



A new discosorid and some other nautiloids from the Givetian of the Rhenish Massif, Germany

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Received: 7 March 2022 / Revised: 2 June 2022 / Accepted: 28 June 2022 / Published online: 22 September 2022
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Abstract

Nautiloids were subordinate inhabitants of Middle Devonian Rhenish reefs and in surrounding neritic carbonate facies. However, a literature review shows the presence of more than 45 orthoconic, cyrtobreviconic, and gyroconic taxa, which are mostly insufficiently known. We report the first discovery of an orthobreviconic representative of the order Discosorida from the initial phase (Binolen Member) of the thick Hagen-Balve Reef Complex in the Hönne Valley (northern Sauerland). It belongs to a new genus and species (*Binoleniceras stichlingi* n. gen. n. sp.) that is characterised by fast conch expansion, fine longitudinal ribbing, and a marginal siphuncle with short, recumbent cyrtocoanitic (dorsally) and suborthochoanitic (ventrally) septal necks, rounded adapical thickenings (bulletes), strongly thickened connecting rings, and irregular lamellae in the septal opening. It has no described relative in the Middle Devonian of Central or Southern Europe. Other taxa discussed are the oncoceratoid *Cranoceras* Hyatt, 1884, with the first Rhenish record of *Cranoceras subdepressum* (Roemer, 1850), and the archiacoceratid *Cyrtoceratites*, with a possibly new species with very large-sized siphuncle.

Keywords Middle Devonian · Reefs · Rhenish Massif · Nautiloids · Discosorida

Introduction

Nautiloids occur as a minor but widespread faunal element in the Middle Devonian (Givetian) of the Rhenish Massif, Germany. The term nautiloid is used in a wide sense for ectocochleate cephalopods excluding all bactritids and ammonoids. The regional knowledge is poor and mostly outdated, which hampers significantly the reconstruction of regional ecosystem and palaeodiversity changes. Our contribution is only a first and minor step towards a required fundamental revision and modern documentation of Rhenish nautiloid faunas.

This article is a contribution to the special issue “The Rhenish Massif: More than 150 years of research in a Variscan mountain chain”

This article is registered in Zoobank under: urn:lsid:zoobank.org:pub:EF317D5D-4D0E-448B-A613-443689BECED8

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Research history of Rhenish Givetian nautiloids

In the early to middle parts of the 19th century, a wide range of nautiloid taxa were listed and described by Schlotheim (1820, 1822), Goldfuss (in Hoeninghaus 1830 and v. Dechen 1832), Bronn (1834–37), d’Archiac and de Verneuil (1842), Roemer (1844), Sandberger (1845), Steininger (1831, 1833, 1853), and Sandberger and Sandberger (1850–56). Specimens derived mostly from neritic, brachiopod-rich peri- and interreefal strata of the Eifel Mountains (see overview of Königshof et al. 2016; facies distribution of rare specimens in Fuchs 1965), the Bergisch Gladbach-Paffrath Syncline of the Bergisches Land (see overview of Hartkopf-Fröder and Weber 2016; Fig. 1), and Villmar in the Lahn Syncline (see overviews of Braun et al. 1994 and Königshof 2007). Most taxa require revisions of type material and new data on internal features, ontogeny, and variability. Records, excluding some names in the faunal lists of Goldfuss (in Hoeninghaus 1830 and v. Dechen 1832) and Sandberger (1842) that remained nomina nuda, are summarised in Table 1. There are more than 45 species in Rhenish faunas with a dominance of orthocones (Orthoceratida and Pseudorthooceratida), breviconic Oncoceratoidea, and cyrto- to gyroconic, depressed Rutoceratoidea (both Oncoceratida).

Table 1 Compilation of nautiloids recorded from around and within Middle Devonian Rhenish reef complexes, using updated taxonomy as far as available.

normal-sized orthocones:

“*Orthoceratites regularis*” sensu d’Archiac and de Verneuil 1842 (non Schlotheim), possibly = *Acromichelino-ceras commutatum* (Giebel, 1852)

“*Orthoceras*” *planiseptatum* Sandberger and Sandberger, 1856

“*Orthoceras*” *arcuatellum* Sandberger and Sandberger, 1856

“*Orthoceras lineare*” sensu Sandberger and Sandberger 1856 (non Münster)

“*Orthoceras*” *simplicissimum* Sandberger and Sandberger, 1856

“*Orthoceras calamiteus*” sensu d’Archiac and de Verneuil 1842 (non Münster)

Geisonoceras sp.

large-sized orthocones:

“*Orthocera gigantea*” sensu Goldfuss 1830 (non Sowerby)

?Spyroceratidae:

“*Orthoceratites annulata*” sensu Goldfuss 1830, 1832 (non Sowerby)

“*Orthoceratites*” *nodulosus* Schlotheim, 1820

orthocones with zigzag colour banding:

“*Michelinoceras*” *anguliferum* (d’Archiac and de Verneuil, 1842)

orthocones with subventral (“excentric”) siphuncle:

“*Orthocera excentrica*” sensu Goldfuss 1832 (non Sowerby)

?*Protobactrites* cf. *pulchellus* (Roemer, 1850) (growth lines not liriate, as in *Plagiostomoceras*)

orthocones with reticulate ornament:

“*Orthoceras*” *clathratum* Sandberger and Sandberger, 1856

“*Orthoceras tubicinella*” sensu Sandberger and Sandberger 1856 (non Sowerby)

orthobreviconic Oncoceratoidea:

“*Orthoceratites*” *inflatus* Quenstedt, 1840 (Goldfuss 1832 nom. nud.)

“*Gomphoceras verneuili*” sensu Holzapfel 1895 (non Barrande)

“*Cyrtoceras*” *subconicus* Sandberger and Sandberger, 1856 nom. dub.

“*Cyrtoceras*” *applanatus* Sandberger and Sandberger, 1856 nom. dub.

“*Gomphoceratites*” *crenulatus* Steininger, 1853 nom. dub.

cyrtobreviconic Oncoceratoidea:

?*Gonatocyrtoceras ventricosum* (Steininger, 1833)

?*Cyrtogomphus subsanus* (Holzapfel, 1895)

Wissenbachia sp.

Archiacoceratidae:

Cyrtoceratites flexuosus (Schlotheim, 1820)

?*Cyrtoceratites* n. sp.

Archiacoceras subventricosum (d’Archiac and de Verneuil, 1842)

Cranoceratidae:

Cranoceras depressum (Bronn, 1835) (Goldfuss 1830, 1832 nom. nud.)

Cranoceras carinatum (d’Archiac and de Verneuil, 1842) (Goldfuss 1832 nom. nud.)

?*Cranoceras lineatum* (d’Archiac and de Verneuil, 1842) (Goldfuss 1832 nom. nud.)

Cranoceras subdepressum (Roemer, 1850)

?“*Orthoceratites*” *nautiloides* Steininger, 1831 ? = “*Orthoceratites*” *calycularis* Steininger, 1831

Parauloceratidae:

Pseudorutoceras quindecimale (Phillips, 1841)

Rutoceratidae:

Kophinoceras ornatum (d’Archiac and de Verneuil, 1842) (Goldfuss 1830, 1832 nom. nud.)

Kophinoceras eifelense (d’Archiac and de Verneuil, 1842)

Kophinoceras aratum (Sandberger and Sandberger, 1856)

Rutoceras lamellosum (d’Archiac and de Verneuil, 1842)

Table 1 (continued)

?*Rutoceras cornucopiae* (Sandberger and Sandberger, 1856)
Aphytoceras quadratoclathratum (Sandberger and Sandberger, 1856)
Aphytoceras acutocostatum (Sandberger and Sandberger, 1856)
 ?*Aphytoceras multistriatum* (Roemer, 1844)
 ?*Goldringia arcuata* (Steining, 1831)
 ?*Goldringia eifliensis* (Steining, 1853) nom. dub.
Nassauoceras sp.

Ptenoceratidae:
Pleuronoceras nodosum (Bronn, 1835)
Pleuronoceras sp. (including *Hortolus convolvans* sensu Steining 1831, non Montford)

Centroceratidae:
Centroceras tetragonum (d’Archiac and de Verneuil, 1842)
Strophiceras binodosum (Sandberger and Sandberger, 1852)

Discosoridae:
Alpenoceras eifliense (Schindewolf, 1942)

Entimoceratidae:
Binoleniceras stichlingi n. gen. n. sp.

Kayser (1872) and Holzapfel (1895) added further Oncoceratoidea and Rutoceratoidea from the middle Givetian deep neritic facies developed at the top of volcanic seamounts in the eastern Rhenish Massif and from the contemporaneous goniatite limestone deposited on an outer reef slope at Fretter (Attendorn-Elspe Syncline, Fig. 1). Torley (1908) described briefly, unfortunately without illustrations, five cephalopod species from brachiopod-rich marginal slope deposits of the Hagen-Balve Reef from northeast of Iserlohn (Schleddenhof beds, Fig. 1). It included orthocones with reticulate ornament (“*Orthoceras tubicinella*” Sowerby, 1814), the cyrtoconic rutoceratoids *Pseudorutoceras quindecimale*

(Phillips, 1841) and *Aphytoceras acutocostatum* (Sandberger and Sandberger, 1856), the orthobreviconic “*Gomphoceras verneuil*” Holzapfel, 1895 (non Barrande, 1865, a homonym), and the cyrtobreviconic *Cranoceras alatum* (Holzapfel, 1895). Much later, Schindewolf (1942) established the first Rhenish discosorid, the cyrtobreviconic *Endodiscosorus* (*Endostokesoceras*) *eifliensis* from the Givetian of the Sötenich region of the Eifel Mountains (see overview of Königshof et al. 2016). This form is now regarded as a species of *Alpenoceras* (Teichert et al. 1964) but due to differences between typical, North American, and European members of the genus, Turek (1976) considered that

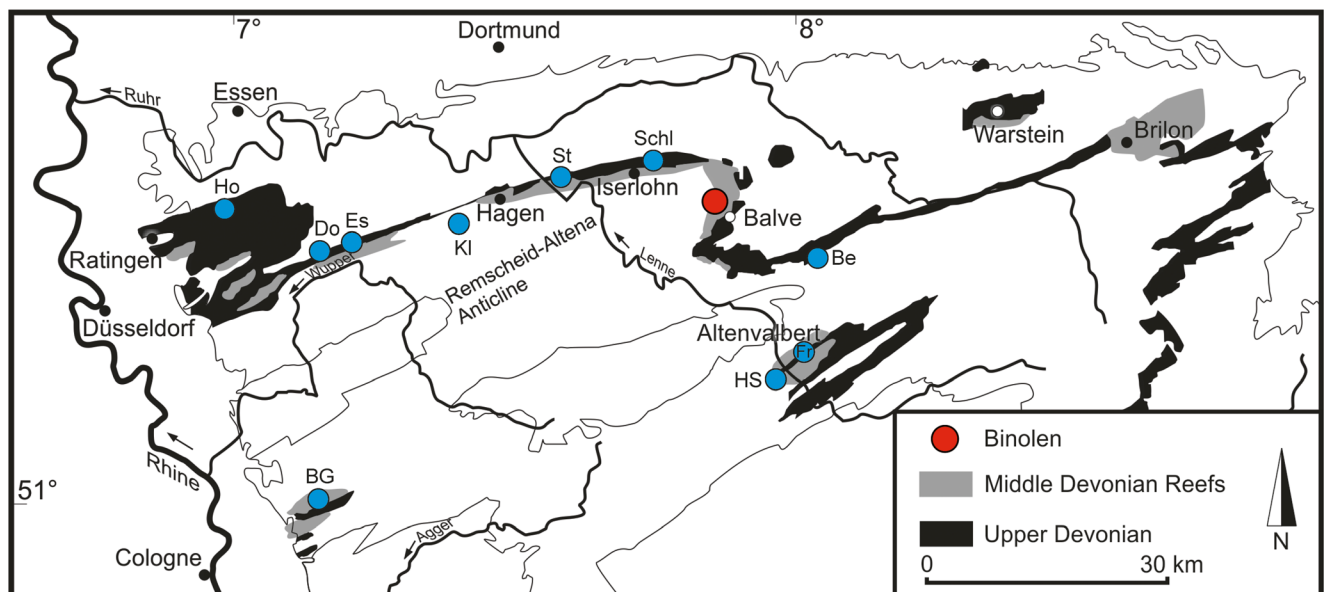


Fig. 1 Position of the Binolen section (red dot) and of other Givetian nautiloid localities (blue dots) in the northern Rhenish Massif east of the Rhine. *BG* Bergisch Gladbach region, *Ho* Hofermühle, *Do* Wuppertal-Dorap, *Es* Eskesberg and Wuppertal-Dorp, *KI* Klutert Cave and Ennepetal-Milspe, *St* Steltenberg in Hagen-Hohenlimburg, *Schl*

Schleddenhof near Iserlohn, *Fr* Fretter. *HS* Heggen-Sange SW of Finnentrop, *Be* Berge Quarry at Oberberge. Thin lines show the outcrop margins of the Rhenish Massif and of pre-Middle Devonian cores of major anticlines.

Schindewolf's *Endostokesoceras* may be resurrected in future. In the 80 years since Schindewolf (1942), no new Givetian nautiloid taxa have been named from the Rhenish Massif and there were no revisions.

Nautiloids from Rhenish Givetian reef environments

Only some previous nautiloid records can be reliably assigned to true reefal (biostromal Schwelm and biohermal Dorp facies) settings of Givetian reef complexes. In the Wuppertal region of the northern Rhenish Massif, Paeckelmann (1913) described, unfortunately without illustrations, a “*Gomphoceras* sp.” from the middle Givetian of Eskesberg (Fig. 1), and another “*Gomphoceras*”, “*Orthoceras*” *simplicissimum* Sandberger and Sandberger, 1856, a larger-sized “*Orthoceras*”, and “*Phragmoceras* aff. *inflatum*” (Quenstedt, 1840) from the upper Givetian to basal Frasnian of Hofermühle (Velbert Anticline, Fig. 1), Dorp, and Dornap-Voßbeck (both western Remscheid-Altena Anticline, Fig. 1). The three latter localities represent reef platform facies with an influx of open shelf faunal elements, such as conodonts. Paeckelmann (1922) provided detailed faunal lists for the biostromal Schwelm Facies of the Wuppertal and Schwelm regions. Michelinoceratidae are represented by “*Michelinoceras*” *anguliferum* (d’Archiac and de Verneuil, 1842), questionable “*Orthoceras*” *simplicissimum* (det. “*Orthoceras* spec. 1”), and ?*Protobactrites* cf. *pulchellus* (Roemer, 1850). The record of Oncoceratoidea includes *Cranoceras depressum* (Bronn, 1835), “*Gomphoceras verneuli*”, and ?*Cyrtogomphus subsanus* (Holzapfel, 1895). The Rutoceratoidea record consists of *Kophinoceras ornatum* (d’Archiac and de Verneuil, 1842) and *Pseudorutoceras quindecimale*. Again, there was no illustration of specimens. *Kophinoceras* is here used for gyroconic forms with distinctive, reticulate and multinodose ornament, which is lacking in the densely frilled, cyrtococonic *Rutoceras* (compare the separate genus recognition in Manda and Turek 2009) as well as in the frilled, gyroconic *Goldringia*. *Aphytoceras* has strongly reticulate ornament with rursiradiate ribs but without nodes/tubercles, e.g. in the middle Givetian *Aph. frechi* (Holzapfel, 1895) and *Aph. westfalicum* (Holzapfel, 1895) from the eastern Rhenish Massif.

There are normally no cephalopods in backreef settings of Rhenish bioherms (e.g. May 1988). As an exception, Paeckelmann (1922) described as “*Orthoceras* spec. 2” either a small protobactritid or bactritid with smooth shell and marginal siphuncle from the top of the lagoonal succession at Wuppertal-Eskesberg (Fig. 1). The biostromal fauna from Schwelm was reviewed by Brauckmann and Koch (1994), who figured new specimens of *Cranoceras depressum* as “*Cyrthoceratites* sp.” and *C. depressus*. They also documented nautiloids from the Steltenberg Reef of Hagen-Hohenlimburg (Fig. 1), which yielded a densely septate longiorthocone, well-preserved *Pseudorutoceras quindecimale*, a fragmentary,

Pleuroncoceras sp., and a possibly new *Nassauoceras*. The longitudinal sections of two Hohenlimburg specimens have much too low whorl expansion rates to belong to *Cranoceras depressum*. It is very difficult to identify such cross-sections. This was acknowledged by using mostly open nomenclature in the description of the unexpectedly diverse nautiloid fauna from a biostrome embedded in the siliciclastic, lower Givetian Upper Honsel Formation at Ennepetal (Klutert Cave, Koch et al. 2018, Fig. 1). Apart from cyrtococones (including a hardly curved *Rutoceras*), narrow gyrocones (*Pleuroncoceras*), and forms with a just touching whorl, there is a single orthobrevicone (“*Gomphoceras*” of their fig. 4D). Specimens from the same region (Ennepetal-Milspe) in the Münster teaching collection consist of a compressed, actinosiphonate cyrtobrevicone with strongly narrowed aperture (probably the genus *Wissenbachia*, GMM B6C.57.3) and an indeterminate, large, compressed orthobrevicone without siphuncle preservation (GMM B6C.57.4).

Further to the south, May (2003) reported an orthocone (*Geisonoceras* sp.) from lower Givetian biostromal limestones at Heggen-Dange in the northern Attendorn-Elspe region (Fig. 1). At the northern margin of the Ostsauerland Anticline to the NE, in the Berge Quarry at Oberberge (Fig. 1), the correlative, biostromal *Sparganophyllum* Limestone contains weathered rutoceratid moulds (?*Kophinoceras* sp., Fig. 2) and an indeterminate coiled and torticonic form with several whorls. These are new records in relation to the long faunal list for the unit in Lotze (1928). It is intriguing that no Givetian nautiloids have been recorded so far from the many outcrops of the extensive Brilon Reef Complex of the eastern Sauerland (see faunal list of May 1987).

New discosorid from Binolen (northern Sauerland)

The unique specimen described here comes from the initial phase of the up to 1000 m thick Hönne Valley Reef (eastern part of Hagen-Balve Reef Complex), which is assigned by Löw et al. (2022) to the biostromal Binolen Member of the Hagen-Balve Formation (former lower “Massenkalk”, Schwelm Facies). It was collected by S. Stichling during his bed-by-bed survey of the Binolen section, which is the western slope of a forest track leading upslope in parallel to the Hönne river in the northern Sauerland (Fig. 1). Preliminary data for the section and its precise location were published by Becker et al. (2016). For details of the section log, associated fauna, micro- and biofacies see Löw et al. (2022, this issue). There are no other cephalopods in the section. The combination of brachiopod data from the underlying Upper Honsel Formation and limited conodont evidence from the Binolen Member date the specimen as upper part of the lower Givetian (probably *Polygnathus timorensis* Zone). Bed 26, the source of our specimen, yielded the simple cone conodont *Dvorakia chattertoni* Klapper and Barrick, 1983, which is zonally non-



Fig. 2 Whorl fragment of a strongly depressed and only weakly ribbed *?Kophinoceras* sp. from the *Sparganophyllum* Limestone of Berge Quarry (Oberberge, northern Sauerland); length 145 mm, max. width 100 mm (specimen kept on display at the quarry gate); scale bars = 5 cm, different for a–c and d–e, respectively. **a** lateral view showing slightly

undulose septa. **b** ventral view showing a wide and low ventral saddle and remnants of dense longitudinal lirae. **c** other lateral view with shallow flank lobe. **d** dorsal view showing a very shallow and wide dorsal lobe and longitudinal lirae. **e** septal view with submarginal position of small, open, circular siphuncle.

diagnostic, and the scolecodont *Oeonites* sp. Considering that more than 45 nautiloid taxa have previously been documented from the Rhenish Middle Devonian, the discovery of a new genus of the Discosorida is surprising and adds to the understanding of the biodiversity of Rhenish reef ecosystems.

Methods, abbreviations, and repository

A plaster cast was produced from the holotype of *Binoleniceras stichlingi* n. gen. n. sp. before it was cut for a polished cross-section through the second septum and for a longitudinal section through the siphuncle. Absolute measurements (in mm) of sections were taken with a Keyence digital microscope at the Institute of Geology and Palaeontology of the Westphalian Wilhelms University (WWU), Münster. Due to their large sizes, other nautiloids were measured with normal rulers.

Dm1 = max. diameter of conch, Dm2 = min. diameter of conch, KL = length of chambers, SAB = distance of siphuncle from conch margin, SiphDm1-Q = max. diameter of siphuncle in cross section, SiphDm2-Q = min. diameter of siphuncle in cross section, SiphDm-L = max. diameter of siphuncle in longitudinal section (placed at Dm2), PerfDm = width of septal perforation in longitudinal section, SC = septal curvature in longitudinal section (distance of most adapical point from the line connecting the margins).

Unless stated otherwise, figured specimens are stored either in the Geomuseum Münster (GMM B6C.57.1) or in the teaching collection of the Institute of Geology and Palaeontology (GMM B6C.57.2-5), WWU Münster.

Systematic palaeontology

As noted above, the taxonomy of most nautiloids described from the Middle Devonian of the Rhenish Massif is insufficiently established. There are some principle uncertainties concerning authorships and generic terminology even in the Treatise on Invertebrate Paleontology (Teichert et al. 1964) or Osnovy Paleontologii (Ruzhentsev et al. 1962; Zhuravleva 1974b). Such aspects are addressed with respect to our list of previous Rhenish records (Table 1) and in relation to previously unpublished specimens from the Münster collection.

Order Oncoceratida Flower in Flower and Kummel, 1950

Superfamily Oncoceratoidea Hyatt, 1884 nom. transl.

Family Archiacoceratidae Teichert, 1939

Discussion: The Archiacoceratidae combine a strictly endogastric and compressed conch, very thick, inflated connecting rings, and encrusted septal necks with strongly actinosiphonate lamellae. While the first three features suggest

a placing in the Discosorida, Crick and Teichert (1979) used the actinosiphonate lamellae as an argument to keep the family in the Oncoceratida, following the systematics of Flower and Kummel (1950) and Zhuravleva (1974a). Indeed, there are various other endogastric, cyrtobreviconic, and actinosiphonate groups within the Oncoceratida (see original, wider content of the Archiacoceratidae in Teichert 1939) but there are also significant similarities of *Archiacoceras* with the Devonian type-genus of the supposed discosorid family Taxyceratidae Zhuravleva, 1972. This implies multiple homoeomorphy, which questions the current systematics of Devonian Oncoceratida/Discosorida that has been volatile in the past (e.g. Zhuravleva 1974a; Mutvei 2013). The study of early representatives of the two groups (Kröger et al. 2009) was not conclusive for this problem.

Cyrtoceratites Goldfuss in Hoeninghaus, 1830 (?Fig. 3)

- * 1830 *Cyrtoceratites* Goldfuss in Hoeninghaus, p. 226.
- * 1832 *Cyrtocera* Goldfuss in v. Dechen, p. 536 [objective junior synonym].
- 1842 *Cyrthoceratites* d'Archiac and de Verneuil, pp. 348–351 [nom. vad. and objective junior synonym].
- 1964 ?*Cyrtoceratites* Sweet in Teichert et al., p. K312.
- non 1964 *Cyrthoceratites* Sweet in Teichert et al., p. K305 [= *Cranoceras*].
- 1974a *Cyrtoceratites* Zhuravleva, p. 95.
- non 1974a *Cyrthoceratites* Zhuravleva, p. 58 [= *Cranoceras*].
- non 1974b *Cyrthoceratites* Zhuravleva, p. 151 [= *Cranoceras*].
- non 2005 *Cyrthoceratites* Clausen and Hauser, p. 66 [= *Cranoceras*].

Type-species: *Cyrtoceratites flexuosus* Schlotheim, 1820.

Discussion: As obvious from the Treatise (Teichert et al. 1964), a genus *Cyrtoceras* has not been correctly established by early cephalopod researchers and cannot be recognised as a valid taxon. Furthermore, there is confusion concerning the correct authorships (e.g. Turner 1962) and existence of supposed separate genera *Cyrtoceratites* and *Cyrthoceratites*, recognised in the Treatise and in Zhuravleva (1974a), but not in the Osnovy (Zhuravleva 1974b), and concerning the validity of the generic names *Cyrtocera* and *Cranoceras*.

The name *Cyrtoceratites* was introduced and briefly defined (“Gewundene Orthoceratiten”) by Goldfuss in Hoeninghaus (1830) but among the taxa listed, the only described species was *Orthoceratites flexuosus* Schlotheim, 1820, an endogastric and compressed form from the Gerolstein area of the Eifel Mountains. Therefore, it became the type-species by monotypy (Sweet in Teichert et al. 1964). The three other species names of Goldfuss in Hoeninghaus (1830) were nomina nuda since there was neither a description



Fig. 3 ?*Cyrtoceratites* n. sp. (GMM B6C.57.5-5, WWU teaching collection), locality unknown, weathered specimen, all figs. x 1. **a** lateral view showing dense septation, endogastric curvature, and the maximum diameter (67 mm) and band of muscle scars at the beginning of the living chamber; max. length = 115 mm. **b** concave siphuncular side, showing the unusually large, actinosiphonate siphuncle. **c** convex

outer side showing the strong terminal constriction of the living chamber. **d** apical view showing the proportionally very large, nummoidal, actinosiphonate siphuncle (16 mm = ca. 46 % of dorsoventral diameter), with widely-spaced main lamellae changing into very fine lamellae internally.

nor an illustration. The same is true for a subsequent species list in v. Dechen (1832, p. 536), which included *depressa* among six Goldfuss names ascribed to “*Cyrtocera* Goldfuss”. This different genus name was explained (“halbmondförmig gebogene Orthocerae”) but, again, the only described species assigned was “*Orthocera flexuosa* Schlotheim, 1822”. It is clear that the two names *Cyrtoceratites* from 1830 and *Cyrtocera* from 1832 meant the same group of species but it is unclear why the 1830 name was not kept. Since both genera included the same only valid species at the time of introduction, *Cyrtocera* is an objective junior synonym of *Cyrtoceratites*, as correctly stated in the Treatise (Sweet in Teichert et al. 1964, p. K312).

The monograph of d’Archiac and de Verneuil (1842) includes no indication that the authors intended to introduce a new genus *Cyrtoceratites*, as accepted in the Treatise. There was no genus characterisation, merely an invalid attempt to conform the spelling of the genus to that of *Orthoceratites*. Following Article 33.2 of the International Code of Zoological Nomenclature, *Cyrtoceratites* in d’Archiac and de Verneuil (1842) is nothing more than an incorrect emendation and objective junior synonym of *Cyrtoceratites* Goldfuss in Hoeninghaus, 1830.

Revision of type-material has still to clarify whether *Cyrtoceratites* Schlotheim, 1820 is a senior synonym of *Archiacoceras* Foerste, 1926. We designate as lectotype of

Cyrto. flexuosus the specimen from Gerolstein illustrated by Schlotheim (1822: pl. VIII, fig. 1). This is essential to exclude the poorly preserved, non-Devonian specimens from Öland mentioned by Schlotheim (1820), which certainly do not belong to the same species. The Schlotheim Collection was purchased in 1833 by the museum of the Berlin University (Hoppe 2001), where the hand-written Quenstedt Catalogue recorded the lectotype under the number 6.1 as “*Lituites flexuosus* Schl.” There is a second specimen (6.2) listed as “*Lituites flexuosus* Schl. *compressus* Goldf.” from Keldenich in the Eifel Mountains. This refers to the names “*Cyrtoceratites compressus*” Goldfuss in Hoeninghaus (1830) and “*Cyrtocera compressa*” Goldfuss in v. Dechen (1832) that were invalid nom. nov. for Schlotheim’s species. Attempts by D. Weyer in March 2022 to find the two catalogued specimens in the systematic collection or Devonian Hall at the Museum für Naturkunde, Berlin, failed but it cannot be excluded that they have been misplaced and that they still exist.

In Fig. 4 we illustrate a compressed, endogastric specimen (GMM B6C.57.5, Münster teaching collection) with very large, strongly actinosiphonate, near-marginal siphuncle, with broad main and fine lamellae, nummoidal segments, serial muscle scars, and markedly contracting body chamber. It may belong to the Archiacoceratidae but its locality is unfortunately unknown. It shares with Schlotheim’s drawing of *Cyrtoceratites flexuosus* that the maximum conch diameter is not reached within the phragmocone, but at the base of the living chamber, unlike as in *Archiacoceras subventricosum* (d’Archiac and de Verneuil, 1842). But the size of its siphuncle (ca. 42 % of diameter) is enigmatic, exceeding that in *Archiacoceras* (ca. 30 %, Crick and Teichert 1979, pl. 98, fig. 3) or in Schlotheim’s drawing of *Cyrtoceratites flexuosus*. We identify the specimen provisionally as ?*Cyrtoceratites* n. sp. but there may be relationships with Middle Devonian Polyelasmoceratidae (see Teichert et al. 1964; Zhuravleva 1972).

Stratigraphical and geographical range: Only known from the Middle Devonian of the Rhenish Massif.



Fig. 4 Fully septate, large whorl fragment of a *Cranoceras subdepressum* (Roemer, 1850) from Dingdorf, Eifel Mountains (GMM B6C.57.2, WWU teaching collection), max. length 158 mm, max. whorl height 90 mm, max. whorl width 132 mm; scale bars = 5 cm, different for a–b and c, respectively. **a** dorsal view showing the straight dorsal conch margin

(without any trace of a keel), straight dorsal sutures, and the extreme mature conch inflation. **b** ventral view showing the evenly convex dorsal to ventral cross-section. **c** septal (apical) view showing the submarginal position and compressed (oval) cross-section of the actinosiphonate siphuncle, at whorl width = 55 mm and whorl height = 51 mm.

Family Cranoceratidae Shimanskiy, 1956

Cranoceras Hyatt, 1884
(Fig. 4)

Type-species: *Cyrtocera depressa* Bronn, 1835.

Diagnosis: Large-sized, narrow cyrtobreviconic coiling, reaching slightly less than a full whorl, with rapid whorl expansion and inflation, smooth shell, flattened to weakly keeled dorsal side, prorsiradiate, straight septa, and a subventral, actinosiphonate siphuncle with moderately short septal necks.

Other species included:

Cranoceras alatum Holzapfel, 1895

Cyrthoceratites depressus var. *carinatus* d'Archiac and de Verneuil, 1842 (a probable synonym of *Cranoceras depressum*)

Cyrthoceras subdepressum Roemer, 1850 (= *depressum*? in Roemer 1843)

Cyrthoceratites wallersheimensis Clausen and Hauser, 2005.

Cranoceras? ellipticum Rowley in Greene, 1901 from the Givetian of Indiana clearly does not belong to the genus.

Discussion: The first description and illustration make Bronn (1835) the author of *Cyrtocera depressa*. Its broad, exogastric coiling and shell form has nothing in common with *Cyrthoceratites flexuosus*; both do not belong to the same nautiloid families and, perhaps, not even to the same order (see above). A second specimen was described and figured by d'Archiac and de Verneuil (1842) and named as “*Cyrthoceratites depressus* Goldf. Bronn”. Much later, Hyatt (1884) selected *Cyrtocera depressa* as the type-species of his new genus *Cranoceras*, which is the valid name for the large-sized Middle Devonian oncoceratids of the Eifel and eastern Rhenish Massif (e.g. Holzapfel 1895; Paeckelmann 1922). Subsequent designations of *Cyrtocera depressa* as type-species of *Cyrthoceratites* d'Archiac and de Verneuil, 1842 by Flower (1950) and Turner (1962) are irrelevant since that name is invalid (see above).

Placing of *Cranoceras* in the family Nothoceratidae Fischer, 1882 (Teichert et al. 1964) is not followed since that family comprises rather heterogeneous forms with cyrtobreviconic to torticonic and even slightly convolute (the type-genus) coiling. Therefore, we accept the Cranoceratidae Shimanskiy, 1956 for cyrtobreviconic and exogastric taxa with continuous actinosiphonate lamellae (see description in Foerste 1929). The closest related genus within the same family seems to be the Middle Devonian *Turnoceras* Foerste, 1926.

A *Cranoceras subdepressum* from Dingdorf in the Eifel Mountains (GMM B6C.57.2, Münster teaching collection) is illustrated as a new Rhenish record in Fig. 3. The species is closely related to *Cranoceras depressum* but lacks a dorsal keel and depressions. The middle Givetian to upper Frasnian *Cranoceras alatum* develops wing-like lateral extensions at maturity, while the Frasnian *Cranoceras wallersheimensis* is much

thinner, only weakly depressed. To some extent, it resembles the problematical, densely septate *Orthoceratites nautiloides* Steininger, 1831, illustrated later by Steininger (1833).

Geographic distribution: Rhenish Massif, Harz Mountains, Thuringia (Müller 1956, p. 21), Germany.

Stratigraphic range: Middle Devonian and Frasnian.

Order Discosorida Flower in Flower and Kummel (1950), nom. transl.

Family Entimoceratidae Zhuravleva, 1972

Genus *Binoleniceras* n. gen.

Derivation of name: After the type locality of the type-species.

Type species: *Binoleniceras stichlingi* n. sp. (monotypic).

Diagnosis: Orthobreviconic Discosorida with the largest diameter just before the living chamber. Phragmocone with subcircular cross-section, rapidly expanding, first with an apical angle of 42°, becoming smaller in the youngest four chambers. Lateral profile adapically straight on all sides, increasingly convex towards the living chamber. Sutures straight, septa short (KL/Dm2 around 0.10), with strong curvature between one and two times the chamber length, and with absolute chamber length increasing ontogenetically. Inner mould shows weak, dense longitudinal ridges that are narrower than the spaces between them. Siphuncle almost marginal (SAB/Dm2 = 0.03–0.06), narrow (SiphDm2-L/Dm2 = 0.13–0.10), with circular cross-section, and with ontogenetic relative size decrease while the distance to the margin increases slightly. Connecting rings inflated, strongly thickened, especially near the septa, with maximum width on both sides near the posterior end of chambers, more convex dorsally than ventrally, giving a sack-like shape. Septal necks very short, suborthochoanitic ventrally, recumbent cyrtchoanitic dorsally, covered by rounded adapical thickenings (bulletes); with irregular, short radial lamellae restricted to septal perforations.

Discussion: The thickened connecting rings of the siphuncular segments and the thickenings around the septal necks (bulletes) identify our new genus as a member of the Discosorida. The irregular and restricted endosiphonal lamellae are less typical for the order. Due to the short, dorsally and ventrally different septal necks, we assign *Binoleniceras* n. gen. with some reservation to the Entimoceratidae. The family-level systematics of the Discosorida requires revision, which is beyond the scope of this contribution.

The combination of a very large adapical angle, subcircular cross-section, the distinctive shape of the siphuncular segments, and an almost marginal siphuncle have not been described in any other genus of the order. In the strongly inflated, superficially similar *Raphanites* Zhuravleva, 1972 (Taxyceratidae) from the Frasnian of the Timan, the siphuncular segments do not constrict adorally or widen adapically, are not sack-shaped, but stay subparallel. The

siphuncle cross-section is ellipsoidal to trapezoidal, not circular, as in *Binoleniceras* n. gen. The dorsal siphuncular necks of *Raphanites* are only slightly recumbent and bulletes seem to be lacking or are very small on the ventral side (Zhuravleva 1972, pl. V, fig. 3b). The siphuncular opening is wider, with no evidence of irregular lamellae. The maximum conch diameter lies in the posterior body chamber, not within the phragmocone. Among *Pachtocheras* Foerste, 1926 from Russia (supposed Taxyceratidae in Zhuravleva 1972), a high apical angle is proven for *P. asiaticum* Zhuravleva, 1972. The genus differs in its more regular actinosiphonate lamellae, recumbent septal necks on both sides, and the lack of surrounding thickenings, which question discosorid affinities (see different systematic position in Pohle and Klug 2018). In the *Pachtocheras* type-species, the siphuncle is much more distant from the venter than in our Binolen form.

Carotites Zhuravleva, 1972 (Ukhtoceratidae) from the Karaganda Basin of Kazakhstan lacks longitudinal lirae, is slender, with a lower apical angle of the phragmocone, and the shape of the connecting rings is different, more elongate, lacking traces of endosiphuncular lamellae. *Comaroceras* Zhuravleva, 1972 (Ukhtoceratidae) possesses a constricted anterior phragmocone and distinctly narrower, almost non-convex siphuncular segments. *Mjandymoceras* Zhuravleva, 1972 (Entimoceratidae) from the Urals has a much lower apical angle, a narrower siphuncle, which is located further away from the shell wall, weakly constricted, thinner connecting rings, and a larger septal perforation. The type-species of *Stagonites* Zhuravleva, 1972 (Entimoceratidae) from the Timan is smaller-sized, also has a much lower adapical angle, and thinner, not constricted connecting rings. The small-sized *Jaregoceras* Zhuravleva, 1972 (Entimoceratidae) from the Timan has a flattened dorsum, lower adapical angle, less constricted connecting rings, and lacks longitudinal ornament. *Kitatites* Zhuravleva, 1972 (Entimoceratidae) from the Devonian of the Kuzbass is a more similar genus, sharing with *Binoleniceras* n. gen. an inflated phragmocone with high apical angle, and irregular endosiphuncular structures. It differs in more symmetrically constricted connecting rings, the lack of bulletes, and weaker septal curvature. In many of the mentioned genera, thickenings (bulletes) around the septal necks are insufficiently documented.

Stratigraphical and geographical range: Restricted to the lower Givetian of the Rhenish Massif.

Binoleniceras stichlingi n. gen. n. sp.
(Figs. 5a–g, Table 2)

Type: Holotype GMM B6C.57.1, Geomuseum, Westfälische Wilhelms-Universität Münster.

Derivation of name: After Sören Stichling, Geological Survey of NRW (Krefeld), who collected the specimen.

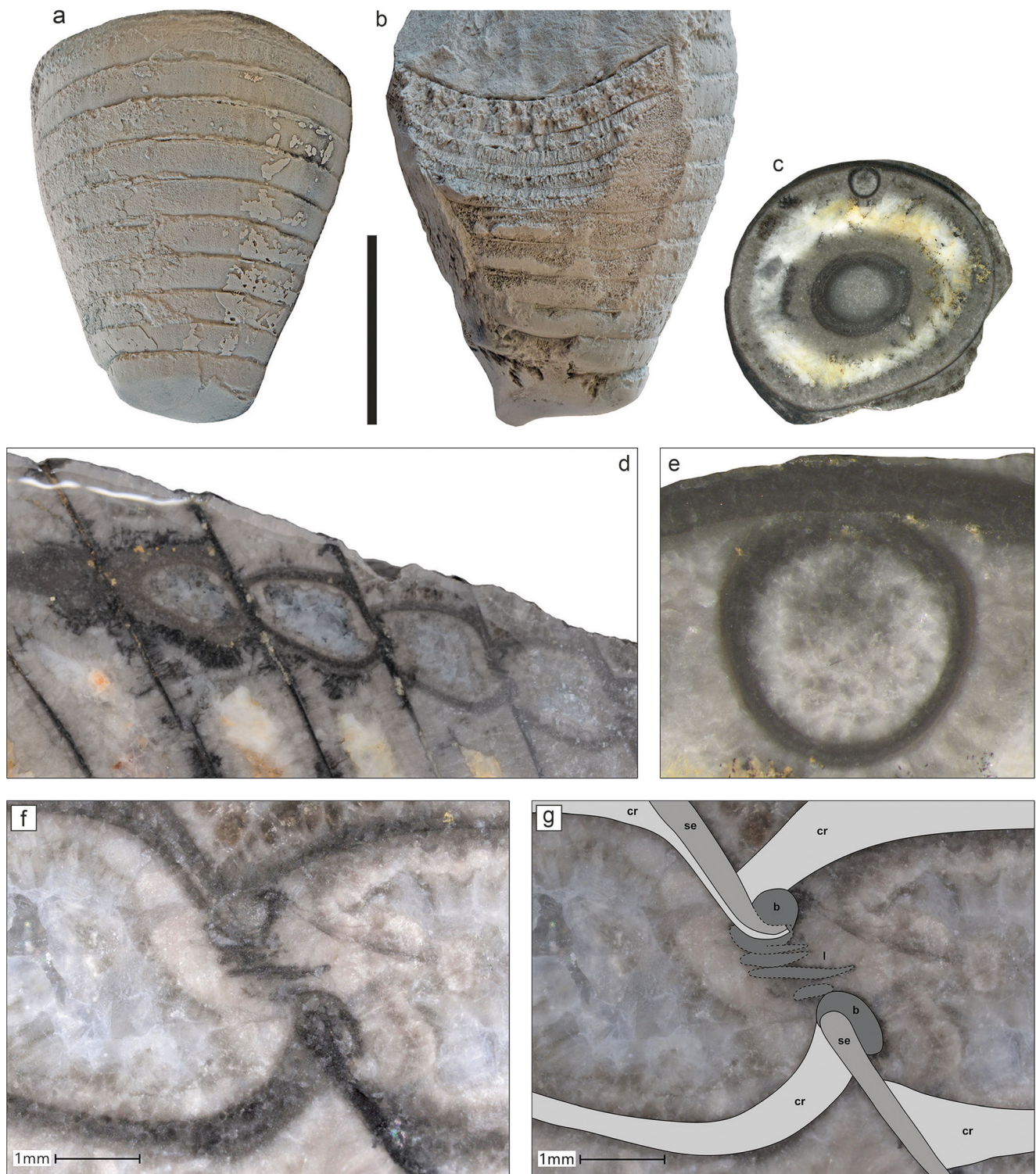
Fig. 5 *Binoleniceras stichlingi* n. gen. n. sp., holotype (GMM B6C.57.1), from the Binolen forest track section along the western slope of the Hönne Valley, northern Sauerland; figs. a–c x 1, with scale bar = 3 cm. **a** ventral (siphuncular) side showing dense longitudinal lirae and the rapid conch expansion (surrounding matrix removed digitally). **b** lateral view showing the strong septal curvature. **c** somewhat distorted subcircular apical cross-section at Dm2 = 31.5 mm, showing the almost marginal position of the circular siphuncle. **d** longitudinal section through the siphuncle, with its maximum width near the posterior end of Chamber 2; length of photo = 30 mm. **e** details of the siphuncle cross-section (diameter = 3.9 mm), showing the ventrally more prominent thickening of the connecting rings. **f** details of siphuncular structures at Dm2 = 39 mm showing the adapically and adorally increasingly thickened connecting rings, very short septal necks, covered apically by subspherical thickenings (bulletes), and longitudinal, irregular lamellae in the siphuncular opening. **g** drawing of the siphuncular structures based on the same chamber, with cr = connecting rings (recumbent style of dorsal part not recognisable due to diagenesis), se = septum, b = bulletes, and l = endosiphuncular lamellae.

Type locality and level: Binolen section, Hönne Valley, GPS 51°22'09.6" N, 7°51'31.1" E, northern Sauerland, Rhenish Massif, Germany, Bed 26, lower Givetian, probably *Polygnathus timorensis* Zone; see Löw et al. (2022, this issue).

Diagnosis: As for the genus.

Description: The incomplete holotype consists of the base of the living chamber and the last ten chambers of the phragmocone (Fig. 5a). The preserved part of the almost orthobreviconic conch (Fig. 5b) is about 63 mm long and the max. diameter of ca. 62 mm lies at the boundary between the first and second chambers before the living chamber (Fig. 5a). Since the chambers become ontogenetically longer, the holotype was likely not yet fully adult. The phragmocone has a subcircular cross-section (Dm1/Dm2 = 1.01–1.08, Fig. 5c, Table 2). The longitudinal section displays a minor asymmetry of curvature. Prior to the last four chambers, the diameter increases quite rapidly with an apical angle of 42°. Then the conch inflation ends gradually (Figs. 5a–b). In the oldest preserved chambers, the profile is straight on all sides, becoming gently convex on all sides towards the living chamber. As far as visible, the sutures are straight and run transversely. The septa are strongly concave (Fig. 5b), with SC/KL = 1.35–1.73 (Table 2). Their length increases ontogenetically from 4.40 to 7.95 mm (Table 2). Longitudinal ridges are weakly preserved on the inner mould (Fig. 5a), narrower than the interspaces, with a distance of 3.5–4 mm. The shell is not preserved, nor are muscle impressions.

The siphuncle is circular in cross-section (SiphDm1-Q/SiphDm2-Q = 1.02, Fig. 5e) and marginally situated in the older part of the phragmocone, but then it moves slightly away from the venter (increasing SAB/Dm2 from 0.03 up to 0.06, Table 2). The proportional width of the connecting rings decreases ontogenetically (SiphDm2-L/Dm2 from 0.13 down to 0.09, Table 2), while their ratio of length to height increases ontogenetically (KL/SiphDm-L = 0.81 up to 1.46). In longitudinal section, they have a characteristic, asymmetric, sack-like



shape, with rapid constriction adapically and more gradual adorally (Fig. 5d). The septal perforation accounts for 0.08–0.13 of the conch diameter. The connecting rings are thickened, especially near the septa, both adapically and adorally (Figs. 5f–g). The septal necks are very short, suborthochoanitic on the ventral side and probably recumbent cyrtochoanitic on the

dorsal side, as indicated by the slight thickening at the siphuncular termination. Black longitudinal structures are best visible in the septal perforation between the sixth and seventh chamber (Figs. 5f–g) but are also present in other septa (Fig. 5d). They indicate irregular, endosiphuncular, radial lamellae at the septal perforation. Annulate thickenings (bulletetes) surround

Table 2 Morphometric data (absolute values in mm) for the holotype of *Binoleniceras stichlingi* n. gen. n. sp., with septa numbering starting backwards from the living chamber. Dm1 = max. diameter in cross-section, Dm2 = min. diameter in cross-section (= diameter in longitudinal

section), Kl = chamber length, SAB = distance of siphuncle from margin, SC = septal curvature (distance of adapical point of septum from the plane of the septal margin). The max. and min diameter of the siphuncle were measured only in a single cross-section (see Fig. 5c).

	Dm1	Dm2	Dm1/ Dm2	Kl	Kl/ Dm1	Kl/ Dm2	SAB	SAB/ Dm2	Siph Dm2	SiphDm 2/Dm2	KL/ SiphDm2	SC	SC/ KL
Sep1	60.52	57.53	1.07	7.95	0.13	0.14	3.02	0.05	5.44	0.09	1.46	10.70	1.35
Sep2	61.90	56.58	1.08	6.92	0.11	0.12	3.57	0.06	5.89	0.10	1.17--	10.97	1.59
Sep3	60.04	57.42	1.07	6.16	0.10	0.10	--	--	--	--		10.68	1.73
Sep4	57.38	53.15	1.08	5.69	0.10	0.11	2.42	0.05	4.93	0.09	1.15	9.16	1.61
Sep5	52.38	49.10	1.07	5.23	0.10	0.11	1.65	0.03	5.32	0.11	0.98	8.44	1.61
Sep6	47.26	44.33	1.07	5.17	0.11	0.12	1.33	0.03	5.61	0.13	0.92	7.42	1.44
Sep7	42.58	40.47	1.05	4.40	0.10	0.11	1.40	0.03	5.40	0.13	0.81	6.38	1.45
Sep8	37.12	36.66	1.01	4.92	0.13	0.13	--	--	--	--	--	--	--

the adapical ends of the septal necks (Figs. 5f–g). Only ventrally, they are in contact with the adoral connecting ring of the previous chamber.

Discussion: No identical species has been described among the Rhenish nautiloids. The only previously described Givetian discosorid, *Alpenoceras eifliense* (Schindewolf, 1942), is cyrtobreviconic. “*Gomphoceras verneuili*” Holzapfel, 1895 (non Barrande, 1865), a nom. nov. introduced for *Orthoceratites subpyriformis* d’Archiac and de Verneuil, 1842 (non Münster, 1840), differs by its extremely enlarged, egg-shaped living chamber, with a maximum diameter closer to the aperture than to the phragmocone end. Unfortunately, Holzapfel’s new name was a homonym and, therefore, this unique form still lacks a valid name. A revision and re-naming is currently impossible since the fate of the type specimen is unknown and since no topotype is known from Bergisch Gladbach-Paffrath.

Concerning other Rhenish orthobrevicones, the poorly known “*Orthoceratites inflatus*” Quenstedt, 1840 from the Eifel Mountains, which was later figured in Quenstedt (1846–49), is a small-sized species without longitudinal lirae. According to a more complete specimen figured in Roemer (1876: pl. 30, figs. 6a–b), the apical angle of the posterior phragmocone is very high (ca. 40°), similar as in the Binolen form, but the cross-section is strongly depressed, not subcircular. The generic affiliation remains dubious. Quenstedt’s type is probably lost, which is also true for most of the C. F. Roemer collection at Breslau (now Wrocław).

In the absence of any illustration, the short description of “*Gomphoceratites crenulatus*” Steininger, 1853 is insufficient to characterise a species; the taxon is a nom. dub. The species name referred to the band of muscle scars at the base of the body chamber, as it is typical in many oncoceratids or discosorids. The fate of the type specimen, said to be from the Eifel collection of Schnur, is unclear; some Schnur material is

housed in the Goldfuß Museum at Bonn University. The only nautiloid of Steininger (1853) that made it into the Berlin collection is “*Cyrtoceceras belgicus*” (see Dienst 1928, p. 102).

Two further orthobreviconic species from the middle Givetian of Villmar were named in Sandberger and Sandberger (1850–56). “*Cyrtoceceras applanatus*” is a very slender form with a slight constriction near the base of the body chamber. The syntypes are preserved in the Natural History State Collection of the Museum Wiesbaden (Schöndorf 1908; museum homepage at www.mwnh.de/samm031.html). “*Cyrtoceceras subconicus*” is based on a short fragment with high apical angle (ca. 30°), subcircular cross-section, very weak, widely spaced longitudinal lirae on the mould, and a submarginal siphuncle. It differs strictly from *Binoleniceras stichlingi* n. gen. n. sp. because of its almost flat, not curved septa. But since the type has been lost (Schöndorf 1908), the species is currently a nom. dub. of unclear generic affinity.

There are some similarities of *Binoleniceras stichlingi* n. gen. n. sp. with *Pachtoceras? laghdadense* Pohle and Klug, 2018 from the upper Givetian of southern Morocco, especially with respect to the presence of irregular endosiphuncular spines and the high apical angle of the phragmocone. However, the Moroccan species has recumbent septal necks on both sides, as typical for *Pachtoceras*, the connecting rings are more cylindrical, and bulletes are not mentioned or recognisable in the published longitudinal section.

Stratigraphical and geographical range: Restricted to the type locality and level.

Acknowledgements The specimen dedicated to Sören Stichling was casted and sectioned by the WWU Münster preparation team under the lead of Rike Zimmermann. Mieke Löw and Till Söte (both also WWU Münster) provided bio- and microfacies details. Dieter Weyer (Berlin) assisted to trace originals in the collection of the Museum für Naturkunde in Berlin. Arthur Fugmann (WWU Münster) translated some

Russian texts. We appreciate the careful reviews by Štěpán Manda (Praha) and an anonymous reviewer.

Funding Open Access funding enabled and organized by Projekt DEAL. Field work of S. Stichling, who collected the specimen, and conodont sampling were funded within the Hönn Valley research project funded by the Lhoist Germany Rheinkalk GmbH.

Declarations

Conflicts of interest The authors declare that they have no conflict of interest.

Data Availability Statement All data generated during or analysed during the current study are included in this published article.

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References

- d'Archiac, V., & de Verneuil, M. E. (1842). On the Fossils of the Older Deposits in the Rhenish Provinces; preceded by a general Survey of the Fauna of the Palaeozoic Rocks, and followed by a Tabular List of the Organic Remains of the Devonian System in Europe. *Transactions of the geological Society of London, Serie 2, 6*, 303–410, pls. 25–38.
- Barrande, J. (1865). *Système silurien du Centre de la Bohême, 1^{ère} partie: Recherches Paléontologiques, vol. II, Classe de Mollusques, Ordre des Céphalopodes*. Serie 6, pls. 1–107. Prague, Paris.
- Becker, R. T., Aboussalam, Z. S., Stichling, S., May, A., & Eichholt, S. (2016). The Givetian-Frasnian Hönn Valley Reef Complex (northern Sauerland) – an outline of stratigraphy and facies development. *Münstersche Forschungen zur Geologie und Paläontologie, 108*, 126–140.
- Brauckmann, C., & Koch, L. (1994). Fossilien aus dem Schwelmer Kalk. V. Nautiliden und Bactriten. *Beiträge zur Heimatkunde der Stadt Schwelm und ihrer Umgebung, Neue Folge, 44*, 17–27.
- Braun, R., Oetken, S., Königshof, P., Komder, L., & Wehrmann, A. (1994). Development and biofacies of reef-influenced carbonates (Central Lahn Syncline, Rheinisches Schiefergebirge). *Courier Forschungsinstitut Senckenberg, 169*, 351–386.
- Bronn, H. G. (1834-37). *Lethaea geognostica oder Abbildung und Beschreibung der für die Gebirgs-Formationen bezeichnensten Versteinerungen. Erster Band, das Übergangs- bis Oolithen-Gebirge enthaltend* (pp. 1–544, pls. 1–47). Stuttgart: Schweizerbart [pp. 9–192 published in 1835].
- Clausen, C.-D., & Hauser, J. (2005). Cyro- and orthocone Nautiloideen aus dem Oberdevon der Wallersheimer Mulde (Wallersheim/Loch, Prümer Mulde; Eifel). *Senckenbergiana lethaea, 85*(1), 63–79.
- Crick, R. E., & Teichert, C. (1979). Siphuncular structures in the Devonian nautiloid *Archiacoceras* from the Eifel of West Germany. *Palaeontology, 22*(4), 98–101.
- Dechen, H., von (1832). *Handbuch der Geognosie von H. T. De La Beche. Nach der zweiten Auflage des Engl. Originals bearbeitet* (pp. 1–612). Berlin: Duncker und Humblot.
- Dienst, P. (1928). *Zusammenstellung der im Geologischen Landesmuseum zu Berlin aufbewahrten Originale. I. Paläozoologischer Teil* (pp. 1–33). Berlin: Preußische Geologische Landesanstalt.
- Fischer, P. (1880–87). *Manuel de Conchyliologie et de Paléontologie conchyliologique* (pp. 1–896). Paris: Savy.
- Flower, R. H. (1950). *Stereotoceras* and the Brevioceratidae. *Palaeontographica Americana, 3*(24), 1–36, pls. 1–6.
- Flower, R. H., & Kummel, B. (1950). A classification of Nautiloidea. *Journal of Paleontology, 24*, 604–616.
- Foerste, A. F. (1926). Actinosiphonate, Trochoceroide and other cephalopods. *Bulletin of the Scientific Laboratories of Denison University, 21*, 285–384.
- Foerste, A. F. (1929). Three Studies of Cephalopods. *Denison University Bulletin, Journal of the Scientific Laboratories, 24*, 265–381, pls. 41–53.
- Fuchs, G. (1965). Geologie des Westteils der Hillesheimer Mulde (Mitteldevon, Eifel). *Fortschritte in der Geologie von Rheinland und Westfalen, 9*, 323–448.
- Greene, G. K. (1898-1904). *Contribution to Indiana Palaeontology, Vol. I, Part I to XX*. (pp. 1–204, 60 pls.) New Albany: Wing & Zeller [part 7 published in 1901].
- Hartkopf-Fröder, C., & Weber, H. M. (2016). From Emsian coastal to Famennian marine environments: palaeogeographic evolution and biofacies in the Bergisch Gladbach-Paffrath Syncline area (Rhenish Massif, Germany). *Münstersche Forschungen zur Geologie und Paläontologie, 108*, 46–75.
- Hoeninghaus, F. W. (1830). Versuch einer geognostischen Eintheilung seiner Versteinerung-Sammlung, nach Berathung der Herren Brongniart, Goldfuss, Bronn, Cordier, Hausmann, von Leonhard, Noeggerath und Delabéche's Karte. Erster Theil. *Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefaktenkunde, 1830*, 228–244.
- Holzappel, E. (1895). Das Obere Mitteldevon (Schichten mit *Stringocephalus Burtini* und *Maeneceras terebratum*) im Rheinischen Gebirge. *Abhandlungen der Königlich Preussischen Geologischen Landesanstalt, Neue Folge, 16*, 1–459, atlas with 16 pls.
- Hoppe, G. (2001). Zur Geschichte der Geowissenschaften im Museum für Naturkunde zu Berlin, Teil 4: Das Mineralogische Museum der Universität Berlin unter Christian Samuel Weiss von 1810 bis 1856. *Mitteilungen aus dem Museum für Naturkunde in Berlin, Geowissenschaftliche Reihe, 4*, 3–27.
- Hyatt, A. (1883–84). Genera of fossil cephalopods. *Proceedings of the Boston Society of Natural History, 22*, 253–338.
- Kayser, E. (1872). Studien aus dem rheinischen Devon. III. Die Fauna des Rotheistensteins von Brilon in Westfalen. *Zeitschrift der Deutschen Geologischen Gesellschaft, 24*, 653–690, pls. 25–27.
- Klapper, G., & Barrick, J. E. (1983). Middle Devonian (Eifelian) conodonts from the Spillville Formation in northern Iowa and southern Minnesota. *Journal of Paleontology, 57*(6), 1212–1243.
- Koch, L., Voigt, S., & Bruckmann, C. (2018). Nautiliden aus der Kluterthöhle (Ennepetal, Nordrhein-Westfalen), aus benachbarten Höhlen und weiteren Fundorten in Oberen Honsel-Schichten (Unter-Givetium). *Geologie und Paläontologie in Westfalen, 90*, 15–24.
- Königshof, P. (2007). Mittel- bis oberdevonische Riffkarbonate in der Lahnmulde (südliches Rheinisches Schiefergebirge) (Exkursion H am 13. April 2007). *Jahresberichte und Mitteilungen des oberrheinischen geologischen Vereins, Neue Folge, 89*, 261–272.

- Königshof, P., Helling, S., Hartenfels, S., De Vleeschouwer, D., Schreiber, G., Becker, R. T., & Brett, C. E. (2016). Eifel Synclines – an overview and Emsian to Frasnian section descriptions. *Münstersche Forschungen zur Geologie und Paläontologie*, 108, 36–45.
- Kröger, B., Zhang, Y.-B., & Isakar, M. (2009). Discosorids and Oncocerids (Cephalopoda) of the Middle Ordovician Kunda and Aseri Regional Stages of Baltoscandia and the early evolution of these groups. *Geobios*, 42, 273–292.
- Löw, M., Söte, T., Becker, R. T., Stichling, S., May, A., Aboussalam, Z. S., & Zoppe, S. F. (2022). The initial phase of the Hönne Valley Reef at Binolen (northern Rhenish Massif, Middle Devonian). In S. Hartenfels, C. Hartkopf-Fröder, & P. Königshof (Eds.), *The Rhenish Massif: More than 150 years of research in a Variscan mountain chain. Palaeobiodiversity and Palaeoenvironments* 102(3) <https://doi.org/10.1007/s12549-022-00540-4>. [this issue]
- Lotze, F. (1928). Das Mitteldevon des Wennetales nördlich der Elspur Mulde. *Abhandlungen der Preußischen Geologischen Landesanstalt, Neue Folge*, 104, 1–104, pls. 1–2.
- Manda, S., & Turek, V. (2009). Revision of the Pragian Rutoceratoidea Hyatt, 1884 (Nautiloidea, Oncocerida) from the Prague Basin. *Bulletin of Geosciences*, 84(1), 127–148.
- May, A. (1987). Der Massenkalk (Devon) nördlich von Brilon (Sauerland). *Geologie und Paläontologie in Westfalen*, 10, 51–84.
- May, A. (1988). Fossilführung und Palökologie des lagunären Massenkalkes (Devon) im Sauerland (Rheinisches Schiefergebirge). *Paläontologische Zeitschrift*, 62(3/4), 175–192.
- May, A. (2003). Die Fossilführung des Mitteldevons im Raum Attendorn-Olpe (West-Sauerland; Rechtsrheinisches Schiefergebirge). *Geologie und Paläontologie in Westfalen*, 60, 47–79.
- Müller, K. J. (1956). Cephalopodenfauna und Stratigraphie des Oberdevons von Schleiz und Zeulenroda in Thüringen. *Beihefte zum Geologischen Jahrbuch*, 20, 1–93, 2 pls.
- Münster, G. Graf zu (1840). Die Versteinerungen des Uebergangskalkes mit Clymenien und Orthoceratiten von Oberfranken. *Beiträge zur Petrefactenkunde*, 3, 33–121, pls. 5–20.
- Mutvei, H. (2013). Characterization of nautiloid orders Ellesmerocerida, Oncocerida, Tarphycerida, Discosorida and Ascocerida: new super-order Multiceratoidea. *GFF*, 135(2), 171–183.
- Paeckelmann, W. (1913). Das Oberdevon des Bergischen Landes. *Abhandlungen der Königlich Preußischen Geologischen Landesanstalt, Neue Folge*, 70, 1–356, pls. 1–7.
- Paeckelmann, W. (1922). Der mitteldevonische Massenkalk des Bergischen Landes. *Abhandlungen der Preußischen Geologischen Landesanstalt, Neue Folge*, 91, 1–111, 1 pl.
- Phillips, J. (1841). *Figures and descriptions of the Palaeozoic fossils of Cornwall, Devon, and west Somerset* (pp. 1–231). London: Geological Survey of Great Britain and Ireland.
- Pohle, A., & Klug, C. (2018). Early and Middle Devonian cephalopods from Hamar Laghdad (Tafilalt, Morocco) and remarks on epicoles and cameral deposits. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 290(1/3), 203–240.
- Quenstedt, F. A. (1840). Über die vorzüglichsten Kennzeichen der Nautilen. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefacten-Kunde*, 1840, 253–291, figs. 1–7.
- Quenstedt, D. A. (1846–49). *Petrefactenkunde Deutschlands. Der ersten Abtheilung erster Band. Die Cephalopoden*. (pp. 1–580, pls. 1–36) Tübingen: Ludwig Friedrich Fuchs.
- Roemer, C. F. (1844). *Das Rheinische Uebergangsgebirge. Eine palaeontologisch-geognostische Darstellung* (pp. 1–96, pls. 1–6). Hannover: Hahn'sche Hofbuchhandlung.
- Roemer, C. F. (1876). *Lethaeae geognostica, oder Beschreibung und Abbildung der für die einzelnen Abtheilungen der palaeozoischen Formationen bezeichnensten Versteinerungen, Teil 1*. (pls. 1–62) Stuttgart: Schweizerbart.
- Roemer, F. A. (1843). *Die Versteinerungen des Harzgebirges* (pp. I–XX, 1–40, pls. 1–12). Hannover: Hahn.
- Roemer, F. A. (1850). Beiträge zur geologischen Kenntniss des nordwestlichen Harzgebirges. *Palaeontographica*, 3, 1–69, pls. 1–10.
- Ruzhentsev, V. E., Zhuravleva, F. A., Balashov, Z. G., Bogoslovskiy, B. I., and Librovič, L. S. (1962). Molyuski, Golovonogie I, Nautiloidei, Endoceratoidei, Actinoceratoidei, Bactritoidei, Ammonoidei. In Orlov, Y. A. (Ed.), *Osnovy Peleontologii* (pp. 1–438, pls. 1–89). Moskva: Akademii Nauk SSSR.
- Sandberger, F. (1845). Kurze Bemerkungen zu der Schrift von F. A. Roemer: „die Versteinerungen des Harz-Gebirges, mit XII Steindruck-Tafeln. Hannover 1843“. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefacten-Kunde*, 1845, 421–440.
- Sandberger, G. (1842). Vorläufige Übersicht über die eigenthümlichen bei Villmar an der Lahn auftretenden jüngeren Kalk-Schichten der älteren (sog. Uebergangs-) Formation, besonders nach ihren organischen Einschlüssen, und Beschreibung ihrer wesentlichsten neuen Arten; nebst einem Vorwort über Namensgebung in der Naturbeschreibung überhaupt und in der Paläontologie insbesondere. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefactenkunde*, 1842, 379–402.
- Sandberger, G., & Sandberger, F. (1850–56). *Die Versteinerungen des rheinischen Schichtensystems in Nassau. Mit einer kurzgefassten Geognosie dieses Gebietes und mit steter Berücksichtigung analoger Schichten anderer Länder* (pp. I–XIV, 1–564, pls. 1–41). Wiesbaden: Kreidel Verlag.
- Schindewolf, O. H. (1942). Discosoriden (Cephal., Nautil.) im deutschen Devon. *Jahrbuch des Reichsamts für Bodenforschung*, 62(for 1941), 499–533, pls. 34–42.
- Schlothheim, E. F., Baron von (1820). *Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteineter und fossiler Überreste des Thier- und Pflanzenreiches der Vorwelt erläutert*. (pp. 1–436, pls. 1–15). Gotha: Becker'sche Buchhandlung.
- Schlothheim, E. F., Baron von (1822). *Nachträge zur Petrefactenkunde* (pp. 1–100, pls. 1–21). Gotha: Becker'sche Buchhandlung.
- Schöndorf, F. (1908). Verzeichnis der im Naturhistorischen Museum zu Wiesbaden befindlichen Originale. Abteilung für Geologie und Paläontologie. 2. Originale zu G. et F. Sandberger, Die Versteinerungen des rheinischen Schichtensystems in Nassau, Wiesbaden 1850-1856. *Jahrbücher des Nassauischen Vereins für Naturkunde in Wiesbaden*, 61, 41–71.
- Shimanskiy, V. N. (1956). *Problemi i zadachi i paleontologicheskikh issledovaniy konspekt lektzii* (pp. 1–95) Moskva: Academia Nauk SSSR.
- Sowerby, J. (1812–1814). *The mineral conchology of Great Britain; or, coloured figures and descriptions of those remains of testaceous animals or shells, which have been preserved at various times and depth in the Earth. Volume 1*. (pp. I–VII, 1–236, pls. 1–102) London: Benjamin Meredith.
- Steininger, J. (1831). *Bemerkungen über die Versteinerungen, welche in dem Uebergangskalkgebirge der Eifel gefunden werden*. (pp. 1–44). Trier: Blattau'schen Buchdruckerei.
- Steininger, J. (1833). Observations sur les fossils du Calcaire Intermédiaire de l'Eifel. *Memoires de la Société géologique de la France, 1e série*, 1, 331–372.
- Steininger, J. (1853). *Geognostische Beschreibung der Eifel* (pp. 1–143, pls. 1–10). Trier: Lintz'sche Buchhandlung.
- Teichert, C. (1939). Nautiloid cephalopods from Devonian of Western Australia. *Journal of the Royal Society of Western Australia*, 25, 103–121.

- Teichert, C., Kummel, B., Sweet, W. C., Stenzel, H. B., Furnish, W. M., Glenister, B. F., Erben, H. K., Moore, R. C., & Nodine Zeller, D. E. (1964). Cephalopoda – general features, Endoceratoidea – Actinoceratoidea – Nautiloidea – Bactritoidea. In R. C. Moore (Ed.), *Treatise on Invertebrate Paleontology, Part K, Mollusca 3* (pp. 1–519). Lawrence: The University of Kansas Press.
- Torley, K. (1908). Die Fauna des Schleddenhofes bei Iserlohn. *Abhandlungen der Königlich Preußischen Geologischen Landesanstalt, Neue Folge*, 53, 1–56, pls. 1–10.
- Turek, J. (1976). Genus *Alpenoceras* Foerste, 1927 (Nautiloidea, Discosorida) from the Devonian of Čelechovice. *Věstník Ústředního ústavu geologického*, 51, 347–355.
- Turner, J. S. (1962). The type-species of *Aganides*, *Clymenia*, and *Cyrthoceratites*. *Geological Magazine*, 99(2), 183–184.
- Zhuravleva, F. A. (1972). Devonskie Nautiloidei. Otriad Discosorida. *Trudy Paleontologicheskogo Instituta, Academia Nauk SSSR*, 142, 1–320, pls. 1–37.
- Zhuravleva, F. A. (1974a). Devonskie Nautiloidei. Otriadiy Oncoceratida, Tarphyceratida, Nautilida. *Trudy Paleontologicheskogo Instituta, Academia Nauk SSSR*, 142, 1–159, pls. 1–27.
- Zhuravleva, F. A. (1974b). Order Discosorida, Order Oncoceratida. In V. E. Ruzhentsev (Ed.), *Fundamentals of Paleontology (Osnovy paleontologii)*, Vol V, *Mollusca – Cephalopoda I, Translation from Russian* (pp. 124–159). Jerusalem: Keter Press.

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