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RESEARCH ARTICLE

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First discovery of nautilids from the Albian–Cenomanian succession of the Koppeh Dagh Basin, NE Iran

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Abstract

The Aitamir Formation, situated in the Koppeh Dagh Basin in the northeast of Iran, is known for its well-exposed Albian-to-Cenomanian succession. Although geologists previously documented a number of macro- and microfossils, no nautilids had been discovered until now to our knowledge. Here, we present lower Albian and middle Cenomanian nautilids from the Koppeh Dagh Basin for the first time. This discovery is also the first record of Cretaceous nautilids from Iran. We identified the specimens as *Eutrephoceras clementianum* (d'Orbigny 1840), *E. sublaevigatum* (d'Orbigny 1850), *E. bouchardianum* (d'Orbigny 1840) and *Eutrephoceras* sp. These specimens occur in horizons situated between several ammonite-bearing levels, which allowed us to more precisely constrain age estimates for the recovered nautilid specimens. *E. clementianum* could not be dated precisely but likely comes from between late Aptian ammonite index *Hypacanthoplites uhligi* and middle Albian *Hoplites* (*Hoplites*) *baylei*. *E. sublaevigatum* occurs just above the late Albian ammonites *Mariella bergeri* and *Semenoviceras michalskii* and below the *Mantelliceras mantelli* Zone. At the upper part of the section, *E. bouchardianum* and *Eutrephoceras* sp. were collected from lower Albian beds, which correspond to the *Mantelliceras mantelli* and *Mantelliceras dixonii* zones. These new findings contribute to our knowledge of the geographical distribution and stratigraphic range of Albian–Cenomanian nautilid species.

Keywords: Nautilids, *Eutrephoceras*, Cretaceous, Koppeh Dagh, Aitamir

Introduction

The Nautiloidea (de Blainville, 1825) is a group of ectocochleate cephalopods that has a long geological record, originating in the late Cambrian (Kröger et al., 2011). Although nautilid fossils have been reported worldwide for some hundred years, a comprehensive study of the mid-Cretaceous nautilids is critically lacking. The genus *Eutrephoceras* (Hyatt, 1894) is one of the most common nautilid taxa in the Cretaceous and an interesting group to study because they survived the K/Pg mass extinction event (e.g., Landman et al., 2014). However, more taxonomic investigations are needed to increase our knowledge on its paleogeographic occurrences and chronostratigraphic position.

The chronostratigraphic range of *Eutrephoceras* extends from the Upper Jurassic to the Miocene (Kummel, 1956; Landman et al., 2018). Most of the mid-Cretaceous occurrences of this taxon were recorded from European Albian and Cenomanian successions (Ayoub-Hannaa et al., 2018; Jattiot et al., 2021; Kennedy et al., 2008; Machalski & Wilmsen, 2015; Tajika et al., 2017; Wilmsen, 2000, 2016). The Koppeh Dagh Basin (northeastern Iran), in which the lower Albian to middle Cenomanian sedimentary rocks are exposed as Aitamir Formation, is known for its rich assemblage of diverse macro- and microfossils, but no nautilid fossils have been documented thus far. Most of the important taxonomic and biostratigraphic studies of this formation have

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focused on the ammonites (Seyed-Emami & Aryai, 1981; Seyed-Emami et al., 1984; Immel et al. 1997; Mosavinia et al., 2007, 2014; Mosavinia, 2008; Mosavinia & Wilmsen, 2011, 2017; Lehmann et al., 2019), and a few studies on planktonic foraminifera (Abdoshahi et al., 2010; Kalanat et al., 2016). We here describe and illustrate the first record of nautilids from the Albian–Cenomanian Aitamir Formation in the Koppeh Dagh Basin.

Geological setting

The Koppeh Dagh Mountains are located within the Alpine–Himalayan orogenic belt and were formed as a result of the collision of the Iran Plate with the southern margin of Eurasia, along the Palaeotethyan suture zone (Afshar-Harb, 1994; Alavi, 1991; Bretis et al., 2012; Wilmsen et al., 2009). Its sedimentary rocks consist of several kilometers of marine successions from the Jurassic up to the Miocene (e.g., Afshar-Harb, 1994). During the Albian and Cenomanian (Aitamir Formation), the Koppeh Dagh Basin was a passive margin siliciclastic shelf (Mosavinia & Wilmsen, 2017). Regional tectonic activities strongly influenced local sedimentation processes and led to various characteristics such as fossil contents and thickness variations of the Aitamir Formation (Mosavinia & Wilmsen, 2011, 2017; Robert et al., 2014). This time interval coincides with extensive volcanic activity in global scale which led to warm conditions, thereby enhancing marine productivity and leading to reduced carbonate contents (Arthur et al., 1985; Larson, 1991; Leckie et al., 2002). These extraordinary paleoecological conditions may have resulted in the presence of glauconitic and pyritized shales and sandstones in the Aitamir Formation.

The study area is located along the Khur anticline, SE of the Kalat-e-Naderi City, near the Taherabad Village (co-ordinates: N 36° 37’ 05", E 60° 04’ 03"). The outcrops in the studied area consist of several lithostratigraphic units from the Upper Jurassic (Mozduran Formation) to the Turonian (Abderaz Formation) as illustrated in Fig. 1. All described nautilid specimens were collected from the Aitamir Formation. The Aitamir Formation includes the lower Albian to middle Cenomanian at the Taherabad section and is composed of a 270-m-thick succession of shales, marls and bioturbated ridge-forming glauconitic and pyritized shales and sandstones. The Aitamir Formation lies conformably on the marls and dark shales of the Sanganeh Formation, and is overlain by the Abderaz

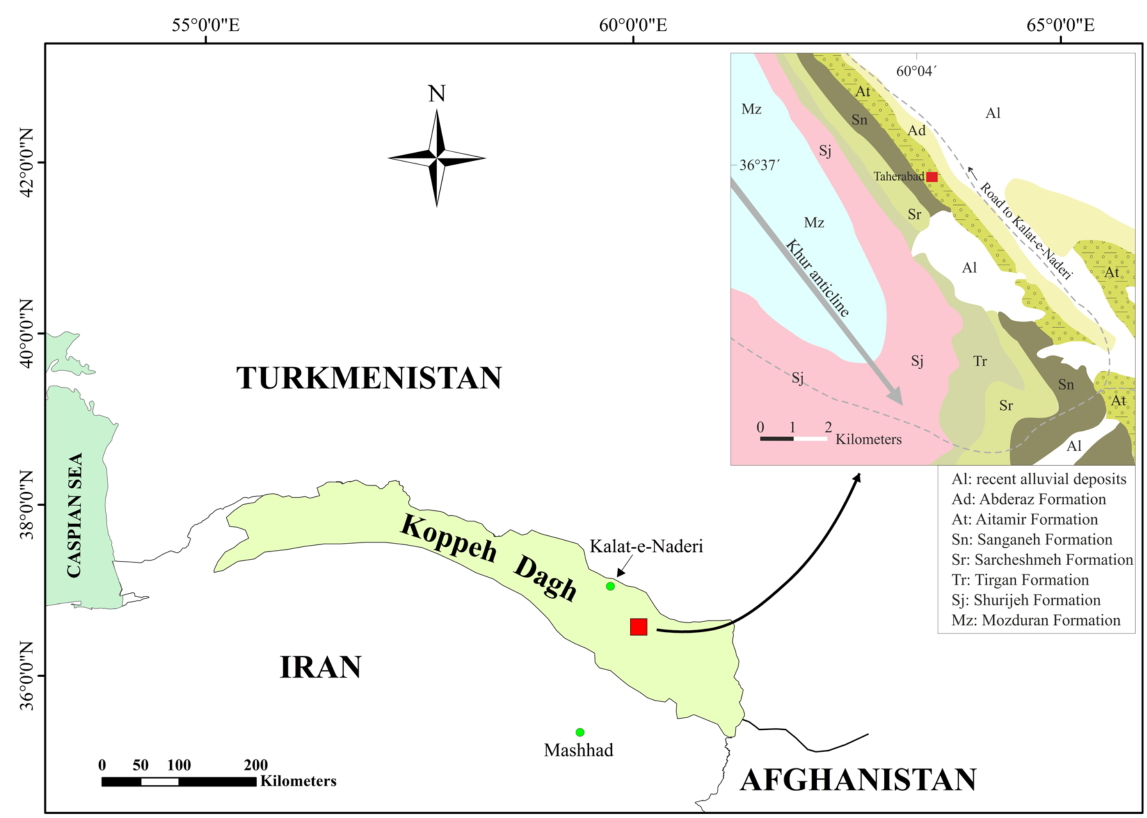

Fig. 1 Geographic position of the Koppeh Dagh Basin in northeast Iran with simplified geologic map of the study area (after Afshar, 1982). Red rectangle shows location of the Taherabad section

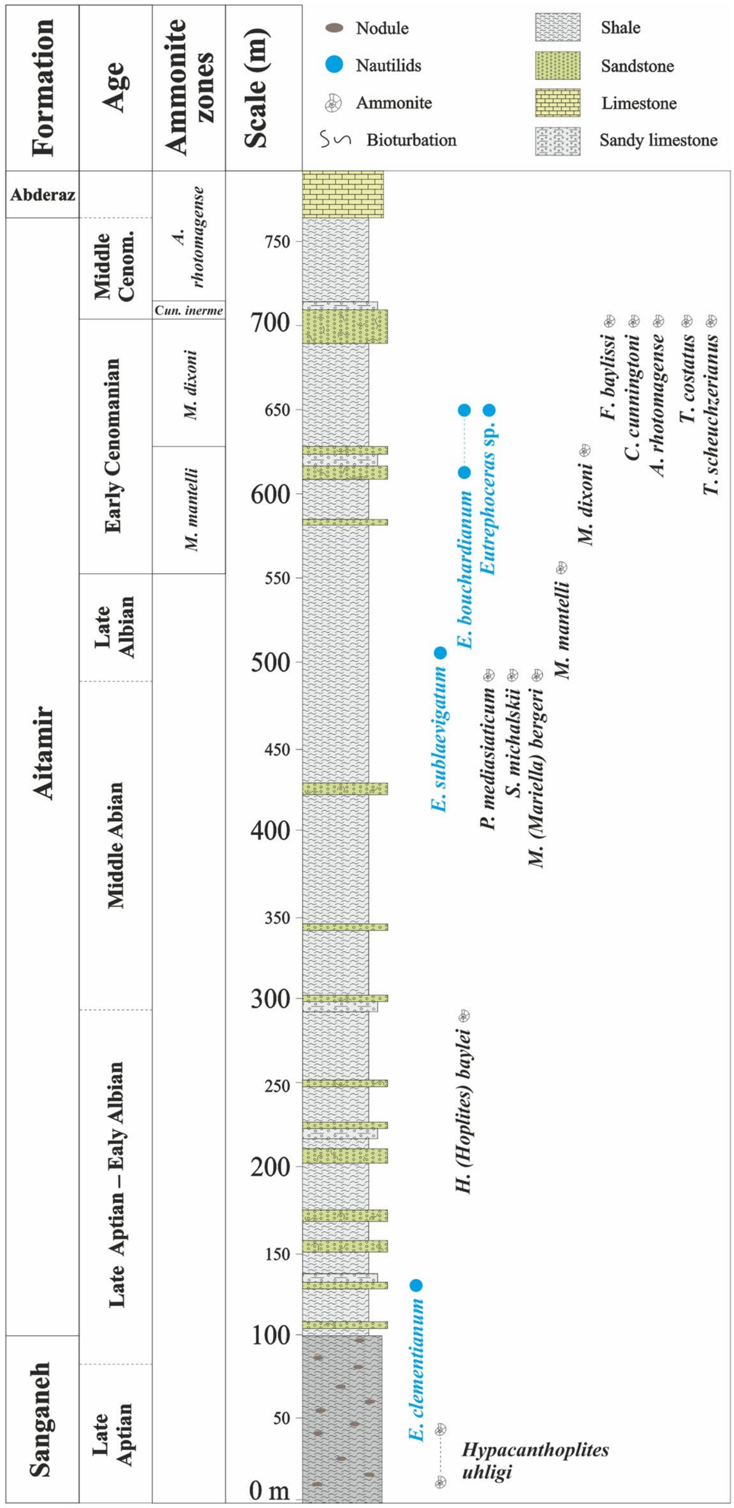

Fig. 2 Stratigraphic distribution of the nautilids in the Taherabad section. Ammonite zonation and substages boundaries are adopted from Mosavinia (2008); Mosavinia and Wilmsen (2011) and (2017); Mosavinia et al. (2014) and Lehmann et al. (2019). Abbreviations of ammonite genera: *H.—Hoplites*; *M.—Mariella*; *P.—Placenticeras*; *S.—Semenoviceras*; *M.—Mantelliceras*; *T.—Turrilites*; *F.—Forbesiceras*; *C.—Cunningtoniceras*; *A.—Acanthoceras*

Formation, which is characterized by chalky limestones and marls. The Taherabad section is one of the well-studied outcrops of the Aitamir Formation in the Koppeh Dagh Basin, and many previous authors have presented detailed lithostratigraphic description of the section (e.g., Kalanat et al., 2016; Mosavinia & Wilmsen, 2017; Mosavinia et al., 2014).

Materials and methods

Five nautilid specimens were collected during 3 days of fieldwork. We took linear measurements of the conch parameters (diameter: dm; whorl width: ww, whorl height: wh) that were also used in Tajika et al. (2020). On the basis of the measurements above, we calculated the whorl expansion rate [$(dm^1/dm^2)^*2$: WER] and whorl width index [$(ww^1/ dm^1)^*2$: WWI]. We also documented the position of the siphuncle, the sutural morphology, and the number of septa per half whorl, wherever possible. Note that the small sample size does not allow for assessing the intraspecific variation, and thus we applied a typologic approach to discuss the taxonomy. As far as the higher taxonomic classification is concerned, we follow Teichert et al. (1964). All five illustrated specimens are housed in the Fossil Preparation Lab at the Department of Geology, Ferdowsi University of Mashhad, labeled with NAT repository codes (NAT-1 to NAT-5).

Results and discussion

All studied specimens belong to the genus *Eutrephoceras*, which is the first record of this genus in the Koppeh Dagh Basin, as well as in Iran. Even though the specimens are rather poorly preserved, we identified the following species (see systematic paleontology below): *E. clementianum* (d'Orbigny, 1840), *E. sublaevigatum* (d'Orbigny, 1850) and *E. bouchardianum* (d'Orbigny, 1840).

Previous studies documented several ammonite-rich beds and proposed the basic age framework for the Taherabad section of the Aitamir Formation and for adjacent areas (Lehmann et al., 2019; Mosavinia, 2008; Mosavinia & Wilmsen, 2011, 2017; Mosavinia et al., 2014). We used the ammonite occurrences and zones to provide the age information for the stratigraphic levels in which we collected our specimens. Figure 2 shows the stratigraphic distribution of the collected nautilids accompanied by ammonite records, and the suggested substage boundaries. Albian ammonite biostratigraphic studies for the Taherabad section were carried out by Mosavinia et al. (2014) and Lehmann et al. (2019), but no zonations were given for the interval in which we collected our specimens. Nevertheless, some of the reported ammonites helped us to constrain the substage boundaries within the Albian. By contrast, Cenomanian ammonites from the Taherabad section documented by Mosavinia and Wilmsen (2011, 2017) indicate a sequence of important bioevents that indicate a position in the *Mantelliceras mantelli* to *Acanthoceras rhotomagense* zones.

The base of the section lies 100 m below the Sanganeh/Aitamir formation boundary, which is referred to as 0 m. The nautilid occurrences in the Taherabad section begin with *E. clementianum* (NAT-1) at the second glauconitic sandstone bed of the Aitamir Formation (= 129 m level). *E. clementianum* occurs between the latest Aptian index ammonite *Hypacanthoplites uhligi* (Fig. 3a–b) (at the 45 m level) and *Hoplites* (*Hoplites*) *baylei* (at the 290 m level), i.e., the middle to late Albian.

E. sublaevigatum (NAT-2) occurred at the 490 m level of the Taherabad section, just above the ammonite taxa *Mariella* (*Mariella*) *bergeri* (Fig. 3d–e), *Semenoviceras michalskii* (Fig. 3f–i) and *Placenticeras mediasiaticum*. *S. michalskii* and *M.* (*M.*) *bergeri* are the main classical components of the late Albian *Dipoloceras cristatum* and *Stoliczkaia dispar* zones. The upper part of the Taherabad section yielded two specimens of *E. bouchardianum*. At 612 m, the first specimen (NAT-3) of this species was found within the *M. mantelli* Zone, indicating an early Cenomanian age. The highest recorded nautilids at Taherabad are *E. bouchardianum* (NAT-5) and *Eutrephoceras* sp. at the 660 m level. They fall within the *Mantelliceras dixonii* Zone. This zone is marked by the middle Albian *Turrilites costatus* (Fig. 3j), *Turrilites scheuchzerianus*, *Forbesiceras baylissi*, *Cunningtoniceras cunningtoni* and *Acanthoceras rhotomagense* (Fig. 3k–m) at the top, suggesting an early Cenomanian age for the stratigraphic interval between the 625 m–700 m levels.

Systematic Paleontology

Order Nautilida Agassiz, 1847

Superfamily Nautilaceae de Blainville, 1825

Family *Nautilidae* de Blainville, 1825

Genus Eutrephoceras Hyatt, 1894

(See figure on next page.)

Fig. 3 Selected age-diagnostic ammonite species from the Taherabad section, reported in previous studies. 1a–b, *Hypacanthoplites uhligi* (Lehmann et al., 2019; Fig, 7.C). 2a–c, *Mariella* (*Mariella*) *bergeri* (Mosavinia et al., 2014; Fig. 8.C). 3a–d, *Semenoviceras michalskii* (Mosavinia et al., 2014; Fig. 5.B). 4, *Turrilites costatus* (Mosavinia & Wilmsen, 2017; Fig. 5.F). 5a–c, *Acanthoceras rhotomagense* (Mosavinia & Wilmsen, 2017; text—Fig. 5.B)

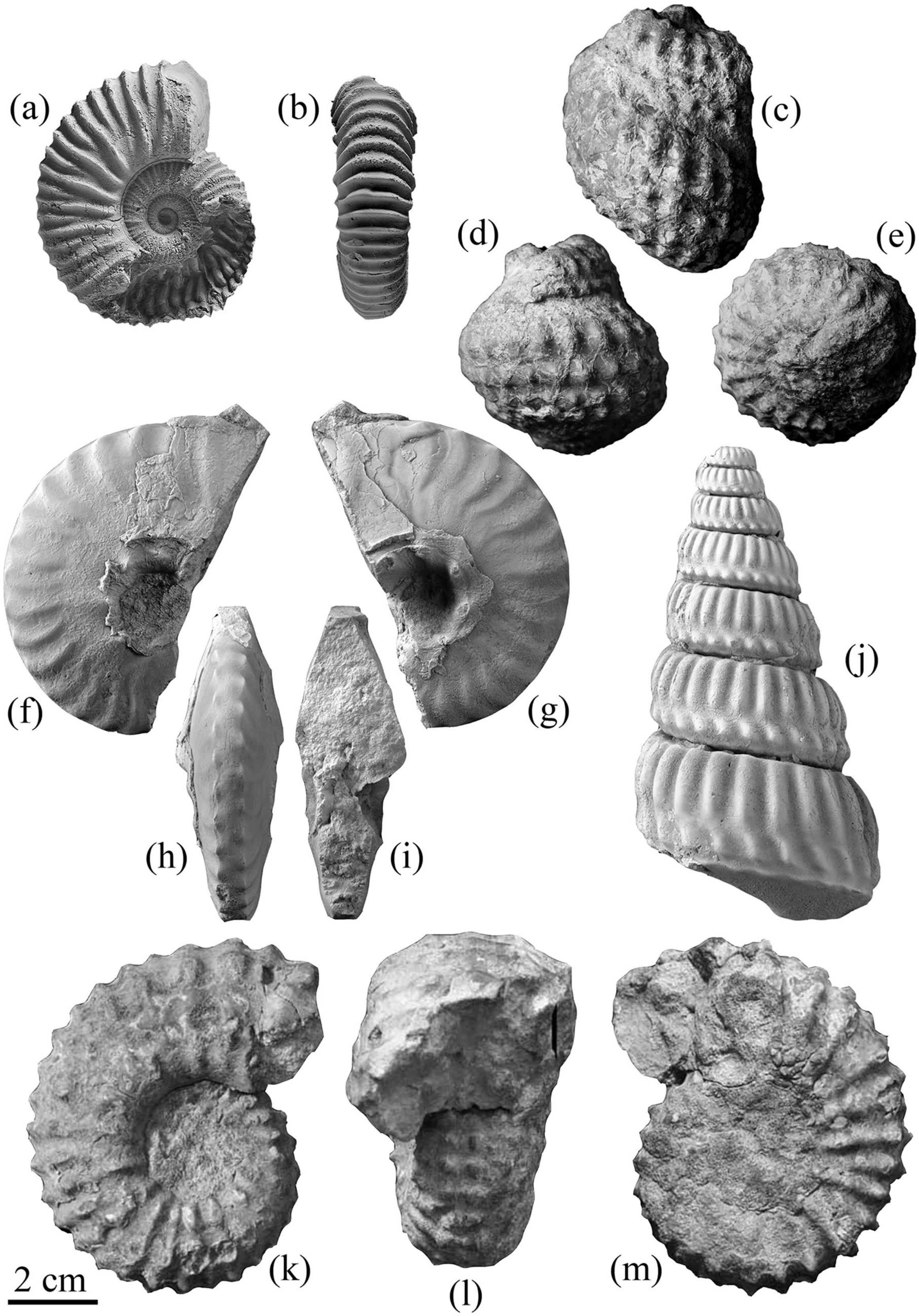

Fig. 3 (See legend on previous page.)

Eutrephoceras bouchardianum (d'Orbigny, 1840)

Figure 4

*1840 *Nautilus bouchardianum* d'Orbigny: 75, pl. 13, Figs. 1–3.

2015 *Eutrephoceras bouchardianum* (d'Orbigny, 1840); Machalski and Wilmsen; p. 497, text-Figs. 3A–D, 4A–B (with synonymy).

Material: Two specimens (NAT-3 and NAT-5 from the early Cenomanian).

Description: NAT-5 (Fig. 4d–g) measures 134 mm in conch diameter. The umbilicus is closed. The whorl section is very involute and depressed (WWI = 0.81–0.92; Table 1). The whorl width is the greatest at the umbilicus. The venter is widely rounded. The shell is only partially preserved and smooth. The suture line is straight to slightly sinuous. There are nine suture lines in a half whorl. The position of the siphuncle was not observable. NAT-3 (Fig. 4a–c) measures 98 mm in conch diameter. The umbilicus appears nearly closed. The whorl section is widely rounded. This specimen is slightly less inflated than NAT-5 (WWI = 0.78–0.80; Table 1). The suture line appears to be nearly straight, although it is only partially exposed. There are 11 septa per half whorl. The siphuncle is not visible.

Discussion: *E. bouchardianum* is characterized by its depressed whorl section (lectotype: ww/dm = 0.82; Wiedmann, 1960), which we tentatively consider a diagnostic character of the species. *E. sublaevigatum* is similar, but has a less inflated whorl section (lectotype: ww/dm = 0.70 Wiedmann, 1960). According to Wiedmann (1960), *E. bouchardianum* has a triangular whorl section, whereas *E. sublaevigatum* is rounded. However, the lectotype figured by Tintant and Gauthier (2006a) shows a somewhat widely rounded venter. Also, the hypotype of *E. bouchardianum* (Wiedmann, 1960, Table 19, Fig. I) exhibits a whorl section that looks similar to the lectotype of *E. sublaevigatum*. Thus, we cannot confirm that whorl section shape is a character that separates the two species. Wiedmann (1960) also mentioned that *E. sublaevigatum* differs from the present species in having a more peripherally located siphuncular position. However, this needs to be comprehensively reinvestigated. For example, Landman et al. (2018) and Tajika et al. (2020) found a significant change in the position of the siphuncle through ontogeny in *Eutrephoceras dekayi* from the lower Maastrichtian in Montana, USA, and Tajika and Klug (2020) also discovered a decreasing ontogenetic trend of siphuncular position in the post-hatching ontogeny of *Nautilus*. The lectotypes of some Albian-to-Cenomanian *Eutrephoceras* species, *E. montmollini* and *E. bouchardianum* are broken phragmocones, whereas *E. sublaevigatum* is a specimen with body chamber preserved. The ontogenetic changes of siphuncular position across/within species have not been investigated. The question arises whether the siphuncle position was always compared between the same growth stages or not. In addition to the above-mentioned characters, *E. sublaevigatum* is more evolute than *E. bouchardianum* according to Machalski and Wilmsen (2015), although we do not see such differences in the lectotypes of each species (i.e., both species seem to have a closed umbilicus). *E. montmollini* appears similar to *E. bouchardianum* in having an inflated whorl section (lectotype: ww/dm = 0.74), but differs in having a wider umbilicus and a central siphuncle. Detailed examinations of the morphological changes occurring during the ontogeny of each species are urgently needed to improve *Eutrephoceras* taxonomy and phylogeny.

Eutrephoceras clementianum (d'Orbigny, 1840)

Figure 5

*1840 *Nautilus Clementianus* d'Orbigny: 77, pl. 13, Figs. 1–6.

1960 *Eutrephoceras clementianum* (d'Orbigny) 1840; Wiedmann: pl. 168, pl. 18, Fig. J (with synonymy).

2006b *Eutrephoceras clementianum* (d'Orbigny, 1840); Tintant and Gauthier: pl. 2, Figs. 5a–b, 6).

2008 *Eutrephoceras clementianum* (d'Orbigny, 1840); Kennedy et al.; pl. 8, Figs. 8, 9.

2018 *Eutrephoceras* cf. *clementianum* (d'Orbigny, 1840); Ayoub-Hannaa et al.; Figs. 4A–E, 5A, B.

Material: One specimen (NAT-1 from the latest Aptian–early Albian).

Description: NAT-1 measures 254 mm in conch diameter with eroded body chamber preserved. The umbilicus is nearly closed. The whorl section is somewhat inflated (WWI = 0.58–0.75) and trapezoidal/rectangular. This specimen has the highest whorl expansion rate among the specimens documented in this paper (WER = 3.43; Table 1). The suture line is slightly sinuous. Septal crowding in the last 13 septa indicates that it is a mature/submature specimen. There are 10 septa in a half whorl. The siphuncle is not visible.

Discussion: According to Wiedmann (1960), this species has a trapezoidal whorl section and is inflated (lectotype: WWI = 0.72). Wiedmann (1960) also mentioned

(See figure on next page.)

Fig. 4 *Eutrephoceras bouchardianum*; **a**–**c** NAT-3, **a** apertural view, **b** and **c** lateral view. **d**–**g**, NAT-5, **d** apertural view, **e** ventral view, **f** and **g** lateral view

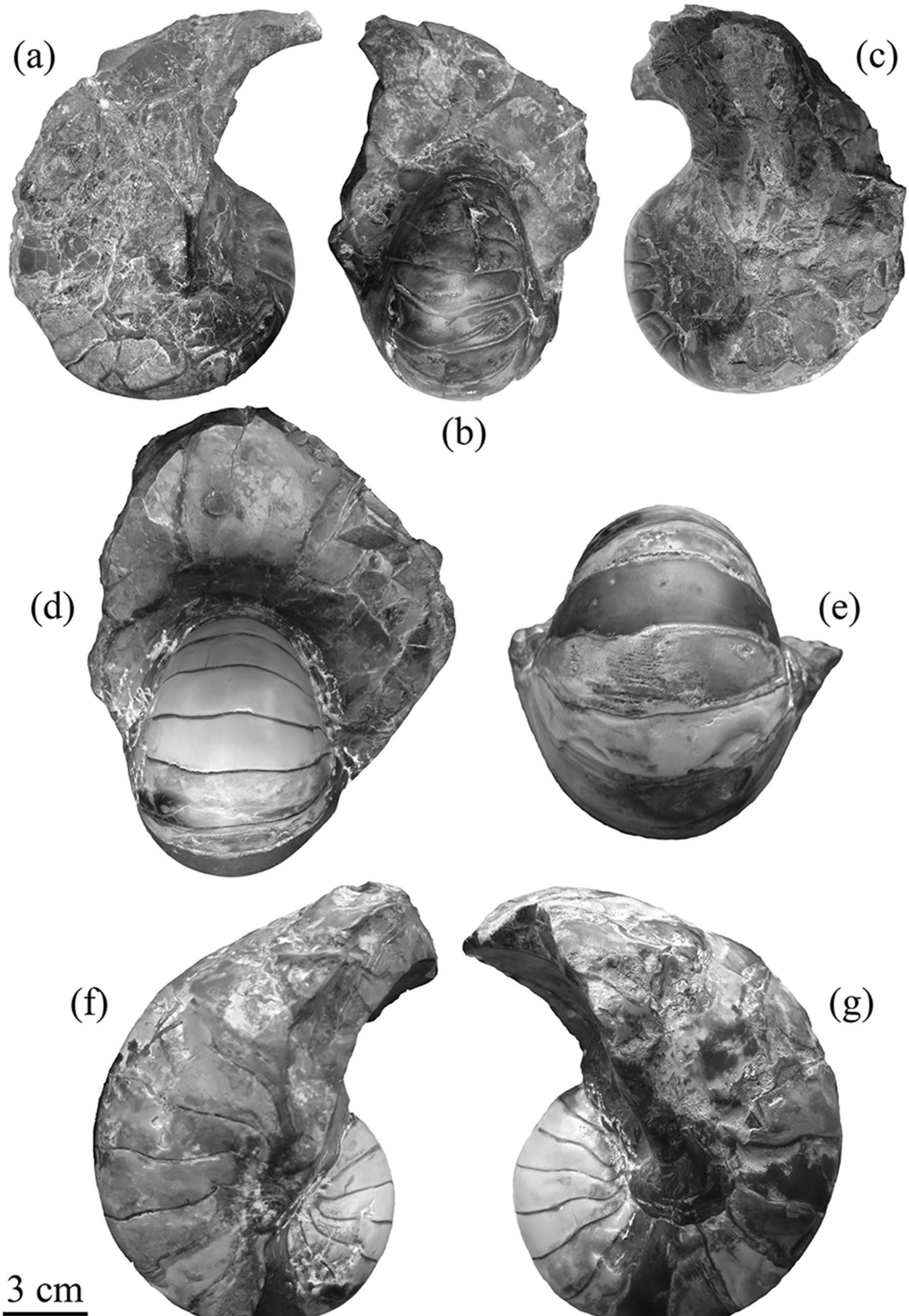

Fig. 4 (See legend on previous page.)

Table 1 Measurements (mm) of studied specimens

Specimen	dm_1	dm_2	ww_1	ww_2	WER	wh_1	wh_2	WWI_1	WWI_2
NAT-5	134	79	109	73	3.39	86	34	0.81	0.92
NAT-2	167	109	114	74	3.06	105	43	0.68	0.68
NAT-3	98	60	76	48	3.27	69	24	0.78	0.80
NAT-1	254	148	147	111	3.43	151	74	0.58	0.75
NAT-4			91						

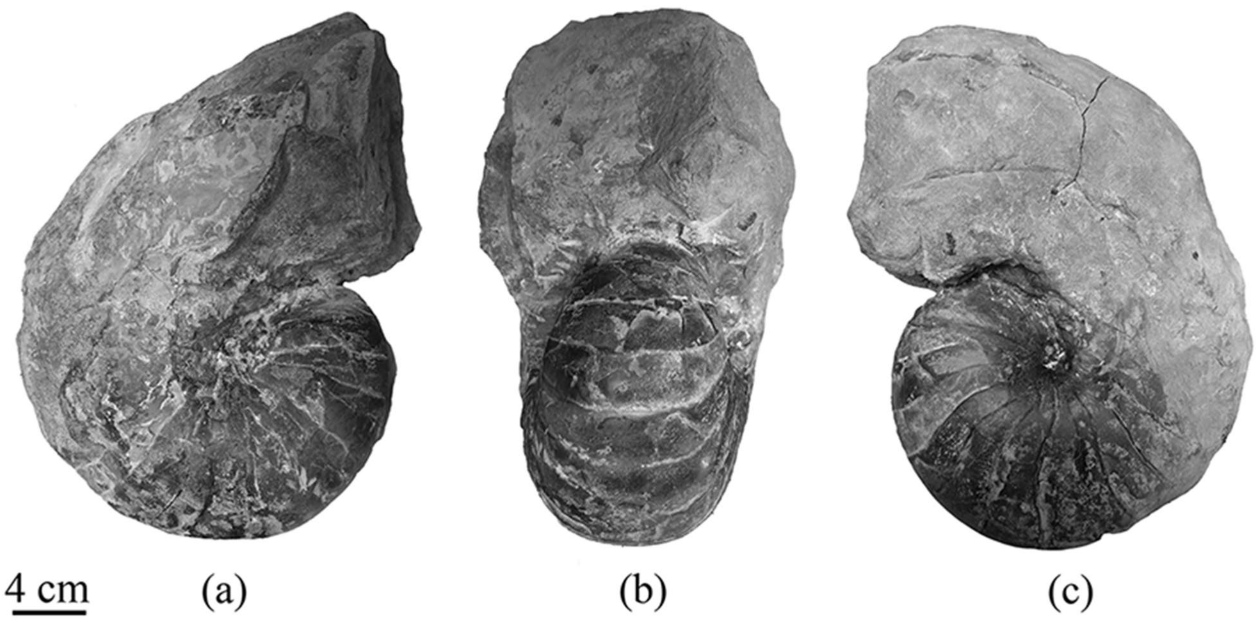

Fig. 5 *Eutrephoceras clementianum*; NAT-1, **a** apertural view, **b** and **c** lateral view

that the siphuncle is dorsally located in this species. However, the lectotype figured by Tintant and Gauthier (2006b; Fig. 5a, b) does not show the siphuncle position since the body chamber of the specimen covers the phragmocone. Presumably, the position of the siphuncle was assumed based on a poorly preserved syntype (a single chamber; Tintant & Gauthier, 2006b; pl 2, Fig. 6). Also, the siphuncular position shifts towards the dorsal margin in at least some taxa (Tajika et al., 2020). The above-mentioned chamber was likely formed slightly before the sexual maturity based on the size. These suggest that the dorsal location of siphuncle may be the result of its ontogenetic change. It is also worth mentioning that our specimen is much larger (254 mm) than the lectotype (180 mm). Assuming that the lectotype is an adult specimen, it is possible that *Eutrephoceras* in Koppeh Dagh Basin grew and reached a much larger adult size than the one in France. In modern *Nautilus*, it is known that different geographic populations exhibit different adult sizes (Saunders, 1987; Tajika et al., 2018). Our discovery may imply that different geographic populations in fossil nautilids have a similar trend.

Eutrephoceras sublaevigatum (d'Orbigny, 1850)

Figure 6

*1850 *Nautilus Sublaevigatus* d'Orbigny: Prodrome II, S. 189.

1960 *Eutrephoceras sublaevigatum* (d'Orbigny) 1960; Wiedmann; p. 165, pl. 19, fig. O, pl. 20, fig. A, pl. 23, fig. L. (with synonymy).

2006c *Eutrephoceras sublaevigatum* (d'Orbigny, 1840); Tintant and Gauthier: pl. 4, fig, 3a, b; pl. 5, Fig. 1a, b, 2a–c.

2017 *Eutrephoceras sublaevigatum* (d'Orbigny, 1850); Tajika et al.; Fig. 5C, C, K, L.

2021 *Eutrephoceras sublaevigatum* (d'Orbigny, 1850); Jattiot et al.; Fig. 27D–P.

Material: One specimen (NAT-2 from the late Albian).

Description: NAT-2 measures 167 mm in conch diameter. The umbilicus is barely visible but appears nearly

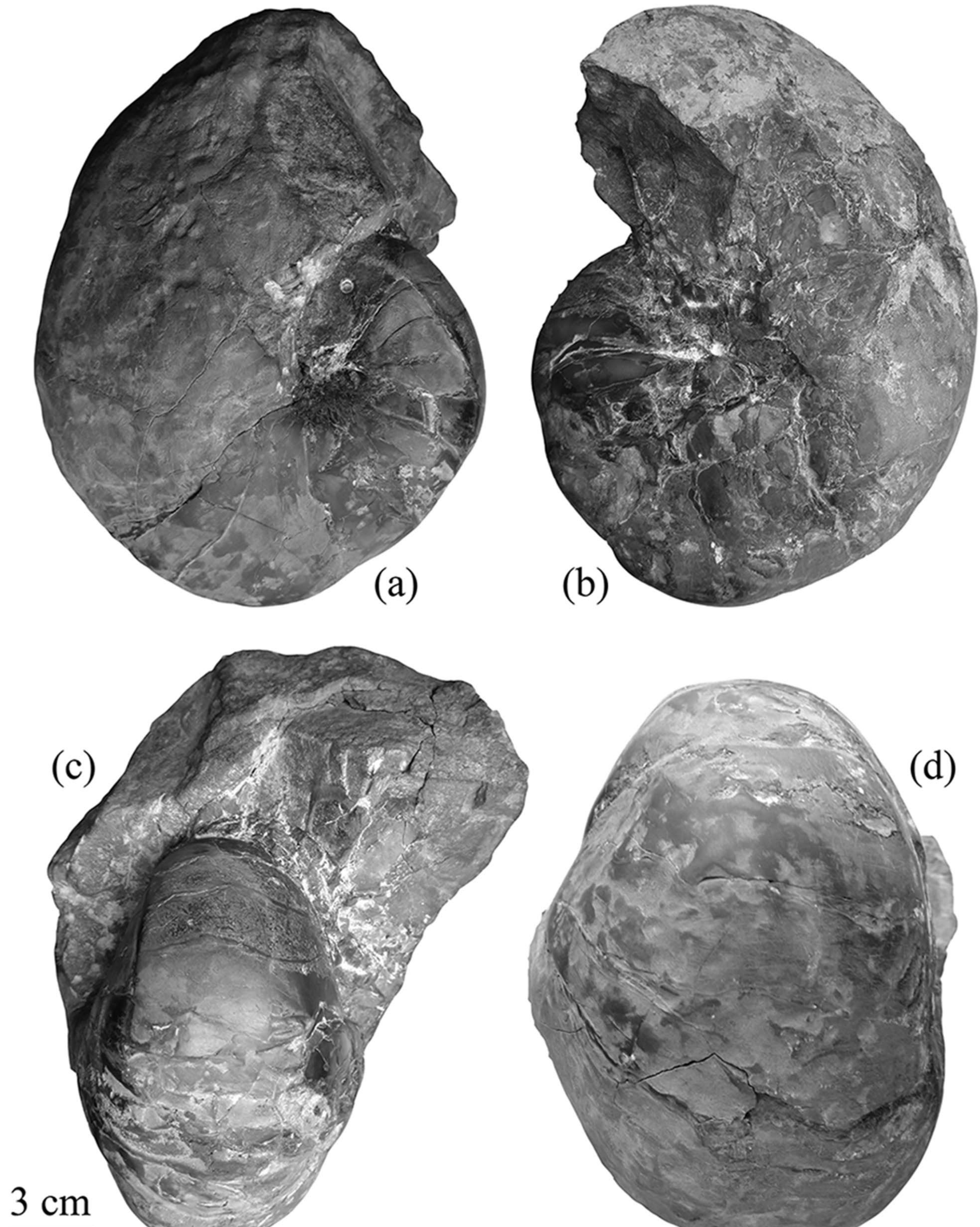

Fig. 6 *Eutrephoceras sublaevigatum*; NAT-2, **a** and **b** lateral view, **c** apertural view, **d** ventral view

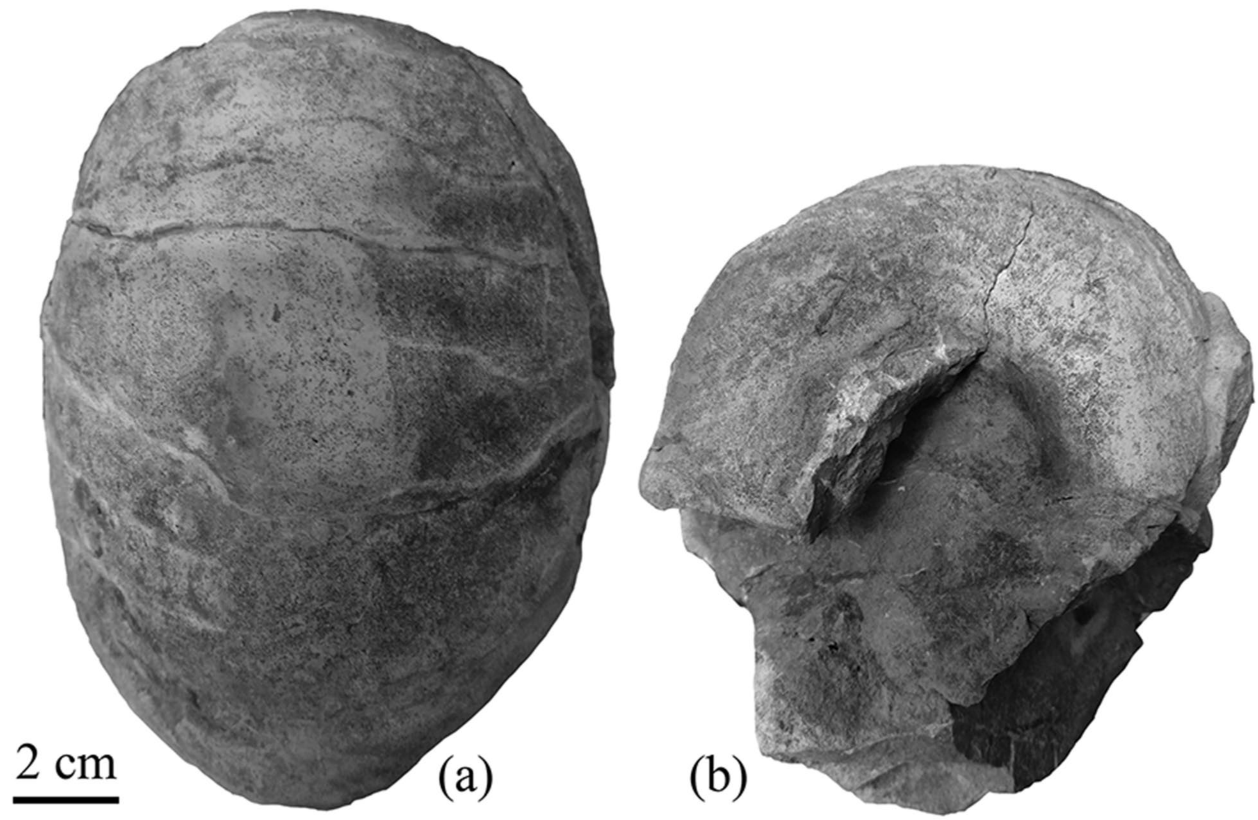

Fig. 7 *Eutrephoceras* sp.; NAT-4, **a** ventral view, **b** apertural view

closed. The whorl section is inflated (WWI = 0.68) and rather narrowly rounded. This specimen bears the smallest whorl expansion rate (WER = 3.06; Table 1) among the documented specimens. The suture is slightly sinuous. There are 13 septa in a half whorl.

Discussion: As discussed above, *E. sublaevigatum* appears similar to *E. bouchardianum* but differs in whorl width index (see the discussion for *E. bouchardianum*). As in *E. clementianum* discussed above, our specimen of *E. sublaevigatum* is larger (167 mm) than the lectotype (110 mm). Provided that the lectotype is an adult specimen, our specimen has a larger adult size, which is congruent with our hypothesis that *Eutrephoceras* attained a larger adult size in Koppeh Dagh Basin.

Eutrephoceras sp.

Figure 7

Material: One incomplete specimen (NAT-4 from the early Cenomanian).

Description: NAT-4 is an incomplete broken phragmocone that measures 91 mm in whorl width. The whorl section is broadly rounded. The suture line is slightly sinuous.

Discussion: The specimen is assigned to *Eutrephoceras* based on the suture line and broadly rounded whorl section. However, the preservation does not allow for species identification.

Conclusions

Five nautilid specimens were collected from the Albian-to-Cenomanian succession of the Taherabad section, situated in the Koppeh Dagh Basin. Lithologically, Taherabad section is composed of a 270-m-thick succession of shales, marls and intercalated ridge-forming sandstones. All the recorded nautilids in the section belong to the genus *Eutrephoceras* and comprise three taxa identified at species level, *Eutrephoceras clementianum* (d'Orbigny, 1840), *E. sublaevigatum* (d'Orbigny, 1850), *E. bouchardianum* (d'Orbigny, 1840) and one specimen at genus rank, *Eutrephoceras* sp. All of them are systematically described and recorded from Iran for the first time. Also, several ammonite bioevents in the Taherabad section provided a basis for the detailed biostratigraphic subdivision and constrained the age of the studied nautilids. *E. clementianum* occurs above the latest Aptian index ammonite *Hypacanthoplites uhligi*; *E. sublaevigatum* came from the late Albian beds and two specimens of *E. bouchardianum* with *Eutrephoceras* sp. are from the early Cenomanian *M. mantelli* and *M. dixonii* zones.

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Authors' contributions
JS, AM and MHTA conceived and planned the idea of this study. They carried out the fieldwork, mechanical cleaning of the nautilids and contributed in interpreting of the stratigraphic position of the recovered nautilids. JS and AT performed the morphologic measurements of the specimens. AT wrote the systematic description of the specimens. JS designed the figures. All authors read and approved the final manuscript.

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Availability of data and materials
All specimens illustrated and described herein are stored at the Fossil Preparation Lab at the Department of Geology, Ferdowsi University of Mashhad, Mashhad, Iran.

Declarations

Competing interests
All authors declare that there are no competing interests.

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