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

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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 cyrtochoanitic (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 The regional knowledge is poor and mostly outdated, which hampers significantly the reconstruction of regional ecosystem and palaeodiversity changes.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.

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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 Pseudorthoceratida), 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 = Acromichelinoceras commutatum (Giebel, 1852)

“Orthoceras” planisectatum Sandberger and Sandberger, 1856

“Orthoceras” arcuatum Sandberger and Sandberger, 1856

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

“Orthoceras” simplicissimum Sandberger and Sandberger, 1856

“Orthoceras calamineus” 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” angulisferum (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 lirate, as in Plagiostomoceras)

orthocones with reticulate ornament:

“Orthoceras” clathratum Sandberger and Sandberger, 1856

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

ortho breviconic 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 (Broml, 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)
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 Aphyctoceras acustocostatum (Sandberger and Sandberger, 1856), the orthobreviconic “Gomphoceras verneuili” 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

Table 1 (continued)

| Family                      | Genus and Species                                      |
|-----------------------------|--------------------------------------------------------|
| Ptenoceratidae              | Pleuroarctoceras nosophorum (Bronn, 1835)              |
|                             | Pleuroarctoceras sp. (including Hortolus convolvans sensu Steininger 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.                |

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 Wuppental-Donap, Es Eskesberg and Wuppental-Dorp, Kl 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 Dorf 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 Hofernühle (Velbert Anticline, Fig. 1), Dorp, and Dormap-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 ?*Protobacitrites cf. pulchellus* (Roemer, 1850). The record of Oncoceratoidea includes *Cranoceras depressum* (Bonn, 1835), “*Gomphoceras penneuli*”, 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 multinodule ornament, which is lacking in the densely frilled, cyrtoconic *Rutoceras* (compare the separate genus recognition in Manda and Turek 2009) as well as in the frilled, gyroconic *Goldringia*. *Aphtyceratites* has strongly reticulate ornament with rursiradiate ribs but without nodes/tubercles, e.g. in the middle Givetian *Aphe. frechi* (Holzapfel, 1895) and *Aphe. 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 probatbactrit or bacitrid 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 “*Cyrtoceratites sp.*” and *C. depressus*. They also documented nautiloids from the Steltenberg Reef of Hagen-Hohenlimburg (Fig. 1), which yielded a densely septate longirothcone, 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 cyrtocones (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 orthococone (*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 *Oenonites* 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.

\[\text{Dm1} = \text{max. diameter of conch}, \text{Dm2} = \text{min. diameter of conch}, \text{KL} = \text{length of chambers}, \text{SAB} = \text{distance of siphuncle from conch margin}, \text{SiphDm1-Q} = \text{max. diameter of siphuncle in cross section}, \text{SiphDm2-Q} = \text{min. diameter of siphuncle in cross section}, \text{SC} = \text{septal curvature in longitudinal section}, \text{PerfDm} = \text{width of septal perforation in longitudinal section}, \text{Dm1} = \text{max. diameter of conch}, \text{Dm2} = \text{min. diameter of conch}, \text{KL} = \text{length of chambers}, \text{SAB} = \text{distance of siphuncle from conch margin}, \text{SiphDm1-Q} = \text{max. diameter of siphuncle in cross section}, \text{SiphDm2-Q} = \text{min. diameter of siphuncle in cross section}, \text{SC} = \text{septal curvature in longitudinal section}, \text{PerfDm} = \text{width of septal perforation in longitudinal section}.\]

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 authorship 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.

*Cyrhoceratites* Goldfuss in Hoeninghaus, 1830

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

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

**Discussion:** As obvious from the Treatise (Teichert et al. 1964), a genus *Cyrtocera* 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 *Cyrhoceratites* and *Cyrtoceratites*, 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 *Cyrrocera* was introduced and briefly defined (“Gewundene Orthozeratiten”) 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
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 (“halbmondformig 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.

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.
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)

Cyrtoceeras 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 Cyrtoceeras 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 Cyrtoceeras 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, suborthocoanitic ventrally, recumbent cyrtochoanitic dorsally, covered by rounded adanal thickening (bullets); with irregular, short radial lamellae restricted to septal perforations.

Discussion: The thickened connecting rings of the siphuncular segments and the thickening around the septal necks (bullets) 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 endosal 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 (Taxoceratidae) from the Frasnian of the Timan, the siphuncular segments do not constrict adorally or widen adapically, are not sack-shaped, but stay subparallel. The
Binoleniceras stichlingi n. gen. n. sp. from the Binolen forest track section along the western slope of the Höhne Valley, northern Sauerland; first published in 1972. The specimen, Holotype GMM B6C.57.1, \textit{Geomuseum, Westfälische Wilhelms-Universität Münster.}

\textit{Type:} Holotype GMM B6C.57.1, \textit{Geomuseum, Westfälische Wilhelms-Universität Münster.}

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

\textit{Type locality and level:} Binolen section, Höhne 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 subcircular apical thickening (bulletes), and longitudinal, irregular lamellae in the siphuncular opening. g drawing of the siphuncular structures based on the same chamber, with cr = connecting rings (recurved style of dorsal part not recognisable due to diagenesis), se = septum, b = bulletes, and l = endosiphuncular lamellae.

\textit{Stratigraphical and geographical range:} Restricted to the lower Givetian of the Rhenish Massif.

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

\textit{Type locality and level:} Binolen section, Höhne Valley, GPS 51°22’09.6” N, 7°51’31.1” E, northern Sauerland, Rhenish Massif, Germany, Bed 26, lower Givetian, probably \textit{Polygnathus timorensis} Zone; see Löw et al. (2022, this issue).

\textit{Diagnosis:} As for the genus.

\textit{Description:} The incomplete holotype consists of the base of the living chamber and the last ten chambers of the phragmococone (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 phragmococone 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 phragmococone, 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 (bulletes) 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. und 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 | SiphDm2/2/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 adapical 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 Wroclaw).

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 “Cyrtoceras belgicus” (see Dienst 1928, p. 102).

Two further orthobreviconic species from the middle Givetian of Villmar were named in Sandberger and Sandberger (1850–56). “Cyrtoceras” 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). “Cyrtoceras” 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? laghadense 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.

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**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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