Biostratigraphy of the Unteres Flöz (Upper Aalenian, Murchisonae Zone, Haugi Subzone, sinon biohorizon) at the type locality of the Eisensandstein Formation (Braunjura Group) at Aalen (E Swabian Alb, SW Germany)

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Source: Palaeodiversity, 16(1) : 7-37

Published By: Stuttgart State Museum of Natural History

URL: https://doi.org/10.18476/pale.v16.a2

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Volker Dietze & Günter Schweigert

A b s t r a c t

The ammonite assemblage of the Unteres Flöz (= "lower seam") at Aalen (SW Germany) represents the herein newly introduced *sinon* biohorizon of the uppermost Haugi Subzone (Murchisonae Zone, Upper Aalenian). The biohorizon is the type horizon of the ammonite taxa *Ludwigia obtusa* (Quenstedt) [= *L. haugi* (Douvillé) auct.], *L. crassa* Horn and *Staufenia sinon* (Bayle). Despite an enormous morphological variation within the representatives of these genera *Ludwigia* Bayle, 1878 and *Staufenia* Pompeckj, 1906 in the *sinon* biohorizon, we consider that they belong to a single chronospecies.

K e y w o r d s : Ammonites, Murchisonae Zone, *sinon* biohorizon, Upper Aalenian, SW Germany.

1. Introduction

In eastern Swabia, the Aalenian Eisensandstein Formation yields several laterally expanded lenses of oolitic iron ore of the "Minette" type. This iron ore was exploited over centuries in the vicinity of Aalen, probably starting in Roman times. The first written account is from 1366 (Bayer 1988). The industrial exploitation in the 19th and 20th century concentrated mostly on the Unteres Flöz as well as on the Aalener Flöz (Figs. 1, 2). In 1948, the mining activity was abandoned there (Dietl & Etzold 1977; Bauer 1982; Bayer 1988). During the exploitation of the iron ore numerous fossils had been collected by the miners and became widespread in various European collections. Acknowledging the importance of this stratigraphically relevant material Mayer (1864) proposed an Aalenian Stage, thus expanding the list of Jurassic stages previously established by d'Orbigny (1850–1852). The later scientific history of this Aalenian Stage was summarized by Rieber (1977). More recently, Aalen has been designated the type locality of the Eisensandstein Formation (Franz & Nitzsch 2009), whereas the Aalenian Stage was redefined in modern terms by a GSSP at its basis at Fuentelsaz, Spain (Cresta et al. 2001) and a GSSP at the basis of the following Bajocian Stage at Cabo Mondego, Portugal (Pavia & Enay 1997).

Recently Dietze et al. (2022a) described and evaluated the ammonite assemblage and biostratigraphy of the Aalener Flöz (Eisensandstein Formation, Braunjura Group) at Aalen-Wasseralfingen. This publication contains information on the genesis and exploitation of the iron ore seams, a summary of the most relevant literature on the ammonites and the bio- and lithostratigraphy of the Eisensandstein Formation in the vicinity of Aalen; also a detailed description of the Braunenberg section at Aalen-Wasseralfingen based on the measurements provided by Schuler (1865), Schleh (1927) and Weber (1964). We here refer to these data and focus on the Unteres Flöz.

Ammonites of the Unteres Flöz at Aalen were described and figured by Zieten (1830), Quenstedt (1843, 1845–1849, 1856–1857, 1886), Oppel (1862–1863) and Spiegler (1966). Many ammonites of the Unteres Flöz, mainly the macroconchs, are easy to identify and distinguishable from other ammonites in the section due to their characteristic preservation. Microconchs also occur but are difficult to assign to an individual bed. Numerous specimens are kept in museums' or universities' collections. This allowed us a study of the ammonite assemblage of the Unteres Flöz and a discussion on its biostratigraphical age. It is, however, impossible to reconstruct the exact locations of the material from the historical labels, on which only "Aalen" or "Wasseralfingen" is stated. Today, the village of Wasseralfingen has become part of the town of Aalen. The bulk of the historical specimens originate either from the former mines at the foothill of the Braunenberg at Aalen-Wasseralfingen or from the "Burgstall" area at Aalen. Nowadays, collecting of fossils in the abandoned mines is no longer possible, and permanent outcrops in the surroundings no longer exist.

The ammonites figured in this publication are kept in the Palaeontological Collection of the Eberhard-Karls-Universität Tübingen (acronym: GPIT) and in the collection of the Staatliches Museum für Naturkunde Stuttgart (acronym: SMNS).

2. The Unteres Flöz and the Eisensandstein Formation in the vicinity of Aalen

In the vicinity of Aalen, the Unteres Flöz shows a variable thickness that ranges between 1 and 2 metres (Etzold 1980): Aalen-Burgstall and Aalen-Grauleshof (each almost 2 m thick), Aalen-Wasseralfingen (1.6 m), Aalen-Attenhofen (1.7 m), Aalen-Oberalfingen (1m–1.2 m). The Unteres Flöz overlies the Unterer-Donzdorf-Sandstein Member (Weber 1964; Franz & Nitsch 2009). In Aalen-Attenhofen and Aalen-Oberalfingen, the base of the Unteres Flöz is formed by a hard sandstone bed ("Sohlstein"), which contains iron ooids in its topmost 0.10–0.15 m (Weber 1964). The iron ore of the Unteres Flöz was mined from 1850 to 1924 in the "Tiefer Stollen" at Aalen-Wasseralfingen as well as in the "Faber-du-Faur-Stollen" at the "Burgstall" at Aalen (until 1888 and again from 1939 to 1948) (Weber 1964; Etzold 1980; Bauer 1982). The Aalenian Eisensandstein Formation is overlain by the Lower Bajocian Wedelsandstein Formation, which starts with the Sowerbyi-Oolith Member.

In the following passages, we provide a brief description of the Eisensandstein Formation at Aalen-Wasseralfingen (Fig. 2), mostly based on Schuler (1865) and Schleh (1927), and simplified from Dietze et al. (2022a).

Eisensandstein Formation: c. 30.5–31 m.

- **Oberer Donzdorf Sandstein Member**: c. 8.5–9 m.
  - Claystone: c. 7.0–7.5 m.
  - Sandstone: c. 1.6 m.
- **Oberer Flözhorizont Member**: c. 6.4 m.
  - Alternating sandstones and ore seams: c. 5.3 m, at the top containing the Geislinger Flöz.
  - Aalener Flöz (= Oberes Flöz): c. 1.1 m, iron-oolitic seam.

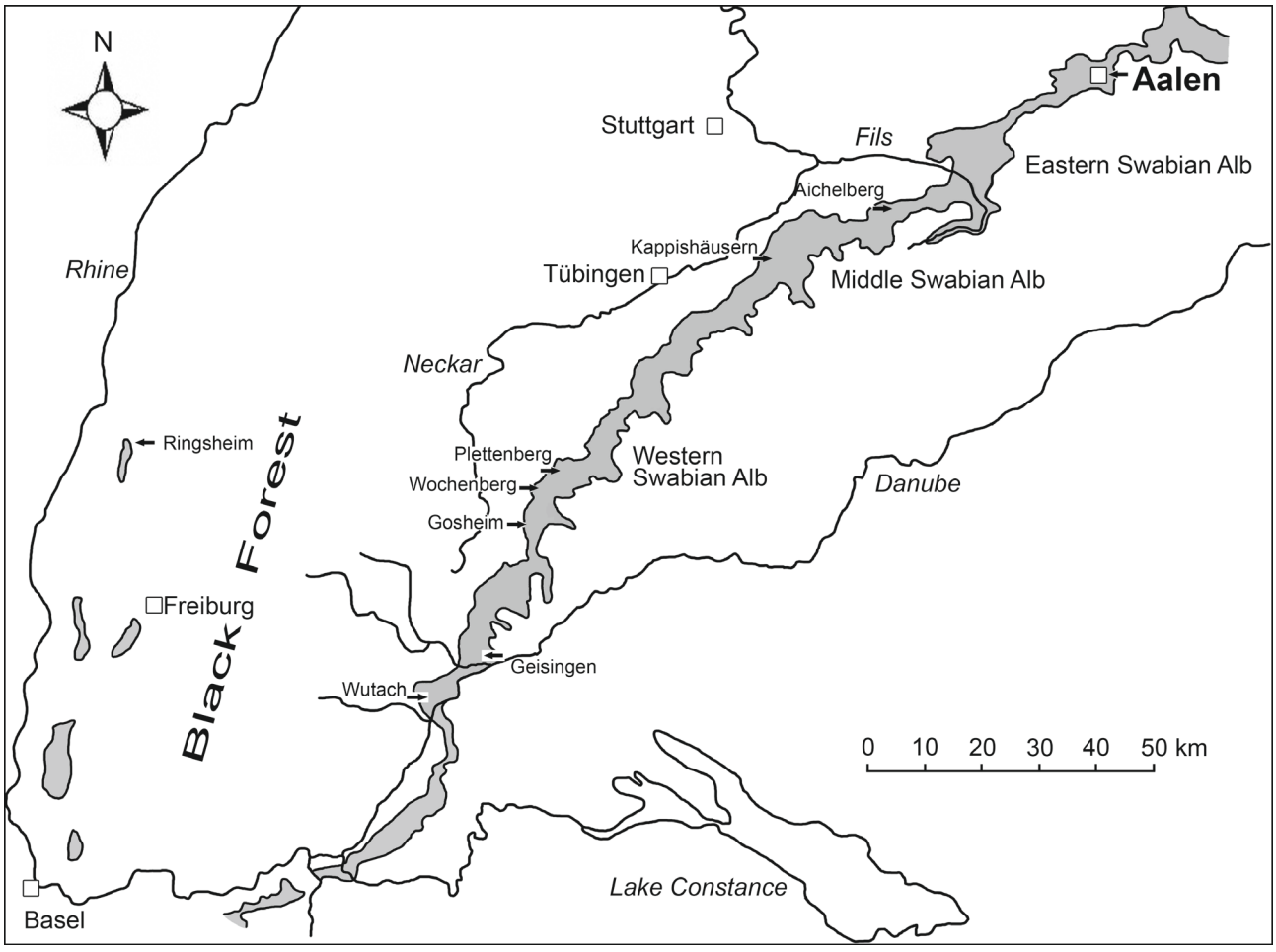

Fig. 1. Locations of the ammonites described in this study from the Middle Jurassic outcrops (gray) of SW Germany (modified after Dietze et al. 2022a).

Ammonites: *Brasilia falcifera*, *B. floccosa*, *B. similis*, *B.* aff. *decipiens*, *B. intralaevis*, *B.* aff. *pinguis*, *B. platychora*, *B.* aff. *platychora*, *B. platys*, *Brasilia* sp., *Ludwigia gradata*, *Lytoceras amplum*, *Ceccaites sieboldi*.

- **Personatensandstein Member**: 10.6 m
  - Sandy shales, claystone and soft sandstones (partly with thin iron-oolitic seams): c. 4.2 m.
  - Unterer Zwischenflözhorizont: c. 2.7 m.

  Ammonites (from the ore seams): *Staufenia staufensis.*
  - Sandy shales, sandstone, claystone, locally iron-oolitic seam: c. 3.7 m.

  Ammonites: *Staufenia discoidea*, *Ludwigia* sp. [c. 1.3–1.6 m above the top of the Unteres Flöz].
- **Unteres Flöz Member**: c. 1.9 m [= average thickness at Aalen-Wasseralfingen]. At the top iron-oolitic (1.6 m).
  - At the base "Sohlstein" (0 m–max. 0.7 m), brown to beige or reddish, very hard calcarenite, blueish-grey in unweathered state, wedging out both towards the north and south.

  Ammonites (from the iron-oolitic part): *Staufenia sinon* [type horizon], *S. sinon* var. *opalinoides*, *Ludwigia crassa* [type horizon], *L.* cf. *crassa*, *L. obtusa* [type horizon], *L.* cf. *obtusa*, *L. obtusiformis*, *L.* cf. *obtusiformis, L.* aff. *patellaria, L.* aff. *subtabulata, L.* aff. *wilsoni,* "*Leioceras*" *comptocostosum*.
- **Unterer-Donzdorf-Sandstein Member**: c. 3.2 m yellow sandstone.

  Ammonites: *Ancolioceras opalinoides*.

The underlying beds of the clayey Lower Aalenian Opalinuston Formation are not described here.

Weber (1964, pl. 3, right column) presented a section starting from the Wasserfallbank (Opalinuston Formation, Zillhausen Member) up to the Sowerbyi-Oolith of Wasseralfingen, which we refigure here in modern biostratigraphical terms (Fig. 3). Further sections of the Eisensandstein Formation at Aalen were described by Schleh (1927), Weber (1964), Dietl & Etzold (1977), Etzold (1980) and Wurm et al. (1990).

3. The ammonite assemblage of the Unteres Flöz

3.1. Historical review

Zieten (1830: pl. 6) was the first to figure several ammonites from the iron ore seams of Aalen. Most of these specimens from the Unteres Flöz are no longer traceable. Subsequently, Quenstedt (1846/1849, 1886) figured additional ammonites from Aalen and introduced several new taxa. Later, Horn (1909) introduced another new ammonite species based on a specimen from the Unteres Flöz of Aalen.

3.2. Ammonite taxa based on ammonites from the Unteres Flöz/Unterer-Donzdorf-Sandstein of Aalen

- ***Ammonites murchisonae acutus* Quenstedt, 1846** [at least four syntypes: Zieten 1830, pl. 6, figs. 1, 3; d'Orbigny 1844, pl. 63, figs. 1–4]

When Quenstedt (1846) introduced this variety ("Varietät") of *A. murchisonae*, he referred it to two specimens from the Unteres Flöz of Aalen illustrated by Zieten (1830, pl. 6, figs. 1, 3) and two further ammonites from the upper Toarcian of northern Alsace illustrated by d'Orbigny (1844, pl. 63, figs. 1–4). In Opinion 2123, Case 999 of the ICZN it was ruled that Quenstedt's third names have to be considered as of subspecies within the species-group and these taxa might by elevated to species rank by the Principle of Coordination (ICZN, Art. 46) (ICZN 2005). Since Quenstedt's taxon *acutus*, introduced in 1846, is preoccupied by *Ammonites acutus* Sowerby, 1813, it would become a junior homonym of the latter and cannot be used any longer in specific rank (Hölder 1958). This nomenclatorial result was widely accepted even earlier (Rieber 1963; Géczy 1967; Contini 1969; Ureta Gil 1983).

- ***Ammonites murchisonae obtusus* Quenstedt, 1846** [lectotype: Quenstedt 1849, pl. 7, figs. 12a, b; designated herein]

In 1846, Quenstedt introduced his variety ("Varietät") *A. murchisonae obtusus* based on an unknown number of specimens from the Unteres Flöz of Aalen (e.g. Quenstedt 1849, pl. 7, figs. 12a, b; Zieten 1830, pl. 6, fig. 2). In Opinion 2123 of the ICZN it was decided that this third name of Quenstedt, despite being a younger homonym, becomes a valid taxon and it was put on the Official List of Specific Names in Zoology (ICZN 2005). This nomenclatorial act lead to the revival of *Ludwigia obtusa*. We here designate the specimen illustrated by Quenstedt (1849, pl. 7, fig. 12a, b) as the lectotype. Consequently, *L. haugi* and *L. obtusa* are now based on the same specimen and both taxa become objective synonyms, with the former being the younger one.

- ***Ammonites opalinoides* Mayer, 1864** [lectotype: Quenstedt 1856, pl. 46, fig. 4 = Quenstedt 1886, pl. 59, fig. 5]

The number of syntypes on which this taxon was based is unknown (i.e. Zieten 1830, pl. 6, figs. 1–3; Quenstedt 1846: 116; Quenstedt 1856: 336, pl. 46, fig. 4). Rieber (1963) designated the specimen from Aalen as the lectotype which was figured twice by Quenstedt (1856, 1886). Since the previously common name *A. murchisonae acutus* is invalid, the later introduced *A. opalinoides* becomes a younger valid synonym for it. Its lectotype, however, does not show the typical preservation of the ammonites from the Unteres Flöz of Aalen. It is not reddish but

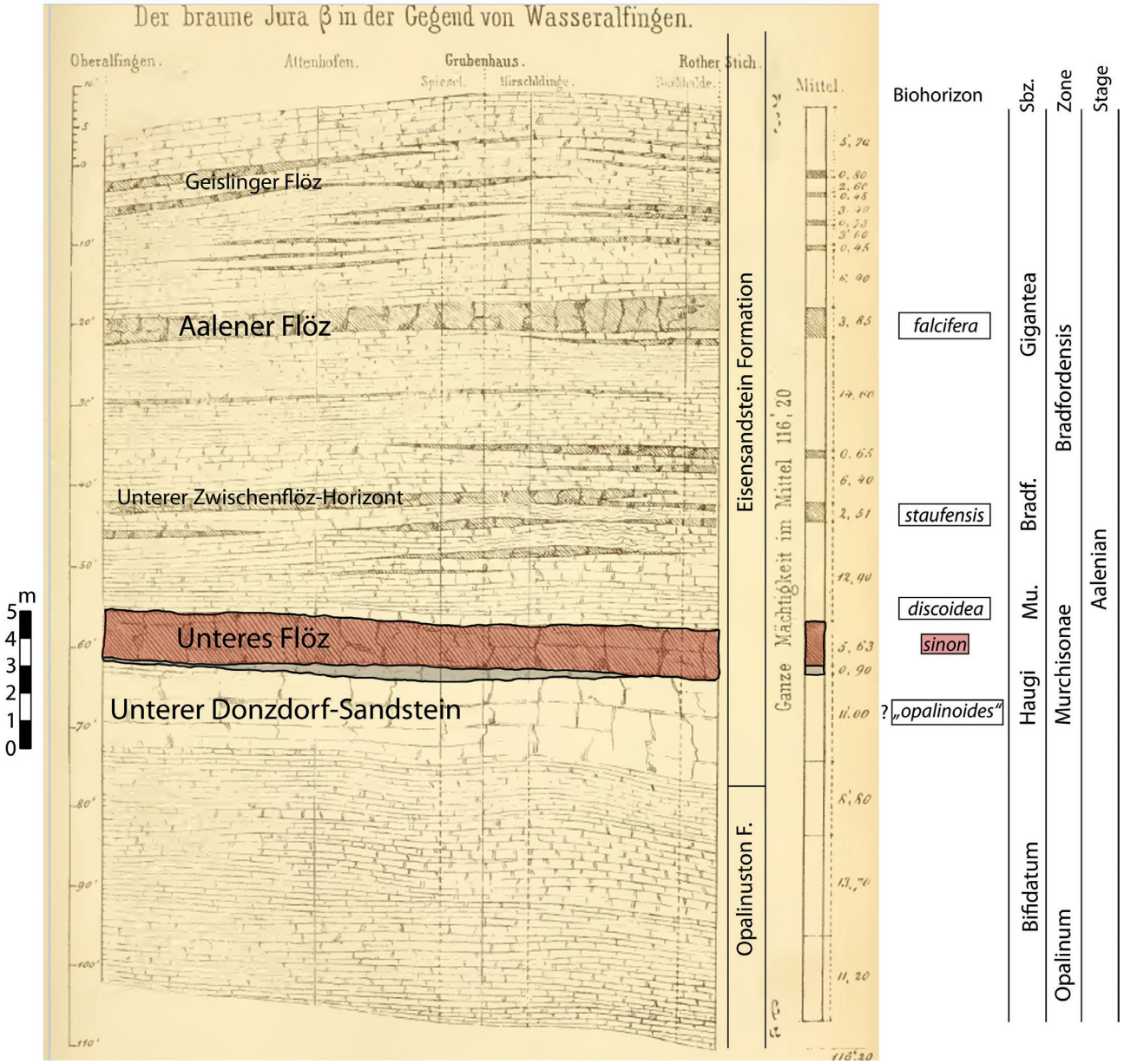

Fig. 2. Section of the Eisensandstein Formation (with the exception of the top of the Oberer-Donzdorf-Sandstein Member) at Aalen-Wasseralfingen (modified from Schuler 1865), to show the wedging out of the smaller iron ore seams over short distances. The "Sohlstein" bed is shaded in grey, and the Unteres Flöz in red. Abbreviations: Mu. = Murchisonae; Bradf. = Bradfordensis; Sbz. = Subzone.

beige-coloured and thus either originates from the basal bed ("Sohlstein") of the Unteres Flöz or from the Unterer-Donzdorf-Sandstein. However, specimens which are morphologically identical to the lectotype but preserved in reddish colour also occur in the Unteres Flöz of Aalen.

- ***Ludwigia sinon* Bayle, 1878** [lectotype: Bayle 1878, pl. 83, fig. 4]

Bayle (1878, pl. 83, figs. 1–4) figured three syntypes of *L. sinon* from the Unteres Flöz of Aalen-Wasseralfingen. Horn (1909) considered only the specimens of figs. 2–4 in Bayle (1878) as belonging to *L. sinon*; however, he failed to select a lectotype for this taxon. Maubeuge (1950) indicated the specimen of Bayle's fig. 4 as "figure type" and based his new genus *Costileioceras* upon it. This nomenclatorial act of Maubeuge (1950) has to be taken as a valid lectotype designation, and consequently Bayle's fig. 4 is the lectotype of *Ludwigia sinon*. In contrast, Rieber (1963) subsequently designated Bayle's fig. 1 as the lectotype. The latter nomenclatorial act was definitely incor-

rect (Ureta Gil 1983: 247). In the latest version of the 'Treatise' the specimen of Bayle's fig. 1 was erroneously noted as being the lectotype (Howarth 2013: 95). Unfortunately, the true lectotype (Bayle 1878, pl. 83, fig. 4) is not traceable in the collection at Lyon and seems lost, whereas the specimen of Bayle's fig. 1 has survived (pers. comm. A. Prieur, Lyon, to V.D.).

- ***Ludwigia haugi* Douvillé, 1885** [lectotype: *Ammonites murchisonae obtusus* Quenstedt, 1849, pl. 7, figs. 12a, b; a younger objective synonym of *L. obtusa* (Quenstedt, 1846)]

Douvillé (1885) replaced *L. murchisonae obtusus* Quenstedt, 1846 by his new species *L. haugi*, however, without type designation. Subsequently, Buckman (1904: 70) designated a specimen illustrated by Haug (1885, pl. 12, fig. 9) as the type of *L. haugi*. We consider this lectotype designation as invalid for several reasons. The specimen illustrated by Haug, then located in Strasbourg, did not belong to the syntype series of Douvillé's taxon. It is rather unlikely that Douvillé had known that specimen and even if he had studied it, we do not know if he would have included it in his new species *L. haugi* because the kinked primaries are typical of the stratigraphically younger species *L. murchisonae* but not of *L. haugi*. Rieber (1963) classified the specimen figured by Quenstedt (1849, pl. 7, fig. 12a, b) as the holotype; this has to be taken as a valid lectotype designation. Indeed, all subsequent researchers took that specimen as the "type" (Géczy 1967; Ureta Gil 1983; Schlegelmilch 1985). It is almost certain that the lost lectotype originated from the Unteres Flöz of Aalen. Despite this nomenclatorial correction we advocate continuation of the usage of the Haugi Subzone of the Middle Jurassic Murchisonae Zone as a valid biostratigraphical unit.

- ***Ludwigia crassa* Horn, 1909** [lectotype: Horn 1909, pl. 13, fig. 2a, b]

Horn (1909) based this species on several ammonites illustrated in the literature and four additional specimens studied by him. Out of these syntypes, Rieber (1963) subsequently designed the specimen from the Unteres Flöz of Aalen illustrated by Horn (1909) on his pl. 13, fig. 2 as the lectotype.

3.3. Remarks on the taxonomy of the ammonites from the Unteres Flöz

In the lower/upper Aalenian transition of SW Germany, the family Graphoceratidae Buckman, 1905 splits into two separate lineages (chronoclines), which range up to the Discites Zone (Lower Bajocian) and Bradfordensis Zone (Upper Aalenian), respectively:

(1) The first of these chronoclines is that of the genus *Ludwigia* Bayle, 1878. In its juvenile stage, the whorl section is broad; in the adult stage it becomes sub-quadrate to high-rectangular or high-triangular. The keeled venter is flattened or roof-shaped and laterally separated by a marked edge from the flanks. In the juvenile stage the flanks are ribbed, whereas they mostly become smooth in the adult stage. In stratigraphically older forms, the ribs may pass on the venter and are prosiphonate. The lobes and saddles of the suture line are rather deep and complex (Rieber 1963).

All ammonites of this chronocline from the Unteres Flöz at Aalen are assigned to *Ludwigia*. Buckman (1887–1907) introduced numerous other genera, e.g., *Welschia*, *Hyattia*, *Kiliania*, and *Apedogyria*. We concur with Howarth (2013) and consider them as younger subjective synonyms of *Ludwigia*. Only for traditional reasons and also for providing a temporal structure for this chronocline, we advocate the purely artificial naming of successive morphologies by the succession of the (morpho-) genera *Ludwigia* → *Brasilia* → *Graphoceras* → *Hyperlioceras* (Chandler et al. 2012). When only a few specimens are studied or transitional forms are neglected these morpho-genera seem to be well-defined. In reality these genera represent a morphological and temporal continuum.

(2) The second chronocline is represented by the genus *Staufenia* Pompeckj, 1906. It is characterized by a discoidal whorl section and a sharp keel that is hardly separated from the slightly convex flanks and a steep or overhanging umbilical wall. The inner whorls can display weak or even coarse ribs; the sculpture disappears at around a diameter of c. 10 cm. The suture line is much simpler than that in *Ludwigia*, with shallower and less incised saddles and lobes but generally variable (Rieber 1963).

A separation of *Staufenia* from the ancestral genus *Leioceras* Hyatt, 1867 is difficult due to a long transitional interval containing numerous intermediate morphologies. Various authors (e.g., Rieber 1963; Contini 1969; Géczy 1967; Ureta Gil 1983; Sadki et al. 2020; Dietze et al. 2021b) assigned the ammonites occurring up to the Opalinum/Murchisonae zonal transition to the genus *Leioceras* (or to synonymous genera, e.g., *Cypholioceras*, *Cylicoceras*). Younger forms originating from the Haugi Subzone were termed as *Staufenia* (*Costileiocras*) (Rieber 1963), *Costileioceras* (Géczy 1967), or *Ancolioceras* and *Staufenia*, respectively (Contini 1969; Ureta Gil 1983; Dietze et al. 2021a). In the Murchisonae Subzone, ammonites of this chronocline are predominantly assigned to *Staufenia* (Rieber 1963; Contini 1969; Chandler 1982; Dietze et al. 2022a).

Here we assign the discoidal graphoceratid ammonites occurring in the Unteres Flöz at Aalen to the genus *Staufenia*. The ammonites of the genus *Staufenia* form a phyletic

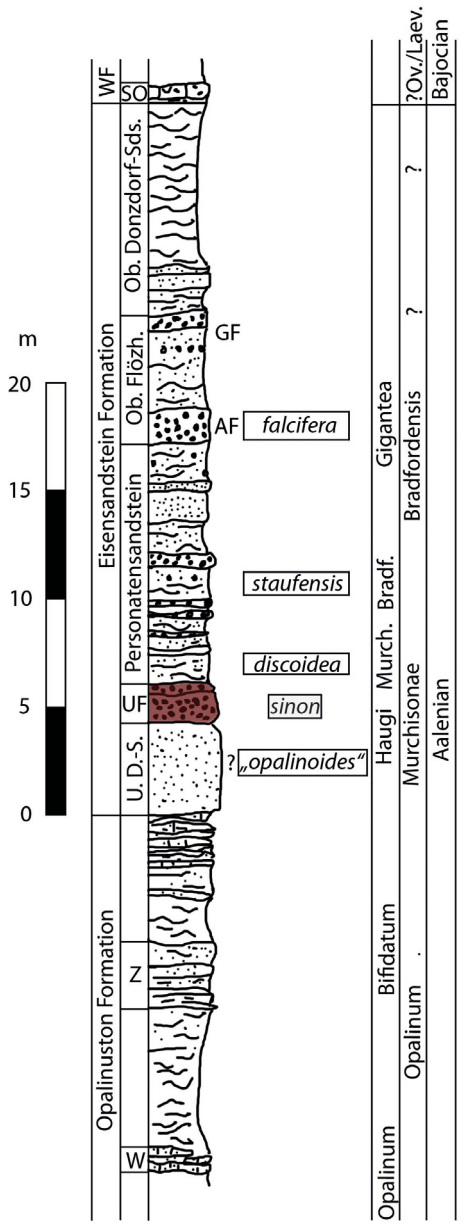

Fig. 3. Section from the Wasserfallbank Member (Opalinuston Formation) and the Eisensandstein Formation up to the Sowerbyi-Oolith Member (Wedelsandstein Formation) of Aalen-Wasseralfingen (SW Germany) (based on Weber 1964, fig. 3, right column). The iron ore beds are indicated by thick dots; the Unteres Flöz is shaded in red. Left of the section: lithostratigraphy; right of the section: biostratigraphy (biohorizons, subzones, zones, stages). Abbreviations: WF = Wedelsandstein Formation; W = Wasserfallbank Member; Z = Zopfplatten Member; U. D.-S. = Unterer-Donzdorf-Sandstein Member; UF = Unteres Flöz; Personatensandstein = Personatensandstein Member; Ob. Flözh. = Oberer Flözhorizont Member; Ob. Donzdorf-Sds. = Oberer-Donzdorf-Sandstein Member; AF = Aalener Flöz; GF = Geislinger Flöz; SO = Sowerbyi-Oolith Member; Murch. = Murchisonae; Bradf. = Bradfordensis; Ov. = Ovale; Laev. = Laeviuscula.

lineage: *S. sinon* → *S. latiumbilicus* → *S. discoidea* α → *S. discoidea* β → *S. staufensis* (see Dietze et al. 2022b). At present, it is still unclear whether *S. sehndensis* is another distinguishable chronospecies of this lineage or if it is a synonym of *S. latiumbilicus*. Since *S. sinon* is the type species of the genus *Costileioceras* Maubeuge, 1950, we consider *Costileioceras* a younger subjective synonym of *Staufenia*.

In contrast to SW Germany, ammonites of the "leioceratid" genera *Leioceras* and *Ancolioceras* Buckman, 1904 occur frequently in beds up to the Bradfordensis Zone of SW England (Buckman 1887–1907; Chandler 1997), whereas ammonites of the genus *Staufenia* range only up to the basal Murchisonae Subzone there (Chandler 1982).

3.4. The genus *Ludwigia* Bayle, 1878 in the Unteres Flöz at Aalen

The bulk of the specimens of *Ludwigia* from the Unteres Flöz at Aalen (Pl. 6, Figs. 1a–2b; Pl. 7, Figs. 1a–5b; Pl. 8, Figs. 1a–4b, Pl. 9, Fig. 1a, b) are morphologically grouped around *L. obtusa* (Quenstedt, 1846) [= *L. haugi* auct.] and *L. obtusiformis* (Buckman, 1899). The same observation was made by Horn (1909) and Rieber (1963) for *Ludwigia* spp. from the lower part of the Oberbeta-Oolith (Haugi Subzone, Murchisonae Zone) at Blumberg-Achdorf in the Wutach area. Rieber (1963) distinguished between *L. haugi haugi* and *L. haugi obtusiformis*, whereas Horn (1909) formally treated both as different species. On the other hand, Horn (1909) pointed to an extremely large variation within the genus *Ludwigia* which led to numerous transitional forms between the two nominal morphospecies so that almost every specimen shows an individual morphology.

In addition to the common morphologies around *L. obtusa* and *L. obtusiformis*, both at Blumberg-Achdorf and in the Unteres Flöz at Aalen, some extreme morphologies, connected by transitional forms with *L. obtusa* and *L. obtusiformis,* also occur. All these forms together show the range of variation within the genus *Ludwigia* in the Haugi Subzone. We include all specimens from the Unteres Flöz as representatives of a chronospecies with highly variable individual morphologies. In a purely biological understanding, this chronospecies represents a (palaeo-) biospecies (cf. Chandler & Callomon 2009).

At one extreme of the variability occur coarsely ribbed specimens with a broad whorl section assigned to *L. crassa* (Horn, 1909) (Pl. 5, Figs. 1a–3b). There also exist transitional forms between *L. crassa* and *L. obtusa* (Pl. 6, Figs. 1a, b).

At the opposite margin of variation both in the Unteres Flöz and in the Wutach area specimens with a high-trapezoidal section and a very weak ventrolateral edge occur (Pl. 9, Figs. 2a–4b). Specimens which are transitional

between *L. obtusiformis* and *L. obtusa* occur as well (Pl. 8, Fig. 4a, b; Pl. 9, Fig. 1a, b). It is worthy to note that neither Horn (1909) nor Rieber (1963) figured any of such examples despite their occasional occurrence in the Haugi Subzone of the Wutach area (coll. SMNS, coll. Auer).

Within the genus *Ludwigia*, *L. crassa* (Pl. 5, Figs. 1a–3b) is characterized by relatively wide-spaced ribs and nodes and a broad whorl section. All specimens illustrated on Pl. 5 are syntypes of Horn's (1909) *L. crassa*.

The specimen figured on Pl. 6, Fig. 1a, b as *L.* cf. *obtusa* is morphologically intermediate between *L. crassa* and *L. obtusa*. A very similar specimen was described by Buckman (1904) under the name *Kiliania armipotens*.

The ammonites figured on Pl. 6, Fig. 2a, b and on Pl. 7, Figs. 2a–3b are both assigned to *L. obtusa* because of their broad whorl section, thickened primaries and generally coarse ribbing. The lost lectotype of this species (Pl. 7, Fig. 4a, b) fits well with the topotypes illustrated on Pl. 7, Figs. 2a–3b.

L. obtusiformis (Pl. 7, Figs. 1a, b; 5a, b, Pl. 8, Figs. 1a, b) has a narrower whorl section than *L. obtusa* and exhibits a somewhat denser, less marked ribbing.

Specimens morphologically transitional between *L. obtusa* and *L. obtusiformis* are determined as *L.* cf. *obtusa* (Pl. 8, Figs. 2a–3b).

We refrain from introducing additional nominal taxa within the genus *Ludwigia* in respect of the already numerous synonyms introduced by S.S. Buckman. Some of these Buckman-taxa can be used for the morphological characterisation of specimens with a high-trapezoidal to high-triangular whorl section, such as *L.* aff. *subtabulata* (Buckman, 1898) (Pl. 9, Fig. 3a, b), *L.* aff. *wilsoni* (Buckman, 1899) (Pl. 9, Fig. 2a, b) and *L.* aff. *pustulifera* (Buckman, 1899) (Pl. 9, Fig. 4a, b). These purely morphological determinations should imply that these are extreme varieties opposite to the morphology of *L. crassa*.

L. cf. *obtusiformis* (Pl. 9, Fig. 1a, b) is transitional between *L. obtusiformis* and these extreme varieties. *L.* cf. *obtusa* (Pl. 8, Fig. 4a, b) is transitional to these extreme variants in respect of the narrowing of the whorl section, to *L. obtusa* in respect of the thickened bases of the primaries) and to *L. obtusiformis* in respect of the narrow whorl section and ribbing density.

3.5. The genus *Staufenia* Pompeckj, 1906 in the Unteres Flöz at Aalen

Specimens of the genus *Staufenia* occurring in a stratigraphically non-condensed horizon are treated as belonging to the same chronospecies and are named the same unless some morphological variation is noted (Rieber 1963; Dietze et al. 2017; Dietze et al. 2022b). Since there is a rather broad morphological variation concerning the strength of the ribbing and correlating whorl section in the specimens of the *sinon* biohorizon, we differentiate the smooth-shelled forms below sub-specific level as "variety *opalinoides*". Varieties are not affected by the strict requirements of the ICZN, especially the Principle of Priority.

The type horizon of *Ancolioceras opalinoides* (Mayer, 1864) must occur below the iron-oolitic part of the Unteres Flöz as is proven by the preservation of the type. There is no doubt that the lectotype of *S. sinon* (Bayle, 1878) originates from the iron-oolitic part of the Unteres Flöz at Aalen-Wasseralfingen. Consequently, the oldest available name for *Staufenia* spp. from the iron-oolitic part of the Unteres Flöz is *Staufenia sinon*. Apart from the lectotype of *A. opalinoides* no other ammonites were reported from the "Sohlstein" or from the Unterer-Donzdorf-Sandstein at Aalen. Hence, it is unclear whether the lectotype of *A. opalinoides* is a representative of the ammonite assemblage termed as *sinon* biohorizon or of an older biohorizon. To solve this problem, we formally assigned all *Staufenia* specimens from the iron-oolitic part of the Unteres Flöz to the chronospecies *S. sinon*. Among these specimens the smooth-shelled examples are informally distinguished as *S. sinon* var. *opalinoides*.

S. sinon var. *opalinoides* (Pl. 1, Figs. 1a–2b, 4a–5b) exhibits weak, densely spaced ribs on the inner whorls (Pl. 1, Figs. 2a, b, 4a, b). The adult whorl section is high and narrow, with an arched venter. A ventro-marginal edge is absent or very weakly developed. On the label of the ammonite illustrated on Pl. 1, Fig. 2a, b it is noticed: "*Ludwigia Sehndensis* … (det. Horn)". This implies that Horn was already aware that the *Staufenia* specimens from Aalen are biostratigraphical younger than the *Ancolioceras* specimens from the Wutach area termed by him as "*Lioceras acutum*".

All specimens of *Staufenia* which are stronger sculptured than *S. sinon* var. *opalinoides* are assigned to *S. sinon* due to their close similarity with Bayle's syntypes (1878, pl. 83, figs. 1–4). The specimen illustrated on Pl. 2, Fig. 2a, b is almost identical to the syntype of Bayle (1878, pl. 83, fig. 1 here refigured on Pl. 2, Fig. 3a, b), which was erroneously taken as the lectotype by some authors. The *Staufenia* specimen illustrated on Pl. 4, Fig. 2a, b is close to Bayle's syntype also, but differs by its more regular and longer persisting ribbing. *Staufenia sinon* specimens which show a coarse ribbing in the inner whorls and a thickened basis of the primaries (Pl. 3, Figs. 1a–2b, 4a–6b; Pl. 4, Fig. 3a, b) are grouped around the lectotype (Pl. 3, Fig. 3) or the third syntype illustrated by Bayle (1878, pl. 83, figs. 2, 3). In the latter the ribs are slightly wider spaced than in the lectotype. The *Staufenia sinon* specimen illustrated on Pl. 2, Fig. 1a, b is somewhat exceptional regarding its very large size, long-persisting ribbing and low aperture. Occasionally, unusually large specimens also occur in *S. latiumbilicus* (Dietze et al. 2022b, pl. 8, fig. 5) or in *S. staufensis* (coll. W. Auer). This anomalous size can be explained as

Concavum	Formosum	yet to be worked out	?Geisingen, Ringsheim, Wutach
	Concavum	*cavatum*	Zollernalb, ?Kappishäusern, ?Metzingen
Bradfordensis	Gigantea	*decipiformis*	Geisingen
		falcifera	Aalen
		geisingensis	Geisingen, Öfingen
		gigantea sensu CONTINI	Geisingen), Wutach (condensed)
	Bradfordensis	*staufensis*	Swabian Alb, Wutach, Geisingen , Ringsheim
Murchisonae	Murchisonae	*discoidea* β	Wochenberg, Plettenberg
		discoidea α	Wochenberg, Gosheim
		latiumbilicus	Wochenberg, ?Gosheim
		yet to be worked out	?Gosheim
	Haugi	*sinon*	Aalen
		opalinoides	Geisingen, Wutach, Wochenberg, ?Gosheim
		subfalcatum	Aichelberg
Opalinum	Bifidatum [ex Comptum]	*viallii*	Wochenberg, ?Gosheim
		evolutum	Aichelberg area
		crassicostatum	Swabian Alb, Wutach, N Franconian Alb
		uncinatum	Aichelberg area
		bifidatum/*rieberi*	Aichelberg area
	Opalinum	*hansrieberi*	Swabian Alb
		opaliniforme	Swabian Alb
		dilucidum	Swabian Alb, Franconian Alb
		opalinum	Swabian Alb, Wittnau

Fig. 4. Biohorizons of the Aalenian in SW Germany. The here newly introduced *sinon* biohorizon is highlighted in gray.

pathologic gigantism either caused by parasitic castration or by a genetic defect (Keupp 2012: 225).

Finally, we noticed remarkable differences in the suture lines of *S. sinon*. Already Horn (1909) found that in the slightly older specimens from the Haugi Subzone of Blumberg-Achdorf (termed by him as "*Lioceras*" *acutum* and "*L.*" *sinon*) the suture line was highly variable, a view about which Rieber (1963) concurred. In some of the specimens studied of the genus *Staufenia* from the Unteres Flöz the suture line is extremely reduced (Pl. 3, Fig. 4a, b), like in the lectotype (Pl. 3, Fig. 3a, b). In the majority of specimens, however, the suture line is more variably differentiated (compare Pl. 2, Fig. 2a, b with Pl. 2, Fig. 2a, b or Pl. 3, Fig. 5a, b with Pl. 4, Fig. 2a, b [suture line on the opposite flank is illustrated in Rieber 1963, text-fig. 13f]). Consequently, as a very flexible character the suture line is not diagnostic.

3.6. Occurrence of "*Leioceras*" *comptocostosum* Chandler & Callomon, 2009 in the Unteres Flöz at Aalen

A single specimen determined here as "*Leioceras*" *comptocostosum* (Pl. 4, Fig. 1a, b), which originates from the collection of the famous F. A. v. Alberti – who introduced the Triassic System –, is markedly different from all other ammonites of the genera *Ludwigia* or *Staufenia* from the Unteres Flöz. It shows a rounded venter of the terminal body-chamber but a keeled phragmocone. In this respect, it falls in the variation of *Leioceras comptocostosum*, a taxon described from the uppermost Lower Aalenian of Dorset (SW England) (cf. Chandler & Callomon 2009, pl. 3, figs. 1a–2b; coll. V.D., coll. R.B. Chandler). Alternatively, this sole specimen could be assigned to *Ancolioceras*; it represents a descendant of "*Leioceras*" – a rare occurrence for SW Germany. The various specimens of *Ancolioceras* described by Horn (1909; pl. 9, figs. 1a–7b, pl. 10, figs. 1a–4b, pl. 11, figs. 1a–8a) from Blumberg-Achdorf differ by a fastigate venter up to the aperture. The lateral lobe as well as the umbilical lobes of the specimen illustrated on Pl. 4, Figs. 1a, b are significantly narrower and much deeper incised than in *Staufenia*. In this respect, there is a closer resemblance to the suture line of *Ludwigia* (cf. Pl. 8, Figs. 1a, b, 3a–4b). The latter examples are distinguished from "*Leioceras*" *comptocostosum* by their whorl section and a stronger ribbing on the outer flanks.

4. Bio-/chronostratigraphy and correlation

4.1. Bio-/chronostratigraphy

The age of the Unterer-Donzdorf-Sandstein Member at Aalen corresponds to the Haugi Subzone (Murchisonae Zone, Upper Aalenian), as indicated by records of *Ancolioceras opalinoides* (Weber 1964; Dietze et al. 2022a). A more detailed age at the level of biohorizons cannot be provided since any further ammonites originating from the Unterer-Donzdorf-Sandstein of Aalen have not been recorded. Weber (1964, section no. 38) noticed *Staufenia* (*Costileioceras*) *sinon*, *Staufenia opalinoides* and *Ludwigia haugi obtusiformis* from the Unterer-Donzdorf-Sandstein of Essingen, only few kilometres west of Aalen. Unfortunately, only few specimens of *S. opalinoides* from his collection have survived and are now in the SMNS collection. Their preservation is identical to that of the lectotype of *A. opalinoides*. The surviving specimens from Essingen are smaller than the *S. sinon* var. *opalinoides* material from Aalen. This provides a valuable argument that the Unterer-Donzdorf-Sandstein of Aalen cannot be assigned to the *sinon* biohorizon.

Except the only locally developed "Sohlstein" bed, the Unteres Flöz dates completely into the herein newly introduced *sinon* biohorizon within the Haugi Subzone (Murchisonae Zone, Upper Aalenian).

4.2. Correlations

SW Germany: We consider that the *opalinoides* biohorizon of the Wutach area (Horn 1909; Rieber 1963) is older than the *sinon* biohorizon of the Unteres Flöz at Aalen. The *Ludwigia* assemblages of the *opalinoides* and *sinon* biohorizons are not distinguishable on the basis of the studied specimens, however, there are differences in respect of *Ancolioceras*/*Staufenia*. The *Staufenia* specimens of the *sinon* biohorizon are larger than their ancestral forms of the genus *Ancolioceras* from the *opalinoides* biohorizon of the Wutach area (cf. Horn 1909, pls. 9–11). Moreover, in the latter the whorl section is on average more inflated and with a slightly stronger expressed ventrolateral edge (cf. Horn 1909, pls. 9–11) compared with *S. sinon* of the Unteres Flöz. In respect of the general evolutionary trends reported from the *Staufenia* chronocline (Dietze et al. 2017, 2022b) we regard the specimens from the Unteres Flöz to be more advanced than those still assigned to *Ancolioceras* of the Oberbeta-Oolith in the Wutach area and therefore must be younger. Consequently, the *sinon* biohorizon must be younger than the *opalinoides* biohorizon as defined in the Wutach area. A further consideration is if the *opalinoides* biohorizon of the Wutach area corresponds to the type horizon of *A. opalinoides* at Aalen. The inner whorls of *A. opalinoides* from the *opalinoides* biohorizon in the Wutach area (Horn 1909, pl. 9, figs. 4a, b, 10a, b, 9a, b), of the lectotype of *A. opalinoides* (Pl. 1, Figs. 3a, b) and inner whorls of *Staufenia sinon* var. *opalinoides* (Pl. 1, Fig. 4a, b) are practically indistinguishable. Although the type horizon of *A. opalinoides*, as explained

above, is slightly older than the type horizon of *S. sinon*, the difference in age lies below biostratigraphical resolution. Therefore, the *opalinoides* biohorizon of the Wutach area must not be renamed.

The *latiumbilicus* biohorizon (Murchisonae Subzone) defined at the Wochenberg hill near Schömberg is the next younger defined biohorizon following above the *sinon* biohorizon (Rieber 1963; Dietze et al. 2022b). This ammonite assemblage differs from that of the *sinon* biohorizon by larger diameters of adult *Staufenia* specimens showing a weaker and shorter ribbing stage. The specimens of *Ludwigia* from here are grouped around *L. murchisonae* (Sowerby, 1829), contrary to those from the *sinon* biohorizon below (Rieber 1963; Dietze et al. 2022b). In these *Ludwigia* specimens the ribs terminate along the ventrolateral edge, whereas they continue towards the venter in specimens of the *sinon* biohorizon. Moreover, in *Ludwigia* specimens of the Haugi Subzone, the ribs are projected forward between the ventrolateral edge and the keel – a feature reminiscent to the ancestral genus *Leioceras*.

Further studies are necessary on the age of the rock interval "Schichten mit *Staufenia sehndensis*" (Rieber 1963). At the Wochenberg hill near Schörzingen, these beds can be assigned to the *latiumbilicus* biohorizon (Dietze et al. 2022b). At Gosheim, many ammonites determined as *Staufenia* "*sehndensis*" in various collections originate from several individual shell beds (lumachelles) occurring at different stratigraphic levels (Fischer 1924). It is planned to sample this interval carefully bed-by-bed in the near future. *Ludwigia* spp. from this interval at Gosheim in museums' and private collections – which are much rarer than coeval *Staufenia* – mostly show morphologies typical of the Haugi Subzone; however, younger forms group around *L. murchisonae* are present as well.

France: After the ammonite taxa listed in Contini (1969) and Contini et al. (1997), only a rough correlation of the *sinon* biohorizon with their Haugi Subzone is possible. From their *obtusiformis* horizon of the Murchisonae Subzone, these authors have neither cited *Ludwigia crassa* nor *Staufenia sinon*.

SW England: A correlation is extremely difficult, since ammonites of the genus *Staufenia* are almost absent in SW England (Chandler 1982, 1997) and the potentially age-diagnostic ammonite taxa of the genus *Ludwigia* listed by Chandler (1997, table 1) have long ranges covering several biohorizons. Chandler (1997, pl. 2, figs. 4a, b, 6a, b) illustrated *Staufenia sehndensis* und *S.* aff. *sehndensis* from the faunal horizon of *Ludwigia obtusiformis*, these specimens are slightly more discoidal and more involute than *S. sinon* var. *opalinoides* of the *sinon* biohorizon. Based on that material, the *sinon* biohorizon has to be placed between the English faunal horizons of *Ancolioceras opalinoides* and of *Ludwigia obtusiformis*.

5. Discussion

The Upper Aalenian ammonite assemblages of Aalen are of low diversity. In addition to a few exotic forms, graphoceratids (*Ludwigia* and *Staufenia*) predominate. The reasons for this marked low diversity are still unclear. When looking at other time-slices in the Jurassic of Southern Germany, however, similar periods of low diversity are recognisable. In the Lower Jurassic, this concerns the Lower Hettangian (psiloceratids), Upper Pliensbachian (amaltheids) and uppermost Toarcian (*Pleydellia*/*Cotteswoldia* and lytoceratids). The Toarcian low diversity trend continues to the Lower Aalenian ammonite assemblages predominated by leioceratids and lytoceratids at the beginning. In the higher part of the Upper Aalenian and in the Lower Bajocian graphoceratids are accompanied by hammatoceratids. Later in the Lower Bajocian ammonite assemblages are dominated by hammatoceratids and morphologically close sonniniids. From the Upper Bajocian onwards, there is a marked increase in generic diversity. Geographically, the diversity of the ammonite assemblages increases towards the southwest (Wutach area, extra-alpine Swiss and French Jurassic), whereas the diversity of ammonites in Northern Germany is similar to that in Southern Germany. In the Aalenian of SW England graphoceratids predominate as well, but to a somewhat lesser extent than in Northern Germany. Both observations suggest that the low diversity of ammonite assemblages in marginal marine basins such as in Southern and Northern Germany was caused by somewhat unfavourable living conditions which forced endemism of more tolerant forms and hampered the spreading of others. However, multidisciplinary studies are necessary to decipher the environmental conditions changing through time.

Acknowledgements

We cordially thank Wolfgang Auer (Altlußheim, Germany), Robert B. Chandler (Whyteleafe, England), Arno Garbe (Dunningen) and Andreas Hofbauer (Wendlingen) for many constructive discussions; Robert B. Chandler also improved the language. Special thanks go to Hans Rieber (Esslingen, Switzerland) for his valuable suggestions and comments. The thorough reviews by András Galácz (Budapest) and Lubomir Metodiev (Sofia) greatly improved the manuscript.

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Manuscript received: 15 December 2022, revised version accepted: 10 January 2023.

Plate 1

Ammonites of the Eisensandstein Formation, Unteres Flöz Member [with the exception of Fig. 3a, b]; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon [with the exception of Fig. 3a, b].

(1a–2b, 4a–5b) *Staufenia sinon* (Bayle, 1878) var. *opalinoides*. (1) SMNS 20373, Aalen-Wasseralfingen [ex coll. Köstlin]. (2) GPIT-PV-108870. (4) GPIT-PV-61339, Aalen-Wasseralfingen [figured in Quenstedt 1886, pl. 59, fig. 3]. (5) GPIT-PV-108869, Aalen-Wasseralfingen. **(3a, b)** *Ancolioceras opalinoides* (Mayer, 1864), lectotype (figured in Quenstedt 1857, pl. 46, fig. 4 and Quenstedt 1886, pl. 59, fig. 5), GPIT-PV-61340, Aalen, "Sohlstein" bed of the Unteres Flöz Member or Unterer-Donzdorf-Sandstein Member, ? "*opalinoides*" biohorizon.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

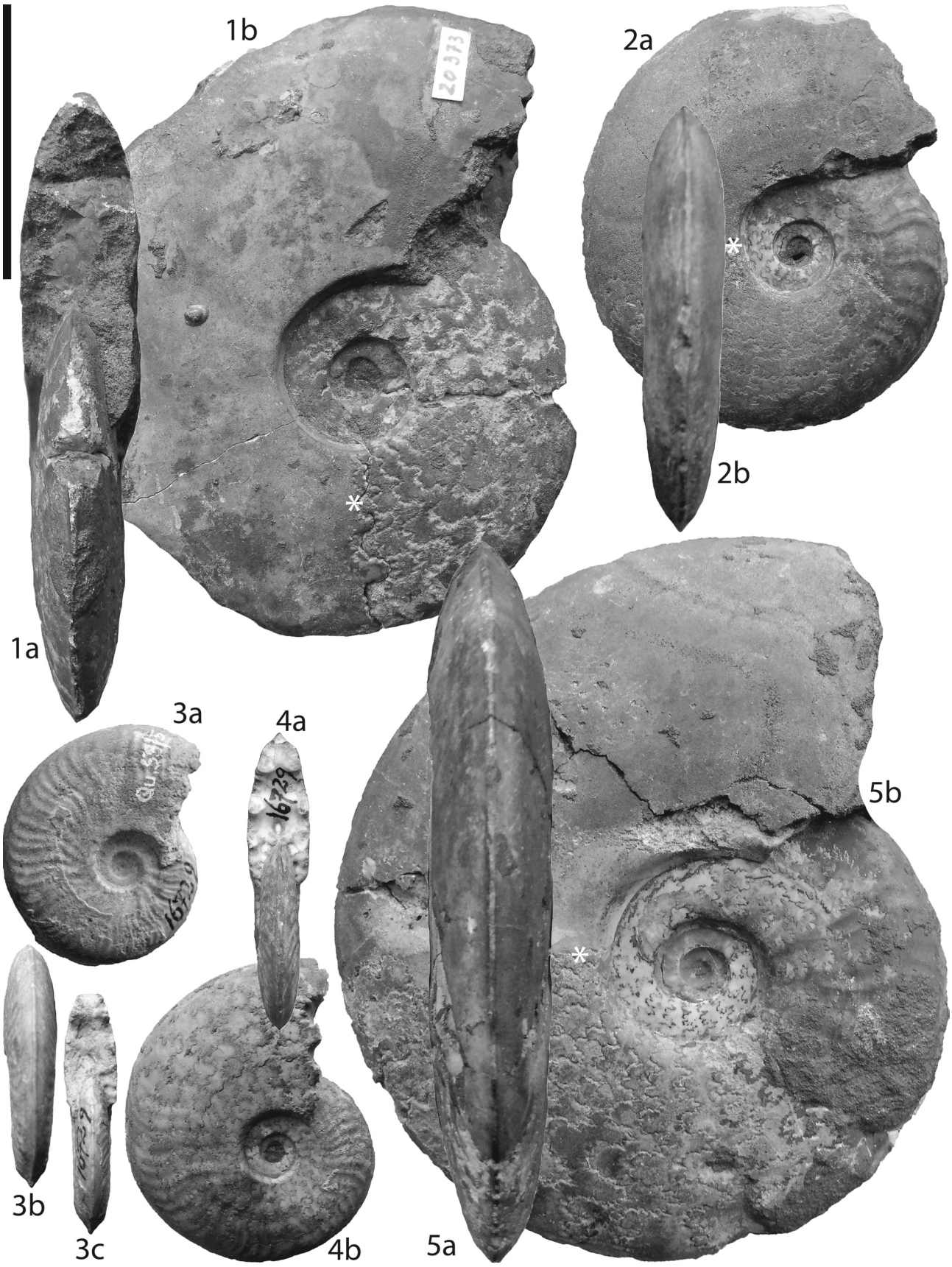

Plate 2

Ammonites of the Eisensandstein Formation, Unteres Flöz Member; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a–3b) *Staufenia sinon* (Bayle, 1878). (1) GPIT-PV-61338, Aalen-Wasseralfingen [figured in Quenstedt 1886, pl. 59, fig. 1]. (2) GPIT-PV-40156 [figured in Quenstedt 1886, pl. 59, fig. 14]. (3) SMNS 70667/1 [cast], Aalen-Wasseralfingen [original specimen EM 1225, coll. Lyon, figured in Bayle 1878, pl. 83, fig. 1, pathogenic; erroneously taken as the lectotype by numerous authors].

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

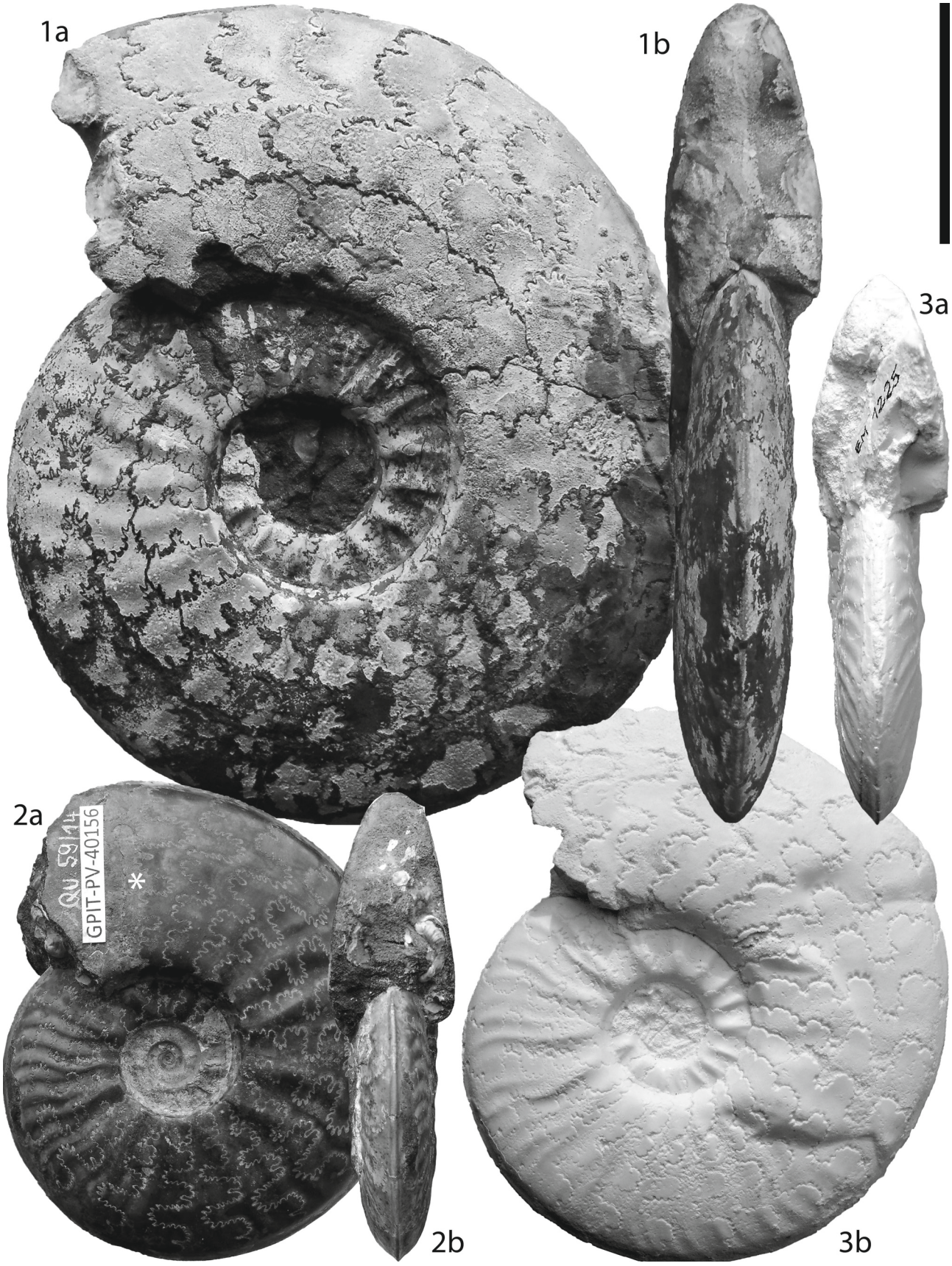

Plate 3

Ammonites of the Eisensandstein Formation, Unteres Flöz Member; at Aalen-Wasseralfingen; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a–6b) *Staufenia sinon* (Bayle, 1878). (1) SMNS 70667/2 [ex coll. Köstlin]. (2) SMNS 69180 [figured in Schwenkel 1933, fig. 39.2]. (3) Lectotype [lost, figured in Bayle 1878, pl. 83, fig. 4]. (4) SMNS 70667/3. (5) SMNS 70667/4. (6) SMNS 70667/5.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

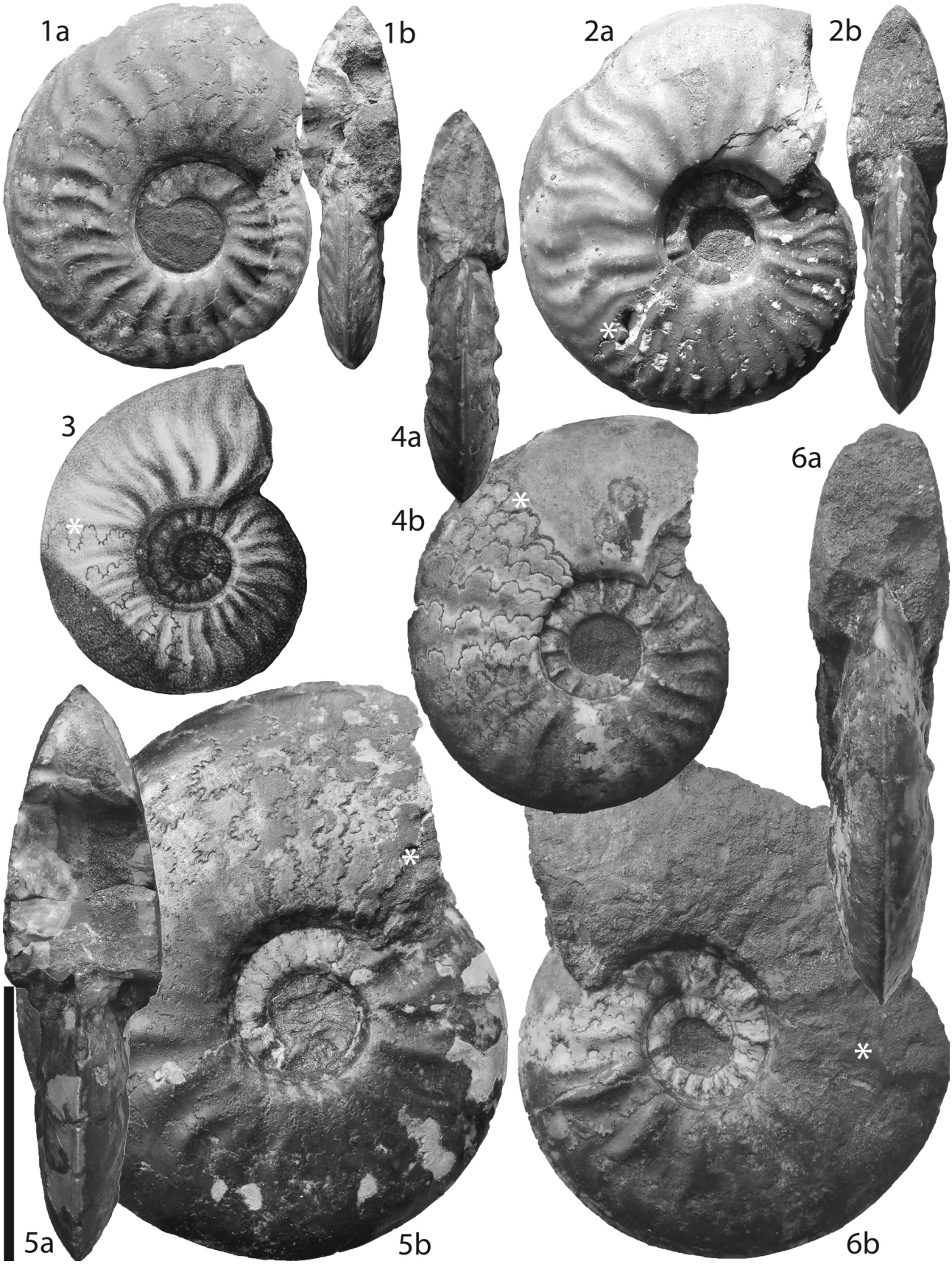

Plate 4

Ammonites of the Eisensandstein Formation, Unteres Flöz Member, at Aalen-Wasseralfingen; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a–b) "*Leioceras*" *comptocostosum* Chandler & Callomon, 2009 [ex coll. F.A. v. Alberti; figured in Olóriz & Rodriguez-Tovar (2011, pl. 479, fig. F) as *Staufenia sinon* and in Schweigert (2018, pl. 14, fig. 1) as *Ludwigia haugi*, SMNS 21776.
(2a–3b) *Staufenia sinon* (Bayle, 1878). (2) GPIT-PV-65900 [suture line illustrated in Rieber 1963, text-fig. 13f]. (3) SMNS 70667/6.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

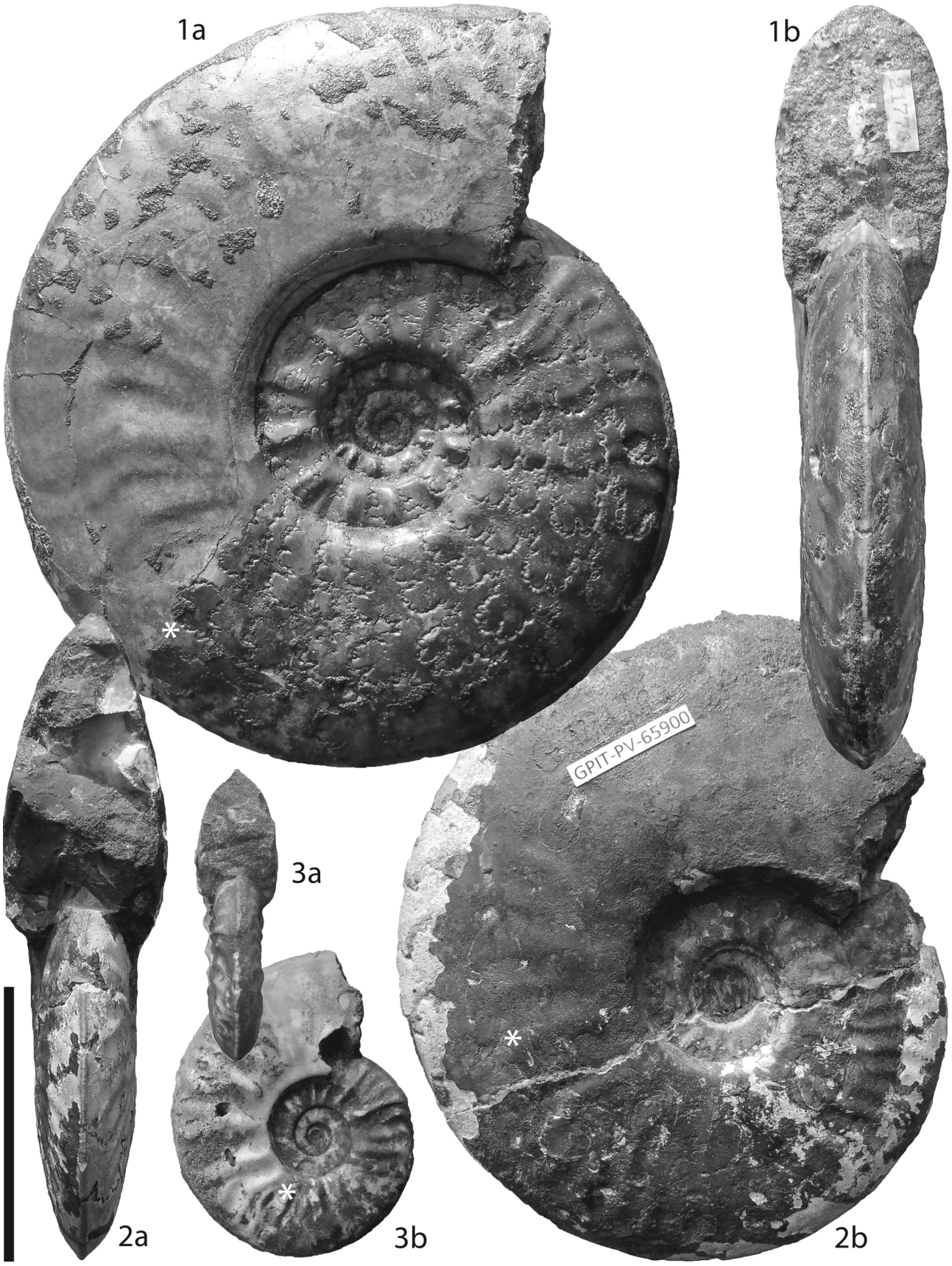

Plate 5

Ammonites of the Eisensandstein Formation, Unteres Flöz Member, at Aalen-Wasseralfingen; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a–3b) *Ludwigia crassa* (Horn, 1909). (1) GPIT-PV-61337 [figured in Quenstedt 1886, pl. 58, fig. 10], Aalen-Wasseralfingen. (2) GPIT-PV-75813 [LT, figured in Horn 1909, pl. 13, fig. 2a, b]. (3) GPIT-PV-61354 [figured in Quenstedt 1886, pl. 59, fig. 2].

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

Plate 6

Ammonites of the Eisensandstein Formation, Unteres Flöz Member; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a, b) *Ludwigia* cf. *obtusa* (Quenstedt, 1886). GPIT-PV-108880, Aalen-Wasseralfingen.
(2a, b) *L. obtusa* (Quenstedt, 1846). GPIT-PV-67053 [figured in Spiegler 1966, pl. 5, fig. 1a as *L. subtabulalta*], Aalen.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

Plate 7

Ammonites of the Eisensandstein Formation, Unteres Flöz Member, at Aalen-Wasseralfingen; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a, b, 5a, b) *Ludwigia obtusiformis* (Buckman, 1899). (1) SMNS 70667/7. (5) SMNS 20719 (ex coll. Köstlin].
(2a–4b) *L. obtusa* (Quenstedt, 1846). (2) SMNS 70667/8 [ex coll. Bechter]. (3) SMNS 70667/9 [ex coll. Bechter]. (4) The lost lectotype [figured in Quenstedt 1846/1849, pl. 7, figs. 12a, b].

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

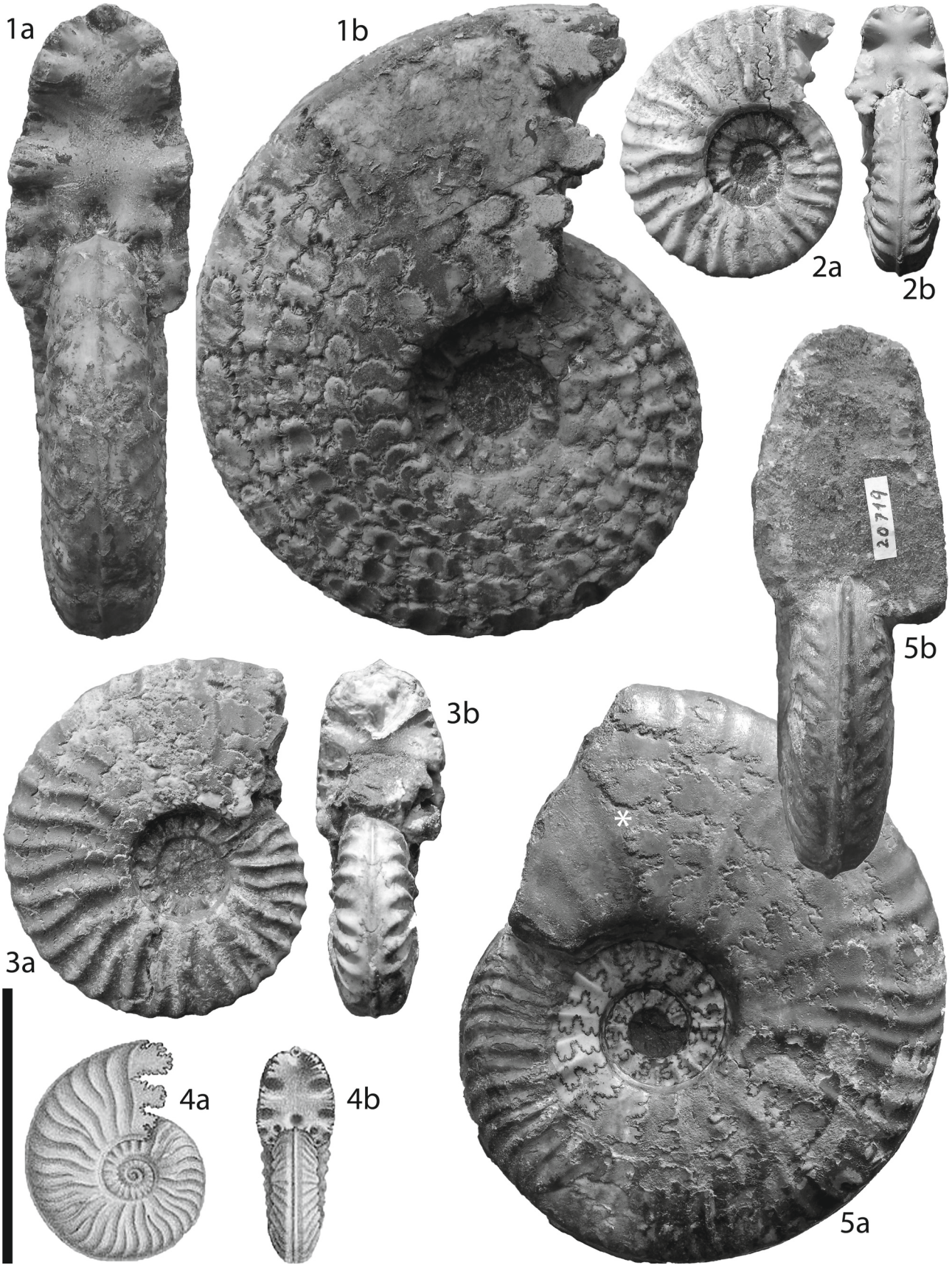

Plate 8

Ammonites of the Eisensandstein Formation, Unteres Flöz Member; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* bio-horizon.

(1a, b) *Ludwigia obtusiformis* (Buckman, 1899). GPIT-PV-61335 [figured in Quenstedt 1886, pl. 58, fig. 8; showing a pathogenic venter], Aalen.
(2a–4b) *L.* cf. *obtusa* (Quenstedt, 1846). (2) SMNS 70667/10, Aalen-Wasseralfingen [ex coll. Bechter]. (3) SMNS 70667/11, Aalen-Wasseralfingen [ex coll. Bechter]. (4) SMNS 70667/12.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.

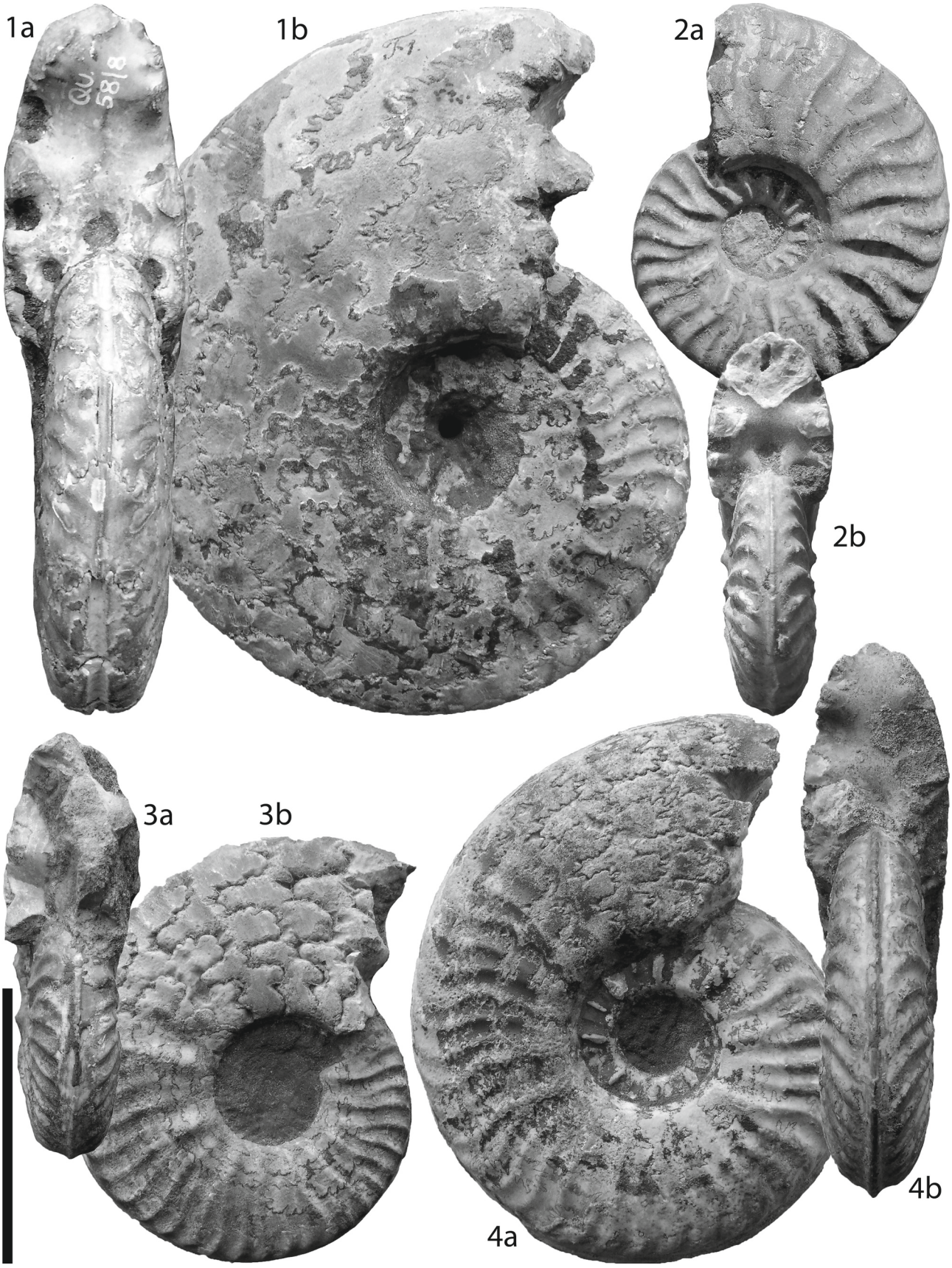

Plate 9

Ammonites of the Eisensandstein Formation, Unteres Flöz Member, at Aalen; Upper Aalenian, Murchisonae Zone, Haugi Subzone, *sinon* biohorizon.

(1a, b) *Ludwigia* cf. *obtusiformis* (Buckman, 1899), SMNS 70667/13.
(2a, b) *L.* aff. *wilsoni* (Buckman, 1899), SMNS 70667/14 [cast; original specimen ex coll. Puzos, coll. Univ. Lyon, EM 20394].
(3a, b) *L.* aff. *subtabulata* (Buckman, 1898), SMNS 70667/15 [ex coll. Köstlin].
(4a, b) *L.* aff. *pustulifera* (Buckman, 1899), GPIT-PV-65964.

Scale bar = 5 cm. Beginning of body-chamber is indicated by an asterisk.