

Upper Albian and Cenomanian (Cretaceous) ammonites from the Debarsu Formation (Yazd Block, Central Iran)

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ABSTRACT:

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New ammonite faunas consisting of 13 taxa provide the first reliable biostratigraphic dating of the Debarsu Formation of the Yazd Block, west-central Iran, indicating several levels in the Upper Albian and Lower Cenomanian, while a foraminiferal assemblage places the top of the Formation in the Middle Turonian. Among the identified ammonite taxa, *Acompsoceras renevieri* (Sharpe, 1857) is recorded from Iran for the first time. The upper part of the lower Upper Albian is proved by the occurrences of mortoniceratinines of the *Mortoniceras* (*M.*) *inflatum* Zone in the lowermost part of the Debarsu Formation. For the upper Upper Albian (traditional *Stoliczkaia dispar* Zone), the *M.* (*Subschloenbachia*) *rostratum* and *M.* (*S.*) *perinflatum* zones are proved by their index taxa. However, there is no evidence of the terminal *Arrhaphoceras* (*Praeschloenbachia*) *briacensis* Zone. The upper part of the lower Lower Cenomanian *Mantelliceras mantelli* Zone (*M. saxbii* Subzone) is proved by *M. saxbii* and *M. cf. mantelli*. Below, there is an ammonite-barren interval of ca. 100 m in thickness between *M.* (*S.*) *perinflatum* zonal strata and the *M. saxbii* Subzone. The upper Lower Cenomanian is documented by the presence of typically *M. dixoni* zonal ammonites such as *Acompsoceras renevieri*. Upper Cenomanian and Turonian ammonites have not been found in the upper part of the Debarsu Formation, but micro-biostratigraphic evidence (planktonic foraminifers) from the uppermost part of the formation indicate that the formation ranges into the Turonian. For the development of the major tectonic unconformity at the base of the overlying Haftoman Formation (which yielded Lower Coniacian inoceramids near its base), only 2–3 myr remain, stressing the geodynamic activity of Central Iran during mid-Cretaceous times.

Key words: Mid-Cretaceous; Central-East Iranian Microcontinent; Taxonomy; Biostratigraphy; Ammonites.

INTRODUCTION

Cretaceous strata are well-exposed in the Khur area of western Central Iran. However, apart from lithostratigraphic mapping (Aistov *et al.* 1984), little is known about the depositional setting and precise

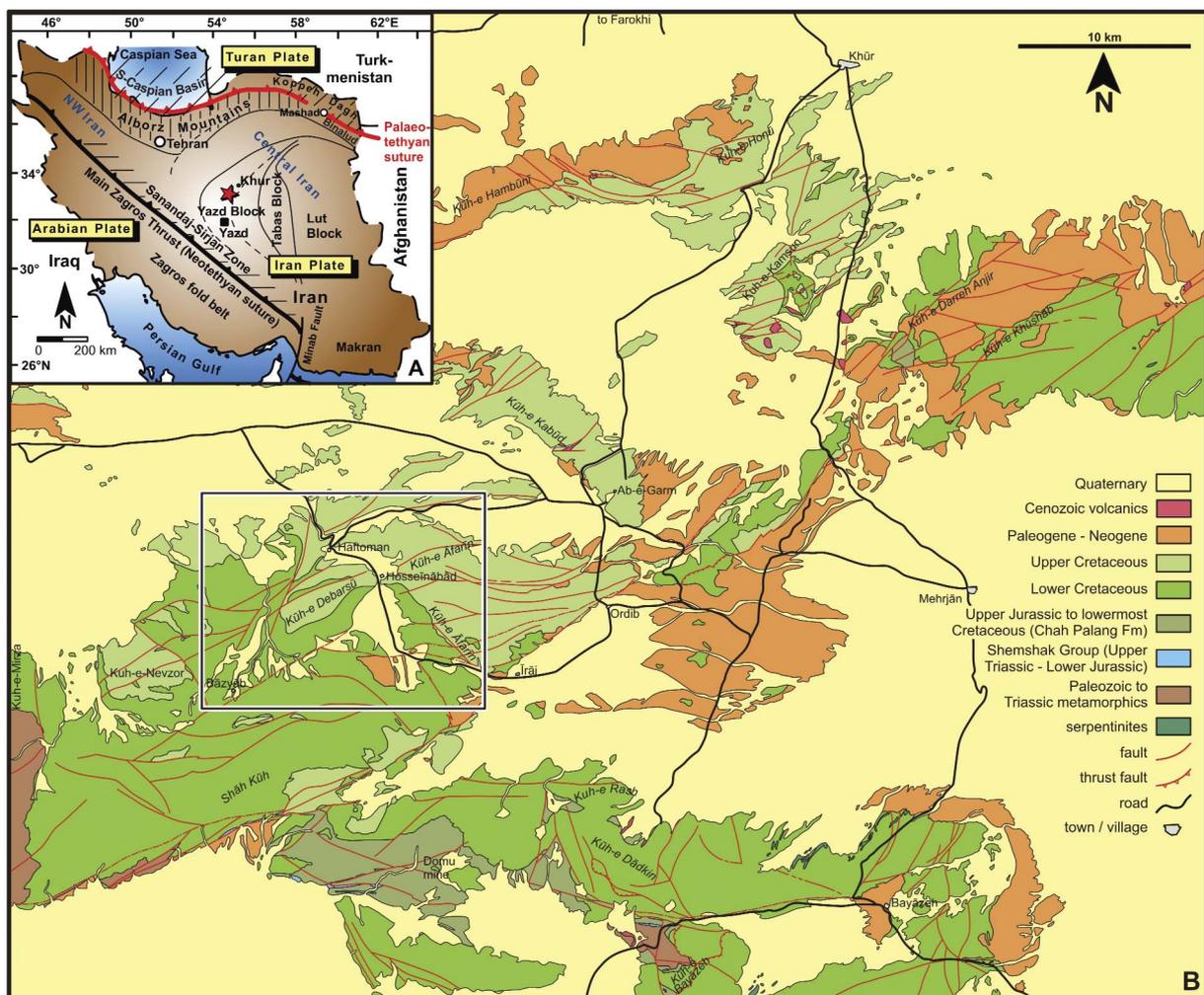
chronostratigraphy of the Cretaceous formations of that area. The only paper dealing with ammonite biostratigraphy was published by Seyed-Emami and Immel (1996) who described a few Albian ammonites from the Bazyab Formation. Starting in 2009, the area was repeatedly re-visited within the framework of the

International Darius Programme, with the aim of understanding the geodynamic significance of the Cretaceous strata of the Yazd Block, Central Iran. Field campaigns by the authors in 2009, 2010 and 2012 yielded important new data on facies development and stratigraphy of the succession and the first results have already been published (Wilmsen *et al.* 2011, 2012, 2013). In this paper we focus on the ammonites collected from the Debarsu Formation, a unit of marls and shallow-water limestones that has only been broadly assigned to the Cenomanian–Turonian, based on poorly age-diagnostic bivalves and echinoids as well as “ammonites *Acanthoceras* sp. that are known from the Cenomanian–Lower Turonian” (Aistov *et al.* 1984, p. 69). No faunal evidence has ever been illustrated and we thus present herein the first unequivocal macrobiostratigraphic data for the chronostratigraphy of the Debarsu Formation.

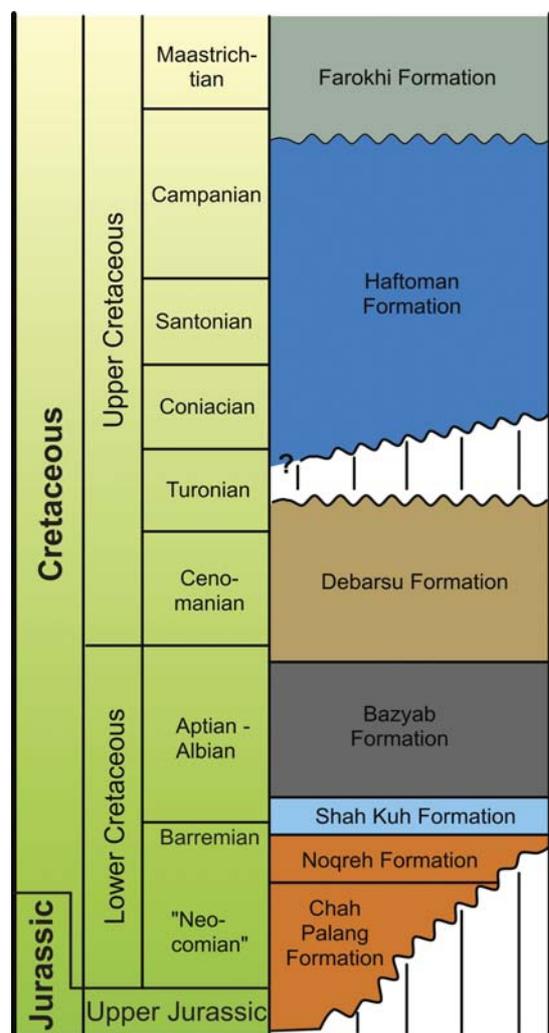
GEOLOGICAL OVERVIEW

General setting

The study area belongs to the so-called “Central-East Iranian Microcontinent” (CEIM; Takin 1972), forming the central part of the Iran Plate (Text-fig. 1). During the Mesozoic Era, the CEIM was a small microplate within the composite plate tectonic mosaic of what is today the Middle East. The CEIM consists of three structural units, i.e. the Yazd, Tabas, and Lut blocks (from west to east; see Berberian and King 1981 and Davoudzadeh 1997 for overviews). Jurassic strata are very thick and well studied on the Tabas Block (see Wilmsen *et al.* 2003, 2009a) while Cretaceous strata are only subordinately developed (Wilmsen *et al.* 2005). In contrast, Jurassic strata are largely absent on the Yazd Block while Cretaceous strata are very thick and widespread.



Text-fig. 1. Geological and geographic framework. **A** – main structural units and sutures of present-day Iran with location of the study area (red asterisk); the Central-East Iranian Microcontinent (CEIM) consists of the Lut, Tabas and Yazd blocks. **B** – geological map of the study area south of Khur (compiled from the Khur Quadrangle map 1:250,000 of Aistov *et al.* 1984 and own field data); the type area of the Debarsu Formation is indicated by a rectangle



Text-fig. 2. Lithostratigraphy of the Cretaceous System in the Khur area, Yazd Block, Central Iran

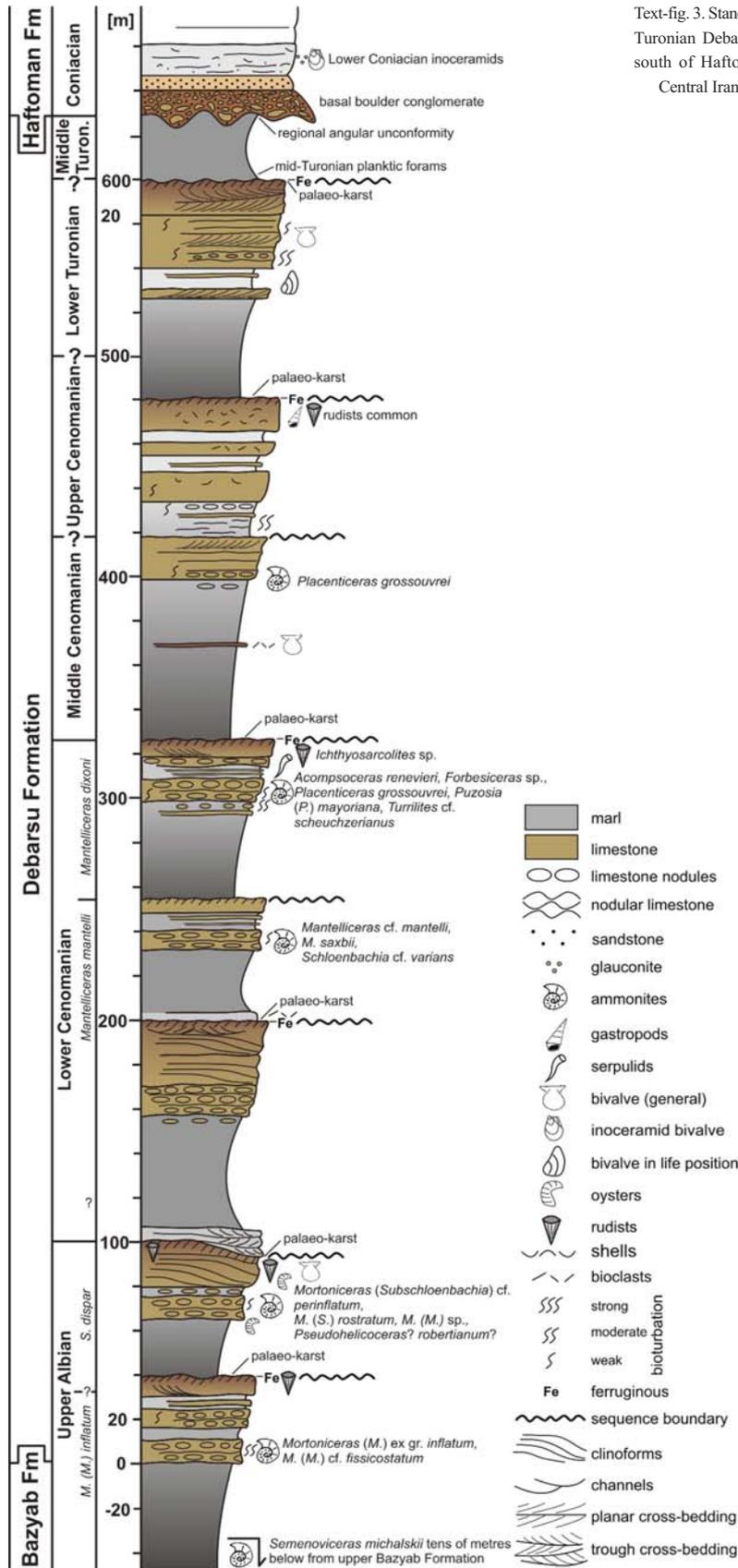
During the Cretaceous Period, the CEIM was separated from the Turan Plate (Eurasia) by narrow oceanic basins (Dercourt *et al.* 1986; Barrier and Vrielynck 2008) which started to open during the Early Cretaceous. Their development may be related to an assumed post-Triassic counter-clockwise rotation of the CEIM around a vertical axis of about 135° with respect to Eurasia (e.g., Davoudzadeh *et al.* 1981; Soffel *et al.* 1996). During the Late Cretaceous and the Paleogene, these small ocean basins closed, as a result of compression in the course of the advance of the Arabian Plate and the closure of the Neotethys (e.g., Stampfli and Borel 2002; Agard *et al.* 2005; Rosetti *et al.* 2010).

This brief geological outline clearly stresses the significance of the Cretaceous sedimentary succession of the Yazd Block for unravelling the Late Mesozoic geodynamic history of the Iran Plate. A key area of the Yazd

Block is around Khur (Text-fig. 1), ca. 200 km north of Yazd. Following the mapping surveys in the early 1980's (Aistov *et al.* 1984), little has been done in terms of geological research in the area apart from the study of some ammonites from the Albian Bazyab Formation (Seyed-Emami and Immel 1996).

Lithostratigraphy

The Cretaceous succession in the Khur area (Text-fig. 2) starts with conglomerates and sandstones of the up to 1,000-m-thick Chah Palang Formation (Aistov *et al.* 1984) covering various basement rocks (metasediments, metamorphics, granitoids) of different ages. These basement units are either part of the Anarak metamorphic complex *sensu lato* (Upper Palaeozoic–Triassic; see Bagheri and Stampfli 2008) or the weakly metamorphic Shemshak Group (Upper Triassic–Middle Jurassic; Fürsich *et al.* 2009a). The basal unconformity is related to the Mid-/Late Cimmerian tectonic event/s (Middle to Late Jurassic; Fürsich *et al.* 2009b; Wilmsen *et al.* 2009b, 2010). The Chah Palang Formation buried a considerable palaeo-relief and has been regarded to be Late Jurassic in age (Aistov *et al.* 1984). However, no biostratigraphic data exist and an entirely earliest Cretaceous age is more likely. Burial of the Cimmerian palaeo-relief continued during the deposition of the succeeding, up to 500-m-thick Noqreh Formation (Aistov *et al.* 1984), consisting of interbedded terrestrial to marginal marine sediments. Wilmsen *et al.* (2013) inferred a Late Barremian age for the top of the formation based on calcareous algae. The next unit is the up to 500 m thick, cliff-forming Shah Kuh Formation (Aistov *et al.* 1984), composed of thick-bedded to massive, often dark-coloured and micritic limestones with abundant orbitolinid foraminifera and rudists, representing a shallow-marine latest Barremian–Early Aptian carbonate platform (Wilmsen *et al.* 2013). It is overlain by the up to 1,500-m-thick basinal marly siltstones and argillaceous marls of the Bazyab Formation (Aistov *et al.* 1984). Ammonites are common and date the formation as Late Aptian to Late Albian (Seyed-Emami and Immel 1996). The succeeding uppermost Albian–Turonian Debarsu Formation (Text-fig. 2) is up to 600 m thick (Text-fig. 3, see below). The Coniacian–Campanian Haftoman Formation of Aistov *et al.* (1984) is up to 1,000 m thick and erosionally overlies the Debarsu Formation and older formations along a major regional tectonic unconformity with a huge basal conglomerate and associated red beds. Up-section, the formation is characterized by bio- and intraclastic limestones of a shallow-water rudist platform. The succeeding Campanian–Maastrichtian Farokhi Formation (Aistov *et al.* 1984) completes the Cretaceous succession of



Text-fig. 3. Standard section of the Upper Albian-Turonian Debarsu Formation in the type area south of Haftoman (Khur area, Yazd Block, Central Iran; see Text-fig. 1 for location)

the Khur area. It consists of marls and limestones deposited in a shallow basinal setting and it attains a thickness of up to 250 m (Wilmsen *et al.* 2012).

The Debarsu Formation

The basinal Bazyab Formation (Aptian–Upper Albian) is replaced by the shallow-water limestones and marls of the up to 600-m-thick Debarsu Formation (Text-fig. 3). The formation mainly consists of decametre-thick units of bioclastic shallow-water limestones with intercalated packages of marl of similar thickness. Without clear biostratigraphic evidence, the formation has been assigned a Cenomanian–Turonian age (Aistov *et al.* 1984). The only validated biostratigraphic data have been provided by Seyed-Emami and Immel (1996) who described and illustrated Late Albian *Mortoniceras ex gr. inflatum* from the base of the Debarsu Formation south of Haftoman.

The basal contact of the Debarsu Formation with the underlying Bazyab Formation is gradational and the formation shows a number of asymmetric, up to 100-m-thick coarsening- and thickening-upward cycles from marl via nodular limestone with ammonites to medium- and thick-bedded skeletal pack- and grainstones, in part showing large-scale clinoforms. Cycle tops are often characterized by palaeo-karst surfaces, terminating the shallowing-upward cycles. Based on the smooth facies transitions and the absence of gravitationally re-deposited sediments, a homoclinal carbonate ramp is inferred for the Debarsu Formation (Wilmsen *et al.* in prep.). The Debarsu Formation is unconformably overlain by the Haftoman Formation (Text-fig. 3).

The type area of the Debarsu Formation is at Kuche-Debarsu, south of Haftoman (Text-fig. 1), where the formation is well-exposed. During several field campaigns in the last years, numerous detailed sections have been logged and a number of ammonites have been collected *in situ*. These ammonites allow the precise dating of the Debarsu Formation for the first time. Unfortunately, only the lower and middle parts of the formation yielded ammonites, indicating the Upper Albian as well as the Lower and Middle Cenomanian substages (see below). However, a micropalaeontological sample from the uppermost marl package yielded a mid-Turonian planktic foraminifera assemblage, thus confirming that the formation ranges into the Turonian.

SYSTEMATIC PALAEOONTOLOGY

The faunule consists of only 30 specimens, mostly moderately well to poorly preserved (composite) inter-

nal moulds. All specimens are kept in the Museum für Mineralogie und Geologie (MMG) of the Senckenberg Naturhistorische Sammlungen Dresden (SNSD), Germany (repository AsK). A Vernier Caliper has been used to measure all linear dimensions (given in millimeters). Abbreviations are: maximum diameter (D), whorl breadth (Wb), whorl height (Wh), diameter of umbilicus (U). Figures in parentheses are dimensions as a percentage of the diameter. The terminology used for the description of the taxa and the systematic order follow Wright *et al.* (1996). In order to keep this paper short, the synonymies only contain the original citation, important revisions and those of regional interest. Due to the in part poor preservation, some specimens had to be kept in open nomenclature following Bengtson (1988).

Suborder Ammonitina Hyatt, 1889
 Superfamily Desmoceratoidea Zittel, 1895
 Family Desmoceratidae Zittel, 1895
 Subfamily Puzosiinae Spath, 1922
 Genus *Puzosia* Bayle, 1878
 Subgenus *Puzosia (Puzosia)* Bayle, 1878

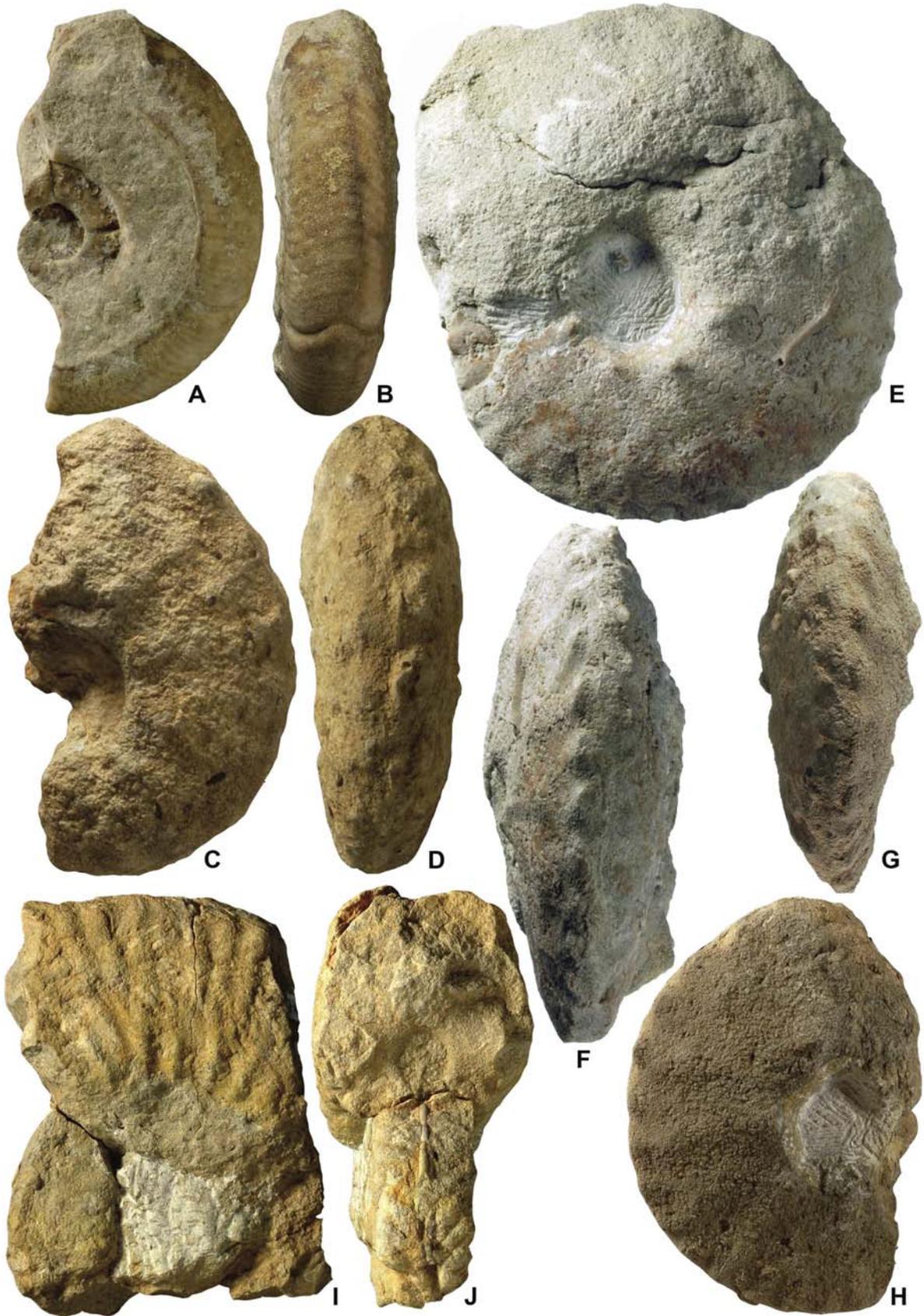
Puzosia (Puzosia) mayoriana (d'Orbigny, 1841)
 (Text-fig. 4A, B)

1841. *Ammonites mayorianus* d'Orbigny, p. 267, pl. 79, figs 1–3.
 1984. *Puzosia (Puzosia) mayoriana* (d'Orbigny, 1841); Wright and Kennedy, p. 55, pl. 3, figs 1, 2, 4, 6, 9–12; pl. 4, figs 1, 2, 5–7; text-figs 1a, b; 2c, h, m; 3n–r; 4a–e. [with synonymy]
 2007. *Puzosia (Puzosia) mayoriana* (d'Orbigny, 1841); Kennedy and Latil, p. 460, pl. 1, figs 1–6; pl. 3, fig. 1. [with additional synonymy]
 2011. *Puzosia (Puzosia) mayoriana* (d'Orbigny, 1841). Gale *et al.*, p. 73, text-figs 14C, E, 15, 18O, 24D
 2011. *Puzosia (Puzosia) mayoriana* (d'Orbigny, 1841). Klein and Vašíček, p. 77. [with additional synonymy]

MATERIAL: A single phragmocone fragment with replaced shell from the Debarsu Formation east of Haftoman.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|----|-----------|-----------|-------|-----------|
| AsK 549 | 68 | 21 (30.8) | 27 (39.7) | 0.78 | 29 (42.6) |

DESCRIPTION: Specimen AsK 549 is fairly evolute (U ~43%) and has a compressed whorl cross-section (Wb/Wh = 0.78). The umbilicus is shallow, the low umbilical wall is near-vertical with a rounded shoulder. The inner flanks are flat, converging to a rounded venter



from mid-flank. There are numerous (~43 per half a whorl) prorsiradiate ribs on the flanks, forming a chevron across the venter. A conspicuous constriction follows the course of the ribs.

REMARKS: Even in fragmentary preservation, the specimen matches *Puzosia (P.) mayoriana* (d'Orbigny) in all major characters (see the comprehensive description and revision by Wright and Kennedy 1984).

OCCURRENCE: In the Debarsu Formation, *Puzosia (P.) mayoriana* has been found in upper Lower Cenomanian strata associated with *Acompsoceras renevieri* (Sharpe, 1857) (Text-fig. 3). The species has a range from the Upper Albian to the Upper Cenomanian, being widespread in Europe, Africa, India, and Japan (Wright and Kennedy 1984). *Puzosia (P.) mayoriana* has already been reported from the Lower Cenomanian of Esfahan (Iran) as *Puzosia (P.) cf. octosulcata* and *Puzosia (P.) cf. subplanulata* (Kennedy *et al.* 1979, p. 24, pl. 1, fig. 13 and pl. 2, fig. 7; Immel and Seyed-Emami 1985, p. 91).

Superfamily Hoplitioidea H. Douvillé, 1890

Family Schloenbachiidae Parona and Bonarelli, 1897

REMARKS: Recently, Cooper and Owen (2011a) proposed a revised classification of the family Schloenbachiidae within the Hoplitioidea, together with a review of the Late Albian representatives. They suggested three subfamilies within the Schloenbachiidae, i.e., Schloenbachiinae, Pleurohoplitinae and Dimorphoplitinae, with 16 included genera. However, a discussion of this fairly far-reaching taxonomic revision (formerly, the family Schloenbachiidae included no subfamilies and contained only one genus, i.e., *Schloenbachia*) is beyond the scope of the present paper. For the time being, we thus use the classification of Wright *et al.* (1996).

Genus *Schloenbachia* Neumayr, 1875

Schloenbachia cf. varians (J. Sowerby, 1817)
(Text-fig. 4C, D)

cf. 1817. *Ammonites varians* J. Sowerby, p. 169 (pars), pl. 176 (top figure, middle figure in row below, figures of lower row).

cf. 2011. *Schloenbachia varians* (J. Sowerby, 1817); Kennedy *et al.*, p. 218, text-figs 10E, F, S–X, 11L–O, Q–T.

cf. 2011. *Schloenbachia varians* (J. Sowerby, 1817); Wilmsen and Mosavinia, p. 174, text-figs 4–7. [with synonymy]

cf. 2013. *Schloenbachia varians* (J. Sowerby, 1817); Kennedy, p. 448, pls 1–14, text-figs 3–9.

MATERIAL: A single, non-septate fragment (half a whorl) from the Debarsu Formation south of Haftoman.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|----|---------|---------|-------|-----------|
| AsK 822 | 40 | 12 (30) | 18 (45) | 0.66 | 11 (27.5) |

DESCRIPTION: The small fragment (AsK 822) is moderately evolute and compressed. The umbilicus is deep with overhanging wall and rounded umbilical shoulder. The flanks are strongly worn but still show primary ribs arising at the umbilical shoulder and shorter intercalatories, the former carrying weak lateral tubercles. All ribs end at distinct ventrolateral clavi forming two rows of opposite clavate tubercles joining a delicate keel on the narrow venter.

REMARKS: Due to its poor preservation, specimen AsK 822 can be assigned to *S. varians* only with some hesitation. However, it shows the the main characters of the species (e.g., see Wilmsen and Mosavinia 2011). *S. varians* has already been recorded from the Lower Cenomanian of Esfahan, ca. 200 km west of the study area (Kennedy *et al.* 1979), and the well known occurrences from the Koppeh Dagh have recently been revised by Wilmsen and Mosavinia (2011), including documentation and palaeoecologic interpretation of all morphological variants.

OCCURRENCE: In the Debarsu Formation, *S. cf. varians* has been found associated with *Mantelliceras saxbii* (Sharpe, 1857) and *M. cf. mantelli* (J. Sowerby, 1814) (Text-fig. 3), indicating a mid-Early Cenomanian age. The species is widely distributed and very common in the Lower Cenomanian of the Boreal Realm, being known from Iran and the Transcaspien area in the east to eastern Greenland in the west (e.g., Kennedy *et al.* 1979; Wilmsen and Mosavinia 2011). This is the first record of *S. cf. varians* from the Central-East Iranian Microcontinent (according to palaeogeographic reconstructions at 15–20° northern palaeo-latitudes), casting

Text-fig. 4. Ammonites from the Debarsu Formation [all specimens are natural size except C, D, which is $\times 2.0$]. **A, B** – *Puzosia (Puzosia) mayoriana* (d'Orbigny, 1841), specimen AsK 549 from the middle part of the formation east of Haftoman. **C, D** – *Schloenbachia cf. varians* (J. Sowerby, 1817), specimen AsK 822 from the middle part of the formation south of Haftoman. **E–H** – *Placentoceras grossouvrei* Semenov, 1899 from the middle part of the formation east of Haftoman; **E, F** – specimen AsK 554; **G, H** – specimen AsK 553. **I, J** – *Mortoniceras (Mortoniceras) cf. fissicostatum* Spath, 1932, specimen AsK 547a from the lowermost part of the formation near Hosseinabad

some doubt on the temperate Boreal affinity of the species, widely reported in the literature (see also Wilmsen and Mosavinia 2011 for discussion).

Family Placenticeratidae Hyatt, 1900

REMARKS: Cooper and Owen (2011b) proposed a revised classification of the Hoplitioidea, transferring Anahoplitinae and Semenovicertinae from the Hoplitidae as primitive rootstocks to the Placenticeratidae. Within the family Placenticeratidae they introduced a subfamily Placenticeratinae, including the genera *Placenticeras* and *Karamaites*. A discussion of these interesting ideas is outside the scope of the present paper and, at this time, we refrain from applying this new taxonomic concept.

Genus *Placenticeras* Meek, 1876

Placenticeras grossouvrei Semenov, 1899 (Text-fig. 4E–H)

1899. *Placenticeras* (?) *grossouvrei* n. sp., Semenov, p. 97, pl. 2, fig. 5a–c.
 1980. *Karamaites grossouvrei* (Semenov, 1899); Marcinowski, p. 282, pl. 2, figs 13, 14.
 1984. *Karamaites grossouvrei* (Semenov); Seyed-Emami *et al.*, p. 163, text-figs 3, figs 1a, b, 2a, b, 4b.

MATERIAL: Three moderately well preserved internal moulds, AsK 553 and 825 being septate fragments of half a whorl, while AsK 554 is a complete specimen including body chamber. Specimen AsK 836 shows shell replacement by calcite but is laterally strongly compacted and consists of two parts. Two more specimens (AsK 559, 581) are too poorly preserved to be safely included in the species. They are left in open nomenclature as *Placenticeras* sp.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|----|-----------|-----------|-------|-----------|
| AsK 553 | 73 | 22 (30.1) | 32 (43.8) | 0.68 | 14 (19.2) |
| AsK 554 | 89 | 27 (30.3) | 41 (46.1) | 0.66 | 19 (21.3) |
| AsK 825 | 95 | 33 (34.7) | 43 (45.2) | 0.76 | 20 (21.1) |

DESCRIPTION: Moderately involute (U ~20%), compressed (Wb/Wh ~0.7) placenticeratids with trapezoidal whorl cross-section and greatest whorl breadth at the umbilical margin. The umbilicus is shallow, with steep umbilical wall and broadly rounded umbilical shoulder. The flanks are only weakly convex and taper towards a very narrow venter. On the lowermost part of the flanks,

at the umbilical margin, there are eight round, conical tubercles per whorl that give rise to low, broad primary ribs that branch at mid-flank and are slightly falcid. Some of the secondary ribs also appear to be intercalated. All ribs end in clavate tubercles at the ventrolateral shoulder, alternating across the weakly sulcate, narrow venter.

REMARKS: In shell shape and tuberculation, the specimens from the Debarsu Formation are very close to the description and illustration of *P. grossouvrei* Semenov (1899, p. 97, pl. 2, fig. 5) and thus assigned to this species. Semenov stressed the (for a placenticeratid) relatively strong inflation, the trapezoidal whorl cross-section with the narrow venter as well as the umbilical and alternating clavate ventrolateral tubercles. He did not mention ribs in the original description but his single specimen is only moderately preserved and their absence may be related to taphonomic processes (specimen AsK 825 also lacks ribs) or intraspecific variability (see below). *P. mediasiaticum* Luppov, 1963 (p. 146, pl. 2, figs 1a, b, text-fig. 2) is relatively involute, more compressed and has a finer ornament (see also Marcinowski *et al.* 1996, pl. 12, fig. 5a, b and Kennedy *et al.* 2008a). *P. guardakense* Luppov, 1963 (p. 144, pl. 1a–e, text-fig. 1) is similar in shell shape but has a much broader venter. Kennedy *et al.* (2008a) noted that there is considerable morphological variation in different contemporaneous *Placenticeras* ‘species’ that may in fact reflect intraspecific variability rather than interspecific differences (e.g., in the Koppeh Dagh, *P. grossouvrei*, *P. mediasiaticum* and *P. guardakense* all have been described from the same lower Middle Cenomanian strata; Seyed-Emami *et al.* 1984; Immel *et al.* 1997). Also, the numerous new genera (and probably also some of the species) introduced by Ilyin (1975) for Cenomanian–Lower Turonian placenticeratids from Central Asia are junior synonyms of *Placenticeras* (cf. Marcinowski 1980). The future study of larger, contemporaneous populations of these placenticeratids will show if they can be combined in a few or even a single, strongly variable species.

OCCURRENCE: The specimens all come from the middle part of the Debarsu Formation, the lowest occurrence associated with upper Lower Cenomanian ammonites [*Acompsoceras renevieri* (Sharpe, 1857)] indicating the *M. dixonii* Zone (Text-fig. 3). The higher occurrences (AsK 836) are probably Middle Cenomanian in age. The holotype of *P. grossouvrei* is from the “zone of *Schloenbachia varians*” of Bichatky in Mangyshlak, i.e. the Lower Cenomanian (Semenov 1899, p. 97). The species is known from the Trans-

caspien area, typically occurring in Lower and Middle Cenomanian strata (Marcinowski 1980; Seyed-Emami *et al.* 1984; Immel *et al.* 1997).

Superfamily Acanthoceratoidea Hyatt, 1900

Family Brancoceratidae Spath, 1934

Subfamily Mortoniceratinae H. Douvillé, 1912

Genus *Mortonicer* Meek, 1876

Subgenus *Mortonicer* (*Mortonicer*) Meek, 1876

Mortonicer (*Mortonicer*) cf. *fissicostatum* Spath, 1932

(Text-fig. 4I, J)

cf. 1932. *Mortonicer* (*Pervinquieria*) *fissicostatum* sp. nov., Spath, p. 396, pl. 38, fig. 6; pl. 47, fig. 1; text-fig. 133.

cf. 2007. *Mortonicer* (*Mortonicer*) *fissicostatum* Spath, 1932; Mosavinia *et al.*, p. 88, fig. 6D, E. [with synonymy]

MATERIAL: AsK 547 is a fragmentarily preserved specimen consisting of one larger septate and another small non-septate part which do not fit together.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|---|----|----|-------|---|
| AsK 547a | | 37 | 40 | 0.92 | |
| AsK 547b | | 43 | 49 | 0.87 | |

DESCRIPTION: The illustrated part of specimen AsK 547 is a fragment of a phragmocone with slightly compressed (~0.9), sub-rectangular whorl cross-section. The flanks are parallel and characterized by conspicuous dense ribbing. Ribs are straight and radial, arising at swellings at the umbilical shoulder and partly bifurcate on the lower part of the flanks. At the marked and narrowly rounded ventrolateral shoulder, indistinct tubercles are developed, and the ribs flex forward towards an elevated keel. The venter is flat.

REMARKS: According to Amédéo *et al.* (2004), *Mortonicer* (*M.*) *fissicostatum* is a subjective junior synonym of *Mortonicer* (*M.*) *inflatum* (J. Sowerby, 1818). However, the dense ribbing is very conspicuous and we follow the view of Mosavinia *et al.* (2007) to retain both species separate pending further revision. Due to the poor preservation, the single specimen is only provisionally assigned to Spath's species and kept in open nomenclature.

OCCURRENCE: *Mortonicer* (*M.*) *fissicostatum* is a taxon from the upper part of the traditional lower Up-

per Albian *Mortonicer* *inflatum* Zone. *Mortonicer* (*M.*) cf. *fissicostatum* occurs in the basal part of the Debarsu Formation (Text-fig. 3), associated with *Mortonicer* ex gr. *inflatum* (J. Sowerby, 1818) (see Seyed-Emami and Immel 1996). The species is known from NW Europe, the northern Caucasus, and NE Iran (Mosavinia *et al.* 2007).

Mortonicer (*Mortonicer*) sp.
(Text-fig. 5A, B)

MATERIAL: One slightly obliquely compacted large specimen from the lower Debarsu Formation near Hosseinabad. Also in the inner whorls, sutures are not preserved.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|-----|-----------|-----------|-------|-----------|
| AsK 550 | 138 | 28 (20.2) | 41 (29.7) | 0.68 | 50 (36.2) |

DESCRIPTION: Relatively densely and regularly ribbed, evolute mortoniceratine (U = 36%) with compressed, sub-rectangular whorl cross-section (Wb/Wh = 0.68) and only weakly convex to flat flanks. The umbilicus is shallow with a rounded umbilical wall. At bulate umbilical tubercles (12–13 per half whorl at D = 110 mm) primary ribs arise that regularly branch into two secondary ribs that occasionally also appear intercalated. On the last preserved part of the whorl, ribs become predominantly primaries. All ribs are slightly concave and prorsiradiate, carrying mid-lateral and strong ventrolateral tubercles at which they sweep forward to form an obtuse ventral chevron fading towards an elevated siphonal keel.

REMARKS: The relatively dense, regular ribbing pattern of specimen AsK 550 resembles a mortoniceratine that has been described and illustrated by Spath (1932, p. 408, pl. 38, fig. 1) as *Mortonicer* (*Pervinquieria*) *kiliani* (Lasswitz, 1904). This specimen has been placed in the synonymy of *Mortonicer* (*M.*) *fallax* (Breistroffer, 1840) by Kennedy *et al.* (2008b, p. 42) who also noted that *M. (M.) fallax* co-occurs with the somewhat similar *M. (M.) pachys* (Seeley, 1865), the former being a stout, coarsely ornamented and the latter a more compressed, less strongly ornamented form. In fact, the specimen from the Debarsu Formation also shows some similarities to *M. pachys* (Seeley) as illustrated by Spath (1932, text-fig. 139) from the Upper Albian of Madagascar and by Atabekian (1992, p. 211, pl. 127, fig. 5, pl. 128, fig. 1) from the lower part of the *S. dispar* Zone of Armenia. Furthermore, already Spath (1932) noted that, in the Cambridge Greensand



of England, there are transitional forms between what he called *M. (P.) kiliani* [= *M. (M.) fallax*] and *M. (Pervinquieria) pachys* at that time. It should also be pointed out that Owen (2012, p. 763) regarded *M. fallax* merely as a slightly more coarsely tuberculate *M. (M.) rostratum*, stating that both are in fact contemporaneous. However, we refrain from a specific assignment based on the poor preservation but think that the specimen from the Debarsu Formation belongs to a group of low-*S. dispar* zonal mortoniceratinae.

OCCURRENCE: Specimen AsK 550 was found in the lower part of the Debarsu Formation near Hosseinabad (*S. dispar* Zone according to associated ammonites; cf. Text-fig. 3). A potential affiliation to *M. (M.) fallax* [= *M. (M.) rostratum* according to Owen 2012) would support an early *S. dispar* zonal age (Kennedy *et al.* 2008b; Owen 2012; see biostratigraphic discussion below).

Subgenus *Subschloenbachia* Spath, 1921

Mortoniceras (Subschloenbachia) rostratum (J. Sowerby, 1817)
(Text-fig. 6A–E)

1817. *Ammonites rostratus* J. Sowerby, p. 163, pl. 173.
?1985. *Mortoniceras (Subschloenbachia) rostratum* (J. Sowerby, 1817); Immel and Seyed-Emami, p. 96, pl. 3, fig. 2.
1998. *Mortoniceras (Subschloenbachia) rostratum* (J. Sowerby, 1817); Kennedy *et al.*, p. 17, text-figs 9–11, 13–18. [with synonymy]
2005. *Mortoniceras (Subschloenbachia) rostratum* (J. Sowerby, 1817); Kennedy *et al.*, p. 367, text-figs 10J, K, 12, 13.
2007. *Mortoniceras (Subschloenbachia) rostratum* (J. Sowerby, 1817); Kennedy and Latil, p. 463, pl. 2, fig. 2; pl. 3, figs 3, 6–9; pl. 4, figs 7, 8. [with additional synonymy]
2011. *Mortoniceras (Subschloenbachia) rostratum* (J. Sowerby, 1817); Gale *et al.*, p. 76, text-figs 26A–D, F–O, 27.

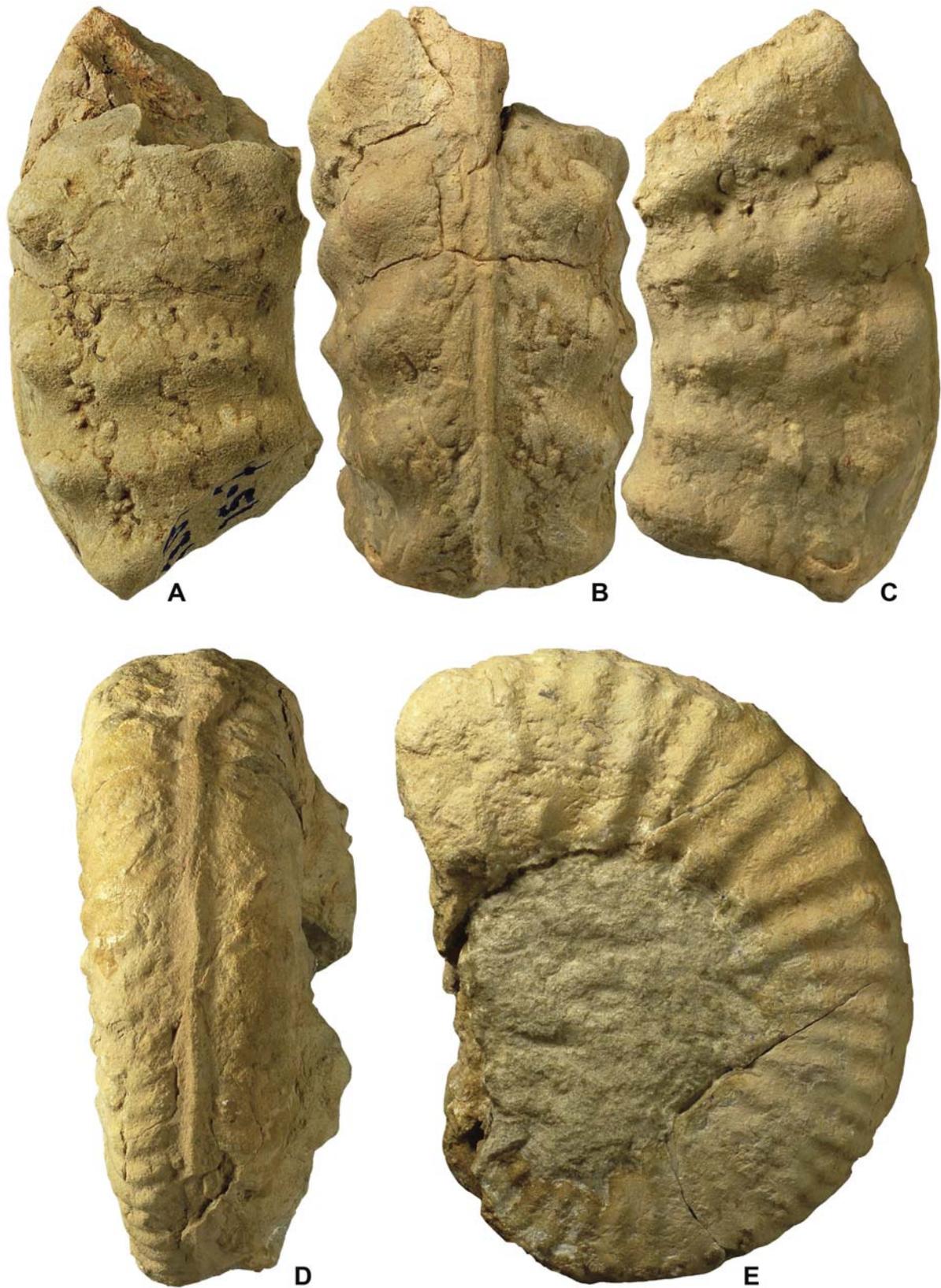
MATERIAL. Two wholly septate internal moulds.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|-----|-----------|-----------|-------|-----------|
| AsK 820 | | 52 | 52 | 1.0 | |
| AsK 817 | 107 | 38 (35.5) | 39 (36.5) | 0.97 | 48 (44.9) |

DESCRIPTION: Specimen AsK 820 is a fragment of a large quadrate phragmocone (Wb/Wh ~1), with a sub-rectangular whorl cross-section in costal view. The intercostal whorl cross-section is more rounded at the ventrolateral shoulders. Primary ribs arise from the umbilical wall and strengthen along the slightly rounded shoulders into bullate umbilical tubercles. The broad straight ribs carry lateral and strong inner-ventrolateral tubercles. Ribs strengthen towards the slightly rounded ventrolateral shoulders where the ribs sweep forward to an elevated siphonal keel, separated by a smooth zone. The venter is broad and flattened. Specimen AsK 817 is very evolute, the umbilicus comprising 44.9 % of the diameter. The whorl is nearly quadrate (Wb/Wh = 0.97), the whorl cross-section is sub-rectangular. Flanks are parallel and flat, the venter is flattened. The umbilical shoulder is narrowly, the ventrolateral shoulder more broadly rounded. Bullate umbilical tubercles (11 per half whorl at D = 107 mm) give rise to primary ribs or pair of ribs. Some single primary ribs branch into two secondary ribs, some secondary ribs are intercalated, resulting in a total number of 22 ribs per half a whorl. The ribbing is dense and regular and ribs are straight and carry lateral, inner ventrolateral and poorly preserved outer ventrolateral tubercles. All ribs flex forward towards an elevated siphonal keel that is flanked by a broad smooth zone.

REMARKS: Both specimens agree well with the descriptions and illustrations provided in recent revisions of *M. (S.) rostratum* (e.g., Kennedy *et al.* 1998, 2005; Kennedy and Latil 2007). The species can be differentiated from *M. (S.) perinflatum* (see below) by means of its less inflated, quadrate whorl cross-section and wider umbilicus. The species has been recorded by Immel and Seyed-Emami (1985) from the glauconitic limestones of Esfahan, although their small and poorly preserved fragment of a body chamber shows only a few of the specific characters.

OCCURRENCE: The two ((specimens were)) collected from the transition between the Bazyab and Debarsu formations at Rudkane-ye Arusan. *M. (S.) rostratum* is the late Late Albian index taxon of the *rostratum* ammonite Zone in the lower part of the traditional *S. dispar* Zone (e.g., Kennedy and Latil 2007; Gale *et al.* 2011; Owen 2012; see also below). The species is known from many places in Europe, Crimea, the Transcaspian area including Iran (Immel and Seyed-Emami 1985) and Texas (Kennedy *et al.* 1998, 2005; Kennedy and Latil 2007).



Text-fig. 6. *Mortonicerias* (*Subschloenbachia*) *rostratum* (J. Sowerby, 1817) from the transition of the Bazyab and Debarsu formations at Rudkane-ye Arusan (all specimens in natural size). A-C – specimen AsK 820. D, E – specimen AsK 817

Mortoniceras (Subschloenbachia) cf. perinflatum
(Spath, 1922)
(Text-fig. 7A, B)

- cf. 1922. *Inflatoceras (Subschloenbachia) perinflata* Spath, p. 113.
cf. 1985. *Mortoniceras (Subschloenbachia) perinflatum* (Spath, 1922); Immel and Seyed-Emami, p. 97, pl. 3, fig. 3.
cf. 2005. *Mortoniceras (Subschloenbachia) perinflatum* (Spath, 1922); Kennedy *et al.*, p. 365, text-figs 10A, 11A–F. [with synonymy]
cf. 2007. *Mortoniceras (Subschloenbachia) perinflatum* (Spath, 1922); Kennedy and Latil, p. 464, pl. 3, figs 2, 4, 5. [with additional synonymy]
cf. 2011. *Mortoniceras (Subschloenbachia) perinflatum* (Spath, 1922); Gale *et al.*, p. 76, text-figs 28A, F, G, 29F.

MATERIAL: A single, septate internal mould (AsK 821) showing the transition into the body chamber from the lower Debarsu Formation near Hosseinabad.

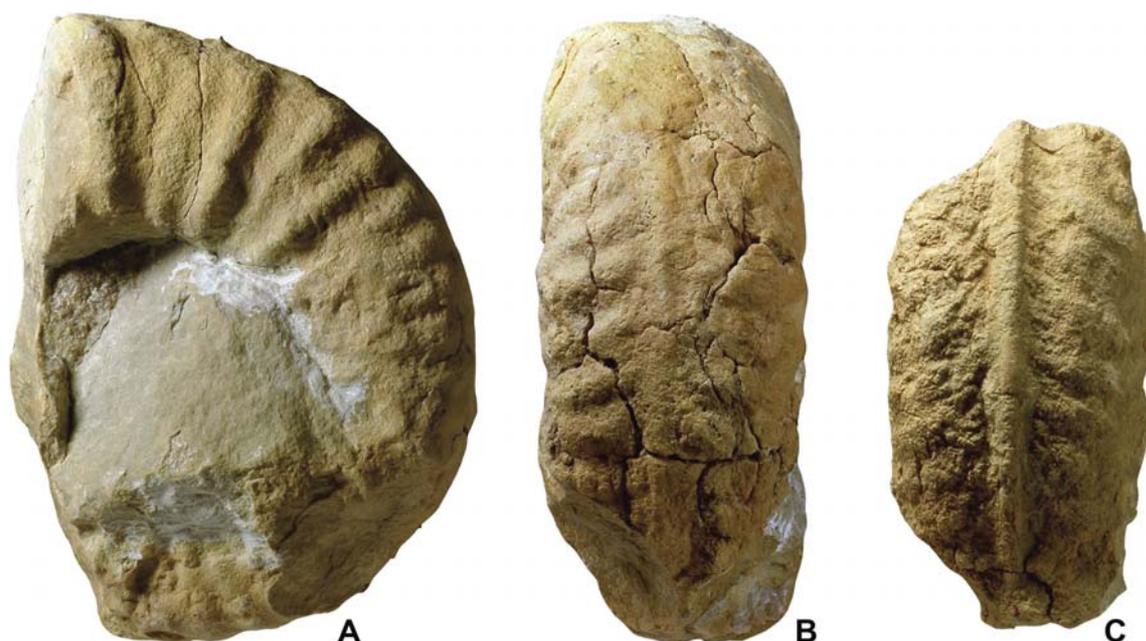
| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|----|-----------|-----------|-------|-----------|
| AsK 821 | 86 | 36 (41.9) | 31 (36.0) | 1.16 | 32 (37.2) |

DESCRIPTION: Evolute (U ~37%) mortoniceratine with a depressed (Wb/Wh = 1.16) sub-rounded whorl cross-section. The umbilicus is deep, the umbilical wall

is high and subvertical, grading into a broadly rounded umbilical shoulder. The flanks are broadly rounded, with greatest whorl breadth below mid flank, and converge in the outer part towards broadly rounded ventrolateral shoulders. The venter is broad and slightly rounded, with a blunt siphonal keel. Primary ribs arise on the umbilical wall, carrying strong umbilical bullae, giving rise to coarse, radial single ribs. Shorter and less prominent ribs are intercalated. At the ventrolateral shoulder, inner and outer ventrolateral tubercles seem to be present, and the ribs sweep forward. They form an obtuse chevron and decline in height, producing smooth grooves along the keel.

REMARKS: The depressed whorl cross-section and ornament approaches specimen AsK 821 to *M. (S.) perinflatum* (for recent descriptions see Kennedy *et al.* 2005 and Kennedy and Latil 2007). *M. (S.) rostratum* is less depressed and more evolute (see above, as well as Kennedy *et al.* 1998 and Kennedy and Latil 2007). The lack of lateral tubercles may a preservational feature, but we prefer to keep the specimen in open nomenclature, only provisionally assigning it to Spath's species as *M. (S.) cf. perinflatum*. Another fragment of a venter (specimen AsK 543, Text-fig. 7C) may also belong here, but we prefer to identify it only to the generic level.

OCCURRENCE: The single specimen has been collected from the lower Debarsu Formation near Hosseinabad (Text-fig. 3). *M. (S.) perinflatum* is the index



Text-fig. 7. Ammonites from the Debarsu Formation (all specimens in natural size). A, B – *Mortoniceras (Subschloenbachia) cf. perinflatum* (Spath, 1922), specimen AsK 821 from the lower Debarsu Formation near Hosseinabad. C – *Mortoniceras (S.)* sp., specimen AsK 543 from the lower Debarsu Formation near Hosseinabad

taxon of an eponymous late Late Albian ammonite zone in the middle part of the traditional *S. dispar* Zone (e.g., Kennedy and Latil 2007; Gale *et al.* 2011; Owen 2012; see also below). The species is known from many places in Europe, possibly Crimea, the Transcaspiian area including Iran (Immel and Seyed-Emami 1985), Angola, South Africa, and Texas (Kennedy *et al.* 2005; Kennedy and Latil 2007).

Family Forbesiceratidae Wright, 1952
Genus *Forbesiceras* Kossmat, 1897

Forbesiceras sp.
(Text-fig. 8D, E)

MATERIAL: One poorly preserved, non-septate fragment (half a whorl).

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|-----|-----------|-----------|-------|---|
| AsK 548 | 114 | 21 (18.4) | 76 (66.6) | 0.27 | |

DESCRIPTION: Strongly compressed forbesiceratid with relatively broad and flat ribs ending at small ventrolateral clavi. Ribs are only preserved on the outer flank. Lateral sides are only weakly convex with maximum whorl breadth in the upper part of the lower flank. The venter is flat, no ornament is visible.

REMARKS: Specimen AsK 548 shows some similarities to *F. chevillei* (Pictet and Renevier, 1866) as described by Wright and Kennedy (1984, p. 93, pl. 13, fig. 2, pl. 15, figs 1, 2, text-fig. 17) and Kaplan *et al.* (1998, p. 112, pl. 1, fig. 6, pl. 9, figs 9, 10, pl. 11, fig. 3), especially with respect to the relatively broad and flat secondaries. *F. baylissi* Wright and Kennedy, 1984 may also be similar with respect to the ribbing on the outer flanks and ornament on the venter (especially the specimen illustrated as *F. cf. baylissi* on their pl. 13, fig. 3a, b). Furthermore, the latter species is known from Iran (Mosavinia and Wilmsen 2011). However, the single specimen from the Debarsu Formation is too poorly preserved and only allows a generic identification.

OCCURRENCE: *Forbesiceras* is a typically Cenomanian genus that is very widespread but usually rare (Wright and Kennedy 1984). The specimen from the Debarsu Formation is from the middle part of the formation (Text-fig. 3), associated with *A. renevieri* (Sharpe, 1857) indicating a late Early Cenomanian age.

Family Acanthoceratidae de Grossouvre, 1894
Subfamily Mantelliceratinae Hyatt, 1903
Genus *Mantelliceras* Hyatt, 1903

Mantelliceras saxbii (Sharpe, 1857)
(Text-fig. 8A–C)

1857. *Ammonites saxbii* Sharpe, p. 45, pl. 20, fig. 3.
1984. *Mantelliceras saxbii* (Sharpe, 1857); Wright and Kennedy, p. 121, pl. 23, fig. 4; pl. 32, figs 1–3; pl. 33, figs 1–4; pl. 34, figs 1–4; pl. 35, figs 1–5; pl. 36, figs 2, 3; pl. 39, fig. 1; text-figs 25B–D, I, 26B, 28L–P. [with synonymy]
2011. *Mantelliceras saxbii* (Sharpe, 1857); Mosavinia and Wilmsen, p. 182, figs 4C, F, G. [with additional synonymy]

MATERIAL: Two internal moulds: AsK 818 is a fragment consisting of three chambers of the phragmocone and a part of the body chamber while AsK 819 shows the inner whorls.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|----|-----------|-----------|-------|------------|
| AsK 819 | 41 | 12 (29.2) | 20 (48.7) | 0.6 | ~9 (~22.0) |
| AsK 818 | 93 | 26 (27.9) | 32 (34.4) | 0.81 | 31 (33.3) |

DESCRIPTION: Specimens AsK 819 is moderately involute ($U = 22\%$) and strongly compressed. The flanks are only weakly convex and covered by densely spaced radial ribs (ca. 18 per half whorl). Primary ribs originate at weak umbilical tubercles and further ribs either intercalate or branch from the primaries on the lower part of the flank. All ribs bear inner and clavate outer ventrolateral tubercles. The ribs are straight and somewhat weakened across the flat to slightly sulcate venter. Specimen AsK 818 represents a later growth stage and is moderately evolute ($U = 33\%$) and less compressed. The ribbing is coarser and consists of a regular alternation of primary and intercalated ribs. Inner ventrolateral tubercles seem to fade and only the strong outer ventrolateral clavi persist onto the body chamber.

REMARKS: The two specimens from the Debarsu Formation agree well in their morphology to specimens of *M. saxbii* as described and illustrated in the literature. The species is strongly dimorphic (Wright and Kennedy 1984), and thus, they may represent micro- and macroconch.

OCCURRENCE: In the study area, *Mantelliceras saxbii* has been found in the middle part of the De-

Text-fig. 8. Ammonites from the Debarsu Formation (all specimens in natural size). **A–C** – *Mantelliceras saxbii* (Sharpe, 1857), specimen AsK 819 from the middle part of the formation south of Haftoman. **D, E** – *Forbesiceras* sp., specimen AsK 548 from the middle part of the formation east of Haftoman. **F, G** – *Mantelliceras* cf. *mantelli* (J. Sowerby, 1814), specimen AsK 823 from the middle part of the formation south of Haftoman



barsu Formation (Text-fig. 3), associated with *M. cf. mantelli* (J. Sowerby, 1814) and *S. cf. varians* (J. Sowerby, 1817). It is an Early Cenomanian species, being particularly common within the upper of three subzones of the *M. mantelli* Zone, i.e. the *M. saxbii* Subzone; as a rarity, the species may range into the succeeding *M. dixonii* Zone (Wright and Kennedy 1984). *M. saxbii* is well known from other parts of Iran (Esfahan area: Kennedy *et al.* 1979; Koppel Dag: Seyed-Emami and Aryai 1981; Mosavinia and Wilmsen 2011) and also occurs in Europe, northern and southern Africa, Madagascar and other parts of the Middle East (Wright and Kennedy 1984; Kennedy *et al.* 2008a).

Mantelliceras cf. mantelli (J. Sowerby, 1814)
(Text-fig. 8F, G)

- cf. 1814. *Ammonites mantelli* J. Sowerby, p. 119, pl. 55 [only lower figure].
cf. 1984. *Mantelliceras mantelli* (J. Sowerby, 1814); Wright and Kennedy, p. 99, pl. 16, fig. 5; pl. 17, figs 1, 3; pl. 18, figs 1–3; pl. 19, figs 1–6; pl. 21, figs 2, 4; pl. 24, fig. 3; pl. 36, fig. 1; text-figs 20A–D, 26A, C, E. [with synonymy]
cf. 2011. *Mantelliceras mantelli* (J. Sowerby, 1814); Mosavinia and Wilmsen, p. 178, text-fig. 3A–E. [with additional synonymy]

MATERIAL: A single specimen consisting of the partly crushed phragmocone and the body chamber.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|-----|-----------|-----------|-------|-----------|
| AsK 823 | 113 | 43 (38.1) | 45 (39.8) | 0.96 | 30 (26.5) |

DESCRIPTION: The inner whorls of specimen AsK 823 are partly crushed but slightly more compressed than the body chamber (Wb/Wh 0.96). The umbilicus is moderately wide (U = 26.5 %) and deep. On the rounded umbilical wall, nine primary ribs per half whorl arise that carry tubercles at the umbilical margin and on the lower flank. Shorter intercalated ribs appear at mid-flank, and there are twice as many ribs on the outer flank as on the inner. Inner and outer ventrolateral tubercles are present, weakening on the body chamber. The venter on the inner whorl is flat to slightly sulcate between the outer ventrolateral tubercles and broadly rounded on the body chamber. All ribs cross the venter. The whorl-breadth to -height ratio increases on the adapertural part of the phragmocone/body chamber and the whorl cross-section becomes sub-rounded.

REMARKS: The preserved characters of the specimen allow an assignment to *M. mantelli* but due to the (at best) moderate preservation we favour to keep it in open nomenclature. In some aspects (coiling, ribbing) similarities exist also to *M. cantianum* Spath, 1926, but this species should have a much more inflated whorl cross-section (Wb/Wh >1.2) and more prominent lateral tubercles. However, as pointed out by Wright and Kennedy (1984, p. 104), there are specimens that appear to be transitional between both species.

OCCURRENCE: *Mantelliceras mantelli* is the ammonoid index of the lower part of the Lower Cenomanian (e.g., Kennedy 1984; Wright *et al.* in Wright and Kennedy 1984; Hancock 1991). In the Debarsu Formation, *Mantelliceras cf. mantelli* occurs in the middle part of the formation (Text-fig. 3), associated with *M. saxbii* (Sharpe, 1857), suggesting a late *M. mantelli* zonal age. The species is widely distributed in Europe, northern Africa, Madagascar, Iran, India, and Japan (Wright and Kennedy 1984; Mosavinia and Wilmsen 2011).

Subfamily Acanthoceratinae de Grossouvre, 1894
Genus *Acompsoceras* Hyatt, 1903

Acompsoceras renevieri (Sharpe, 1857)
(Text-fig. 9A–E)

1857. *Ammonites renevieri* Sharpe, p. 44, pl. 20, fig. 2a, b.
1987. *Acompsoceras renevieri* (Sharpe, 1857); Wright and Kennedy, p. 140, pl. 43, fig. 2, text-figs 34G, 35D–F, 36A–F, 37–40, 43D, E. [with full synonymy]
2011. *Acompsoceras renevieri* (Sharpe, 1857); Kennedy *et al.*, p. 223, text-fig. 12A–C.

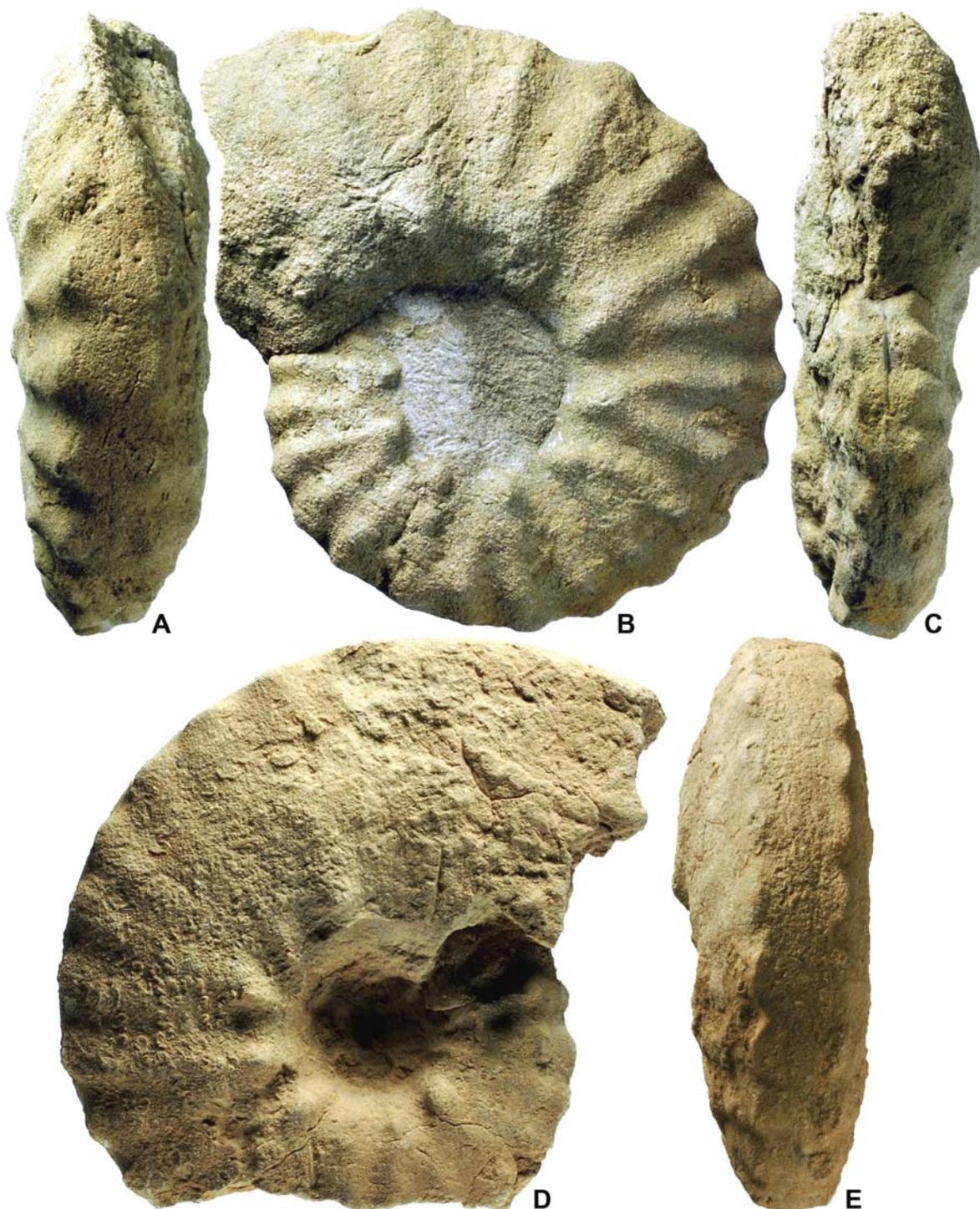
MATERIAL: Six specimens; AsK 558a is a fragmentary body chamber (half a whorl), AsK 558c, d are fragmentary septate internal moulds, while AsK 558e is a septate fragment with shell preservation (replaced by calcite). AsK 557 and 558b are nearly complete internal moulds.

| Specimen | D | Wb | Wh | Wb/Wh | U |
|----------|-----|-----------|-----------|-------|-----------|
| AsK 558a | 157 | 49 (31.2) | 72 (45.8) | 0.68 | 36 (22.9) |
| AsK 558b | 115 | 32 (27.8) | 51 (44.3) | 0.62 | 19 (16.5) |
| AsK 557 | 109 | 29 (26.6) | 49 (44.9) | 0.59 | 30 (27.5) |
| AsK 558c | 88 | 26 (29.5) | 42 (47.7) | 0.6 | 16 (18.1) |
| AsK 558d | 77 | 20 (25.9) | 35 (45.4) | 0.57 | 16 (20.8) |
| AsK 558e | | 24 | 35 | 0.68 | |

DESCRIPTION: All specimens have compressed, sub-rectangular whorl cross-sections with a tabulate venter. The umbilicus is moderately wide (U = 16.5–27.5 %)

and has a broadly rounded umbilical shoulder. Primary ribs arise at the umbilical wall and are strengthened into conspicuous, blunt umbilical bullae (ten at $D = 109$ mm). Rib number is doubled by secondaries either branching from the umbilical bullae or, rarely, being in-

tercalated. Ribs are straight and radial, ending in outer ventrolateral clavi which face each other across the flat venter. Inner ventrolateral tubercles are present but seem to fade in specimen AsK 558b. Overall, ornament is stronger in specimen AsK 557.



Text-fig. 9. *Acompsoceras renevieri* (Sharpe, 1857) from the middle part of the Debarsu Formation east of Haftoman (all specimens in natural size). A-C – specimen AsK 557. D, E – specimen AsK 558b

REMARKS: The specimens can be assigned to Sharpe's species without hesitation, corresponding to it in all important characters and shell proportions. According to Wright and Kennedy (1987), a few specimens of *A. renevieri* may also show a weak siphonal ridge at some growth stages. This subordinate feature is not present in the material from the Debarsu Formation. Comprehensive descriptions and illustrations of the species have been provided by Wright and Kennedy (1987), who also noted that there are more strongly and less strongly ornamented forms (which can be seen in the material from the Debarsu Formation), and that the species is dimorphic with microconchs reaching 135 mm and macroconchs up to 350 mm in diameter (recently, Kennedy *et al.* 2011 described a large macroconch from the condensed Lower Cenomanian Tourtias of Sassegnies, northern France). *A. renevieri* can be separated from the somewhat similar and contemporaneous *A. inconstans* (Schlüter, 1871) on the basis of the absence of mid-lateral tubercles in the former.

OCCURRENCE: *Acompsoceras renevieri* has been recorded with several specimens from a single interval within the middle part of the Debarsu Formation (Text-fig. 3), associated with *Puzosia (P.) mayoriana* (d'Orbigny, 1841), *Placenticeras grossouvrei* Semenov, 1899 and *Forbesiceras* sp., considerably above the level with *Mantelliceras saxbii* and *M. cf. mantelli* (i.e., the upper *M. mantelli* Zone). According to Wright and Kennedy (1987) and Kennedy *et al.* (2011), the species is of Early Cenomanian age, being particularly common in the *M. dixoni* Zone, and this age is also inferred for the specimens from Iran. *A. renevieri* was hitherto known from several places in Europe, northern Africa, Madagascar, and questionably Nigeria. This is the first record of *A. renevieri* from Iran.

Suborder Ancyloceratina Wiedmann, 1966
 Superfamily Turrilitoidea Gill, 1871
 Family Turrilitidae Gill, 1871
 Genus *Turrilites* Lamarck, 1801

Turrilites cf. *scheuchzerianus* Bosc, 1801
 (Text-fig. 10A)

- cf. 1801. *Turrilites scheuchzerianus* Bosc, p. 190.
 cf. 1984. *Turrilites scheuchzerianus* Bosc; Seyed-Emami *et al.*, text-fig. 3, fig. 3.
 cf. 1985. *Turrilites (Turrilites) scheuchzerianus* Bosc, 1801; Atabekian, p. 81, pl. 31, figs 6–11; pl. 32, figs 1–8; pl. 33, figs 1–8; pl. 34, figs 1–7.
 cf. 1996. *Turrilites scheuchzerianus* Bosc, 1801; Wright and

Kennedy, p. 349, pl. 106, figs 7, 8, 11, 12; pl. 107, figs 1–7; text-figs 137G, J, 138C, D, F, G–I, N, 139D–I, 140A,D, E–I, 143H, 147A, B. [with synonymy]

cf. 2007. *Turrilites scheuchzerianus* Bosc, 1801; Wilmsen *et al.*, p. 435, text-fig. 5A, B, J.

MATERIAL: One strongly worn internal mould (AsK 545) that has slightly been laterally compressed by compaction. Sutures are not preserved.

DESCRIPTION: Large turrilitid (preserved height 132 mm) with three adult whorls in tight contact. Apical part missing, complete size may have reached 300 mm. Outer whorls faces broadly convex, covered by oblique (prosi-riate) ribs that are hardly visible due to the poor preservation. Tubercles and crenulations at inter-whorl junctions are lacking. The specimen has an apical angle of 12°.

REMARKS: The specimen is not well preserved. Nevertheless, it can be provisionally assigned to *T. scheuchzerianus* based on the presence of the characteristic, non-tuberculated oblique ribs, the shape of the whorls and the large size. The relatively low apical angle (normally around 20°) may be explained by taphonomic alteration (compaction). The genus *Turrilites* Lamarck, 1801 and included species were recently monographed by Wright and Kennedy (1996).

OCCURRENCE: *T. cf. scheuchzerianus* has been found in the middle part of the Debarsu Formation, associated with typically upper Lower Cenomanian (*M. dixoni* Zone) ammonites (Text-fig. 3). The species has already been recorded from the Iranian (Seyed-Emami *et al.* 1984) and Turkmenian part of the Koppeh Dagh (Atabekian 1985). *T. scheuchzerianus* is cosmopolitan in distribution and ranges from the Lower Cenomanian *M. dixoni* Zone (where it is particularly common) into the Middle Cenomanian *A. jukesbrownei* Zone (Wright and Kennedy 1996).

Genus *Pseudhelicoceras* Spath, 1921

Pseudhelicoceras? robertianum? (d'Orbigny, 1842)
 (Text-fig. 10B)

- ? 1842. *Turrilites robertianus* d'Orbigny, p. 585, pl. 142, figs 1–6.
 ? 1985. *Pseudhelicoceras robertianum* (d'Orbigny, 1842); Atabekian, p. 23, pl. 1, figs 1–5, pl. 2, figs 1–3.
 ? 2006. *Pseudhelicoceras robertianum* (d'Orbigny, 1842); Kennedy and Juignet, p. 169, pl. 47, figs 7a, b, 8–10.

MATERIAL: One fragmentary internal mould of two outer, non-septate whorls (AsK 546).

DESCRIPTION: Somewhat loosely coiled turricone with rounded whorl cross-section (31 mm high in last preserved whorl). Ribs are dense, simple, prorsiradiate and more-or-less evenly spaced on the broadly rounded whorl faces. Every third to fourth rib carries two round, relatively small tubercles, forming two rows in the middle to lower part of the exposed whorl face. A third row of tubercles is weakly indicated on the lower side of the outer whorl.

REMARKS: *Pseudhelicoceras robertianum* is well characterized as a large, loosely coiled species of the genus distinguished by the other species by three rows of large, round tubercles (Kennedy and Juignet 2006). The specimen from the Debarsu Formation shares some of the

specific characters, but appears finer ribbed, has smaller tubercles and is more tightly coiled. *Mariella (M.) circumtaeniata* (Kossmat, 1895) has also three rows of tubercles, a generally rounded whorl section, and looped and intercalated ribs (see Klinger and Kennedy 1978, p. 26, pl. 5, figs A–C). However, the tubercles are quite strong in this species. Based on these uncertainties and the very poor preservation, we assign our single specimen to *P. robertianum* only with great hesitation, both specifically and generically. With respect to the systematic position, we follow Wright *et al.* (1996) and place the genus *Pseudhelicoceras* Spath in the Turrititidae Gill although others (Scholz 1979; Monks 2010) prefer to place it with the Anisoceratidae Hyatt.

OCCURRENCE: The specimen from the Debarsu Formation was found in the lower part of the Debarsu Formation near Hosseinabad associated with *S. dispar* Zone



Text-fig. 10. Ammonites from the Debarsu Formation (all specimens in natural size). **A** – *Turritites* cf. *scheuchzerianus* Bosc, 1801, specimen AsK 545 from the middle part of the formation south of Haftoman. **B** – *Pseudhelicoceras?* *robertianum*? (d'Orbigny, 1842), specimen AsK 546 from the lower Debarsu Formation near Hosseinabad

mortoniceratine ammonites (Text-fig. 3). *P. robertianum* is widespread (Texas, several places in Europe, Madagascar, Transcaspien area), being also well known from the Turkmenian part of the Koppeh Dag (Atabekian 1985). It is an essentially Late Albian species, ranging from the upper *M. inflatum* into the *S. dispar* Zone. This questionable record would be the first proof from Iran.

BIOSTRATIGRAPHIC CONCLUSIONS

The recently collected ammonite faunas from the Debarsu Formation of the Yazd Block, west-central Iran, consists of 13 taxa. Due to the in part poor preservation, several specimens have to be kept in open nomenclature. Nevertheless, the faunas are very important as they provide the first reliable macro-biostratigraphic evidence for the chronostratigraphy of the Upper Albian–Turonian Debarsu Formation and the hiatus at the base of the unconformably overlying Coniacian–Campanian Haftoman Formation.

Among the identified taxa, *Acompsoceras renevieri* (Sharpe, 1857) is recorded from Iran for the first time. The collected faunas allows the recognition of the following ammonite biozones (Text-fig. 11; biozonation compiled after Kennedy 1984; Wright *et al.* in Wright and Kennedy 1984; Hancock 1991; Cecca 1997; Gale *et al.* 2005, 2011; Amédro 2008; Kennedy and Latil 2007 and Owen 2012).

The Upper Albian is proven by the occurrences of mortoniceratines in the lower part of the Debarsu Formation. The finds of *Mortoniceras* (*M.*) *ex gr. inflatum* (J. Sowerby, 1818) (Seyed-Emami and Immel 1996) and *Mortoniceras* (*M.*) *cf. fissicostatum* Spath, 1932 place the lowermost part of the formation into the upper part of the traditional lower Upper Albian *M. inflatum* Zone (see also Mosavinia *et al.* 2007 for data from the Koppeh Dag). The find of *Semenoviceras cf. michalskii* (Semenov, 1899) indicates that the upper part of the underlying Bazyab Formation is of mid-early Late Albian age (middle part of the *M. inflatum* Zone according to Cecca 1997; the ammonites of the Bazyab Formation will be treated in forthcoming paper) and that there can thus be no major break in sedimentation between both formations; the contact is gradual in the study area albeit Aistov *et al.* (1984) report an unconformity with a basal conglomerate from other places. The upper Upper Albian *S. dispar* Zone can be subdivided into three to four zones depending on authors, i.e. the *M. (M.) fallax* and *M. (Subschloenbachia) rostratum* zones (which, however, are contemporaries according to Owen 2012, and are consequently not separated in Text-fig. 11), the *M. (S.) perinflatum* Zone, and the *Arrhapoceras*

(*Praeschloenbachia) briacensis* Zone, the latter ranging into the earliest Cenomanian (e.g., Kennedy and Latil 2007; Gale *et al.* 2011, p. 69; Text-fig. 11). The *M. (S.) rostratum* and *M. (S.) perinflatum* zones are documented by their index taxa. However, there is no evidence for the *A. (P.) briacensis* Zone which, according to Gale *et al.* (2011) is an ill-defined biostratigraphic unit and difficult to recognize outside the Boreal Realm where hoplitids are absent.

The upper part of the lower Lower Cenomanian *Mantelliceras mantelli* Zone (*M. saxbii* Subzone) is indicated by *M. saxbii* (Sharpe, 1857) and *M. cf. mantelli*

| | | Haftoman Formation (Coniacian - Campanian) | | | | | |
|--|-------------------|--|---|--|--------------|----------------------------------|-----------------------------------|
| Bazyab Fm | ammonite evidence | no ammonites | Upper Albian | | | | |
| | | | Mortoniceras inflatum | <i>Mortoniceras (Mortoniceras) inflatum</i> | | | |
| | | | | <i>Hysterocheras varicosum</i> | | | |
| | | | | <i>Semenoviceras michalskii</i> | | | |
| | | | | <i>Dipoloceras cristatum</i> | | | |
| | | | Stoliczkaia dispar | <i>Arrhapoceras (Praeschloenb.) briacensis</i> | | | |
| | | | | <i>Mortoniceras (Subschloenb.) perinflatum</i> | | | |
| | | | | <i>Mortoniceras (Subschloenbachia) rostratum</i> | | | |
| | | | Debarsu Formation | ammonite evidence | no ammonites | Lower Cenomanian | |
| | | | | | | Mantelliceras spp. | <i>Mantelliceras mantelli</i> |
| | | | | | | | <i>Mantelliceras saxbii</i> |
| | | | | | | | <i>Sharpeiceras schlueteri</i> |
| | | | | | | | <i>Neostlingoceras carcitense</i> |
| M. Cenomanian | indirect proof | no ammonites | | | | <i>Cunningtoniceras inerme</i> | |
| | | | | | | <i>Acanthoceras rhotomagense</i> | |
| | | | | | | <i>Acanthoceras jukesbrownei</i> | |
| | | | | | | <i>Turrilites acutus</i> | |
| | | | | | | <i>Turrilites costatus</i> | |
| | | | <i>Calycoceras (Calycoceras) naviculare</i> | | | | |
| U. Cenom. | no ammonites | no ammonites | <i>Metoicoceras geslinianum</i> | | | | |
| | | | <i>Neocardioceras juddii</i> | | | | |
| | | | <i>Watinoceras devonense</i> | | | | |
| Low. Tur. | no ammonites | no ammonites | <i>Fagesia catinus</i> | | | | |
| | | | <i>Mammites nodosoides</i> | | | | |
| | | | <i>Mantelliceras dixonii</i> | | | | |
| Haftoman Formation (Coniacian - Campanian) | ammonite evidence | no ammonites | Middle Turonian | | | | |

Text-fig. 11. Biostratigraphy of the Upper Albian–Turonian Debarsu Formation in the type area south of Haftoman (see Text-fig. 1 for location; pf = planktic foraminifers). Ammonite zonation compiled after data in Kennedy (1984), Wright *et al.* in Wright and Kennedy (1984), Hancock (1991), Marcinowski *et al.* (1996), Cecca (1997), Gale *et al.* (2005, 2011), Kennedy and Latil (2007), Amédro (2008), and Owen (2012)

(J. Sowerby, 1814). Below, there is an ammonite-barren interval of ca. 100 m thickness between *M. (S.) perinflatum* zonal strata and the *M. saxbii* Subzone. It is suggested that these sediments document the Cenomanian part of this stratigraphic interval and that the palaeo-karst above the *M. (S.) perinflatum* Zone indicates a stratigraphic gap in the Albian–Cenomanian boundary interval that characterizes many sections in Cretaceous basins elsewhere (e.g., Robaszynski *et al.* 1998; Wilmsen 2003; Amédro 2009; Owen 2012). The upper Lower Cenomanian is proven by the presence of typically *M. dixoni* zonal ammonites such as *Acompsoceras renevieri* (Sharpe, 1857). Above another conspicuous palaeo-karst, Middle Cenomanian strata may (indirectly) be indicated by the presence of Lower–Middle Cenomanian *Placentoceras grossouvrei* Semenov, 1899. Unequivocal Middle Cenomanian as well as Upper Cenomanian and Turonian ammonites have not been found in the upper 200 m of the Debarsu Formation, but micro-biostratigraphic evidence (planktonic foraminifers) from the uppermost part of the formation indicate that the formation ranges into the Middle Turonian. The upper part of the Debarsu Formation of the Khur area thus corresponds to the nearshore strata in the Shotori Mountains of the Tabas Block (that have been dated with ammonites) ca. 200 km to the west, as already suggested by Wilmsen *et al.* (2005).

The new chronostratigraphic data for the Debarsu Formation furthermore have considerable geodynamic significance: for the development of the major tectonic unconformity at the base of the overlying Haftoman Formation (which yielded Lower Coniacian inoceramids near its base in a section south of Khur), only a short interval of geological time (less than 3 myr according to Ogg and Hinnov 2012), remains, stressing the considerable synsedimentary tectonic activity of the Yazd Block of Central Iran during mid-Cretaceous times.

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REFERENCES

- Agard, A., Omrani, J., Jolivet, L. and Mouthereau, F. 2005. Convergence history across Zagros (Iran): constraints from collisional and earlier deformation. *International Journal of Earth Science*, **94**, 401–419.
- Aistov, L., Melnikov, B., Krivyakin, B., Morozov, L. and Kiristaev, V. 1984. Geology of the Khur area (Central Iran). Explanatory text of the Khur quadrangle map 1:250,000. *V/O Technoexport, Report*, **20**, 1–130.
- Amédro, F. 2008. Support for a Vraconnian Stage between the Albian *sensu stricto* and the Cenomanian (Cretaceous System). *Carnets de Géologie / Notebooks on Geology, Memoir*, **2008/02**, 1–83.
- Amédro, F. 2009. Stratigraphie séquentielle des successions Albiennes du Bassin Anglo-Parisien et du Bassin de Mons (Belgique). *Bulletin d'Information des Géologues du Bassin des Paris*, **46**, 12–36.
- Amédro, F., Matrimon, B., Tomasson, R., Magniez, F. and Colleté, C. 2004. L'Albien supérieur de Vallentigny dans la région stratotypique (Aube, F.): nouvelles données et révision de l'ammonite *Mortonoceras (M.) inflatum* (J. Sowerby, 1818). *Bulletin de la Société géologique de Normandie et des Amis du Muséum du Havre*, **90**, 5–28.
- Atabekian, A.A. 1985. Turrilitids of the Late Albian and Cenomanian of the southern part of USSR. *Transactions of the Academy of Sciences of the USSR*, **14**, 1–112. [In Russian]
- Atabekian, A.A. 1992. Ammonites from the Upper Albian and Cenomanian of the southern USSR. *Trudy Vserossiiskij Nauchno-Issledovatel'skij Geologicheskij Institut, novaya seriya*, **350**, 201–217. [In Russian]
- Bagheri, S. and Stampfli, G.M. 2008. The Anarak, Jandaq and Posht-e-Badam metamorphic complexes in central Iran: New geological data, relationships and tectonic implications. *Tectonophysics*, **451**, 123–155.
- Barrier, E. and Vrielynck, B. 2008. Map 6: Cenomanian (99.6–93.5 Ma). In: Barrier, E. and Vrielynck, B. (Eds), Palaeotectonic maps of the Middle East – tectono-sedimentary–palinospastic maps from the Late Norian to Pliocene. Commission for the Geological Map of the World (CGMW / CCGM), Paris.
- Bayle, É., 1878. Fossiles principaux des terrains. *Explication de la Carte Géologique de France*, **4(1)**, 158 pls (Atlas).
- Bengtson, P. 1988. Open nomenclature. *Palaeontology*, **31**, 223–227.
- Berberian, M. and King, G.C.P. 1981. Towards a palaeogeography and tectonic evolution of Iran. *Canadian Journal of Earth Sciences*, **18**, 210–265.
- Bosc, L.A.G., 1801. (An 10). In: Roissy, F. de (ed.), Histoire naturelle générale et particulière, des Mollusques, animaux sans vertèbres et a sang blanc. Ouvrage faisant suit aux Ouvres de Leclerc de Buffon, et partie du Cours complet d'Histoire naturelle, rédigé par C.S. Sonnini, membre de

- plusieurs Sociétés savants. Continué par F. de Roissy. Deterville, Paris, viii+448+3pp.
- Breistroffer, R. 1840. Révision des ammonites de l'Albien de Salazac (Gard) et considérations générales sur ce sous-étage Albien. *Travaux du Laboratoire de l'Institut de Géologie de l'Université de Grenoble*, **22** (1938–39), 17–171 (1–101).
- Cecca, F. 1997. The Late Albian genus *Semenoviceras* (Hoplitidae, Ammonitina): palaeontologic study of a fauna of the *Semenoviceras litschkovi* Zone from Mangyshlak (west Khazakstan). *Rivista Italiana die Paleontologia e Stratigrafia*, **103**, 323–342.
- Cooper, M.R. and Owen, H.G. 2011a. Evolutionary relationships among Schloenbachiidae (Cretaceous Ammonoidea: Hoplitidae), with a revised classification of the family. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **262**, 289–307.
- Cooper, M.R. and Owen, H.G. 2011b. The phylogeny and classification of primitive Placenticeratidae (Cretaceous Hoplitina, Hoplitidae). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **260**, 331–342.
- Davoudzadeh, M. 1997. Iran. In: Moores, E.M., Fairbridge, R.M. (Eds), *Encyclopedia of European and Asian regional geology*, pp. 384–405. *Encyclopedia of Earth Sciences Series*, Chapman and Hall; London.
- Davoudzadeh, M., Soffel, H. and Schmidt, K. 1981. On the rotation of the Central-East Iran microplate. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **1981**, 180–192.
- Dercourt, J., Zonenshain, L.P., Ricou, L.-E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbertshikov, I.M., Geysant, J., Lepvrier, C., Pechersky, D.H., Boulin, J., Sibuet, J.-C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhenov, M.L., Lauer, J.P. and Biju-Duval, B. 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamir since the Lias. *Tectonophysics*, **123**, 241–315.
- Douvillé, H. 1890. Sur la classification des Cératites de la Craie. *Bulletin de la Société Géologique de France (series 3)*, **18**, 275–292.
- Douvillé, H. 1912. Évolution et classification des Pulchellidés. *Bulletin de la Société Géologique de France (series 4)*, **11**, 285–320.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K. and Majidifard, M.R. 2009a. Lithostratigraphy of the Upper Triassic–Middle Jurassic Shemshak Group of northern Iran. In: Brunet, M.-F., Wilmsen, M. and Granath, J. (Eds), *South Caspian to central Iran basins. Geological Society London, Special Publication*, **312**, 129–160.
- Fürsich, F.T., Wilmsen, M., Seyed-Emami, K. and Majidifard, M.R. 2009b. The Mid-Cimmerian tectonic event (Bajocian) in the Alborz Mountains, northern Iran: Evidence of the break-up unconformity of the South Caspian Basin. In: Brunet, M.-F., Wilmsen, M. and Granath, J. (Eds), *South Caspian to central Iran basins. Geological Society London, Special Publication*, **312**, 189–203.
- Gale, A.S., Kennedy, W.C., Voigt, S. and Walaszczyk, I. 2005. Stratigraphy of the Upper Cenomanian–Lower Turonian Chalk succession at Eastbourne, Sussex, UK: ammonites, inoceramid bivalves and stable carbon isotopes. *Cretaceous Research*, **26**, 460–487.
- Gale, A.S., Bown, P., Caron, M., Crampton, J., Crowhurst, S.J., Kennedy, W.J., Petrizzo, M.R. and Wray, D.S. 2011. The uppermost Middle and Upper Albian succession at the Col de Palluel, Hautes-Alpes, France: An integrated study (ammonites, inoceramid bivalves, planktonic foraminifera, nannofossils, geochemistry, stable oxygen and carbon isotopes, cyclostratigraphy). *Cretaceous Research*, **32**, 59–130.
- Gill, T. 1871. Arrangement of the families of mollusks. *Smithonian Miscellaneous Collections*, **227**, i–xvi, 1–49.
- Grossouvre, A. de 1894. Recherches sur la Craie supérieure. Deuxième part: Paléontologie. Les ammonites de la Craie supérieure. *Memoirs du Service de la Carte Géologique détaillée de la France*, **1893**, 1–264.
- Hancock, J.M. 1991. Ammonite scales for the Cretaceous system. *Cretaceous Research*, **12**, 259–191.
- Hyatt, A. 1889. Genesis of the Arietidae. *Smithonian Contributions to Knowledge*, **673** (vol. 26), i–xi + 1–238.
- Hyatt, A. 1900. Cephalopoda. In: Zittel, K.A. von (Ed.), *Textbook of Palaeontology*, pp. 502–592. Macmillan; London and New York.
- Hyatt, A. 1903. Pseudoceratites of the Cretaceous. *United States Geological Survey Monographs*, **44**, 1–352.
- Ilyin, V.D. 1975. Ammonites of the family Placenticeratidae Hyatt from the Upper Cretaceous deposits of Central Asia. *Trudy Vsesoyuznyi, Nauchno-Issledovatel'skii Geologorazvedochny Neftyanoi Institut*, **171**, 154–174. [In Russian]
- Immel, H. and Seyed-Emami, K. 1985. Die Kreideammoniten des Glaukonitkalkes (O.Alb – O.Cenoman) des Kolah-Qazi-Gebirges südöstlich von Esfahan (Zentraliran). *Zitteliana*, **12**, 87–137.
- Immel, H., Seyed-Emami, K. and Afshar-Harb, M. 1997. Kreide-Ammoniten aus dem iranischen Teil des Koppehdagh (NE-Iran). *Zitteliana*, **21**, 159–190.
- Kaplan, U., Kennedy, W.J., Lehmann, J. and Marcinowski, R. 1998. Stratigraphie und Ammonitenfaunen des westfälischen Cenoman. *Geologie und Paläontologie in Westfalen*, **51**, 1–236.
- Kennedy, W.J. 1984. Ammonite faunas and the „standard zones“ of the Cenomanian to Maastrichtian Stages in their type areas, with some proposals for the definition of the stage boundaries by ammonites. *Bulletin of the Geological Society of Denmark*, **33**, 147–161.
- Kennedy, W.J. 2013. On variation in *Schloenbachia varians*

- (J. Sowerby, 1817) from the Lower Cenomanian of western Kazakhstan. *Acta Geologica Polonica*, **63**, 443–468.
- Kennedy, W.J. and Juignet, P. 2006. *Pseudhelicoceras robertianum*. In: Gauthier, H. (Ed.), Révision critique de la Paléontologie Française d'Alcide d'Orbigny. Volume IV, Céphalopodes Crétacés, pp. 169–170. Backhys; Leiden.
- Kennedy, W. J. and Latil, J.-L. 2007. The Upper Albian ammonite succession in the Montlaur section, Hautes-Alpes, France. *Acta Geologica Polonica*, **57**, 453–478.
- Kennedy, W.J., Chahida, M.R. and Djafarian, M.A. 1979. Cenomanian cephalopods from the Glauconitic Limestone southeast of Esfahan, Iran. *Acta Palaeontologica Polonica*, **14**, 3–50.
- Kennedy W.J., Cobban W.A., Gale A.S., Hancock J.M. and Landman N.H. 1998. Ammonites from the Weno Limestone (Albian) in Northeast Texas. *American Museum Novitates*, **3236**, 1–46.
- Kennedy, W.J., Cobban, W.A., Hancock, J.M. and Gale, A.S. 2005. Upper Albian and Lower Cenomanian ammonites from the Main Street Limestone, Grayson Marl and Del Rio Clay in northeast Texas. *Cretaceous Research*, **26**, 349–428.
- Kennedy, W.J., King, C. and Ward, D.J. 2008a. The upper Albian and lower Cenomanian succession at Kolbay, eastern Mangyshlak (southwest Kazakhstan). *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre*, **78**, 117–147.
- Kennedy, W.J., Jagt, J.W.M., Amédro, F. and Robaszynski, F. 2008b. The late Late Albian (*Mortoniceras fallax* Zone) cephalopod fauna from the Bracquegnies Formation at Strépy-Thieu (Hainaut, southern Belgium). *Geologica Belgica*, **11**, 35–69.
- Kennedy, W.J., Amédro, F., Robaszynski, F. and Jagt, J.W.M. 2011. Ammonite faunas from condensed Cenomanian-Turonian sections ('Tourtias') in southern Belgium and northern France. *Netherlands Journal of Geosciences*, **90**, 209–238.
- Klein, J. and Vašíček, Z. 2011. Fossilium Catalogus I: Animalia. Pars 148. Lower Cretaceous Ammonites, part V, Desmoceratoidea, 311 pp. Backhuys/Margraf; Weikersheim.
- Klinger, H. and Kennedy, W.J. 1978. Turrilitidae (Cretaceous Ammonoidea) from South Africa, with a discussion of the evolution and limits of the family. *Journal of Molluscan Studies*, **44**, 1–48.
- Kossmat, F. 1895–98. Untersuchungen über die Südindische Kreideformation. *Beiträge zur Paläontologie und Geologie Österreich-Ungarns*, **9** (1895), 97–202 (1–107), pls 15–25 (1–11); **11** (1897), 1–46 (108–153), pls 1–8 (12–19); **11** (1898), 89–152 (154–217), pls 14–19 (20–25).
- Lamarck, J.-B.P.A. de 1801. *Système des animaux sans vertèbres*, i–viii + 432pp. Deterville; Paris.
- Lasswitz, R. 1904. Die Kreideammoniten von Texas (collection F. Foemer). *Geologische und Paläontologische Abhandlungen (Neue Serie)*, **6**, 223–259.
- Luppov, N.P. 1963. New Cenomanian and Lower Turonian ammonites of the genus *Placentoceras* from Central Asia. *Trudy Vsesoyuznogo Nauchno-Issledovatel'skogo Geologicheskogo Instituta, novaya seriya*, **109**, 135–160. [In Russian]
- Marcinowski, R. 1980. Cenomanian ammonites from the German Democratic Republic, Poland, and the Soviet Union. *Acta Geologica Polonica*, **30**, 215–325.
- Marcinowski, R. 1983. Upper Albian and Cenomanian ammonites from some sections of the Mangyshlak and Tuarkyr regions, Transcaspiya, Soviet Union. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **1983**, 156–180.
- Marcinowski, R., Walaszczyk, I. and Olszewska-Nejbert, D. 1996. Stratigraphy and regional development of the mid-Cretaceous (Upper Albian through Coniacian) of the Mangyshlak Mountains, Western Kazakhstan. *Acta Geologica Polonica*, **46**, 1–60.
- Meek, F.B. 1876. A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country. In: Hayden, F.V. (Ed.), *Report of the United States Geological Survey of the Territories*, **9**, i–lxiv + 629 pp.
- Monks, N. 2010. Heteromorph ammonites. In: Young, J.R., Gale, A.S., Knight, R.I. and Smith, A.B. (Eds), *Fossils of the Gault. Palaeontological Association Field Guide to Fossils*, **12**, 194–208.
- Mosavinia, A. and Wilmsen, M. 2011. Cenomanian Acanthoceratoidea (Cretaceous Ammonoidea) from the Aitamir Formation (Koppeh Dagh, NE Iran): taxonomy and stratigraphic implications. *Acta Geologica Polonica*, **61**, 175–192.
- Mosavinia, A., Wilmsen, M., Asghar Aryai, A., Chahida, M.R. and Lehmann, J. 2007. Mortoniceratinae (Ammonitina) from the Upper Albian (Cretaceous) of the Atamir Formation, Koppeh Dagh Mountains, NE Iran. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **246**, 83–95.
- Neumayr, M. 1875. Die Ammonitiden der Kreide und die Systematik der Ammonitiden. *Zeitschrift der deutschen Geologischen Gesellschaft*, **27**, 854–942.
- Ogg, J.G., Hinnov, L.A., 2012. Cretaceous. In: Gradstein, F.M., Ogg, J.G., Schmitz, M., Ogg, G.M. (Eds), *The geologic time scale 2012*, Volume 2, pp. 793–853. Elsevier; Amsterdam.
- Orbigny, A. d. 1840–1842. *Paléontologie Française. Terrain Crétacé I, Céphalopodes*, 662 pp., 148 pls (1–120: 1840; 121–430: 1841; 431–662: 1842). Masson; Paris.
- Owen, H.G. 2012. The Gault Group (Early Cretaceous, Albian), in East Kent, S.E. England; its lithology and ammonite biozonation. *Proceeding of the Geologists' Association*, **123**, 742–765.
- Parona, C.F. and Bonarell, G. 1897. Fossili Albiani d'Escra-

- gnolles del Nizzardo e della Ligurias occidentale. *Palaeontographica Italia*, **2**, 53–112.
- Pictet, F.J. and Renevier, E. 1866. Notices géologiques et paléontologiques sur les Alpes Vaudoises et les régions environnantes. IV, Céphalopodes de Cheville. *Bulletin de la Societe vaudoise des Sciences Naturelles*, **9**, 93–114.
- Robaszynski, F., Juignet, P., Gale, A.S., Amédéo, F. and Hardenbol, J. 1998. Sequence stratigraphy in the Cretaceous of the Anglo-Paris Basin, exemplified by the Cenomanian stage. In: Jaquin, T., de Graciansky, P. and Hardenbol, J. (Eds), Mesozoic and Cenozoic sequence stratigraphy of European basins. *SEPM (Society for Sedimentary Geology) Special Publication*, **60**, 363–385.
- Rosetti, F., Nasrabad, M., Vignaroli, G., Theye, T., Gerdes, A., Razavi, M.H. and Vaziri, M. 2010. Early Cretaceous migmatitic granulites from the Sabzevar range (NE Iran): implications for the closure of the Mesozoic peri-Tethyan oceans in central Iran. *Terra Nova*, **22**, 26–34.
- Schlüter, C. 1876. Cephalopoden der Oberen Deutschen Kreide. *Palaeontographica*, **21**, 1–24, pl. 1–8.
- Scholz, G. 1979. Die Ammoniten des Vracon (Oberalb, *dispar*-Zone) des Bakony-Gebirges (Westungarn) und eine Revision der wichtigsten Vracon-Arten der West-Mediterranen Faunenprovinz. *Palaeontographica A*, **165**, 1–136.
- Seeley, H.G. 1865. On ammonites from the Cambridge Greensand. *Annals and Magazine of Natural History (series 3)*, **16**, 225–247.
- Semenov, W.P., 1899. The fauna of the Cretaceous deposits of Mangyshlak and some other localities in the Transcasian province. *Travaux de la Société impériale des Naturalistes de St. Pétersbourg (Section Géologie et Minéralogie)*, **28**, 1–178. [In Russian]
- Seyed-Emami, K. and Aryai, A.A. 1981. Ammoniten aus dem unteren Cenoman von Nordostiran (Koppeh-Dagh). *Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie*, **21**, 23–39.
- Seyed-Emami, K. and Immel, H. 1996. Ammoniten aus dem Alb (höhere Unterkreide) des Zentralirans. *Palaeontographica A*, **241**, 1–26.
- Seyed-Emami, K., Förster, R. and Mojtehed, A. 1984. Ammoniten aus dem mittleren Cenoman von Nordostiran (Koppeh-Dagh). *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, **1984**, 159–172.
- Sharpe, D. 1853–1857. Description of the fossil remains of Mollusca found in the Chalk of England. I, Cephalopoda. *Palaeontographical Society (London) Monograph*, 68 pp., 27 pls (1853, 1–26, pls 1–10; 1855, 27–36, pls 11–16; 1857, 37–68, pls 17–27).
- Soffel, H., Davoudzadeh, M., Rolf, C. and Schmidt, S. 1996. New palaeomagnetic data from Central Iran and a Triassic palaeoreconstruction. *Geologische Rundschau*, **85**, 293–302.
- Sowerby, J. 1812–1822. The mineral conchology of Great Britain; or coloured figures and descriptions of those remains of testaceous animals or shells, which have been preserved at various times and depths in the Earth. Parts 1–4. Meredith, London, 383 pls [1, pls 1–9 (1812), pls 10–44 (1813), pls 45–78 (1814), pls 79–102 (1815); 2, pls 103–114 (1815), pls 115–150 (1816), pls 151–186 (1817), pls 187–203 (1818); 3, pls 204–221 (1818), pls 222–253 (1819), pls 254–271 (1820), pls 272–306 (1821); 4, pls 307–318 (1821), pls 319–383 (1822)].
- Spath, L.F. 1922. On Cretaceous Ammonoidea from Angola, collected by Professor J.W. Gregory, D.Sc., F.R.S. *Transactions of the Royal Society of Edinburgh*, **53**, 91–160.
- Spath, L.F. 1923–1943. A monograph of the Ammonoidea of the Gault. *Palaeontographical Society Monographs*, 787 pp. [1–72 (1923); 73–110 (1925); 111–146 (1925a); 147–186 (1926a); 187–206 (1927a); 207–266 (1928); 267–311 (1930); 313–378 (1931); 379–410 (1932); 411–442 (1933); 443–496 (1934); 497–540 (1937); 541–608 (1939); 609–668 (1941); 669–720 (1942); 721–787, i–x (1943)].
- Spath, L.F. 1926. On new ammonites from the English Chalk. *Geological Magazine*, **63**, 77–83.
- Stampfli, G.M. and Borel, G.D. 2002. A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones. *Earth and Planetary Science Letters*, **196**, 17–33.
- Takin, M. 1972. Iranian geology and continental drift in the Middle East. *Nature*, **235**, 147–150.
- Wiedmann, J. 1966. Stammesgeschichte und System der post-triadischen Ammonoideen, ein Überblick (2. Teil). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **127**, 13–81.
- Wilmsen, M. 2003. Sequence stratigraphy and palaeoceanography of the Cenomanian Stage in northern Germany. *Cretaceous Research*, **24**, 525–568.
- Wilmsen, M. and Mosavinia, A. 2011. Phenotypic plasticity and taxonomy of *Schloenbachia varians* (J. Sowerby, 1817). *Paläontologische Zeitschrift*, **85**, 169–184.
- Wilmsen, M., Fürsich, F.T. and Seyed-Emami, K. 2003. Revised lithostratigraphy of the Middle and Upper Jurassic Magu Group of the northern Tabas Block, east-central Iran. *Newsletters on Stratigraphy*, **39**, 143–156.
- Wilmsen, M., Wiese, F., Seyed-Emami, K. and Fürsich, F.T. 2005. First record and significance of Cretaceous (Turonian) ammonites from the Shotori Mountains, east-central Iran. *Cretaceous Research*, **26**, 181–195.
- Wilmsen, M., Niebuhr, B., Wood, C.J. and Zawischa, D. 2007. Fauna and palaeoecology of the Middle Cenomanian *Praeactinocamax primus* Event at the type locality, Wunstorf quarry, northern Germany. *Cretaceous Research*, **28**, 428–460.

- Wilmsen, M., Fürsich, F.T., Seyed-Emami, K. and Majidifard, M.R. 2009a. An overview of the lithostratigraphy and facies development of the Jurassic System on the Tabas Block, east-central Iran. In: Brunet, M.-F., Wilmsen, M. and Granath, J. (Eds), South Caspian to central Iran basins. *Geological Society London, Special Publication*, **312**, 323–344.
- Wilmsen, M., Fürsich, F.T., Seyed-Emami, K., Majidifard, M.R. and Taheri, J. 2009b. The Cimmerian orogeny in northern Iran: tectono-stratigraphic evidence from the foreland. *Terra Nova*, **21**, 211–218.
- Wilmsen, M., Fürsich, F.T., Seyed-Emami, K., Majidifard, M.R. and Zamani-Pedram, M. 2010. Facies analysis of a large-scale Jurassic shelf-lagoon: The Kamar-e-Mehdi Formation of east-central Iran. *Facies*, **56**, 59–87.
- Wilmsen, M., Fürsich, F.T. and Majidifard, J. 2011. Cretaceous stratigraphy and facies development of the Yazd Block, Khur area, Central Iran. *Darius Newsletter*, **2**, 9–10.
- Wilmsen, M., Fürsich, F.T. and Majidifard, M.R. 2012. *Porosphaera globularis* (Phillips, 1829) (Porifera, Calcarea) from the Maastrichtian Farokhi Formation of Central Iran. *Cretaceous Research*, **33**, 91–96.
- Wilmsen, M., Fürsich, F.T. and Majidifard, J. 2013. The Shah Kuh Formation, a latest Barremian – early Aptian carbonate platform of Central Iran (Khur area, Yazd Block). *Cretaceous Research*, **39**, 183–194.
- Wilmsen, M., Storm, M., Fürsich, F.T. and Majidifard, M.R. in prep. Depositional setting of the Upper Albian–Turonian Debarsu Formation (Cretaceous of the Yazd Block, Central Iran). *Facies*.
- Wright, C.W. 1952. A classification of the Cretaceous ammonites. *Journal of Paleontology*, **26**, 213–222.
- Wright, C.W. and Kennedy, W.J. 1984. The Ammonoidea of the Lower Chalk. Part I. *The Palaeontographical Society Monograph*, **567** (137), 1–126.
- Wright, C.J. and Kennedy, W.J. 1987. The Ammonoidea of the Lower Chalk. Part II. *The Palaeontographical Society Monograph*, **573** (139), 127–218.
- Wright, C.J. and Kennedy, W.J. 1996. The Ammonoidea of the Lower Chalk. Part V. *The Palaeontographical Society Monograph*, **601** (150), 320–403.
- Wright, C.W., Callomon, J.H. and Howarth, M.K. 1996. Cretaceous Ammonoidea. In: Kaesler, R.L. (Ed.), *Treatise on Invertebrate Paleontology, Part L, Mollusca 4*, 1–362 pp. The Geological Survey of America and University of Kansas.
- Zittel, K.A. von 1895. *Grundzüge der Paläontologie*, i–viii + 971 pp. Oldenbourg; München and Leipzig.

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