Acta Geologica Polonica, Vol. 65 (2015), No. 4, pp. 495–506
DOI: 10.1515/agp-2015-0021

DE GRUYTER OPEN

Taxonomy and taphonomy of Cenomanian (Upper Cretaceous) nautilids from Annopol, Poland

MARCIN MACHALSKI[1] and MARKUS WILMSEN[2]

[1]*Institute of Paleobiology, Polish Academy of Sciences, ul. Twarda 51/55, PL 00-818 Warszawa, Poland.*
E-mail: mach@twarda.pan.pl
[2]*Senckenberg Naturhistorische Sammlungen Dresden, Museum für Mineralogie und Geologie, Sektion Paläozoologie, Konigsbrücker Landstr. 159, D-01109 Dresden, Germany.*
E-mail: markus.wilmsen@senckenberg.de

ABSTRACT:

Machalski, M. and Wilmsen, M. 2015. Taxonomy and taphonomy of Cenomanian (Upper Cretaceous) nautilds from Annopol, Poland. *Acta Geologica Polonica*, **65** (4), 495–506. Warszawa.

A nautilid faunule of seven specimens, comprising *Eutrephoceras bouchardianum* (d'Orbigny, 1840), *Cymatoceras deslongchampsianum* (d'Orbigny, 1840), and *Cymatoceras tourtiae* (Schlüter, 1876) is described from a condensed middle Cenomanian interval at Annopol, Poland. *C. tourtiae* is recorded for the first time in Poland. The studied material consists of reworked phosphatised internal moulds of phragmocones, which may be of early or middle Cenomanian age, given the stratigraphic range of the associated ammonites. The nautilid moulds vary in inferred mode of infilling, and in intensity of abrasion, bioerosion and mineralisation. The sediment entered the phragmocones in two ways: 1) through punctures in the shell, the result of bioerosion or mechanical damage; 2) through siphonal openings by intracameral currents. In contrast to the fossil moulds from the Albian phosphorites of Annopol, which originated *via* direct precipitation of apatite around and/or inside fossils, the present nautilid moulds seem to have originated through secondary phosphatisation of the initially calcareous moulds. Diversity of taphonomic signatures in nautilid material from the middle Cenomanian interval at Annopol is compatible with the complex, multi-event depositional scenario proposed for this level.

Key words: Nautilids; Condensed deposits; Taphonomy; Cenomanian; Cretaceous; Annopol; Poland.

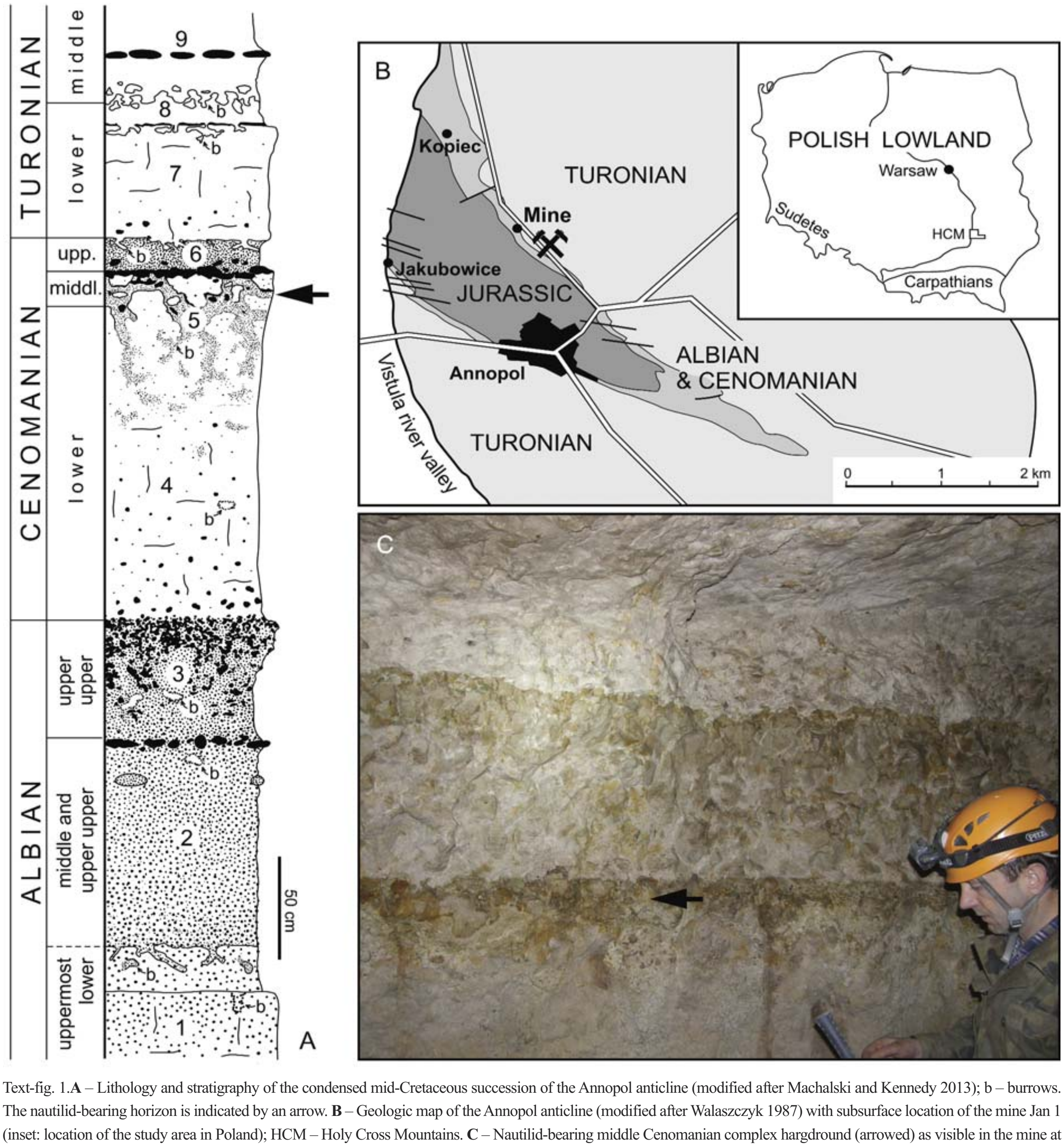
INTRODUCTION

Cretaceous nautiloids are fairly conservative in terms of evolutionary development (bradytelic), morphologically rather poor in characters and commonly long-ranging in their stratigraphic distribution. Modern systematic and stratigraphic studies on mid-Cretaceous taxa in Europe are comparatively rare (e.g., Frank 2010; Frank *et al.* 2013) and there are no recent papers at all on the mid-Cretaceous nautilids from Poland. The latest contributions on this latter subject are those by Cieśliński (1959), who described several Albian and Cenomanian taxa from the northern border of the Holy Cross Mountains, Marcinowski (1970) and Marcinowski and Radwański (1983) who described and/or illustrated specimens of *Eutrephoceras sublaevigatum* (d'Orbigny, 1840) and *Cymatoceras deslongchampsianum* (d'Orbigny, 1840) from the Polish Jura. Additionally, Dzik (1984) figured *Pseudocenoceras archiacianum* (d'Orbigny, 1840) from the lower Cenomanian of the classic Polish Fossil-Lagerstätte at Annopol.

Renewed interest and exploration of the Annopol site resulted recently in a series of papers on various aspects of the mid-Cretaceous palaeontology (Machalski and Kennedy 2013; Machalski and Martill 2013; Popov and Machalski 2014; Machalski and Olszewska-Nejbert 2015; Bardet *et al*. 2015; Fraaije *et al.* 2015; Kapuścińska and Machalski 2015; Kennedy and Machalski 2015). Other studies are in progress. The present note on the taxonomy and taphonomy of a nautilid faunule from a middle Cenomanian at Annopol is another contribution to this project.

GEOLOGIC BACKGROUND

The nautilids studied come from the middle Cenomanian interval of the mid-Cretaceous (uppermost lower Albian–lower Turonian) condensed, phosphorite-bearing succession exposed along the limbs of the Annopol anticline, central Poland (Text-fig. 1A–C). The reader is referred to Machalski and Kennedy (2013) for a more detailed summary of the lithologic development, biostratigraphy and palaeontology of the Annopol succession.



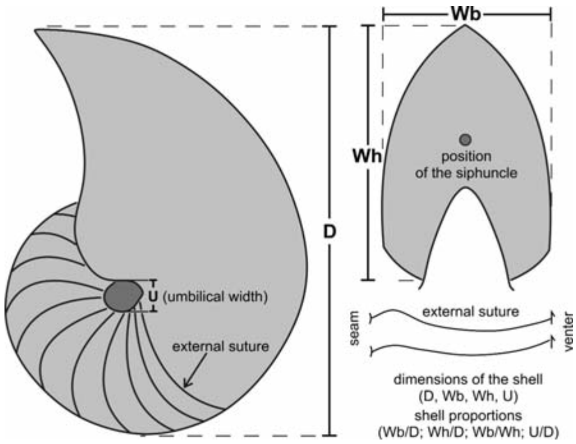
Text-fig. 1.**A** – Lithology and stratigraphy of the condensed mid-Cretaceous succession of the Annopol anticline (modified after Machalski and Kennedy 2013); b – burrows. The nautilid-bearing horizon is indicated by an arrow. **B** – Geologic map of the Annopol anticline (modified after Walaszczyk 1987) with subsurface location of the mine Jan 1 (inset: location of the study area in Poland); HCM – Holy Cross Mountains. **C** – Nautilid-bearing middle Cenomanian complex hargdround (arrowed) as visible in the mine at Annopol. Note that the overlying upper Cenomanian unit 6 (Text-fig. 1A) is reduced almost to zero in the photographed outcrop (present only in places as light green patches)

The nautilid-bearing interval (unit 5 in Text-fig. 1A) is very thin and residual in nature, being restricted to the glauconitic marls infilling large burrows and cavities in the underlying lower Cenomanian limestone (unit 4 in Text-fig. 1A). Both burrow infillings and intervening hummocks of the lower Cenomanian limestone are truncated by a complex nodular hardground with strong phosphate and glauconite impregnation (Text-fig. 1C). This is a highly fossiliferous level, yielding numerous phosphatised sponge fragments and phosphatic moulds, more or less incomplete, of diverse gastropods, bivalves, echinoids, nautilids, and ammonites (Samsonowicz 1925, 1934; Marcinowski 1980, Marcinowski and Walaszczyk 1985; Walaszczyk 1987).

According to Marcinowski and Walaszczyk (1985), the ammonite assemblage from this level is composed of numerous lower Cenomanian taxa plus those characteristic of the middle Cenomanian *Acanthoceras rhotomagense* Zone (with mixed elements of both the *Turrilites costatus* and *T. acutus* subzones). Foraminiferal assemblages include the planktonic *Rotalipora cushmani*, which is a middle to early late Cenomanian form and is compatible with the ammonite-based dating of this unit (Walaszczyk 1987). Given the age-range of the associated ammonites, which are preserved as mineralised moulds, the studied nautilid material is best considered as early to/or middle Cenomanian in age. In general, unit 5 with its mixed *remanié* phosphatic fossils may be regarded as a local reflection of the so-called mid-Cenomanian eustatic low, distinguished worldwide by Hancock (1990, 2004). The classic regressive Rouen Fossil Bed replete with phosphatised ammonite moulds (Juignet and Kennedy 1976) may be a close analogue. Also, a glauconite-stained "Hg grün" in the Hannover area, for which Ernst *et al.* (1983) coined the term "Mid-Cenomanian Event", seems to represent a comparable horizon (see also Wilmsen 2003 and Wilmsen *et al.* 2005).

SYSTEMATIC PALAEONTOLOGY

Significant contributions to the taxonomy and systematics of post-Triassic nautiloids were presented by Kummel (1956, 1964), Wiedmann (1960), and to some extent by Dzik (1984), while Shimansky (1975) focused mainly on Cretaceous species and their phylogenetic relationships. A series of papers on Upper Cretaceous nautilids of Japan is also important in this respect (Matsumoto 1983; Matsumoto and Miyauchi 1983; Matsumoto and Muramoto 1983; Matsumoto *et al.* 1984a, b). Despite these efforts, classification at the familiar and generic levels is still under debate, especially with respect to the



Text-fig. 2. Taxonomically important features of the nautilid shell

family Cymatoceratidae Spath, 1927 (see discussion in Wilmsen 2000; Wilmsen and Yazykova 2003; Wilmsen and Esser 2004; Frank 2010; and Frank *et al.* 2013). Herein, we follow Shimansky (1975), placing most of the 'cymatoceratid' genera within the family Nautilidae Blainville, 1825 (e.g., Wilmsen 2000; Cichowolski 2003; Frank *et al.* 2013). Because the present paper is only a short communication, synonymies are kept to a minimum (first reference, regional records, important revisions). Morphological features and terms are used according to Teichert (1964) and measurements, obtained using a Vernier Caliper, of maximum diameter (D), whorl breadth (Wb), whorl height (Wh), and size of umbilicus (U) are given in mm and % of maximum diameter (in brackets; Text-fig. 2). The material is stored in the collections of the Instutute of Paleobiology of the Polish Academy of Sciences, Warszawa (abbreviated ZPAL N.III).

Order Nautilida Agassiz, 1847
Family Nautilidae Blainville, 1825
Genus *Eutrephoceras* Hyatt, 1894

TYPE SPECIES: *Nautilus dekayi* Morton, 1834 (p. 33, pl. 8, fig. 4).

Eutrephoceras bouchardianum (d'Orbigny, 1840)
(Text-figs 3A–D, 4A, B)

*1840. *Nautilus bouchardianus* d'Orbigny, p. 75, pl. 13, figs 1–3.
1891. *Nautilus bouchardianus*, d'Orbigny; Foord, p. 261. [see for pre-1890 synonymies]
1956. *Eutrephoceras bouchardianus* (d'Orbigny); Kummel, p. 380.

1960. *Eutrephoceras bouchardianum* (d'Orbigny); Wiedmann, p. 161, pl. 19, figs H, I; pl. 23, fig. J; pl. 24, figs 6–9; text-fig. 6. [see for synonymy]
1975. *Eutrephoceras bouchardianum* (d'Orbigny); Shimansky, p. 60, pl. 5, figs 2–3; text-figs 16 –17.
2000. *Eutrephoceras bouchardianum* (d'Orbigny); Wilmsen, p. 38, pl. 4, fig. 1a–b, pl. 5, figs 9, 22.
2006a. *Eutrephoceras bouchardianum* (d'Orbigny); Tintant and Gauthier, p. 20, pl. 3, figs 1a–b, 2a–c.
2010. *Eutrephoceras bouchardianum* (d'Orbigny); Fricot, p. 197, fig. 135B.

TYPE: Lectotype is specimen LPMP-R4251 (d'Orbigny collection no 5747 A-1, Laboratoire de Paléontologie du Muséum, Paris) from the Albian of Wissant, France (Tintant and Gauthier 2006a).

MATERIAL: Two wholly septate internal moulds with parts of the shell preserved (ZPAL N.III/60 and /64).

Dimensions

Specimen ZPAL	**D**	**Wb (%)**	**Wh (%)**	**Wb/Wh**	**U (%)**
N.III/60	76.4	66.5 (87)	50.0 (65)	1.33	occluded
N.III/64	79.2	68.8 (87)	52.2 (66)	1.32	occluded

DESCRIPTION. Depressed (Wb/Wh ~ 1.3) nautilid with occluded umbilicus. Greatest whorl breadth is at the umbilical margin from where the flanks converge towards the venter without any ventrolateral shoulder, forming a semi-circular whorl cross-section. The suture is nearly straight and the septa widely separated (there are ca. eight septa in the last half whorl). The position of the siphuncle cannot be established due to matrix covering the last preserved septum. An iron-stained spot in the centre of the septum in ZPAL N.III/60 may indicate its sub-central position.

REMARKS: The present specimens correspond well in shell proportions and closed umbilicus as well as simple suture and distant septa to *Eutrephoceras bouchardianum* (d'Orbigny, 1840) as described and illustrated in the literature (e.g., Wiedmann 1960, Shimansky 1975). This is also true when compared to the lectotype of the species from the Albian of Wissant (Pas de Calais, France) as designated and illustrated by Tintant and Gauthier in 2006a (pl. 3, figs 1a, b: Wb = 87%, Wb/Wh = 1.39). *E. sublaevigatum* (d'Orbigny, 1850) is a similar and also contemporaneous species that already has been reported from the Cenomanian of Poland (Cieśliński 1959; Marcinowski 1970; Marcinowski and Radwański 1983). However, it is less strongly inflated, more evolute and has a reniform whorl cross-section. *E. indicum* (d'Orbigny, 1850) is also more compressed and has a more sinuous suture. *E. sphaericum* (Forbes, 1845), on the other hand, is much more inflated (Wb = 100%, Wb/Wh ~ 1.5) and the latter two species are typically occurring in higher stages of the Upper Cretaceous.

OCCURRENCE: *Eutrephoceras bouchardianum* is known from the upper Lower Cretaceous (Albian) of France, Switzerland, and Spain, and the Upper Cretaceous of Spain, Poland, Russia, India and Madagascar (Wiedmann 1960; Cieśliński 1959; Marcinowski 1970; Shimansky 1975; Wilmsen 2000; Fricot 2010).

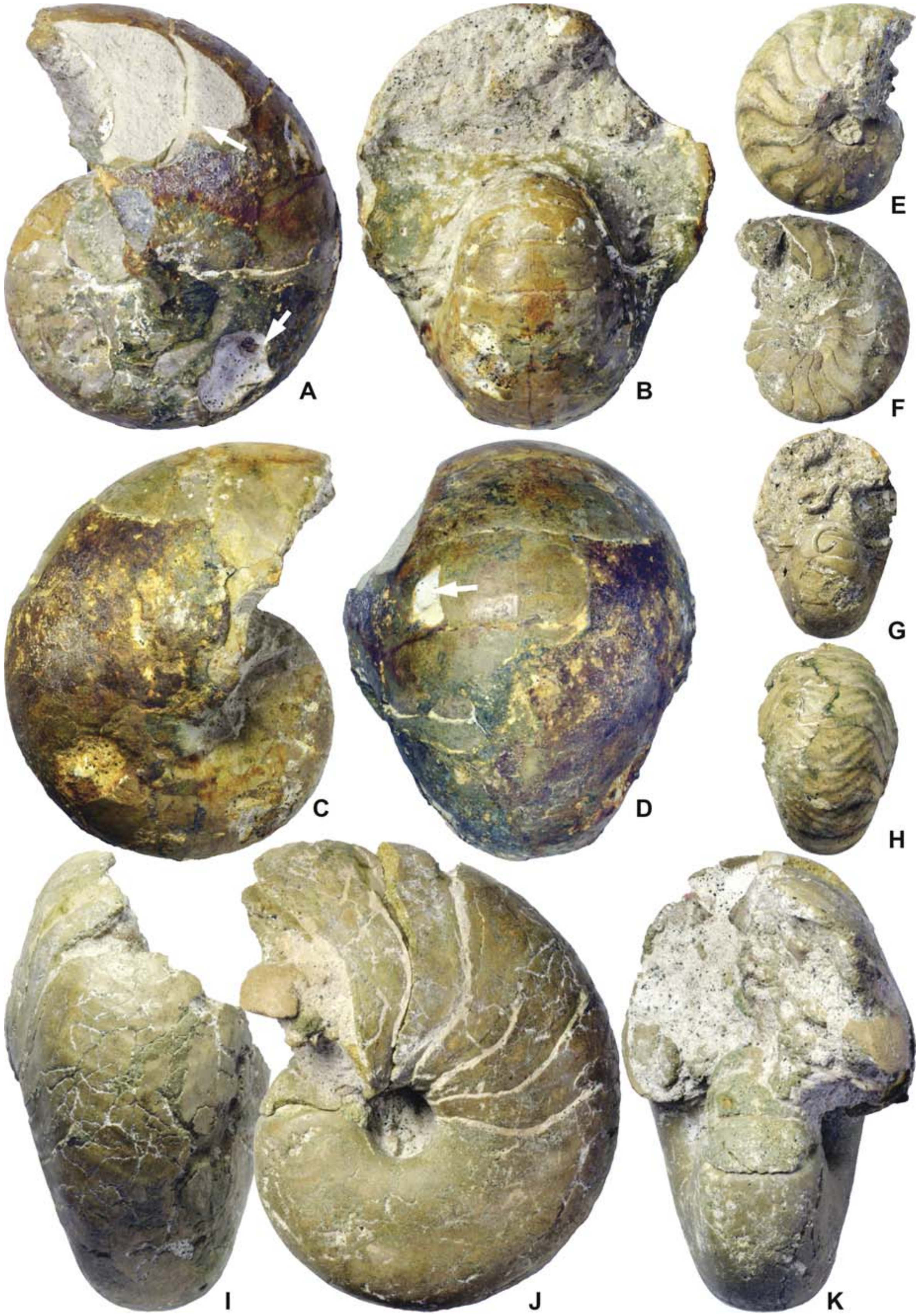
Genus *Cymatoceras* Hyatt, 1884

TYPE SPECIES: *Nautilus pseudoelegans* d'Orbigny, 1840 (p. 70, pl. 8, by original designation).

Cymatoceras deslongchampsianum (d'Orbigny, 1840) (Text-figs 3E–H, 4C–E)

*1840. *Nautilus deslongchampsianus* d'Orbigny, p. 90, pl. 20, figs 1–4.
1853. *Nautilus deslongchampsianus*, d'Orbigny; Sharpe, p. 12, pl. 3, figs 1a, b, 2.
1876. *Nautilus deslongchampsianus*, d'Orbigny; Schlüter, p. 172, pl. 47, figs 7–8.
1891. *Nautilus delongchampsianus*, d'Orbigny; Foord, p. 252. [see for pre-1890 synonymies]
1956. *Cymatoceras deslongchampsianum* (d'Orbigny); Kummel, p. 424, text-fig. 23K.
1959. *Cymatoceras deslongchampsianum* (d'Orbigny); Cieśliński, p. 30, text-fig. 11.
1970. *Cymatoceras deslongchampsianum* (d'Orbigny, 1840). Marcinowski, p. 427, pl. 2, fig. 3a, b.
2002. *Cymatoceras deslongchampsianum* (d'Orbigny); Kennedy, p. 225, text-fig. 10.2a.
2006b. *Pseudocenoceras*? *deslongchampsianum* (d'Orbigny); Tintant and Gauthier, p. 23, pl. 6, figs 4a–b, 5a–c.

Text-fig. 3. Nautilids from the middle Cenomanian of Annopol; all figures in natural size. **A-D** – *Eutrephoceras bouchardianum* (d'Orbigny, 1840), specimen ZPAL N.III/ 60 in lateral (A, C), apertural (B) and ventral (D) views. **E-H** – *Cymatoceras deslongchampsianum* (d'Orbigny, 1840), specimen ZPAL N.III/61 in lateral (E, F), apertural (G) and ventral (H) views. **I-K** – *Cymatoceras tourtiae* (Schlüter, 1876), specimen ZPAL N.III/ 62 in ventral (I), lateral (J) and apertural (K) views. Unphosphatised interior of the mould is arrowed in A and D


A
B
E
F
G
C
D
H
I
J
K

TYPE: Lectotype and paralectotype are the specimens LPMP-B46142 and B46143, respectively (d'Orbigny collection no 6104-1 and -2, Laboratoire de Paléontologie du Muséum, Paris), from the Cenomanian of Rouen (Seine-Maritime), France (Tintant and Gauthier 2000b).

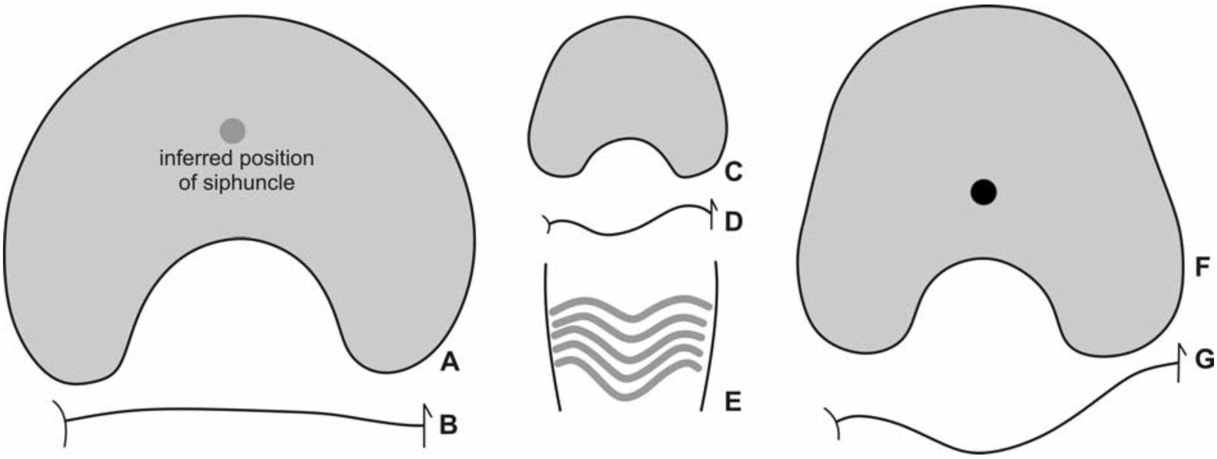
MATERIAL: Two wholly septate internal moulds of the inner whorls with some parts of the shell remaining in ZPAL N.III/61 and /65.

Dimensions

Specimen	**D**	**Wb (%)**	**Wh (%)**	**Wb/Wh**	**U (%)**
ZPAL					
N.III/61	37.5	26.3 (70)	21.6 (58)	1.22	3.8 (10)
N.III/65	41.7	31.9 (76)	26.3 (63)	1.21	4.1 (10)

DESCRIPTION: Depressed (Wb/Wh ~ 1.2) nautilids with subglobose, involute shell (U = 10%). The deep umbilicus has an oblique, outward-inclined umbilical wall and a sharp umbilical shoulder, which is the point of the greatest whorl breadth. The flanks are slightly flattened and converge towards broadly rounded ventrolateral shoulders. The venter is broad and weakly convex. Strong and sharp ribs arise at the umbilical margin, increase in strength and are prorsiradiate and convex on the flanks and curve backwards across the ventrolateral shoulder, forming a conspicuous ventral concavity. The ribs are feebly broadened at the venter. The suture has distinct saddle at the umbilical shoulder, a broad lateral lobe, a low saddle at the ventrolateral shoulder and a broad shallow ventral lobe. The siphuncle is not visible.

REMARKS: The ornament, shape of suture and the conspicuous, sharp-rimmed conical umbilicus show the Annopol specimens to be *Cymatoceras deslongchampsianum* (d'Orbigny, 1840). Tintant and Gauthier (2006b) placed the species with doubt in *Pseudocenoceras* Spath, 1927 and designated a lectotype (specimen LPMP-B46142 from the Cenomanian of Rouen, Seine-Maritime, France, illustrated on pl. 6, fig. 4a, b). However, we do not follow this generic assignment because Spath's genus comprises compressed forms without ornament. Matsumoto in Matsumoto and Muramoto (1983) erected a new genus *Eurocymatoceras* nov. gen. with *Nautilus deslongchampsianus* d'Orbigny, 1840 as type species. However, the minor differences to *Cymatoceras* in the shell form and suture are not sufficient for the establishment of a new genus in our view. *Nautilus archiacianus* d'Orbigny, 1840 (p. 91, pl. 21, figs 1–4), also from the Cenomanian of Rouen [*Pseudocenoceras*? *archiacianum* (d'Orbigny, 1840) in Tintant and Gauthier 2006c] differs from *C. deslongchampsianum* only in the absence of ornament but shares the same shell proportions, suture shape and position of the siphuncle as well as the conspicuous conical umbilicus. The presence/absence of ornament in (Cretaceous) nautilids may strongly depend on taphonomic processes (e.g., Frank *et al*. 2013), and Tintant and Gauthier (2006c, p. 23) already indicated the possibility that the two taxa are conspecific. Both taxa have now also been reported from Annopol because Dzik (1984, pl. 47, fig. 9a, b, 10a, b) illustrated *Pseudocenoceras archiacianum* (d'Orbigny, 1840) from the lower Cenomanian of Annopol. C. *deslongchampsianum* has also been reported from the Cenomanian of the northern border of the Holy Cross Mountains, including the Annopol area, by Cieśliński (1959) and Marcinowski (1970).



Text-fig. 4. Whorl cross-sections and sutures of nautilids from the middle Cenomanian of Annopol; not to scale. **A, B** – *Eutrephoceras bouchardianum* (d'Orbigny, 1840), whorl cross-section (A) and suture (B). **C–E** – *Cymatoceras deslongchampsianum* (d'Orbigny, 1840), whorl cross-section (C), suture (D) and ventral ornament (E). **F, G** – *Cymatoceras tourtiae* (Schlüter, 1876), whorl cross-section (F) and suture (G)

OCCURRENCE: Cenomanian of England, France, Switzerland, Germany and Poland (e.g., Foord 1891; Cieśliński 1959; Kennedy 2002).

Cymatoceras tourtiae (Schlüter, 1876)
(Text-figs 3I–K, 4F, G)

1876. *Nautilus tourtiae*, sp. n. Schlüter, p. 170, pl. 46, figs 1–4.
1956. *Cymatoceras tourtiae* (Schlüter); Kummel, p. 426, text-fig. 23C.
1975. *Cymatoceras tourtiae* (Schlüter); Shimanski, p. 90, 91.
?1999. *Cymatoceras tourtiae* (Schlüter); Wittler *et al*., p. 10, text-figs 8–12.
2002. *Cymatoceras tourtiae* (Schlüter); Kennedy, p. 228, text-fig. 10.2D.

TYPE: The specimen STIPB-Schlüter-94, illustrated by Schlüter (1876) on pl. 46, figs 1 and 2, hosted in the Goldfuss-Museum, University of Bonn, is designated as lectotype herein.

MATERIAL: Three fully septate internal moulds (ZPAL N.III/62, /66 and /67).

Dimensions

Specimen	D	Wb (%)	Wh (%)	Wb/Wh	U (%)
ZPAL					
N.III/62	86.9	~52 (60)	48.0 (55)	1.08	12.5 (14)
N.III/66	80.8	51.7 (64)	47.7 (59)	1.08	8.2 (10)
N.III/67	33.5	21.8 (65)	20.1 (60)	1.08	3.8 (11)

DESCRIPTION: Slightly depressed (Wb/Wh = 1.08) nautilids with open, deep and relatively large umbilicus (U = 10–14%). The umbilical wall is overhanging and the umbilical shoulder narrowly rounded. The whorl cross-section is trapezoidal, with greatest breadth on the lower flanks, just outside the umbilical shoulder. The flanks are flat to feebly concave and converging towards the rounded ventrolateral shoulder. The venter is broad and weakly convex. There are weak ribs on the outer flanks and the venter. They are convex across the ventrolateral shoulder and form a concave arc across the venter. On the last preserved half whorl, every third or fourth rib is slightly strengthened, producing weak folds on the ventrolateral shoulder and venter. The suture shows a weak saddle at the umbilical shoulder and the lower flank, followed by a broad lateral lobe. It is nearly straight across the venter. The siphuncle is close to the dorsal margin of the septum.

REMARKS: The trapezoidal, slightly depressed whorl cross-section, the ribbing pattern and the dorsal position of the siphuncle indicate the Annopol specimens to be *Cymatoceras tourtiae* (Schlüter, 1876). The specimens described and illustrated by Wittler *et al*. (1999) from the Cenomanian Essen Grünsand Formation of the Münsterland Cretaceous Basin (Germany), a unit of glauconitic nearshore sediments, are placed in *C. tourtiae* only with doubt because they are very inflated, subglobose and have nearly closed umbilici. The lower Cenomanian specimen from the "Chalk with siliceous grains" of Chardstock (England) illustrated by Sharpe (1853, pl. 5, fig. 1a, b) as "*Nautilus radiatus* Sow." and referred to *Cymatoceras deslongchampsianum*? (d'Orbigny) by Wright and Wright (1951, p. 33) is close to Schlüter's species based on its relatively fine and dense ribbing and general shell form but may differ slightly in more involute coiling and position of the siphuncle (Schlüter 1876, p. 171). *Pseudocenoceras largilliertianum* (d'Orbigny, 1840) has a similar shell from and wide umbilicus but is slightly compressed and lacks ribbing. *Pseudocenoceras dorsoplicatum*, erected by Wiedmann (1960) on the basis of material figured by Sharpe (1853, pl. 6, fig. 2 only) and Parona and Bonarelli (1897, pl. 10, fig. 6) as *Nautilus largilliertianus*, has distinct concave folds which are restricted to the chambered part of the shell and are also present on internal moulds (Wilmsen 2000).

OCCURRENCE: *Cymatoceras tourtiae* is known from the Cenomanian of England, Germany, and Poland (first record herein).

TAPHONOMY

The nautilid specimens studied are preserved as internal moulds, occasionally with phosphatised shell remnants still adhering to their surface. Seven better preserved specimens, which form a basis of the taxonomic part of this study (Text-fig. 3A–K) are more or less intact phragmocones without body chambers. These specimens display phosphatic and glauconite mineralisation, corroded and abraded surfaces, occasional borings and encrusters (not figured here), and signs of physical damage. These are taphonomic signatures typical for phosphatic *remanié* fossil assemblages described e.g., from the basal Cenomanian Glauconitic Marl of south-east England (Kennedy and Garrison 1975), testifying to their formation through repeated cycles of cementation, mineralisation, burial and re-exposure (*op. cit.*). In view of the stratigraphic range of the associated amonites in phosphate preservation (see above), these cycles may represent an extended time interval from early to middle Cenomanian. On the other hand, it should be noted that similar taphonomic alterations including epizoan encrustation, shell damage, traces of boring organisms and sediment filling of the phragmocones have been observed in varying degrees in modern *Nautilus* shells from New Cale-

Text-fig. 5. External surfaces and sagittal sections of underterminate nautilid moulds from the middle Cenomanian of Annopol; all figures in natural scale. **A, B** – ZPAL N.III/58. **C, D** – ZPAL N.III/59. Arrowed are: boundary between the phragmocone and surrounding phosphatic matrix (p/m); borings filled with unphosphatised sediment (bor) and lamination of the internal sediment visible in several chambers (lam). See text for further explanations donia with resting times on the sea-floor of only between 14–42 years (Mapes *et al*. 2010).

One specimen (Text-fig. 3A–D) displays an internal, white limestone infilling of chambers under a phosphatic crust covering its surface. This suggests secondary phosphatisation of an originally calcareous mould, compatible with the classic replacement model proposed for the Glauconitic Marl specimens by Kennedy and Garrison (1985). There is thus a difference between the present material and the phosphatic moulds of fossils recovered from the upper Albian unit 3 at Annopol (Machalski and Olszewska-Nejbert 2015; see Text-fig. 1A for position of this level in the section). These latter formed through direct precipitation of apatite around and/or inside fossils (Machalski and Olszewska-Nejbert 2015).

Two moulds of indeterminate nautilids from unit 5 have been sectioned in order to study their internal structure and the fabric of the infill. These specimens illustrate different taphonomic histories. Specimen ZPAL N.III/58 (Text-fig. 5 A, B) is more complete, retaining part of the body chamber. It has been filled by two generations of internal sediment which is patchy in distribution and lacks internal lamination. This suggests that the sediment entered this shell *via* the aperture and punctures in the shell. These holes could be caused by physical damage or bioerosion, as documented for the ammonite and nautilid moulds from the Maastrichtian of Western Australia (Henderson and McNamara 1985; see also Mapes *et al*. 2010, p. 607, for data on infilling of modern *Nautilus* shells).

Specimen ZPAL N.III/ 59 (Text-fig. 5C, D) is a strongly phosphatised fragment of a single whorl of a phragmocone. Zones of phosphatised matrix with incorporated older phosphatic intraclasts adhere to the phragmocone. Boundaries between the phragmocone and surrounding phosphatic matrix are marked by distinct zones of glauconite impregnation (arrowed in Text-fig. 5C). Borings filled with white, unphosphatised sediment are clearly visible, both on the external surface of the specimen and in the cross-section (arrowed in Text-fig. 5C, D). The specimen thus bears evidence for multiphase growth and reworking, representing a typical "Hiatus-Konkretion" (hiatus concretion) in the sense of Voigt (1968).

Information about the infilling scenario of ZPAL N.III/59 is provided by internal lamination visible in several chambers, which is picked up by differences in size and density of glauconite grains (pellets) (arrowed in Text-fig. 5D). These suggest a different mode of sediment entry into the shell than that for the ZPAL N.III/58, namely by intracameral currents introducing the sediment through siphonal openings into successive chambers (see discussion and references in Kennedy and Garrison 1975).

SUMMARY

Phosphatised internal moulds of *Eutrephoceras bouchardianum* (d'Orbigny, 1840), *Cymatoceras deslongchampsianum* (d'Orbigny, 1840) and *Cymatoceras tourtiae* (Schlüter, 1876) are decribed here from a highly condensed middle Cenomanian interval at Annopol. The last-named species is recorded from Poland for the first time. Given the age-range of the associated ammonites, the studied nautilid material is early to/or middle Cenomanian in age.

Previous workers proposed a multi-event depositional scenario for this unit, which involved several episodes of reworking, phosphatisation and burial of fossils (Marcinowski and Walaszczyk 1985, fig. 2). The taphonomical analysis of the nautilid material generally supports these conclusions. Observed variation of the taphonomic signatures in the present material is compatible with heterogeneity of the fossil assemblages from unit 5 and its multi-event history proposed by Marcinowski and Walaszczyk (1985).

Acknowledgements

W.J. Kennedy (Oxford) and an anonymous referee are thanked for their insightful reviews as well as I. Walaszczyk (Warszawa) for editorial handling and G. Geyer (Würzburg) for the discussion of taxonomic issues. The present work was supported by the National Centre of Science grant no. (grant no. DEC-2012/05/B/ST10/00710 to Marcin Machalski) Wiesław Liwiński, mayor of the town of Annopol, is thanked for support and assistance. Michał Andziak, Agnieszka Kapuścińska, Adam Zaremba, Zbigniew Lis, Maciej Duda, Maciej Małysiak, Witold Biernat, Artur Komorowski, and Krzysztof Nejbert, are thanked for their participation in field work. Ronald Winkler and Grażyna Dziewińska are thanked for excellent photographs of the studied specimens, and Aleksandra Hołda-Michalska for computer processing of Text-fig. 1. G. Heumann (Bonn) helped in locating type material of Schlüter.

REFERENCES

Agassiz, L. 1847. An introduction to the study of natural history, in a series of lectures delivered in the hall of the College of Physicians and Surgeons. 58 pp., Greeley & McGrath, New York.

Blainville, H.M.D. de 1825–27. Manuel de malacologie et de conchyliologie. 664pp. Paris and Strasbourg (Levrault).

Bardet, N., Fischer, V. and Machalski, M. 2015. Large predatory marine reptiles from the Albian–Cenomanian of Annopol, Poland. *Geological Magazine*, http://doi.org/10.1017/S0016756815000254 [in press]

Cichowolski, M. 2003. The nautiloid genus *Cymatoceras* from the Cretaceous of the Neuquén and Austral basins, Argentina. *Cretaceous Research*, **24**, 375–390.

Cieśliński, S. 1959. The Albian and Cenomanian in the northern periphery of the Święty Krzyż Mountains. *Prace Instytutu Geologicznego*, **28**, 1–95. [In Polish, with English summary]

Dzik, J. 1984. Phylogeny of the Nautiloidea. *Palaeontologia Polonica*, **45**, 1–220.

Ernst, G., Schmid, F. and Seibertz, E. 1983. Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. *Zitteliana*, **10**, 531–554.

Foord, A.H. 1891. Catalogue of the fossil Cephalopoda in the British Museum (Natural History). Part 2. Containing the remainder of the suborder Nautiloidea, consisting of the families Lituitidae, Trochoceratidae, and Nautilidae, with a supplement. Eyre and Spottiswoode, London, 407 pp.

Forbes, E. 1845. Report on the fossil Invertebrata from Southern India, collected by Mr. Kaye and Mr. Cunliffe. *Transactions of the Geological Society of London, Series 2,* **7**, 97–174.

Fraaije, R.H.B., Van Bakel, B., Jagt, J.W.M. and Machalski, M. 2015. A new hermit crab from the upper Albian (Cretaceous) of Annopol. *Zootaxa*, **3955 (4)**, 588–594.

Frank, J. 2010. Taxonomy and palaeoecology of Cretaceous nautilids *Angulithes galea* (Fritsch in Fritsch and Schlönbach, 1872) and *Angulithes westphalicus* (Schlüter, 1872). *Bulletin of Geosciences*, **85**, 487–496.

Frank, J., Wilmsen, M. and Košťák, M. 2013. The endemic and morphologically remarkable nautilid genus *Deltocymatoceras* Kummel, 1956 from the Late Cretaceous of central Europe. *Bulletin of Geosciences*, **88**, 793–812.

Fricot, C. 2010. Le nautile *Cymatoceras pseudoelegans* (d'Orbigny, 1840) dans l'Albien stratotypique. In: Colleté, C. (coord.), Stratotype Albien. Muséum national d'Histoire naturelle, Paris, Biotope, Mèze, 197–199; BRGM (Orléans).

Hancock, J.M. 1990. Sea-level-changes in the British region during the Late Cretaceous. *Proceedings of the Geologists' Association*, **100** (for 1989), 565–594.

Hancock, J. 2004. The mid-Cenomanian eustatic low. *Acta Geologica Polonica*, **54**, 611–627.

Henderson, R.A. and McNamara, K.J. 1985. Taphonomy and ichnology of cephalopod shells in a Maastrichtian chalk from Western Australia. *Lethaia*, **18**, 305–322.

Hyatt, A. 1894. Phylogeny of an acquired characteristic. *Proceedings of the American Philosophical Society*, **32** (for 1893), 349–647.

Juignet, P. and Kennedy, W.J. 1976. Faunes d'ammonites et biostratigraphie comparée du Cénomanien du nord-ouest de la France (Normandie) et du sud de l'Angleterre. *Bulletin trimestriel de la Société Géologique de Normandie*, **63**, 1–193.

Kapuścińska, A. and Machalski, M. 2015. Upper Albian chelonioid turtles from Poland. *Geobios*, **48**, 385–395.

Kennedy, W.J. 2002. Nautiloids. In: A.B. Smith and D.J. Batten (Eds), Fossils of the Chalk. *Palaeontological Association Field Guide to Fossils,* **2** (2nd ed.), 219–231.

Kennedy, W.J. and Garrison, R.E. 1975. Morphology and genesis of nodular phosphates in the Cenomanian Glauconitic Marl of south-east England. *Lethaia,* **8**, 339–360.

Kennedy, W.J. and Machalski, M. 2015. A late Albian ammonite assemblage from the mid-Cretaceous succession at Annopol, Poland. *Acta Geologica Polonica*, **65**, 461–469.

Kummel, B. 1956. Post-Triassic Nautiloid genera. *Bulletin of the Museum of Comparative Zoology at Harvard College in Cambridge,* **114**, 319–494.

Kummel, B. 1964. Nautiloidea–Nautilida. In: Moore, R.C. (Ed.), Treatise on Invertebrate Paleontology, Part K, Mollusca 3. K383–K457. Geological Society of America, Boulder and University of Kansas Press; Lawrence.

Machalski, M. and Kennedy, W.J. 2013. Oyster-bioimmured ammonites from the Upper Albian of Annopol, Poland: stratigraphic and palaeobiogeographic implications. *Acta Geologica Polonica*, **63**, 545–554.

Machalski, M. and Martill, D.M. 2013. First pterosaur remains from the Cretaceous of Poland. *Annales Societatis Geologorum Poloniae*, **83**, 99–104.

Machalski, M. and Olszewska-Nejbert, D. 2015. A new mode of ammonite preservation – implications for dating of condensed phosphorite deposits. *Lethaia*, http: //dx.doi.org/10.1111/let.12132 [in press]

Mapes, R.H., Landman, N.H., Cochran, K., Goiran, C., de Forges, B.R. and Renfro, A. 2010. Early taphonomy and significance of naturally submerged *Nautilus* shells from the New Caledonia region. *Palaios*, **25**, 597–610.

Marcinowski, R. 1970. The Cretaceous transgressive deposits east of Częstochowa (Polish Jura Chain). *Acta Geologica Polonica*, **20**, 413–449.

Marcinowski, R. 1980. Cenomanian ammonites from German Democratic Republic, Poland, and the Soviet Union. *Acta Geologica Polonica*, **30**, 215–325.

Marcinowski, R. and Radwański, A. 1983. The mid-Cretaceous transgression onto the Central Polish Uplands (marginal part of the Central European Basin). *Zitteliana*, **10**, 65–96.

Marcinowski, R. and Radwański, A. 1989. A biostratigraphic approach to the mid-Cretaceous transgressive sequence of the central Polish Uplands. *Cretaceous Research*, **10**, 153–172.

Marcinowski, R. and Walaszczyk, I. 1985. Middle Cretaceous deposits and biostratigraphy of the Annopol section, Central Polish Uplands. *Österreichische Akademie der Wissenschaft, Schriftenreihe der Erdwissenschaftlichen Komissionen*, **7**, 27–41.

Matsumoto, T. 1983. Cretaceous nautiloids from Hokkaido – I. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **129**, 9–25.

Matsumoto, T. and Muramoto, K. 1983. Cretaceous nautiloids from Hokkaido – II, Part 2. Three nautiloid species from the Santonian and Campanian of Hokkaido. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **130**, 85–95.

Matsumoto, T. and Miyauchi, T. 1983. Cretaceous nautiloids from Hokkaido – III, Part 3. Some nautiloids from the Campanian of Soya, northern Hokkaido. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **132**, 220–229.

Matsumoto, T., Takahashi, T., Obata, I. and Futakami, M. 1984a. Cretaceous nautiloids from Hokkaido – IV, Part 4. An interesting nautiloid species from the Cenomanian of Hokkaido. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **133**, 288–299.

Matsumoto, T., Miyauchi, T., Kanie, Y., Miyata, Y and Ueda, Y. 1984b. Cretaceous nautiloids from Hokkaido – V, Part 5–7. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **134**, 335–346.

Morton, S.G. 1834. Synopsis of the organic remains of the Cretaceous group of the United States. 88 pp., pls 1–19. Philadelphia.

Orbigny, A. d’ 1840–1842. Paléontologie Française. Terrains crétacés I, Céphalopodes. Masson, Paris, 662 pp. (1–120: 1840; 121–430: 1841; 431–662: 1842).

Orbigny, A. d’ 1850. Prodrome de paléontologie stratigraphique universelle des animaux mollusques et rayonnés faisant suite au cours élémentaire de paléontologie et de Géologie stratigraphiques. Masson, Paris, tome 2, 1–427.

Popov, E.V. and Machalski, M. 2014. Late Albian chimaeroid fishes (Holocephali, Chimaeroidei) from Annopol, Poland. *Cretaceous Research*, **47**, 1–18.

Samsonowicz, J. 1925. Esquisse géologique des environs de Rachów sur la Vistule et les transgressions de l’Albien et du Cénomanien dans les sillon nord-européen. *Sprawozdania Państwowego Instytutu Geologicznego*, **3**, 45–118. [in Polish, French summary]

Samsonowicz, J. 1934. Explication de la feuille Opatów (zone 45, colonne 33). Service géologique de Pologne, Carte Géologique Générale de la Pologne au 100.000-e, 1–97. Warszawa.

Schlüter, C.A. 1876. Cephalopoden der oberen deutschen Kreide. 2. Abtheilung, Lieferung 6–9. *Palaeontographica*, **24**, i–x, 121–263.

Sharpe, D. 1853–1909. Description of the fossil remains of Mollusca found in the Chalk of England. Cephalopoda. Palaeontographical Society (London) Monograph, 68pp., 27 pls. (1853: p. 1–26, pls. 1–10; 1854: p. 27–36, pls. 11–16; 1855: p. 37–68, pls. 17–27; 1909: general title-page and index).

Shimansky, V.N. 1975. Cretaceous Nautiloids. *Trudy Paleontologičeskogo Instituta Akademii Nauk SSSR,* **150**, 1–208. [In Russian]

Spath, L.F. 1927. Revision of the Jurassic cephalopod fauna of Kachh (Cutch). *Memoir of the Geological Survey of India, New Series*, **9**, 1–84.

Teichert, K. 1964. Morphology of hard parts. In: Moore, R.C. (Ed.), Treatise on Invertebrate Paleontology, Part K, Mollusca 3. K13–K53. Geological Society and University of Kansas Press.

Tintant, H. and Gauthier, H. 2006a. *Eutrephoceras bouchardianum* (d’Orbigny, 1840). In: Gauthier, H. (Ed.), Révision critique de la Paléontologie Française d’Alcide d’Orbigny. Volume IV, Céphalopodes Crétacés: p. 20. Backhys; Leiden.

Tintant, H. and Gauthier, H. 2006b. *Pseudocenoceras*? *deslongchampsianum* (d’Orbigny, 1840). In: Gauthier, H. (Ed.), Révision critique de la Paléontologie Française d’Alcide d’Orbigny. Volume IV, Céphalopodes Crétacés: p. 23. Backhys; Leiden.

Tintant, H. and Gauthier, H. 2006c. *Pseudocenoceras*? *archiacianum* (d’Orbigny, 1840). In: Gauthier, H. (Ed.), Révision critique de la Paléontologie Française d’Alcide d’Orbigny. Volume IV, Céphalopodes Crétacés: p. 23. Backhys; Leiden.

Voigt, E. 1968. Über Hiatus-Konkretionen (dargestellt an Beispielen aus dem Lias). *Geologische Rundschau*, **58**, 281–296.

Walaszczyk, I. 1987. Mid-Cretaceous events at the marginal part of the Central European Basin (Annopol-on-Vistula section, Central Poland). *Acta Geologica Polonica*, **37**, 61–74.

Wiedmann, J. 1960. Zur Stammesgeschichte jungmesozoischer Nautiliden unter besonderer Berücksichtigung der iberischen Nautilinae d’Orb. *Palaeontographica, Abteilung A*, **115** (Liefg. 1-6), 144–206.

Wilmsen, M. 2000. Late Cretaceous nautilids from northern Cantabria, Spain. *Acta Geologica Polonica*, **50**, 29–43.

Wilmsen, M. 2003. Sequence stratigraphy and palaeoceanography of the Cenomanian Stage in northern Germany. *Cretaceous Research*, **24**, 525–568.

Wilmsen, M. and Yazykova, E.A. 2003. Campanian (Late Cretaceous) nautiloids from Sakhalin, Far East Russia. *Acta Palaeontologica Polonica*, **48**, 481–490.

Wilmsen, M. and Esser, K. 2004. Latest Campanian to Early Maastrichtian (Cretaceous) nautiloids from the white chalk of Kronsmoor, northern Germany. *Acta Geologica Polonica*, **54**, 489–498.

Wilmsen, M., Niebuhr, B. and Hiss, M. 2005. The Cenomanian of northern Germany: facies analysis of a transgressive biosedimentary system. *Facies*, **51**, 242–263.

Wittler, F.A., Roth, R. and Legant, J. 1999. Die Nautiliden der oberen Kreide vom Süd- und Westrand des Münsterländer Beckens. *Arbeitskreis Paläontologie Hannover*, **27**, 1–52.

Wright, C.W. and Wright, E.V. 1951. A survey of the fossil Cephalopoda of the Chalk of Great Britain. Primarily a nomenclatorial revision of Daniel Sharpe's „Description of the fossil remains of Mollusca found in the Chalk of England. Part I, Cephalopoda" (1853–1857). *The Palaeontographical Society (London) Monographs (for 1950),* 41 pp.

Manuscript submitted: 28th April 2015
Revised version accepted: 30th October 2015