Remark.** *Vernoniella? caytonensis* was described from the Blagdeni Subzone in England; our specimen comes from the Concavum Zone and therefore has been tentatively placed in this species.

**Family Schulerideidae** Mandelstam, 1959

**Genus Asciocythere** Swain, 1952

"Asciocythere" sp.
Fig. 11: 10

**Material.** 4 C, 3 LV in samples He19-25–26 and Ha19-4.

**Occurrence.** Upper Aalenian to Lower Bajocian; SW Germany.

**Remark.** We have set *Asciocythere* in quotation marks, because the generic assignment of this species is doubtful.

**Genus Eocytheridea** Bate, 1963

*Eocytheridea elongata* Bate, 1963
Fig. 11: 11

**Material.** 2 C, 7 RV, 5 LV in samples He19-21, Mue19-1 and Ro19-1–5.

**Distribution.** Upper Aalenian; England, SW Germany.

**Eocytheridea lacunosa** Bate, 1963
Fig. 11: 12

**Material.** 52 C, 183 RV, 209 LV in samples He19-23–29 and Ro19-1–5.

**Distribution.** Upper Aalenian to Lower Bajocian; England, SW Germany.

**Genus Praeschuleridea** Bate, 1963

*Praeschuleridea ornata* (Bate, 1963)
Fig. 9: 9

**Material.** 57 C, 106 RV, 136 LV in samples He19-18–29, Ha19-1–5 and Ro19-1–5.

**Distribution.** Lower Aalenian to Lower Bajocian; England, Germany.

*Praeschuleridea punctulata* (Plumhoff, 1963)
Fig. 8: 5

**Material.** 36 C, 49 RV, 47 LV in samples He19-13–29, Ha19-1–5 and Ro19-1–5.

**Distribution.** Upper Toarcian to Lower Bajocian; Germany, Spain, Switzerland.

*Praeschuleridea cf. subtrigona* (Jones & Sherborn, 1888)
Fig. 11: 13, 14

**Material.** 4 C, 5 RV, 13 LV in samples Ro19-1–5.

**Occurrence.** Upper Aalenian, Concavum Zone; SW Germany.

**Remark.** The specimens from the Roschbach section closely resemble *Praeschuleridea subtrigona* from the Upper Bajocian to Upper Callovian. It is only tentatively placed in this species because of the remarkable difference in age.

*Praeschuleridea ventriosa* (Fischer in Plumhoff, 1963)
Fig. 7: 10

**Material.** 118 C, 52 RV, 76 LV in samples He19-2–21, Mue19-1, Ha19-1–3 and Ro19-1–5.
Distribution. Upper Toarcian to Lower Bajocian; Germany, Spain, Switzerland.

Praeschuleridea sp. A (Ainsworth, 1986)
Fig. 8: 6
Material. 1 C, 2 LV in samples He19-17–25.
Distribution. Toarcian to Aalenian; Germany, Ireland.

Praeschuleridea sp. 1
Fig. 11: 15–17
Material. 4 C, 2 RV, 4 LV in samples He19-27 and Ha19-5.
Occurrence. Upper Aalenian, Concavum Zone to Early Bajocian; SW Germany.
Description. Medium-sized, subovate. Left valve larger than right valve, overlapping along complete outline. Anterior margin slightly asymmetrical rounded, extremity just below mid-height. Posterior margin triangular, upper margin straight, lower margin convex, the two joining at an angle below mid-height. Dorsal margin convex, ventral margin convex with slight concavity in front of mid-length in the right valve. Anterior cardinal angle rounded, posterior cardinal angle sloping straight to the posterior margin. Valve ventrolaterally swollen. Small-sized pits irregularly distributed over the anterior valve surface, significantly denser in the posterior third. A narrow channel with densely arranged pits parallels the anterior margin. Anteroventrally and posteroventrally there is a row of finest denticles.

The partly broken (? paleohemimerodont) hinge shows terminal serrated teeth and remains of teeth in the median hinge area of the right valve.

Family Protocytheridae Ljubimova, 1955
Genus Southcavea Bate, 1964

? Southcavea sp.
Fig. 9: 10, 11
Material. 3 C, 7 RV, 4 LV in samples He19-18–25 and Ro19-1–2.
Occurrence. Upper Aalenian, Bradfordensis Zone (Gigantea Subzone); SW Germany.

Genus Pleurocythere Triebel, 1951
Pleurocythere kirtonensis Bate, 1963
Fig. 9: 12
Material. 1 RV, 1 LV in sample He19-18.
Distribution. Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Lower Bajocian; England, southwest Germany.

Pleurocythere ohmerti Franz et al., 2018
Fig. 11: 18
Material. 20 C, 29 RV, 27 LV in samples He19-24–29, Ha19-4–5 and Ro19-1–3.
Distribution. Upper Aalenian, Concavum Zone to Early Bajocian; SW Germany.

Pleurocythere sp. 1
Fig. 8: 7
Material. 1 LV in sample He19-16.
Occurrence. Upper Aalenian, Murchisonae Zone; SW Germany.
Remark. This specimen resembles Pleurocythere kirtonensis in the arrangement of the ribs. In contrast to P. kirtonensis the ribs are broad and rounded. Possibly the median rib touches the ventral rib anteroventrally. More material is required for clarification.

? Pleurocythere sp.
Fig. 7: 8
Material. 1 RV, 1 LV in sample He19-1.
Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.
Remark. The two specimens may represent an ancestor of the genus Pleurocythere.

Family Progonocytheridae Sylvester-Bradley, 1948
Genus Acrocythere Neale, 1960

Acrocythere pumila Plumhoff, 1963
Fig. 7: 9
Material. 4 C, 2 RV, 4 LV in samples He19-1–12.
Distribution. Lower Aalenian, Opalinum Zone; Germany, Switzerland.

Acrocythere aff. pumila Plumhoff, 1963
Fig. 9: 13
Material. 3 LV in samples He19-18 and He19-27.
Occurrence. Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; Germany.
Remark. In addition to the differentiation from Acrocythere pumila in Plumhoff, 1963, it should be noted that the reticulation between the median rib and the ventral rib in the posterior section is alternating here, whereas it is clearly linear in A. pumila.
Genus *Homocytheridea* Bate, 1963

*Homocytheridea* sp. 1

**Fig. 8: 8**

**Material.** 1 LV in sample He19-15.

**Occurrence.** Upper Aalenian, Murchisonae Zone; SW Germany.

*Homocytheridea* sp. 2

**Fig. 8: 9**

**Material.** 22 C, 15 RV, 18 LV in samples He19-15–28, Mue19-1 and Ro19-4.

**Occurrence.** Upper Aalenian, Murchisonae to Conchavum zones; SW Germany.

Genus *Camptocythere* Triebel, 1950

*Camptocythere pusilla* Plumhoff, 1963

**Fig. 12: 1**

**Material.** 30 C, 43 RV, 36 LV in samples He19-24–28 and Ro 1–3.

**Distribution.** Upper Aalenian; Germany.

Genus *Aalenella* Plumhoff, 1963

*Aalenella* sp.

**Material.** 1 C in sample He19-18.

**Occurrence.** Aalenian, Bradfordensis Zone; SW Germany.

Genus *Progonocythere* Sylvester-Bradley, 1948

*Progonocythere scutula* Franz et al., 2018

**Fig. 8: 10**

**Material.** 1 C, 6 RV, 6 LV in sample He19-17.

**Distribution.** Upper Aalenian, Bradfordensis Zone; SW Germany.

*Progonocythere triangulata* Braun in Ohmert, 2004

**Fig. 12: 11**

**Material.** 11 C, 34 RV, 34 LV in samples Ha19-4–5.

**Distribution.** Lower Bajocian; SW Germany. *Progonocythere triangulata* is the index species of the Triangulata ostracod Subzone (Ohmert 2004).

Genus *Kinkelinella* Martin, 1960

*Kinkelinella (Kinkelinella) adunca* Malz, 1966

**Fig. 12: 2**

**Material.** 1 C, 4 RV, 16 LV in samples He19-23–29.

**Distribution.** Upper Aalenian to Lower Bajocian, Conchavum to Discites zones; SW Germany.

*Kinkelinella (Kinkelinella) fischeri* Malz, 1966

**Fig. 8: 11**

**Material.** 6 C, 18 RV, 22 LV in samples He19-14–18, Ha19-6, Lin 18-4, Mue19-1 and Ro19-1–5.

**Distribution.** Upper Aalenian to Lower Bajocian; France, Germany, Russia, Spain, Switzerland.

*Kinkelinella (Kinkelinella) levata* Ohmert, 2004

**Fig. 12: 3**

**Material.** 4 C, 76 RV, 109 LV in samples He19-21–28 and Ro19-1–5.

**Occurrence.** Upper Aalenian to Lower Bajocian, Conchavum to Discites zones; SW Germany.

*Kinkelinella (Kinkelinella) sermoisensis* (Apostolescu, 1959)

**Fig. 7: 11**

**Material.** 2 C, 1 RV in sample He19-9.

**Distribution.** Lower Toarcian to Lower Bajocian; England, France, Germany, Ireland, Portugal, Russia, Spain, N Switzerland.

*Kinkelinella (Kinkelinella) cf. sermoisensis* (Apostolescu, 1959)

**Fig. 12: 4**

**Material.** 9 C, 14 RV, 10 LV in samples Mue19-1 and Ro19-1–5.

**Distribution.** Upper Aalenian to Lower Bajocian; SW Germany.

*Kinkelinella (Ektyphocythere) triangula* (Brand, 1961)

**Fig. 12: 12**

**Material.** 5 RV in samples Ha19-4–5.

**Distribution.** Early Bajocian; England, France, Germany, N Switzerland.

*Kinkelinella sp. B* Ohmert, 2004

**Fig. 12: 5**

**Material.** 9 RV, 8 LV in samples He19-25–26, Mue19-1, Ha19-5 and Ro19-3–5.

**Occurrence.** Upper Aalenian to Early Bajocian, Conchavum to Discites zones; SW Germany.
**Kinkelinella sp. 2**  
Fig. 8: 12

**Material.** 5 RV, 5 LV in samples He19-14–17 and Ro19-2.

**Occurrence.** Lower to Upper Aalenian, Opalinum Zone (“Comptum” Subzone) to Bradfordensis Zone; SW Germany.

**Description.** Anterior margin broadly rounded, accompanied by a flat marginal bulge. The dorsal margin slightly convex, with the greatest height in front of midlength of the valve. Posterior end flat, with narrowly rounded posterior margin. Ventral margin obscured by the the overhanging ventro-lateral curvature. The central part of the valve is ventrally strongly inflated, and clearly set off against the anterior and posterior ends. Remnants of two ventral ribs are visible parallel to the ventral margin. The remaining part of the valve shows only weak hints of a very fine, irregular reticulation.

**Ektyphocythere aff. anterocosta** Boomer, 1988  
Fig. 8: 13

**Material.** 1 RV in sample He19-14.

**Occurrence.** Toarcian to Lower Aalenian; England, SW Germany.

**Family Neurocytheridae** Gründel, 1975  
**Genus Fuhrbergiella** Brand & Malz, 1962  
**Fuhrbergiella (Praefuhrbergiella) horrida bicostata** Brand & Malz, 1962  
Fig. 12: 13

**Material.** 2 LV in samples Ha19-4–5.

**Distribution.** Lower Bajocian, Discites Zone; Germany.

**Family Cytheridae** Baird, 1850  
**Genus Minyocythere** Lord et al., 2020  
**Minyocythere tuberculata** (Luppold, 2012)  
Fig. 12: 6

**Material.** 5 C, 3 RV, 5 LV in samples Mue19-1 and Ro 3–5.

**Distribution.** Upper Aalenian to Lower Bajocian, Concavum to Humphriesianum zones; Germany.

**Genus Plumhofficythere** Luppold, 2003  
**Plumhofficythere clavatoides** Luppold, 2003  
Fig. 12: 7

**Material.** 6 C, 30 RV, 24 LV in samples He19-23–28, Mue19-1 and Ro19-1–3.

**Distribution.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to ? Lower Bajocian; England, France, Germany, Luxembourg.

**Ostracoda incertae sedis**

**aff. Ostracode A Ballent, 1991**  
Fig. 7: 12

**Material.** 2 RV in samples He19-2 and He19-12.

**Distribution.** Aalenian to Bajocian; Argentina, SW Germany.

**Gen. et sp. 9 Tesakova, 2017**  
Fig. 8: 14

**Material.** 1 RV in sample He19-17.

**Distribution.** Lower to Upper Aalenian, Opalinum to Bradfordensis zones; SW Germany, N Switzerland.

**Gen. et sp. indet. 3 Franz et al., 2018**  
Fig. 7: 13

**Material.** 2 RV in samples He19-2 and He19-5.

**Occurrence.** Lower Aalenian, Opalinum Zone; SW Germany.

**Gen. et sp. indet. 5 Franz et al., 2018**  
Fig. 7: 14

**Material.** 4 RV, 1 LV in samples He19-3–27.

**Distribution.** Lower to Upper Aalenian, Opalinum to Concavum zones; SW Germany, N Switzerland.

**Gen. et sp. indet. 7**  
Fig. 12: 8, 9

2019 Gen. et sp. indet. I. – Dietze et al., pl. 11, fig. 13.

**Material.** 4 RV, 1 LV in sample He19-22; one further RV from Thanheim.

**Distribution.** Upper Aalenian, Bradfordensis Zone (Gigantea Subzone) to Concavum Zone; SW Germany.

**Gen. et sp. indet. 8**  
Fig. 7: 15

**Material.** 2 RV in samples He19-5–12.

**Distribution.** Lower Aalenian, Opalinum Zone; SW Germany.

**Gen. et sp. indet. 9**  
Fig. 8: 15

**Material.** 1 RV, 1 LV in samples He19-17–18.

**Occurrence.** Upper Aalenian, Bradfordensis Zone; SW Germany.
Gen. et sp. indet. 10
Fig. 7: 16

Material. 1 RV, 2 LV in samples He19-12–15.
Occurrence. Lower to Upper Aalenian, Opalinum to Murchisonae zones; SW Germany.

Gen. et sp. indet. 11
Fig. 7: 17

Material. 1 LV in sample He19-8.
Occurrence. Lower Aalenian, Opalinum Zone; SW Germany.

Gen. et sp. indet. 12
Fig. 8: 16

Material. 1 LV in sample He19-16.
Occurrence. Upper Aalenian, Murchisonae Zone; SW Germany.

4. Description of the ammonite fauna

4.1 General remarks

The ammonite fauna of the Upper Aalenian of SW Germany is dominated by members of the subfamily Graphoceratinae Buckman, 1905, besides rare Hammatoceratinae Buckman, 1887. The Graphoceratinae originate in the subfamily Leioceratinae Spath, 1936. The family Graphoceratidae itself descends from the Upper Toarcian genus Pleydellia Buckman, 1899 (Grammoceratinae Buckman, 1905 within the family Hildoceratidae Hyatt, 1867) (Chandler 1997; Chandler et al. 2012, Howarth 2013). The evolution within the Graphoceratidae occurred in a chronoecline ranging from the lowermost Aalenian (Opalinum Zone, Opalinum Subzone) to the lowermost Bajocian (Discites Zone), with an immense morphological variability within each of the temporally succeeding faunas. In this plexus, individual morphologies sometimes have a long temporal range, whereas the variability of the succeeding faunas as a whole shifts – that is the reason why we can distinguish and define faunal biohorizons. Faunal biohorizons reflect the change of variation in the course of evolution of ammonites, here of Graphoceratidae (e.g., Chandler 1997, 2019; Chandler and Callomon 2009; Dietze et al. 2017b; fauna described morphospecifically). Chandler (1997) demonstrated convincingly the evolution of the Graphoceratidae and the intersection of the nominal morphogenera in the Aalenian of Horn Park Quarry near Beaminster (Dorset, SW England).

In the literature, there are many attempts to classify the plexus of the Graphoceratidae into categories (families, subfamilies, morphogenera, morphospecies). The results of these attempts and the erection of new genera and species depended often by chance, depending on where the author had material from, often without any accurate stratigraphy. The great number of genera and species described in the literature (e.g. Buckman 1887–1907; Horn 1909; Hoffmann 1913; Althoff 1940; Rieber 1963; Géczy 1967; Contini 1969; Ureta Gil 1983; Henriques 1992; Chandler 1997; Howarth 2013) does by no means reflect the number of monophyletic genera and biological species, which was in fact much smaller (Chandler and Callomon 2009). These authors demonstrated the variation of a palaeobiospecies of the Leioceratinae, Leioceras compocostosum, within one timeslice of the Scissum Zone (Lower Aalenian).

We here determined the ammonites conventionally as morphogenera and morphospecies, since we do not have enough material to describe these ammonites chronospecifically (palaeobiospecifically). However, it is most likely that all graphoceratid ammonites from the cavatum horizon described here represent a single palaeobiospecies.

4.2 Short comments on the ammonite fauna

4.2.1 Family Graphoceratidae Buckman, 1905, Subfamilies Leioceratinae Spath, 1936 and Graphoceratinae Buckman, 1905

Leioceras opalinum [M] and L. opaliniforme [M] occur about 10 m below the "Wasserfallschichten" in the Heiligenbach creek. The ammonites from the "Comptum" Subzone are represented by L. "comptum", L. crassicostatum, L. evolutum, L. paucicostatum and L. striatum. They are significantly smaller than the L. "comptum" faunas from the Wochenberg and Gosheim (western Swabian Alb) which comprise more evolute morphs. These ammonites will be described later in detail.

A single Brasilia bravfordensis (Fig. 19: 1a, b) of the Bradfordensis Zone (Bradfordensis Subzone) was recovered from bed 2 of the Heiligenbach section. The graphoceratid fauna of the Inopernabank (Bradfordensis Zone, Gigantea Subzone) and from the Kon-
glomeratbank to the Rostrote Kalkbank (Concavum Zone, Concavum Subzone) is characterized by the predominance of the morphogenus Graphoceras; less common are representatives of the morphogenus Brasilia and a substantial number of ammonites with various combinations of both morphogenea (cf. Rieber 1922: 47, 51). In the slightly older decipiformis horizon of the Gigantacea Subzone (Bradfordensis Zone, see Fig. 26) ammonites of the genus Brasilia exhibit larger-sized and smooth shells, with generally broader whorl sections and a wider umbilicus compared to Graphoceras (Chandler 1997; Dietze et al. 2014). The ammonites determined as B. decipiens (Fig. 13: 1a, b, Fig. 18: 1), B. aff. decipiens (Fig. 20: 3a, b) and B. cf. decipiformis (Fig. 16: 2a, b, 5a, b) are very similar to examples of the genus Brasilia from the Bradfordensis Zone (Gigantacea Subzone, decipiformis horizon) of Geisingen (SW Germany) and Dorset (SW England) (Dietze et al. 2014; Buckman 1887–1907; Chandler 1997). Some of the studied ammonites show mixed characters and are obviously intermediates between Brasilia and Graphoceras: B. aff. and G. cf. decipiens (Fig. 18: 4a, b, Fig. 19: 5a, b) show already the more compressed and involute morphology of Graphoceras (Howarth 2013), whereas in all other features it is still very close to Brasilia. Graphoceras aff. magnum (Fig. 20: 1a, b) and G. cf. cavatum (Fig. 20: 2a, b) show the broad whorls of Brasilia, but the ribbing style of primitive Graphoceras. The bulk of the ammonites belong to the genus Graphoceras. Besides G. cf. concavum (Fig. 16: 1, 4; Fig. 15: 1a, b) the poorly sculptured G. cavatum (Fig. 13: 2a, b, 9a, b; Fig. 18: 2; Fig. 21: 2a, b) and G. cf. cavatum (Fig. 21: 1a, b) are typical. Graphoceras with more sculptured flanks are assigned to G. decorum (Fig. 15: 2; Fig. 22: 1a, b), G. aff. apertum (Fig. 15: 3a, b), G. pulchrum (Fig. 15: 5a, b; Fig. 22: 3a, b), G. cf. pulchrum (Fig. 20: 4a, b), G. cf. v-scriptum (Fig. 18: 3) and G. formosum (Fig. 22: 2a, b, 5a, b), respectively. The strongest sculptured Graphoceras belong to G. fallax (Fig. 18: 5; Fig. 22: 4), G. aff. fallax (Fig. 13: 3) and G. cf. caduceiferum (Fig. 17: 1a, b).

We here follow Chandler (1997) in the determination of the microconchs and assign these to Ludwigiella. They show often specifically distinguished morphologies (Buckman 1887–1907; Contini 1969; Chandler 1997) ranging from nearly smooth to strongly ribbed morphotypes: Ludwigiella tenuis (Fig. 13: 4), L. attenuata (Fig. 13: 6), L. arcitenens (Fig. 16: 3a, b; Fig. 15: 6a, b; Fig. 17: 3), L. cornu (Fig. 19: 2) L. aff. tenuis (Fig. 13: 5), L. sp. (Fig. 17: 5), L. micra (Fig. 19: 4), and L. attracta (Fig. 13: 7, 8; Fig. 19: 3).

4.2.2 Family Hammatoceratidae Buckman, 1887, Subfamily Hammatoceratinae Buckman, 1887

A single record from the Inopernabank (Fig. 14: 1a–c) resembles in its nucleus Bredyia diadematoidea (Mayer) as figured by Rieber (1963) from Kapfshiphäusern near Metzingen (Rieber 1963); however, its body chamber recalls the slightly more evolute Planammatoceras planiforme Buckman (typical of the Lower and lower Upper Aalenian; Kovács 2009; Sandoval et al. 2020) or Pl. lepisiusi (Gemmellaro). Due to the combination of these characters we here determined this ammonite as Planammatoceras sp. Most of the few hammatoceratids from the cavatum biohorizon of the Concavum Subzone in the studied sections are rather large, with smooth, high-oval outer whorls, very complex suture lines and a narrow umbilicus on the inner whorls (Fig. 14: 2a, b; Fig. 17: 4). The best match in literature we could find is with Euaptetoceras infernense sensu Buckman. The original type series of E. infernense (Roman) consists of small nuclei, which are very similar to the innermost whors of the ammonite figured on Fig. 14: 2a, b. A more evolve variant is E. cf. kochi (Prinz) (Fig. 24: 1a, b). There is a striking homoeomorphy of this specimen with Brasilia decipiformis or Sonninia carinodiscus (Quenstedt [LT: Sonninia sowerbyi carinodiscus] Quenstedt, 1886, p. 502, pl. 63, Fig. 3). A fragmentary E. cf. euaptetum (Fig. 23: 1a–c) recalls in its habitat already the slightly younger E. amplexent; however, the umbilicus of the latter is more involute. These smooth, large-sized hammatoceratids already resemble their presumed descendants, the Early Bajocian Fissillobiceras ovale (Quenstedt). A nearly complete compressed specimen from bed 49 of the Heiligenbach section (SMNS 70602) belongs to the genus Euaptetoceras as well; however, due to its bad preservation a specific determination is impossible.

5. Bio-/Chronostratigraphy

5.1 Ostracods (M. Franz)

5.1.1 Opalinum Zone

Pygmaea-pumila faunal assemblage (Franz et al. 2018; samples He19-1–12)

The ostracod assemblage consists of 360 individuals (average of 30 individuals per sample) representing 34 species. The assemblage is characterized by Praeschulerea ventriosa, Aphelocythere pygmaea, Metacytheropteron opalinum, Acrocythere pumila, Eucytherura transversiplicata, Euc. michelseni, Cardobairdia tesakovae, Eucytherura sp. 1 Franz et al., Euc. sp. 3 Franz et al., and Cytheropterina cribra.

The zonal index species Aphelocythere kuhni (Ohmert 2004) is missing in our samples. Stratigraphically important are Metacytheropteron opalinum, Cardobairdia tesakovae, Eucytherura plumhoffi, Euc. foveolata sp. nov. and Procytherura euglyphea in addition to the nominal species of this community. The very rare Procytherura celtica as well as Gen. et sp. indet. 3 and Gen. et sp. indet. 4 (Franz et al. 2018) have also only been found in the Opalinum Zone. A range chart is given in Appendix 1.

In samples He19-7–12, eight species have their last occurrences in this faunal assemblage: Acrocythere pumila, Procytherura euglyphea, Eucytherura plumhoffi, Ostracode A Ballent, Eucytherura foveolata, Cardobairdia tesakovae, Metacytheropteron opalinum, and Eucytherura sp. 1 Franz et al.
Figure 6. (1) Cardobairdia tesakovae Franz et al., SMNS 70521/1, LV, L: 0.426 mm; sample He19-6; (2) Patellacythere cf. vulsa, SMNS 70521/2, LV, L: 0.51 mm; sample He19-9; (3) Procytherura celtica Ainsworth, SMNS 70521/3, RV, L: 0.301 mm; sample He19-12. (4, 5) Procytherura euglyphea Ainsworth, (4) SMNS 70521/4, RV, L: 0.320 mm; sample He19-1; (5) SMNS 70521/5, LV, L: 0.327 mm; sample He19-12. (6, 7) Procytherura multicostata Ainsworth, (6) SMNS 70521/6, LV, L: 0.336 mm; sample He19-9; (7) SMNS 70521/7, RV, L: 0.319 mm; sample He19-16. (8) Procytherura sp. 2 Franz et al., SMNS 70521/8, RV, L: 0.325 mm; He19-8. (9–11) Eucytherura eberti sp. nov., (9) holotype, SMNS 70521/9, C, left view, L: 0.306 mm; sample He19-18; (10) Paratype, SMNS 70521/10, C, right view, L: 0.292 mm; sample He19-21; (11) Paratype, SMNS 70521/11, C, dorsal view, L: 0.318 mm; sample He19-26. (12–14) Eucytherura foveolata sp. nov., (12) holotype, SMNS 70521/12, C, left view, L: 0.327 mm; sample G08Fr; (13) paratype, SMNS 70521/13, C, right view, L: 0.318 mm; sample G12Fr; (14) paratype, SMNS 70521/14, C, right view (detail), image width: 0.07 mm; sample G12Fr; (15) Eucytherura liassica Bate and Coleman, SMNS 70521/15, LV, L: 0.304 mm; sample He19-17. (16) Eucytherura michelseni (Finger), SMNS 70521/16, LV, L: 0.324 mm; sample He19-18. (1–6, 8–14) Opalinuston Formation, Lower Aalenian, Opalinum Zone; (7, 9–11, 15–16) Achdorf Formation, Upper Aalenian, (7) Murchisonae Zone, (15) Bradfordensis Zone (Bradfordensis Subzone), (9, 10, 16) Bradfordensis Zone (Gigantea Subzone), (11) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 7. (1) *Eucytherura plumhoffi* Tesakova, SMNS 70521/17, C, left view, L: 0.309 mm; sample He19-7. (2) *Eucytherura transversipli-cata* (Bate and Coleman), SMNS 70521/18, LV, L: 0.316 mm; sample He19-3. (3) *Eucytherura* sp. 1 Franz et al., SMNS 70521/19, RV, L: 0.320 mm; sample He19-12. (4) *Eucytherura* sp. 3 Franz, SMNS 70521/20, C, right view, L: 0.300 mm; sample He19-18. (5) *Aphelocythere dilgeri* Franz et al., SMNS 70521/21, RV, L: 0.460 mm; sample He19-18. (6) *Aphelocythere pygmaea* Plumhoff, SMNS 70521/22, C, right view, L: 0.343 mm; sample He19-12. (7) *Aphelocythere* sp. 1, SMNS 70423/119, C, right view, L: 0.308 mm; sample G08Fr. (8) *Pleurocythere* sp., SMNS 70521/23, LV, L: 0.354 mm; sample He19-1. (9) *Acrocythere pumila* Plumhoff, SMNS 70521/24, LV, L: 0.343 mm; He19-12. (10) *Praeschuleridea ventriosa* (Fischer in Plumhoff), SMNS 70521/25, LV, L: 0.650 mm; sample Mue19-1. (11) *Kinkeliniella* (Kink.) *sermoisensis* (Apostolescu), SMNS 70521/26, LV, L: 0.656 mm; sample He19-9. (12) aff. *Ostracode A* Ballent, SMNS 70521/27, RV, L: 0.290 mm; sample He19-2. (13) Gen. et sp. indet. 3, Franz et al., SMNS 70521/28, RV, L: 0.342 mm; sample He19-5. (14) Gen. et sp. indet. 5 Franz et al., SMNS 70521/29, RV, L: 0.310 mm; He19-18. (15) Gen. et sp. indet. 8 Franz, SMNS 70521/30, RV, L: 0.280 mm; sample He19-12. (16) Gen. et sp. indet. 10, SMNS 70521/31, LV, L: 0.300 mm; sample He19-12. (17) Gen. et sp. indet. 11, SMNS 70521/32, LV, L: 0.324 mm; sample He19-8. (1–3, 6–8, 10–12, 15–17) Opalinuston Formation, Lower Aalenian, Opalinum Zone; (4–5, 9, 14) Achdorf Formation, Upper Aalenian; (4–5, 14) Bradfordensis Zone (Gigantea Subzone), (9) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 8. (1) Cytherella apostolescui Ainsworth, SMNS 70521/33, RV, L: 0.793 mm; sample He19-27. (2) Cytherelloidea cf. catenulata (Jones and Sherborn), SMNS 70521/34, LV, L: 0.438 mm; sample He19-17. (3) Bythoceratina (Praebyth.) sp. 1, SMNS 70521/35, RV, L: 0.416 mm; sample He19-18. (4) Procytherura cf. serangodes Ballent and Whatley, SMNS 70521/36, C, right view, L: 0.331 mm; sample He19-15. (5) Praeschuleridea punctulata (Plumhoff), SMNS 70521/37, C, right view, L: 0.606 mm; sample He19-15. (6) Praeschuleridea sp. A Ainsworth, SMNS 70521/38, LV, L: 0.733 mm; sample He19-17; (7) Pleurocythere sp. 1, SMNS 70521/39, RV, L: 0.585 mm; sample He19-16. (8) Homocytheridea sp. 1, SMNS 70521/40, LV, L: 0.707 mm; He19-15. (9) Homocytheridea sp. 2, SMNS 70521/41, RV, L: 750 mm; sample Mue19-1; (10) Progonocythere scutula Franz et al., SMNS 70521/42, RV, L: 0.464 mm; sample He19-17; (11) Kinkelinella (Kink.) fischeri Malz, SMNS 70521/43, C, left view, L: 0.412 mm; sample Lin18-4. (12) Kinkelinella sp. 2, SMNS 70521/44, RV, L: 0.444 mm; sample He19-17; (13) Ektyphocythere aff. anterocosta Boomer, SMNS 70521/45, RV, L: 0.281 mm; sample He19-14; (14) Gen. et sp. 9 Tesakova, SMNS 70521/46, RV, L: 0.296 mm; He19-17; (15) Gen. et sp. indet. 9, SMNS 70521/47, LV, L: 0.235 mm; sample He19-18. (16) Gen. et sp. indet. 12, SMNS 70521/48, LV, L: 0.306 mm; sample He19-16. Achdorf Formation (13) Opalinum Zone, ("Comptum" Subzone), (4–5, 7–8, 16) Murchisonae Zone, (2, 6, 10, 12, 14) Bradfordensis Zone (Bradfordensis Subzone), (3, 15) Bradfordensis Zone (Gigantea Subzone), (1, 7) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 9. (1) Cytherelloidea lordi Ainsworth, SMNS 70521/49, C, right view, L: 0.688 mm; sample He19-19. (2) Bairdiacypris triangularis Ainsworth, SMNS 70521/50, C, right view, L: 0.309 mm; sample He19-19. (3) Macrocypris aequabilis Oertli, SMNS 70521/51, C, left view, L: 0.349 mm; sample He19-21. (4) Eucytherura cf. parairegularis Brand, SMNS 70521/52, C, right view, L: 0.281 mm; sample He19-19; (5) Eucytherura cf. yunga Ballent and Whatley, SMNS 70521/53, RV, L: 0.304 mm; sample He19-27. (6) Eucytherura sp. 5 Franz, SMNS 70521/54, RV, L: 0.295 mm; sample G11Fr;. (7) Eucytherura sp. 11 Franz, SMNS 70521/55, RV, L: 0.327 mm; sample He19-25. (8) Balolowellia catena (Franz et al.), SMNS 70521/56, RV, L: 0.308 mm; sample He19-24. (9) Praeschuleridea ornata (Bate), SMNS 70521/57, RV, L: 0.578 mm; sample He19-21; (10, 11) ? Southcavea sp., (10) SMNS 70521/58, LV, L: 0.315 mm; (11) SMNS 70521/59, RV, L: 0.368 mm; sample He19-24; (12) Pleurocythere kirtoneisis Bate, SMNS 70521/60, RV, L: 0.597 mm; sample He19-18. (13) Acrocythere aff. pumila Plumhoff, SMNS 70521/61, LV, L: 0.406 mm; sample He19-27; (6) Opalimuston Formation, Lower Aalenian, Opalinum Zone, (1–5, 7–13) Achdorf Formation, Upper Aalenian (1–4, 9, 12) Bradfordensis Zone (Gigantea Subzone), (5, 7–8, 10–11, 13) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 10. (1) *Polycope* *cf.* *riegrafi* Brand, SMNS 70521/62, C, right view, L: 0.345 mm; sample He19-27. (2) *Liasina cylindrica* Ainsworth, SMNS 70521/63, RV, L: 0.412 mm; sample Lin18-1. (3) *Cardobairdia toarcensis* Ainsworth, SMNS 70521/64, LV, L: 0.545 mm; sample He19-26. (4) *Macrocypria* *liassica* Bate and Coleman, SMNS 70521/65, C, right view, L: 0.750 mm; sample He19-27. (5) *Patellacythere paravulsa* *cf.* *tenuis* Brand, SMNS 70521/66, LV, L: 0.522 mm; sample He19-27. (6) *Patellacythere ungulina* (Triebel and Bartenstein), SMNS 70521/67, LV, L: 0.405; sample Mue19-1; (7) *Monoceratina* “aff. posteroarcinata” Brand, SMNS 70521/68, C, right view, L: 0.324 mm; sample He19-21. (8) *Tanycythere posteroelongata* Cabral et al., SMNS 70521/69, C, right view, L: 0.676 mm; He19-27. (9) *Cytheropterina alacostata* Franz et al., SMNS 70521/70, LV, L: 0.368 mm; sample He19-27; (10–13) *Cytheropterina crassicostata* sp. nov., (10) holotype, SMNS 70521/71, RV, L: 0.516 mm; sample He19-27; (11) paratype, SMNS 70521/72, LV, L: 0.556 mm; sample He19-26; (12) paratype, SMNS 70521/73, RV, ventral view, L: 0.655 mm; sample He19-27; (13) paratype, SMNS 70521/74, LV, inner view, L: 0.555 mm; sample Ro19-4; (14) *Procytherura* sp. 5, SMNS 70521/75, RV, L: 0.363 mm; He19-24; (15) *Eucytherura* aff. *yunga* Ballent and Whatley, SMNS 70521/76, LV, L: 0.312 mm; sample He19-27. (16) *Eucytherura* sp. B Boomer and Ballent, SMNS 70521/77, RV, L: 0.277 mm; sample He19-25. (17, 18) *Eucytherura* sp. 10, (17) SMNS 70521/78, LV, L: 0.392; sample He19-25, (18) SMNS 70521/79, RV, L: 0.278 mm; sample He19-24. Achdorf Formation, Upper Aalenian, Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 11. (1) Balowella catena (Franz et al.), SMNS 70521/80, C, right view, L: 0.329 mm; sample He19-18. (2, 3) ? Cytheropteron sp. 1, SMNS 70521/81, LV, L: 0.322 mm; sample He19-27; (3) SMNS 70521/82, RV, L: 0.355 mm; sample He19-27. (4) Procytheropteron aff. grammni Brand, (4) SMNS 70521/83, LV, L: 0.373 mm; sample He19-26; (5) SMNS 70521/84, RV, L: 0.305 mm; sample He19-22. (6) Procytheropteron sp. 1 Franz et al., SMNS 70423/66, LV, L: 0.322 mm; sample G20b; (7) Aphelocythere recta Ohmert, SMNS 70521/85, C, right view, L: 0.460 mm; sample Ro19-4. (8) Aphelocythere aff. recta, SMNS 70521/86, C, right view, L: 0.466 mm; sample Ro19-4. (9) Aphelocythere sp. 1, SMNS 70521/87, RV, L: 0.630 mm; sample He19-27; (10) Asciothyre sp., SMNS 70521/88, RV, L: 436 mm; sample He19-26. (11) Eocytheridea elongata Bate, SMNS 70521/89, RV, L: 0.573 mm; sample He19-21. (12) Eocytheridea lacunosa Bate, SMNS 70521/90, RV, L: 0.705 mm; sample He19-25; (13, 14) Praeschuleridea cf. subtrigona, (13) SMNS 70521/91, C, right view, L: 0.512 mm; sample Ro19-5; (14) SMNS 70521/92, RV, inner view, L: 0.512 mm; sample Ro19-5; (15–17) Praeschuleridea sp. 1, (15) SMNS 70521/93, C, right view, L: 0.490 mm; sample He19-27; (16) SMNS 70521/93, C, right view, (detail); (17) SMNS 70521/94, RV, L: 0.620 mm; L: 0.620 mm; sample He19-27. (18) Pleurocythere ohmerti Franz et al., SMNS 70521/94, RV, L: 0.479 mm; sample Tst. 38-1988 (= He19-27). Achdorf Formation, Upper Aalenian, (1, 6) Bradfordensia Zone (Gigantea Subzone), (2–5, 7–18) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 12. (1) Camptocythere pusilla Plumhoff, SMNS 70521/95, RV, L: 0.446 mm; sample He19-24; (2) Kinkelinella (K.) adunca Malz, SMNS 70521/96, LV, L: 0.598 mm; sample He19-24. (3) Kinkelinella (Kink.) levata Ohmert, SMNS 70521/97, RV, L: 0.636 mm; sample He19-27; (4) Kinkelinella (Kink.) cf. sermoisensis, SMNS 70521/98, LV, L: 0.640 mm; sample Mue19-1. (5) Kinkelinella sp. B Ohmert, SMNS 70521/99, LV, L: 0.623 mm; sample Ha19-5. (6) Minocythere tuberculata (Luppold), SMNS 70521/100, RV, L: 0.400 mm; sample Mue19-1. (7) Plumhofficythere clavatoides Luppold, SMNS 70521/101, LV, L: 0.408 mm; sample He19-27; (8) Gen. et sp. 7, SMNS 70521/102, RV, L: 0.306 mm; sample He19-22. (9) SMNS 70521/103, RV, L: 0.291 mm; sample He19-22. (10) Vernoniella? caytonensis Bate, SMNS 70521/104, C, left view, L: 0.535 mm; sample Ro19-5. (11) Progonocythere triangulata Braun in Ohmert, SMNS 70521/105, RV, L: 0.712 mm; sample Ha19-4; (12) Kinkelinella (Ekt.) triangula Brand, SMNS 70521/106, RV, L: 0.523 mm; sample Ha19-4. (13) Fuhrbergiella horrida bicostata Brand and Malz, SMNS 70521/107, LV, L: 0.560 mm; sample Ha19-5. Achdorf Formation, Upper Aalenian, (5) Bradfordensis Zone (Gigantea Subzone), (1–4, 6–11) Concavum Zone. Scale bars (if not indicated otherwise): 20 μm.
Figure 13. (1a, b) Brasilia decipiens (Buckman) [M], SMNS 70519/7. (2a, b, 9a, b) Graphoceras cavatum (Buckman) [M], (2) SMNS 70519/8, (9) SMNS 70519/9. (3) G. aff. fallax (Buckman) [M], SMNS 70519/10. (4) Ludwigella tenuis (Buckman) [m], SMNS 70519/11. (5) L. aff. tenuis (Buckman) [m], SMNS 70519/12. (6) Ludwigella attenuata (Buckman) [m], SMNS 70519/13. (7, 8) L. attracta (Buckman) [m], (7) SMNS 70519/14, (8) SMNS 70519/15. (1a–8) Jungingen (Starzel); Achdorf Formation, Bed 4, Upper Aalenian, Bradfordensis Zone (Gigantea Subzone). Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 14. (1a–c) Planammatoceras sp. [M], SMNS 70519/16. Jungingen (Starzel); Achdorf Formation, Bed 4, Upper Aalenian, Bradfordensis Zone (Gigantea Subzone). (2a, b) Euaptetoceras infernense sensu Buckman [M] (2b: innermost whorls from reverse flank), SMNS 70519/17. Hechingen-Beuren (Hanneswiesle); Achdorf Formation, Bed 4 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), cavatum biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 15. (1a, b) *G. cf. concavum* (Sowerby) [M], with *Propeamussium pumilum* (Lamarck), SMNS 70519/18. (2) *G. decorum* Buckman [M], SMNS 70519/19. (3a, b) *G. aff. apertum* (Buckman) [M], SMNS 70519/20. (4a, b) *G. cf. pulchrum* (Buckman) [M], SMNS 70519/21. (5a, b) *G. pulchrum* (Buckman) [M], SMNS 70519/22. (6a, b) *Ludwigella arcitenens* (Buckman) [m], SMNS 70519/23. (1a–6b) Hechingen-Beuren (Hanneswiesle); Achdorf Formation, Bed 4 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), cavity biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 16. (1, 4) Graphoceras cf. concavum (Sowerby) [M], (1) SMNS 70519/24, (4) SMNS 70519/25. (2a, b, 5a, b) Brasilia cf. decipiformis Dietze et al. [M], (2) SMNS 70519/26, (5) SMNS 70519/27. (3a, b) Ludwigella arcitenens (Buckman) [m], SMNS 70519/28. (1–5b) Balingen-Zillhausen (Roschbach), Upper Aalenian, Achdorf Formation, Concavum Zone (Concavum Subzone); (3a, b) Bed 26; (1–2b, 4–5b) Bed 28 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), cavatum biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 17. (1a, b) Graphoceras cf. caduciferum (Buckman) [M], Bed 40 [Inopernabank], Bradfordensis Zone, (Gigantea Subzone), SMNS 70519/29. (2) Graphoceras sp., Bed 45 [Konglomeratbank], Bradfordensis Zone, (Gigantea Subzone), SMNS 70519/30. (3) Ludwigella arcitenens (Buckman) [m], Bed 45 [Calceolabank], SMNS 70519/31. (4) Euaptetoceras infernense sensu Buckman [M], Bed 45 [Calceolabank], SMNS 70519/32. (5) L. sp. [m], Bed 45 [Calceolabank], SMNS 70519/33. (3–5) Upper Aalenian, Concavum Zone (Concavum Subzone), cavatum biohorizon. (1a–5) Hechingen-Beuren (Heiligenbach), Achdorf Formation. Asterisk marks beginning of the body chamber. Scale bar: 5 cm (shorter bar for Fig. 17.4).
Figure 18. (1) Brasilia decipiens (Buckman) [M], SMNS 70519/34. (2) Graphoceras cavatum (Buckman) [M], SMNS 70519/35. (3) G. cf. v-scriptum Buckman [M], SMNS 70519/36. (4a, b) B. aff. decipiens (Buckman) [M], SMNS 70519/37. (5) G. fallax (Buckman) [M], SMNS (70519/38. (1–5) Hechingen-Beuren (Heiligenbach), Achdorf Formation, Upper Aalenian, Concavum Zone (Concavum Subzone), cavaturn biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 19. (1a, b) *Brasilia bradfordensis* (Buckman) [M], Bed 2, Bradfordensis Zone, (Bradfordensis Subzone), SMNS 70519/39. (2) *Ludwigella cornu* (Buckman) [m], SMNS 70519/40. (3) *L. attracta* (Buckman) [m], SMNS 70519/41. (4) *L. micra* (Buckman) [m], SMNS 70519/42. (5a, b) *B. cf. decipiens* (Buckman) [M], SMNS 70519/43. (1a–5b) Jungingen (Mühlbächle), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian. (2–5b) Concavum Zone (Concavum Subzone), *cavatum* biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 20. (1a, b) *Graphoceras* aff. *magnum* (Buckman) [M], SMNS 70519/44. (2a, b) *G. cf. cavatum* (Buckman) [M], SMNS 70519/45. (3a, b) *B. aff. decipiens* (Buckman) [M], SMNS 70519/46. (1a–3b) Jungingen (Mühlbächle), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), *cavatum* biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 21. (1a, b) *Graphoceras* cf. *cavatum* (Buckman) [M], SMNS 70519/47. (2a, b) *G. cavatum* (Buckman) [M], SMNS 70519/48. (1a–2b) Jungingen (Mühlbächle), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), *cavatum* biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 22. (1a, b) *Graphoceras decorum* Buckman [M], SMNS 70519/49. (2a, b, 5a, b) *G. formosum* (Buckman) [M], (2) SMNS 70519/56, (5) SMNS 70519/50. (3a, b) *Graphoceras pulcrum* (Buckman) [M], SMNS 70519/51. (4) *G. fallax* (Buckman) [M], SMNS 70519/52. (1a–5b) Jungingen (Mühlbächle), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), *cavatum* biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 23. (1a–c) Euaptetoceras cf. euaptetum Buckman [M], SMNS 70519/53. Jungingen (Mühlbächle), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian, Concavum Zone (Concavum Subzone), cavatum biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 5 cm.
Figure 24. (1a, b) *Euaptetoceras* cf. *kochi* (Prinz) [M], collection S. Pfister. Jungingen (excavation pit in the street "Im Binder", about 0.5 km NW of the Mühlbächle stream), Achdorf Formation, Bed 14 [Calceolabank], Upper Aalenian, *Concavum* Zone (*Concavum* Subzone), *cavatum* biohorizon. Asterisk marks beginning of the bodychamber. Scale bar: 10 cm.
Figure 25. (1, 2) *Gryphaea calceola* Quenstedt, Jungingen, Mühlbächle, Calceolabank, SMNS 70528/1–2. (3, 4) juveniles of *Gryphaea calceola* Quenstedt, Jungingen, Mühlbächle, marlstone above Calceolabank, SMNS 70528/3–4. (5) *Inoperna sowerbyana* (d’Orbigny), Jungingen, Starzel river, Inopernabank, SMNS 70528/5. (6) Pinna sp., Jungingen, Starzel river, Inopernabank, SMNS 70528/6. (7) *Trigonia alemanica* Rollier, Balingen-Zillhausen, Roschbach, Calceolabank, SMNS 70528/7. (8) *Pholadomya lirata* (Sowerby), Jungingen, Starzel river, Inopernabank, SMNS 70528/8. (9) *Pholadomya fidicula* (Sowerby), Hechingen-Beuren, Heiligenbach, Inopernabank, SMNS 70528/9. (10) *Goniomya literata* (Sowerby), Hechingen-Beuren, Heiligenbach, Inopernabank, SMNS 70528/10. (11) *Mytiloceramus polyplocus* (Roemer), Jungingen, Mühlbächle, Rostrote Kalkbank, SMNS 70528/11. (12) *Oxytoma inaequivalvis* (Sowerby), Jungingen, Starzel river, Inopernabank, SMNS 70528/12. (13) *Pleuromya cf. uniformis* (Sowerby), Jungingen, Starzel river, Inopernabank, SMNS 70528/13. (14) Belemnite rostrum, Hechingen-Beuren, Heiligenbach, Calceolabank SMNS 70529. (15) *Asteracanthus personati* (Quenstedt), Zillhausen Member, Starzel river in Schlatt, SMNS 97005. Scale for 1, 2: 50 mm; for 3-14: 20 mm, for 15a, b: 20 mm.
5.1.2 "Comptum" Subzone (samples He19-13–14)

The stratigraphical significance of the ostracod assemblage from the "Comptum" Subzone is rather limited (8 species, represented by only 65 specimens). The assemblage is characterized by the extinction of the previously typical species Aphelocythere pygmaea, Acrocythere pumila, Procythere aeglypha, Proc. celtica, Eucytherura plumhoffi, Euc. foveolata, Euc. sp. 1 Franz et al., Metacytheropteron opalinum, and Cardobairdia tesakovaee. Aphiocycthere pygmaea has its last appearance (very rare) in the claystones directly above the Comptumbank. Only Cytherella apostolescui appears for the first time, like in the Geisingen clay pit (Franz et al. 2018); the newly appearing species Praeschuleridea punctulata, Kinkelina (K.) fischeri, Kinkelina sp. 2 and Ektypocythere aff. anterocosta are already known from older strata in Geisingen and some other sections.

Dominant species include Praeschuleridea ventriosa, Pr. punctulata and Kinkelina (K.) fischeri.

5.1.3 Murchisonae Zone (samples He19-15–16)

The samples from the clays above the "Doppelbank" 20 + 21 yielded 126 specimens of 17 species, 12 of which were found in single specimens. Dominant species are Praeschuleridea ventriosa, Pr. punctulata and Homocytheridea sp. 1. Nine species are new; most important are Homocytheridea sp. 1, Bythoceratina (Prabithoceratina) sp. 1, Eucytherura sp. 3 Franz et al. and, to a minor degree, the very rare Pleurocythere sp. 1. The still undescribed Gen. et sp. indet. 10 Franz has its last appearance. Homocytheridea sp. 2, Procythere aff. serangodes, Aphelocythere cf. pygmaea, Pleurocythere sp. 1 and Gen. et sp. indet. 12 were found only in single specimens in this assemblage.

Homocytheridea sp. 1 differs from Homocytheridea cf. punctulata from the Concavum Zone in the Geisingen clay pit. The stratigraphic distribution of Homocytheridea in the Upper Aalenian can be clarified only after investigation of further material.

5.1.4 Bradforadsensis Zone, Bradforadsensis Subzone (sample He19-17)

In this sample, we found 12 species (only 25 specimens), the majority of which are again represented by single specimens. Among the newly appearing species the solely abundant Progonocythere scutula (13 specimens) is particularly noteworthy. It was first described by Franz et al. (2018) from the Geisingen-Oolith (Gigantea Subzone). Progonocythere scutula and Gen. et sp. 9 Tesakovaee were observed in this sample only. A stratigraphical interpretation is not possible so far.

5.1.5 Bradforadsensis Zone, Gigantea Subzone (samples He19-18–21)

The stratigraphical significance of this assemblage (35 species, represented by 169 specimens) is restricted. Eighteen species occur for the first time respectively re-occur in this part of the section: Praeschuleridea omata, Pr. ventriosa, Balowella catena, Cytherelloidea londi, Pleurocythere kirtonensis and rare Kinkelina levata and Eucytheridea elongata in the uppermost sample. Dominant species are Praeschuleridea omata and Pr. ventriosa, which alone account for > 22% of the total assemblage, Cythero-pterina bucineuta, Praeschuleridea punctulata and Balowella catena. Eucytherura michelseni, Eucyth. sp. 3 Franz et al., Cytherelloidea cf. catenulata and Gen. et sp. indet. 9 have their last appearances in this section. Cytherelloidea londi, Pleurocythere kirtonensis, Aalenienija compressa and Eucytherura sp. 5 Franz were found in this assemblage only.

As already observed in Geisingen (Franz et al. 2018) and Thannerheim (Dietze et al. 2018), Kinkelina levata – contrary to Ohmert (2004) – already occurs in the Bradfordensis Zone. The lower boundary of the Levata ostracod zone must therefore be significantly shifted downwards.

5.1.6 Concavum Zone (samples He19-21–28, Mue19-1, Ha19-1–3, Ro19-3–5)

The Concavum-Zone comprises the claystones immediately below and above the Inopernabank up to the Sowerbyi-Oolith. Since the claystones above the Rostrote Kalk bank are not exposed along the Heiligenbach creek, their basal part was sampled at the Mühlbächle creek in Jun- geningen and, for comparison purposes, at the Roschbach in Balingen-Zillhausen. The 14 samples obtained there show ostracod (and foraminifers) assemblages relatively rich in species and individuals. The upper half of these claystones and the basal Wedelsandstein Formation were sampled in the Hauserberg section. The claystones in this level are fine sandy and very poor in microfossils. In some samples only one foraminiferal and one ostracod species were found in small (foram.) to very small (ostr.) numbers.

This assemblage (including the samples from the Roschbach valley) comprises 2,365 specimens from 58 species, 34 of which appear for the first time in this section. Dominant species are Cytherella apostolescui, Praeschuleridea omata and the newly appearing Eucytheridea lacunosa and Camptocythere pusilla. The still persisting Praeschuleridea ventriosa, Pr. punctulata, Balowella catena, Cytheropterina bicuneata, Eucytherura everti and Bythoceratina (Praebith.) sp. 1 are common as well. Of 34 species appearing here for the first time, the following ones are somewhat more common and useful for stratigraphic purposes (in the order of their first occurrence in this section): Eucytheridea lacunosa, Plumhoffocythere clavatoides, Kinkelinka (Kink.) aduncu, Camptocythere pusilla, Pleurocythere ohmerti, Kinkelinka (Kink.) sp. B Ohmert, Cytheropterina crassicostata, Cyth. alacostata, Kinkelinka (Kink.) cf. semoisensis, Praeschuleridea cf. subtrigona, and Minocythere tuberculata.

The two species of Cytheropterina are very conspicuous, but Cytheropterina alacostata is often represented by very small specimens. Camptocythere pusilla, the index species of the Pusila Ostracod Zone (Ohmert 2004), has been found here in
large numbers. The very noticeable Pluhmofficicythere clavatoïdes, which also occurs in Northern Germany (Plumhoff 1963; Luppold 2003) and England (Bate 1963b), is obviously limited to the Bradforderensis Zone (Gigantea subzone) and Concavum Zone and would therefore also have stratigraphic significance.

Eucytherura eberti sp. nov., which has been found in rare specimens from the uppermost Opalinum Zone upwards, has its acme at this level. A number of further, mostly small species appear here for the first time. Although they are partly very conspicuous (e.g., ?Cytheropteron sp. 1, Eucytherura sp. 10), they are rather unsuitable for stratigraphic purposes due to their scarcity. Additionally, some of these rare species occur earlier elsewhere. A range chart for the Achdorf Formation is given in Appendix 2.

Bajocian

5.1.7 Discites Zone (samples Ha19–4–6)

The appearance of Kinkelinella (Ekt.) triangula and Progonocythere triangulata, together with Cytherelloidea cf. cadomensis and rare Fuhrbergiella horrida bicostata in this assemblage (374 specimens) clearly indicates the base of the Triangula Ostracod Zone, Triangulata Ostracod Subzone (= Discites Zone; Ohmert 2004). All other of the 15 species persist from the Aalenian. Praeschuleridea onata, Progonocythere triangulata, Cytherella apostolescui and Cytherelloidea cf. cadomensis are dominant. Nine of the 15 species, including the dominant and the zonal index species, were also found at this level in the Thanheim section (Dietze et al. 2019). In contrast to Ohmert (2004), Kinkelinella (Ekt.) triangula appears in the Hausterberg section directly at the base of the Lower Bajocian.

5.2 Ammonites

Aalenian

5.2.1 Opalinum Zone

Opalinum and "Comptum" subzones: The strata of the Opalinum Zone were not in the focus of this investigation. However, the Opalinum Subzone reaches at least up to the "Wasserfallschichten" in the area. About 8 m above the "Zopfplatten" of the Heiligenbach section the "Comptum" Subzone is verified by numerous small-sized ammonites of the L. "comptum" – L. evolutum group.

5.5.2 Murchisonae Zone

At present, we cannot confirm strata of this age with ammonites.

| Zones       | Subzones | Biohorizons | Localities                                      |
|-------------|----------|-------------|-------------------------------------------------|
| Concavum    | Formosum | yet to be worked out | ?Gösgen, Ringheim, Wustra       |
| Bradforderensis | Gigantea | ? | Zollernalb, Gailing, Offingen, (Plumhoff 1963) |
| Bradforderensis | Gigantea | ? | Gailing, Offingen, (plumhoff 1963) |
| Bradforderensis | Gigantea | ? | Gailing, Offingen, (plumhoff 1963) |
| Murchisonae | Murchisonae | ? | Wachterberg (Platenberg, Gailing) (Rieber 1963) |
| Murchisonae | Murchisonae | ? | Gailing, Offingen, (plumhoff 1963) |
| Opalinum | Opalinum | ? | Wachterberg (Rieber 2004) |

Figure 26. Biohorizons in the Aalenian of SW Germany. The biohorizons recorded in the Zollernalb area are shaded in grey.
5.2.3 Bradfordensis Subzone

**Bradfordensis Subzone:** Beds 20–22 in the Roschbach section and bed 2 of the Mühlbächle section belong to the Bradfordensis Subzone. Ammonites are *Brasilia bradfordensis* and *Staufenia staufensis*.

**Gigantaea Subzone:** For the moment, we place the ammonite fauna of the Inopernabank bed into the uppermost Gigantaea Subzone. The graphoceratid fauna of this bed itself is not diagnostic enough to decide definitely, if this bed should be placed in the youngest Gigantaea Subzone (younger than *decipiformis* biohorizon) or in the oldest Concavum Subzone (older than *cavatum* biohorizon). However, the single *Planammatoceras* sp. is very close to some of the hammatoceratids from the *decipiformis* biohorizon (Gigantaea Subzone) of Geisingen, but very different from the hammatoceratids of the *cavatum* biohorizon (Concavum Subzone).

Hence, we tentatively assign these beds in the Gigantaea Subzone. Ammonites: *Brasilia decipiens*, *Graphoceras cava* tum, *G. cf. caduciferum*, *G. aff. fallax*, *Ludwigella tenuis*, *L. aff. tenuis*, *L. attenuata*, *L. attracta*, *Planammatoceras* sp.

5.2.4 Concavum Zone

**Concavum Subzone (cavatum horizon):** The Calceolabank (Roschbach: Bed 28, Mühlbächle: Bed 14, Heiligenbach: Bed 45, Hanneswiesle: Bed 4) belongs to the *cavatum* biohorizon of the Concavum Subzone. The fauna is a mixture of *Brasilia* spp., the dominant *Graphoceras* spp. and transitional morphologies besides *Euapetoceras infernense* sensu Buckman. Ammonites: *Brasilia decipiens*, *B. cf. decipiens*, *B. aff. decipiens*, *B. cf. decipiformis*, *Graphoceras cavatum*, *G. cf. cavatum*, *G. cf. concavum*, *G. fallax*, *G. aff. magnum*, *G. decorum*, *G. pulchrum*, *G. formosum*, *Ludwigella arctiensens*, *L. attracta*, *L. mira*, *L. cornu*, *Euapetoceras* cf. *euapetum*, *E. infernense* sensu Buckman, *E. cf. kochi*.

**Formosum Subzone:** There is no evidence for this subzone in the Zollernalb.

**5.2.5 Discites Zone**

The Sowerbyi-Oolith bed belongs to the Discites Zone (see Dietze et al. 2019).

**Table 4.** Number of species, genera and families in relation to zones and subzones. Indeterminable individuals were not considered. The maxima of the species within the zones are in bold. Indiv. = individuals.

| Zone /Subzone | Heiligenbach |
|---------------|--------------|
|               | no. of indiv. | indiv. / sample | species / new | genera / new | families / new |
| Discites-Ovale | 374          | 125             | 15            | 4            | 9              |
| Concavum      | 2572         | 161             | 58            | 34           | 29             |
| Gigantaea     | 169          | 42              | 35            | 18           | 20             |
| Bradfordensis | 25           | 25              | 12            | 5            | 7              |
| Murchisonae   | 126          | 63              | 17            | 9            | 11             |
| Comptum       | 65           | 33              | 8             | 1            | 6              |
| Opalinum      | 3691         | 28              | 34            | 15           | 9              |
| Total         | 3691         | 109             | 38            | 15           |                |

6. Correlation

6.1 Ostracods (M. Franz)

As Plumhoff (1963: 59) already stated, species of the genera *Cytherella* and *Cythereelloidea* dominate in the Upper Aalenian of the Swabian Alb, while they are absent in NW Germany in sediments of the same age. Nevertheless, the correlation succeeds by means of the genera and species occurring at different frequencies in both parts of the basin as listed in Plumhoff (1963: 59). Additionally, *Plumhofficythere clavatoidei* Luppold (= *Cythereidae*, n. gen. sp. nov. 1 in Plumhoff 1963) is now also known from several sections in SW Germany.

In the present study and in the Geisingen section, a total of 33 genera and species were identified which are also known from the English, Scottish and Irish Aalenian and Lower Bajocian. *Cythereella apostolescui*, *Cythereelloidea catenulata*, *Cyth. lori*, *Cythereopterina cibra*, *Eucythereidea elongata*, *Eoc. lacunosus*, *Eucytherura liassica*, *Euc. michelseni*, *Euc. transversiplicata*, *Kinkelina* (Ekt.) *triangula*, *Macrocypris aquabilis*, *M. liassica*, *Procycytherura celtica*, *Proc. euglypha*, *Proc. multicolor*, and many others indicate a marine connection between these two sedimentary basins across the Paris Basin.

**6.1.1 Opalinum Zone**

Of the 34 species detected in the Heiligenbach section in the upper part of the Opalinuston Formation, 21 species are restricted to the Opalinum Zone or occur here for the last time. In accordance with the Geisingen clay pit (Franz et al. 2018), these are, in the order of their first occurrence: *Aphelocythere pygmaea*, *Acrocythere pumila*, *Eucytherura plumhoffii*, *Eucytherura sp. 1* Franz et al., Gen. et sp. indet. *3 Franz et al., Eucytherura foveolata* sp. nov., *Cardobairdia tesakvae*, *Metacytheropteron opalinum*, Gen. et sp. indet. *4 Franz et al., Procycytherura sp. 2* Franz et al., and *Procycytherura celtica*.

The ostracod assemblage of the upper Opalinuston Formation, Zillhausen Subformation (Franz and Nitsch 2009) can be well correlated with neighbouring regions. Although the zonal index *Aphelocythere kuhni* is missing here, *Aphelocythere pygmaea*, *Acrocythere pumila* and *Metacytheropteron opalinum* are also indicative for the upper Opalinum Zone in the Western and Middle Swabian Alb (Dilger 1963; Franz et al. 2018), Northern Germany and Northern Switzerland – there additionally *Eucytherura plumhoffii* and *Cardobairdia tesakvae*.

**6.1.2 Opalinum Zone ("Comptum" Subzone) to Murchisonae Zone**

The stratigraphically insignificant ostracod fauna assemblage of the "Comptum" Subzone and Murchisonae Zone has little in common with previously studied sections of the Swabian Alb. According to Dilger (1963), only *Cythereella apostolescui* and *Cythereopterina bicuneata* are common in this section. Besides these two species Franz et al.
(2018) mentioned also Praeschuleridea punctulata and Kinkelinhella fischeri. The composition of the ostracod assemblage in northern Germany is very different. According to Ainsworth (1986), Cytherella apostolescui is already present in the Toarcian of the Fastnet Basin (off Ireland).

6.1.3 Bradfordens Zone

The ostracod assemblage of this part of the section shows good accordance with that of the Geisingen section with 15 common species. In contrast, the similarities with Dilger (1963) are limited to Aphelocythere dilgeri and Cytherelloidea lardi.

Progonocythere scutula, first described from the Geisingen Oolite (Gigantea Subzone; Franz et al. 2018: 78), occurs in the Heiligenbach section only in sample 17 (below the Staufenisiban). Which presumably corresponds to the Bradfordens Subzone. Due to the rarity of this species, a further stratigraphic interpretation is not possible.

The samples following higher up yielded Balowella catena, an index species of the Ohmerti-caten assemblage (Franz et al. 2018: 82). The second index species, Pleurocythere ohmerti, occurs here only above the Koniglomeratbank, in the Concavum Zone.

6.1.4 Concavum Zone

Ohmert (2004) placed an ostracod assemblage with Kinkelinhella (Kink.) levata, Aphelocythere recta and Pleurocythere cf. kirtonenis (= Pleurocythere ohmerti) from beds of the lower Discites Zone in the Pusilla ostracod zone (Concavum to Discites zones). The index species and additionally Plumhofficythere clavatoides, Cytheropterina alacostata and C. crassicostata, occur in the Zollernalb already in the Concavum Zone; Kinkelinhella (Kink.) levata sporadically even in the uppermost Gigantea Subzone of the Bradfordens Zone. Dilger (1963), who had summarized the interval from the Staufenisiban to the Sowerbyi-Oolith, also mentioned Camptocythere pusilla from the Balingen section (Zollernalb).

Apart from the zonal index species Camptocythere pusilla, Plumhofficythere clavatoides (Cytheridae, n. gen. sp. nov. 1 Plumhoff) is restricted to the Concavum Zone in northern Germany (Plumhoff 1963: 55). The latter occurs very rarely already in the Gigantea Subzone in Geisingen (Franz et al. 2018).

Reisdorf et al. (2016) and Tesakova (2017) did not mention any of the characteristic species of the Concavum Zone, which is a very thin interval in Northern Switzerland.

6.2 Ammonites

Herein we focus on the ammonites from the Inopernabank up to the Rostrote Kalkbank.

**SW Germany**: From the few data available it is most likely that the ammonites from the Inopernabank and the Rostrote Kalkbank are slightly younger compared to the ammonites from the decipiformis biohorizon of Geisingen (westernmost Swabian Alb). The few Graphoceras specimens from the Inopernabank are slightly more depressed and more involute compared to the "Graphoceras-morphology" of B. decipiformis (in a chronospecific sense as described in Dietze et al. 2014). Furthermore, Euapetoceras infernense sensu Buckman – typical of the Concavum Subzone (Chandler and Sole 1996) – is unknown from the decipiformis biohorizon at Geisingen, where the highly variable Bredyia diadematoidea and Planammatoceras spp. are the most common hammatoceratids; the latter was also recorded in the Inopernabank. Very close in depositional age to the Inopernabank and to the Calceolabank is the "Concava-Bank" around Metzingen and Kappishäusern (Middle Swabian Alb) (Rieber 1963). However, these outcrops and their ammonite content is still under investigation. Possibly the sections around Metzingen and Kappishäusern are slightly condensed.

The cavatum biohorizon (index species: Graphoceras cavatum; Calceolabank and Rostrote Kalkbank) is younger compared to the decipiformis biohorizon of Geisingen (Dietze et al. 2014) and younger than the ammonite faunas from the underlying Inopernabank and Koniglomeratbank. The decipiformis biohorizon is characterised by smooth, large-sized Brasilia decipiformis, which occur only rarely in the cavatum biohorizon. The Brasilia fauna of the cavatum biohorizon consists of specimens with a smaller size, sometimes already showing the ribbing style of Graphoceras. The morphogenus Graphoceras is much more common in the cavatum biohorizon than in the decipiformis biohorizon, where most of the specimens belonging to the morphogenus Graphoceras are also less depressed. Variants of Bredyia diadematoidea are abundant in the decipiformis biohorizon and not recorded in the cavatum biohorizon, where Euapetoceras infernense sensu Buckman is common.

Ammonites of the Formosum Subzone occur in the "Bunte Mergel" and "Tonhorizont E1" of Ringsheim (Upper Rhine Valley) and in the Koniglomeratbank/basal part of the Sowerbyi-Oolith near Achen (Wutach area). However, these beds are not yet subdivided into biohorizons.

**SW England**: The decipiens biohorizon (Bradfordens Zone, Gigantea Subzone) is slightly older than the cavatum biohorizon of SW Germany, because therein occur Graphoceras and large-sized Brasilia (up to 0.4 m in diameter) in roughly equal numbers (Chandler 1997). The herein described cavatum biohorizon can be correlated with the cavatum biohorizon (Concavum Zone) of Dorset (Chandler 1997).

7. Additional macrofauna of the Upper Aalenian in the Zollernalb

Besides the ammonites described and discussed above, the macrofauna of the Achdorf Formation is mainly composed of bivalves. Only two species, Gryphaea calceola (Quenstedt, 1843) and Inopera sowerbyana (d'Orbigny, 1850) are more abundant, especially the former, which oc-
curs in masses, but only in a few beds. Gryphaea calceola (Fig. 25: 1–4) was first described from the vicinity of Jun- 
gingen, which is hence considered the type locality. This 
small oyster is especially abundant in the name-bearing 
Calceolabank. The shells are embedded not in live position, 
but as isolated valves in a chaotic arrangement (Fig. 25: 1). 
In a few other beds only small-sized specimens occur (Fig. 
25: 3, 4). Probably these small specimens did not reach 
the maximum size due to less favourable life conditions 
and thus represent ecophenotypes, very similar to Early 
and Middle Jurassic species of Gryphaea (e.g., Bayer et al. 
1985). Despite their smaller size they undoubtedly belong to 
the same taxon and should not be confused – as Quenstedt 
(1843) did – with a superficially similar small oyster, Ostrea 
calceola Zieten, 1833, described from Upper Aalenian beds 
in eastern Swabia (Aalen-Wasseraffingen). The identity of 
the latter was checked by topotypic material in the SMNS 
collection. Inopera sowerbyana (d’Orbigny, 1850) (Fig. 25: 
5) was already mentioned by Quenstedt (1857, as Modiola 
procata) from the vicinity of Juningen. In the studied sec-
tions, it is restricted to the Inoperabank, which is why we 
here name the bed after this bivalve. Inopera was proba-
bly a shallow endobenthic sediment stacker (Fürsich and 
Werner 1988), very similar in its life-style to Pinna, which is 
rarely recorded as well (Fig. 25: 6). Isolated calcitic valves of 
Trigonia alemanica Roller, 1912 (Fig. 25: 7) occur in the 
Calceolabank and were probably washed out of the sedi-
ment during storm events. This observation corresponds to 
the chaotic embedding of the above mentioned Gryphaea. 
Epibenthic bivalves do not occur earlier than in the Lower 
Bajocian Sowerbyibank. They are represented by fragments 
of thick-shelled oysters (Actinostreon sp.) and limids (Cten-
ostreon sp.). Deeper endobenthic taxa such as Pholadomya 
irata (Sowerby, 1818) (Fig. 25: 8), Pholadomya fidalci (J. 
de C. Sowerby, 1826) (Fig. 25: 9), Goniomya literata (Sow-
ery, 1819) (Fig. 25: 10), and Pleuronyx cf. uniformis (Sow-
ery, 1813) (Fig. 25: 13), always preserved as steinkerns, 
are rare in the Upper Aalenian clasticstones.

Bysseate bivalves are represented by isolated valves of 
Mytiloceramus polyplus (Roemer, 1857), Oxytoma inaequivalvis (Sowerby, 1819) and the pectinids Prope-
amssum pumilum (Lamarck, 1819), Chlamys textoria (Schlotheim, 1820) and Entolium corneolum (Young & 
Bird, 1828). Mytiloceramus polyplus (Fig. 25: 11) is a 
geographically wide-spread taxon, which was originally 
reported from the Aalenian of northern Germany. In the 
studied Aalenian sections of the Zollernalb, all records 
come from a single bed, the Rostrote Kalkbank (Mühl-
bächle, Starzel river near Keller), which is otherwise 
very poor in fossils. Possibly these bivalves lived attached 
to driftwood or empty ammonite shells and thus had a 
pseudoplanctic life-style. Propeamussum pumilum (Fig. 
15: 1) is rare in the area, probably because of unfavour-
able environmental conditions. In contrast, it is extremely 
common in various sandstones of the coeval Eisensand-
stein Formation of eastern Swabia. Chlamys textoria and 
Entolium corneolum are stratigraphically long-ranging and 
geographically widespread taxa (Johnson 1984). In the 
studied sections, however, they have been only recorded 
by a few specimens. Other determinable molluscs com-
prise a single belemnite rostrum (Fig. 25: 14) and a poorly 
preserved nautiloid (Cenoceras sp.), both from the Heili-
genbach section.

Crinoid remains were noticed in the field in some beds of 
the Zillhausen Member and in polished sections of the 
Onkoidbank bed. Among arthropods, in the Upper Aalen-
ian claystones of the Zollernalb occasionally tanaidacean 
remains occur. Specimens preserved in claystones had 
been originally misidentified and described as tiny sala-
manders by F. v. Huene (see Schweigert and Etter 2008). 
A well-preserved new record comes from a microfossil sam-
ple below the Konglomeratbank in the Heiligenbach sec-
tion and will be described in another context elsewhere.

Finally, a single tooth of Asteracanthus personati (Quen-
stedt, 1857) Fig. 25: 15) is the only vertebrate remain from 
our studied sections and outcrops. It was found in a bed of 
the Zillhausen Member of the Starzel river.

8. Conclusions

The consideration of small species results in a much high-
er diversity of the ostracod fauna of the Upper Aalenian 
in SW Germany than previously known. The Heiligenbach 
section and the Geisingen clay pit (Franz et al. 2018) yield-
ed a total of 115 species from the Upper Aalenian (includ-
ing the species ‘incertae sedis’), 31 of which were record-
ed in both sections.

The uppermost Lower Aalenian is well characterized by 
the presence of Aphelocythere pygmaea, Acrocysthe pum-
ila and Metacytheropteran opalinum. Eucythera foveola-
ta and Cardobairdia tesakovae have also only been found 
in this part of the section so far. Cytherella apostolescui 
appears for the first time at the base of the Achdorf For-
mation. Higher up in the Achdorf Formation, especially 
in the Gigantea subzone, several stratigraphically 
important species appear like Balowella catena, Cythere-
loidea lordi, Cytheropterina alacostata, Eucythera eberti, 
Kinkellevia levata, Pleurocythere ohmerti, Procythera 
multicostata, and Progonocythere scutula.

Among the ostracod assemblages, cytherurids show 
the most striking development with the first appearance 
of five species in the Gigantea Subzone and 14 species 
in the Concavum Zone. During the same period the total 
number of genera increases from 7 (from 5 families) in 
the Bradfordsen Zone to 20 (9 families) in the Gigantea 
Subzone and 29 (13 families) in the Concavum Zone.

The variation within ammonites of the family Grapho-
ceratidae in southwestern Germany reflects the evolution of 
Graphoceratidae from the geisingensis biohorizon via 
deiciforimis biohorizon (uppermost Bradfordsen Zone; see Dietze et al. 2014) to the here newly introduced 
cavatum biohorizon (basal Concavum Zone). The faunas 
gradually change in the successive biohorizons from the 
morphogenus Brasilia to the morphogenus Graphoceras, 
with numerous transitional forms and a gradual shift to-
wards smaller, more involute and slender shells. In each 
biohorizon, the ammonites of the family Graphoceratidae
probably represent a single palaeobiocomponent, the variation of which changes through time, whereas each morphospecies may range across several biohorizons. The integrative study of ammonite and ostracod faunas allows an excellent combination of both stratigraphic lines of evidence. This allows significantly improved correlations between sections and areas, where either ammonites or ostracods are absent or very rare.

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Appendices

Appendix 1. Range chart of all taxa in the Opalinuston Formation determined to the specific level. Single representatives of a genus are also listed, even when the species is unknown.
Appendix 2. Range chart of all taxa in the Achdorf Formation determined to the specific level. Species persisting from the Opalinuston Formation are also shown.

| Zone            | Subzone |
|-----------------|---------|
| Opalinum        | Apheloctythera dilgeri FRANZ et al. |
| Mur.            | Praeschulenbergia ventricosa (FISCHER IN PLUMHOFF) |
| Bradfordsensis  | Eucytherina transversiplicata (BATE & COLEMAN) |
| Concavum        | Gen. et sp. indet. 5 FRANZ et al. |
| Disc.           | Eucytherina klesiaca BATE & COLEMAN |
|                 | Eucytherina michelaeoni (FINGER) |
|                 | Procytherina multicostata ANSWORTH |
|                 | Eucytherina sp. 3 FRANZ et al. |
|                 | Polycope pelta FISCHER |
|                 | Eucytherina elberti n. sp. |
|                 | Gen. et sp. indet. 10 |
|                 | Praeschulenbergia punctulata (PLUMHOFF) |
|                 | Kinkelina (F.) fischeri MALZ |
|                 | Cytherina apostolescui ANSWORTH |
|                 | Kinkelina sp. 2 FRANZ |
|                 | Ectyphocythera aff. anteroocosta BOOMER |
|                 | Homocytheridae sp. 1 |
|                 | Polycope sp. |
|                 | Homocytheridae sp. 2 |
|                 | Procytherina cf. sarangodes BALLENT & WHATLEY |
|                 | Apheloctythera cf. pygmaea PLUMHOFF |
|                 | Cytheropodina bicuneata (BRAUN) in FRANZ et al. |
|                 | Bythoceratina (Pseudothyloceratina) sp. 1 |
|                 | Pleurocythera sp. 1 |
|                 | Gen. et sp. indet. 12 |
|                 | Praeschulenbergia sp. A. ANSWORTH |
|                 | Cythereidoidea cf. catenula (JONES & SHERBORN) |
|                 | Gen. et sp. indet. 9 |
|                 | Progonoctythera scutula FRANZ et al. |
|                 | Gen. et sp. 9 TSUKAKA |
|                 | Praeschulenbergia ornata (BATE) |
|                 | ? Southcavea sp. |
|                 | Balowella costata FRANZ et al. |
|                 | Acnoctythera aff. pumila PLUMHOFF |
|                 | Eucytherina sp. 11 |
|                 | Cythereidoidea iordi ANSWORTH |
|                 | Pleurocythera katoriensis BATE |
|                 | Asterinella compressa PLUMHOFF |
|                 | Eucytherina cf. paramargaretulis (BRAND) |
|                 | Eucytherina cf. yungo BALLENT & WHATLEY |
|                 | Bairdiocypris triangularis ANSWORTH |
|                 | Microcypris aequalels OMTU |
After submission of the original draft of this manuscript, the 'Comptum' Subzone of the Opalinum Zone has been renamed Bifidatum Subzone, and the number of distinguished biohorizons in the Opalinum Zone (Opalinum and Bifidatum subzones) (Fig. 26) has remarkably increased (see Dietze V, Gräbenstein S, Franz M, Schweigert G, Wetzel A (2021) The Middle Jurassic Opalinuston Formation (Aalenian, Opalinum Zone) at its type locality near Bad Boll and adjacent outcrops (Swabian Alb, SW Germany). Palaeodiversity 15: 14–113, published online 05 March 2021). These changes could not be included in the present paper and have to be considered.