Terminal Maastrichtian ammonites from Turkmenistan, Central Asia

MARCIN MACHALSKI, JOHN W.M. JAGT, ALEXANDER S. ALEKSEEV, and ELENA A. JAGT-YAZYKOVA

Machalski, M., Jagt, J.W.M., Alekseev, A.S., and Jagt-Yazykova, E.A. 2012. Terminal Maastrichtian ammonites from Turkmenistan, Central Asia. *Acta Palaeontologica Polonica* 57 (4): 729–735.

A complete uppermost Maastrichtian–Danian succession in the Sumbar River section, western Kopet Dagh (southwest Turkmenistan, Central Asia), constitutes one of the few instances in the world where the fossil record of the last ammonites can be directly positioned with respect to the iridium-rich, impact-related clay layer, which defines the Cretaceous–Paleogene (K–Pg) boundary. Two ammonite taxa, *Baculites* cf. *vertebralis* and *Hoploscaphites constrictus johnjagti*, range up to a level directly beneath the K–Pg boundary clay in the Sumbar River section. Thus, these two forms probably survived until the very end of the Maastrichtian in the western Kopet Dagh area. The terminal Maastrichtian ammonite records from the Sumbar River area represent the southeasternmost occurrences of these essentially Boreal taxa.

Key words: Ammonoidea, extinction, palaeobiogeography, Maastrichtian, Danian, Cretaceous–Paleogene boundary, Turkmenistan, Kopet Dagh.

Marcin Machalski [mach@twarda.pan.pl], Instytut Paleobiologii, Polska Akademia Nauk, ul. Twarda 51/55, PL-00-818 Warszawa, Poland;
John W.M. Jagt [john.jagt@maastricht.nl], Natuurhistorisch Museum Maastricht, de Bosquetplein 6-7, NL-6211 KJ Maastricht, the Netherlands;
Alexander S. Alekseev [aaleks@geol.msu.ru], Moscow State University, Faculty of Geology, Leninskie Gory 1, Moskva 119 991, Russia; and Borissiak Paleontological Institute of Russian Academy of Sciences, Profsoyuznaya 123, Moskva 117 997, Russia;
Elena A. Jagt-Yazykova [eyazykova@uni.opole.pl], Uniwersytet Opolski, Zakład Paleobiologii, Katedra Biosystematyki, ul. Oleska 22, PL-45-052 Opole, Poland.

Received 25 July 2011, accepted 18 December 2011, available online 24 February 2012.

Introduction

Detailed spatial and temporal patterns of the ammonite extinction at or near the Cretaceous–Paleogene (K–Pg, formerly K–T) boundary are still far from clear (see Landman et al. 2007 for the overview). This is mainly due to the presence of a hiatus at the K–Pg boundary in many ammonite-bearing sections, resulting from the erosional removal of the topmost Maastrichtian and lowermost Danian strata during early, but not earliest, Danian sea level oscillations (Keller and Stinnesbeck 1996; Smit 1997). Clearly reworked, worn and/or mineralised ammonite moulds in the Danian transgressive lags testify to the occurrence of these fossils in the sedimentary units once present (e.g., Machalski and Walaszczyk 1988), but data on their original vertical distribution in relation to the K–Pg boundary have been lost.

The best sections to analyse the last phases of ammonite evolution are those which preserve the iridium-rich, Chicxulub impact-related clay layer, which is sandwiched between the Maastrichtian and Danian, usually carbonate strata (Alvarez et al. 1980; Smit 1999; Schulte et al. 2010). The base of this clay defines the Cretaceous–Paleogene boundary, which is thus determined precisely by the moment of an extraterrestrial body impact (Molina et al. 2006). If preserved, the sedimentary and geochemical record of the impact, corresponding to a globally synchronous fallout of impact products, is the best proof available of continuous geological and palaeontological record across the K–Pg boundary at any given site (Claeys et al. 2002; Racki et al. 2011).

Unfortunately, only few sites worldwide with preserved K–Pg boundary clay have yielded an adequate ammonite record. These are exemplified by the celebrated Stevns Klint section, eastern Denmark, where some ammonite taxa range up to the K–Pg boundary clay (Birkelund 1993) and even oc-

Fig. 1. Location of the study area in the western Kopet Dagh Mountains (Sumbar River region near the village of Kara-Kala, Turkmenistan). An arrow indicates the approximate position of the ammonite-bearing Cretaceous–Paleogene Sumbar River section.

cur above it, which led to the hypothesis of ammonite survival into the early Danian (Machalski and Heinberg 2005). Another example is provided by ammonite assemblages from the GSSP (Global Stratotype Section and Point) for the base of the Danian at El Kef, Tunisia, where ammonites totally disappear from the fossil record in the 2 m-thick interval just below the boundary clay (Goolaerts et al. 2004; Goolaerts 2010).

In the present paper we add a new point to the global picture of the ammonite extinction by describing and discussing two terminal Maastrichtian ammonite taxa from a complete K–Pg succession in the Sumbar River area, western Kopet Dagh (southwest Turkmenistan, Central Asia). The completeness of the Sumbar River section was first noted by Alekseev et al. (1988), who recognised a boundary clay layer with a prominent iridium anomaly at the very base of the Danian. The impact-related signature of the clay layer was subsequently confirmed by Wolbach et al. (1990), Meisel et al. (1995), and Heymann et al. (1996). Alekseev et al. (1988) provided biostratigraphical data for the section and preliminary notes on the ammonite assemblage from the top of the upper Maastrichtian; the present paper is based on the material referred to in that paper. It was collected by one of us (ASA) during two visits to the section in 1983 and 1985.

Institutional abbreviations.—MGUH, Statens Naturhistorisk Museum, København, Denmark (formerly Geologisk Museum, Universitet København); NHMM, Natuurhistorisch Museum Maastricht, Maastricht, the Netherlands; VSEGEI, Vserossijskij Nauchno-Issledovatel'tskij Geologicheskij Institut im. A.P. Karpinskogo, Sankt-Peterburg, Russia.

Geographical and geological setting

The Sumbar River ammonite-bearing section is situated in western Kopet Dagh, southwest Turkmenistan, Central Asia (Fig. 1). The section is located 6 km northwest of the village of Kara-Kala on the slope of the Isak Mountain, on both sides of the road to the city of Khizyl-Arvat (Alekseev et al. 1988). Reference is made to Atabekian and Likhacheva (1961) for general data on the Upper Cretaceous deposits of western Kopet Dagh.

The Sumbar River section (Fig. 2A, B) starts with light-grey marls, ca. 10 m thick (unit 1 in Fig. 2A), which in the upper part contain rare holasteroid echinoids (*Echinocorys* sp. of typically Maastrichtian appearance) and common moulds of ammonites (Alekseev et al. 1988). Higher up, there is a layer of reddish-grey clay, 6 cm thick (unit 2 in Fig. 2A), with an anomalous iridium concentration at the base (up to 66.3 ng/g;

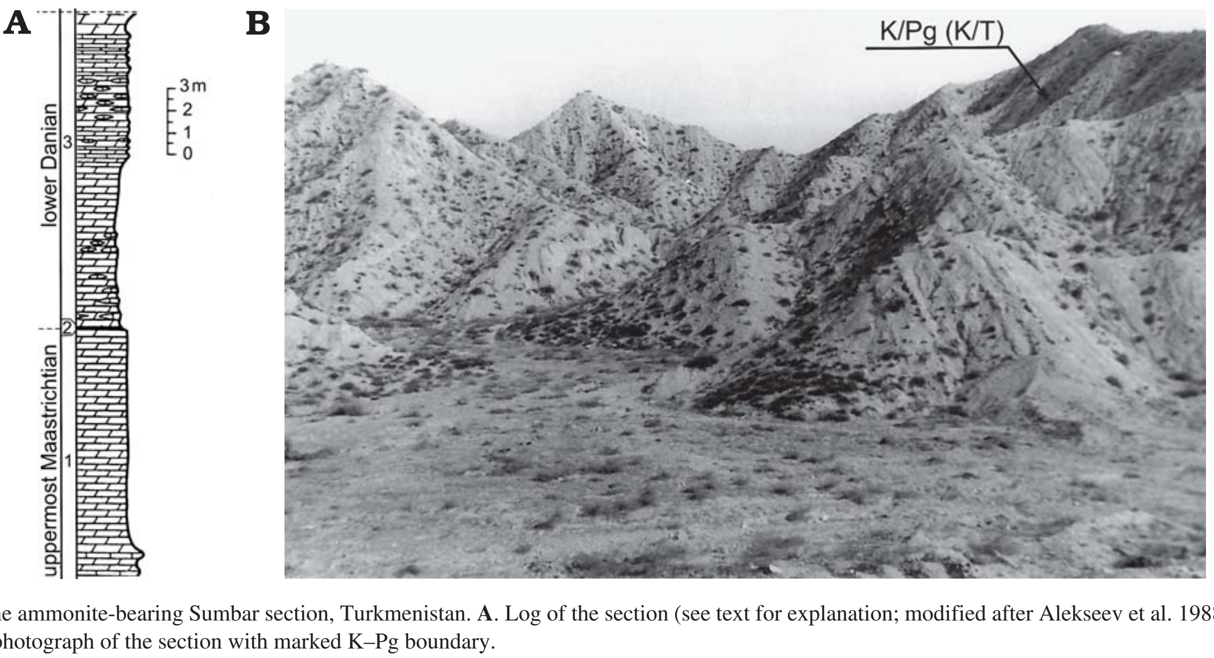

Fig. 2. The ammonite-bearing Sumbar section, Turkmenistan. **A**. Log of the section (see text for explanation; modified after Alekseev et al. 1988: fig. 1). **B**. Field photograph of the section with marked K–Pg boundary.

see Alekseev et al. 1988). Soot particles (Wolbach et al. 1990), osmium and strontium isotopic ratios consistent with the impact scenario (Meisel et al. 1995), as well as the fullerenes C_{60} and C_{70} which probably formed during global wildfires in the aftermath of the Chicxulub impact (Heymann et al. 1996), have also been identified in the clay layer. This passes gradually upwards into marls with lens-like limestone intercalations, ca. 15 m thick (unit 3 in Fig. 2A). These strata contain early Danian echinoids, including *Cyclaster integer* (= *C. danicus*), which occurs near the base of that unit (Alekseev et al. 1988). Biostratigraphical data for the Sumbar River section rely mainly on the foraminiferal record, which is definitely Boreal in character (Alekseev et al. 1988; ASA unpublished data). These data indicate that unit 1 represents the upper Maastrichtian *Pseudotextularia elegans* Zone, the base of unit 2 corresponding to the lowermost Danian *Guembelitria cretacea* Zone, and the remainder of the section being referable to the higher Danian *Globigerina eugubina* Zone (Alekseev et al. 1988). The clay layer (unit 2) with its unique geochemical anomaly corresponds to the K–Pg boundary clay as recorded elsewhere in the world.

There is no physical evidence of a hiatus around the K–Pg boundary in the Sumbar River ammonite-bearing section, in contrast to other outcrops in the same area which are located between 2 and 11 kilometres to the west. At the latter sites, the clay layer is missing and there is an indurated level (hardground) at the top of the Maastrichtian, which is penetrated by burrows (1–2 cm in diameter), filled with overlying sediment, which pipe down to 30 cm. The lowermost part of the Danian contains small limestone pebbles (3–4 cm in size) which clearly must have resulted from erosion and reworking of the underlying Maastrichtian. There is no iridium anomaly at the base of the Danian in these sections, the iridium levels approaching background values only (Alekseev et al. 1988). This picture is reminiscent of other parts of the world where locally complete (with the boundary clay) and incomplete (i.e., terminated by an erosional surface) sections are in close proximity, usually as a result of a complex interplay of local or regional topography, synsedimentary tectonics and sea level changes (e.g., Surlyk 1997; Machalski 2005b).

Ammonite preservation and vertical distribution

The material studied is preserved as yellowish to orange brown, composite moulds, in light grey, indurated marl and, when originating from closer to the K–Pg boundary, in more clayey matrix which shows a tendency to flake after having been soaked in water. Preservation varies widely, from near-complete specimens (Fig. 3F–H), isolated body chambers (e.g., Fig. 4A) and nuclei (e.g., Fig. 3C, E) to associated phragmocones on a bedding plane (Fig. 4E, F). Most specimens are crushed to varying degrees, so that measurements cannot be but approximate. All specimens studied come from the topmost part of the upper Maastrichtian portion of the Sumbar River section (Fig. 2); where known, the exact level is noted in the figure captions (Figs. 3, 4). There is also a single scaphitid record above the boundary clay, in the lower Danian portion of the section (see below).

Systematic palaeontology

Order Ammonoidea von Zittel, 1884

Suborder Ancyloceratina Wiedmann, 1966

Superfamily Turrilitoidea Gill, 1871

Family Baculitidae Gill, 1871

Genus *Baculites* Lamarck, 1799

Type species: *Baculites vertebralis* Lamarck, 1801, upper Maastrichtian of the Maastricht area, the Netherlands, by subsequent designation of Meek (1876).

Baculites cf. *vertebralis* Lamarck, 1801

Fig. 4C.

Material.—NHMM 2011 041a, Sumbar River section, Turkmenistan, topmost part of the upper Maastrichtian.

Description.—Small, fragmentary body chamber, 42 mm in length; greatest whorl height 11.8 mm, whorl breadth to height ratio ca. 0.48, but diagenetically compressed, making measurements approximate; straight, slowly expanding, whorl section oval, sides flattened and smooth; no sutures seen.

Discussion.—Although no sutures are seen and the specimen is slightly diagenetically compressed, the lack of ornament and the oval whorl section compare favourably with late Maastrichtian material from northwest Europe assigned to *B. vertebralis* Lamarck, 1801 (see Kennedy 1986, 1987).

Stratigraphical and geographical range.—Where well dated, *Baculites vertebralis* is apparently restricted to the upper Maastrichtian, with records from Denmark, the southeast Netherlands, northeast Belgium, northwest and southern France, southern Sweden, northern Germany, Poland, Ukraine, southern Russia, and southwest Turkmenistan.

Superfamily Scaphitoidea Gill, 1871

Family Scaphitidae Gill, 1871

Genus *Hoploscaphites* Nowak, 1911

Type species: *Ammonites constrictus* Sowerby, 1817, upper Maastrichtian of Cotentin, northwest France, by original designation.

Hoploscaphites constrictus johnjagti Machalski, 2005a

Figs. 3A–H, 4A, B, E, F, D?.

Material.—NHMM 2011 033–040, 2011 042–044, and, possibly, 2011 046, comprising at least two macroconchs, three

http://dx.doi.org/10.4202/app.2011.0110

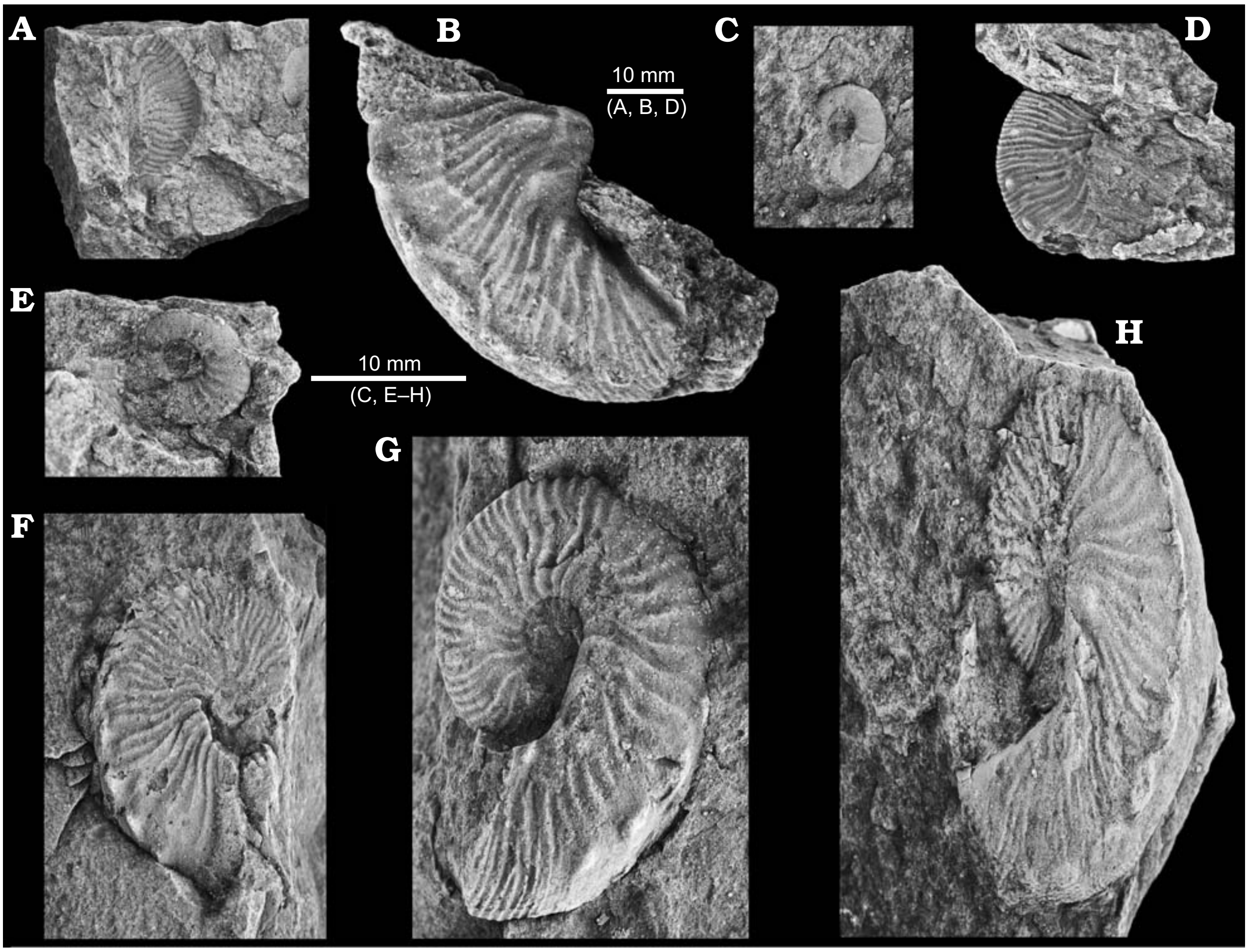

Fig. 3. Scaphitid ammonoid *Hoploscaphites constrictus johnjagti* Machalski, 2005a, Sumbar River section, Turkmenistan, upper Maastrichtian, Upper Cretaceous, all collected by ASA, with indications in brackets of centimetres below K/Pg boundary (where known). **A**. NHMM 2011 037, external mould of phragmocone. **B**. NHMM 2011 039, partial body chamber of macroconch. **C**. NHMM 2011 036, nucleus. **D**. NHMM 2011 034, partial phragmocone of ?macroconch (15 cm). **E**. NHMM 2011 038, nucleus (5 cm). **F**. NHMM 2011 033, near-complete ?microconch (18 cm). **G**. NHMM 2011 035, microconch (5 cm). **H**. NHMM 2011 040, macroconch.

microconchs and around ten phragmocones, Sumbar River section, topmost part of the upper Maastrichtian.

Description.—Material quite variable in ribbing style, onset of tuberculation and size and shape of tubercles; phragmocones involute, with tiny umbilicus (e.g., Fig. 4E, F); most specimens highly compressed with flat-sided phragmocone; flexuous primary ribs arising at umbilical seam (e.g., Fig. 3G), being either feebly concave or near-straight and prorsiradiate on inner flank, convex at mid-flank, concave on outer flank and ventrolateral shoulder and weakly convex over venter; primary ribs dividing at various heights on flank, intercalatories inserting on inner to outer flank; ventrolateral tubercles develop at variable phragmocone diameters (Fig. 3A, D); umbilical bullae developed both in micro- and macroconchs (Fig. 3G, H), with shaft of body chamber coarsely ribbed and ventrolateral tubercles either continuing almost to aperture or disappearing earlier (Fig. 3B, F–H). NHMM 2011 035, a well-preserved microconch, measures 31 mm in greatest length, while NHMM 2011 040, a macroconch, attains an approximate length of 36 mm.

Specimen NHMM 2011 046 (Fig. 4D) is tentatively assigned here. It was not collected in the field, but recognised in a fragment of marly matrix in sample bag SM4/12 during preparation for microfossil analysis at Moscow University. It is a limonitised, fragmentary mould of a phragmocone, found in the Danian portion of the section, in the interval 22–24 cm above the base of the boundary clay. It was referred to as "Pachydiscidae gen. et sp. indet." by Alekseev et al. (1988).

The phragmocone is slightly compressed and filled with a porous aggregate of ferro-hydroxides which probably are products of pyrite oxidation. In cross section, the thick ferruginous crust with smooth outer surface is visible and the ribs of the ammonite are underneath. The ventral portion of the body chamber is crushed and poorly preserved. The greatest diameter of the preserved part of the shell is 16 mm. The shell reveals flexuous primary ribs and intercalatories on the outer flank and is indistinguishable in this respect from nuclei of *Hoploscaphites constrictus johnjagti*.

Associated aptychi (NHMM 2011 047–048) are of the general scaphitid type and correspond closely to material il-

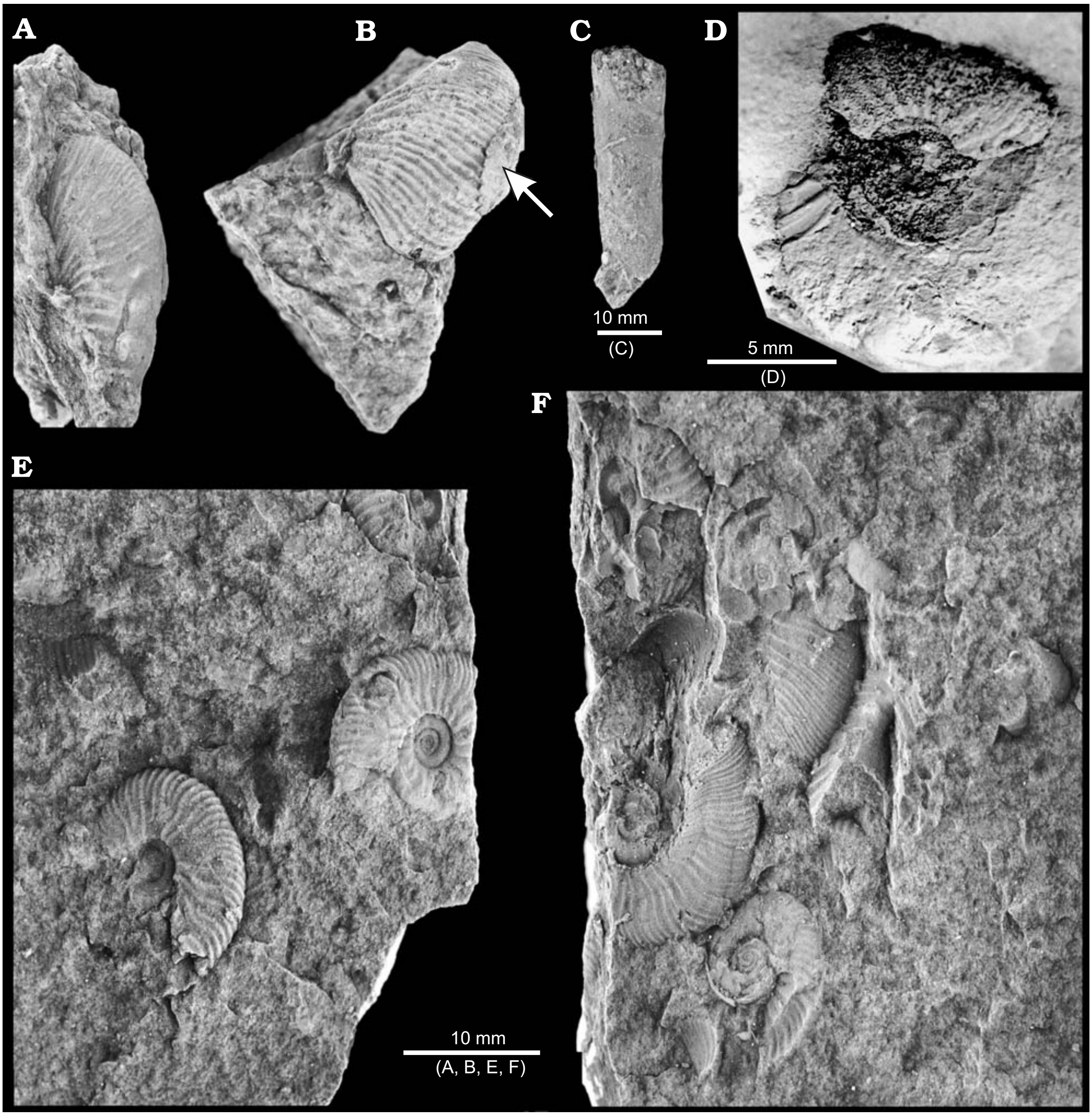

Fig. 4. Ammonites from the Sumbar River section, Turkmenistan, upper Maastrichtian, Upper Cretaceous, collected by ASA and Mikhail A. Nazarov, with indications in brackets of centimetres below K–Pg boundary (where known). **A**, **B**, **E**, **F**. Scaphitid ammonoid *Hoploscaphites constrictus johnjagti* Machalski, 2005a. **A**. NHMM 2011 044, microconch body chamber. **B**. NHMM 2011 043, apertural portion of body chamber, with epizoic craniid brachiopod (arrowed). **E**. NHMM 2011 042b, pair of phragmocones (10–15 cm). **F**. NHMM 2011 042a, set of phragmocones (10–15 cm). **C**. Baculitid ammonoid *Baculites* cf. *vertebralis* Lamarck, 1801, NHMM 2011 041a, partial body chamber. **D**. Scaphitid phragmocone from the Danian portion of the Sumbar River section, NHMM 2011 046, probably *Hoploscaphites constrictus johnjagti* Machalski, 2005a (= Pachydiscidae indet. sensu Alekseev et al. 1988: fig. 1).

lustrated by Birkelund (1993: pl. 17: 2–4) and Machalski (2005a: fig. 26).

Discussion.—These specimens clearly represent the youngest evolutionary stage of the *Hoploscaphites constrictus* lineage, which is defined by the presence of ribbing all over the body chamber in macroconchs (see Machalski 2005a: 667, figs. 7C, 8, 12). This subspecies, *Hoploscaphites constrictus johnjagti*, is restricted to the upper upper Maastrichtian in northwest and central Europe, as documented by Machalski (2005a, b), who listed material from eastern (Stevns Klint, Sjælland) and northern (Jylland) Denmark, as well as southern Sweden, central and eastern Poland, northeast Belgium, and the southeast Netherlands. Machalski (2005a, b) also noted that macroconchs ranged in maximum length between 36 and 51 mm, microconchs between 27 and 33 mm, and that in numerous macroconchs ventrolateral tubercles persisted until the apertural margin. Thus, the complete macroconch

http://dx.doi.org/10.4202/app.2011.0110

(NHMM 2011 040; Fig. 3H) is relatively small, while the other, incomplete specimen (NHMM 2011 039; Fig. 3B) would appear to be more closely comparable to material from Denmark, Poland, and the southeast Netherlands. The elongate appearance of the ventrolateral tubercles in both micro- and macroconchs (see Fig. 3B, F–H) is interpreted as a taphonomic feature, the tops of the tubercles having been eroded.

Stratigraphical and geographical range.—Uppermost Maastrichtian of Denmark, southern Sweden, Poland, northeast Belgium, the southeast Netherlands, France, southwest Turkmenistan, Mangyshlak (Kazakhstan), and Crimea (Ukraine), as well as lowermost Danian of Denmark and the southeast Netherlands (Machalski and Heinberg 2005; Machalski et al. 2009; Jagt 2012). The record from Crimea is based on unpublished material collected by the late Professor Dmitry P. Naidin and by one of us (ASA) in the uppermost Maastrichtian, and currently housed in the VSEGEI collections (EAJ-Y and JWMJ, unpublished data).

Concluding remarks

In terms of the end-Cretaceous extinction debate, the present study demonstrates that in the western Kopet Dagh area two ammonite taxa, i.e., *Baculites* cf. *vertebralis* and *Hoploscaphites constrictus johnjagti*, representing two families (Baculitidae and Scaphitidae), probably did survive up to the end of the Maastrichtian. Whether or not the single scaphitid mould recovered above the K–Pg boundary clay represents a Danian survivor as suggested for better-preserved and documented material from Stevns Klint, Denmark (Machalski and Heinberg 2005; Machalski et al. 2009) or simply represents a remanié specimen, cannot be determined at this time. Obviously, more extensive collecting across the K–Pg boundary at the Sumbar River section is needed to test this possibility.

As far as the evolution and biostratigraphical potential of scaphitids are concerned, the present study confirms that *Hoploscaphites constrictus johnjagti* is the last member of the *H. constrictus* evolutionary lineage (Machalski 2005a, b). At the classic locality of Stevns Klint, Denmark, this temporal subspecies is restricted to the Grey Chalk, a 0–4 m thick unit situated immediately below the K–Pg boundary clay, and its acme is at the top of this unit (Machalski 2005b), much like in the Sumbar River section. Bed-by-bed collecting down the Sumbar River section may be expected to yield additional data which would form an independent test for Machalski's concept of successive chronosubpecies of this lineage (Machalski 2005a). In anticipation of this, the results presented here show that *Hoploscaphites constrictus johnjagti* may be regarded as a good biostratigraphic proxy for the K–Pg boundary in sections where the boundary clay is absent.

Palaeobiogeographically, the ammonite taxa recorded from the Sumbar River section are essentially Boreal forms (see above). The records of these taxa in the Sumbar River section represent their southeasternmost occurrences known to date. They may have reached the Kopet Dagh region during the late Maastrichtian sea level rise as documented by Mahboubi et al. (2006). The relatively deep-water environment (outer shelf) of the ammonite-bearing marls from the Sumbar River section is confirmed by a high percentage of planktic species in foraminiferal assemblages (76–89%; see Alekseev et al. 1988). Again, more data from the lower part of the succession are needed to obtain a reliable picture of environmental changes towards the K–Pg boundary at this site.

From the perspective of regional ammonoid diversity, the present study complements the rather meagre list of Maastrichtian ammonites known to date from Central Asia (Kazakhstan, Turkmenistan). We are aware of only a handful of records. From Maastrichtian strata in western Kopet Dagh, Moskvin (1959: pls. 3: 3, 4: 1–4) illustrated two heteromorphs, *Baculites vertebralis* and *Discoscaphites constrictus* var. *niedzwiedzkii* (= *Hoploscaphites constrictus*), the former from the Sumbar River region. Subsequently, Krymgol'ts (1974: pl. 55: 2) recorded *Bostrychoceras schloenbachi* (= *Nostoceras schloenbachi*) from the lower Maastrichtian of Kene-Beurme, Turkmenistan. To this, Arkadiev and Bogdanova (1997: pls. 53: 5, 55: 4, 58: 3) (see also Arkadiev et al. 2000: pls. 15: 3a, b; 16: 4–6) added *Pseudokossmaticeras galicianum* (lower Maastrichtian, *Hauericeras sulcatum* Zone; Kredin Canyon, western Kopet Dagh) and *Hoploscaphites constrictus* (upper lower and upper Maastrichtian; Isak, Ayshem and Seitkerderi mountains, western Kopet Dagh).

Acknowledgements

We thank Barry W.M. van Bakel (Oertijdmuseum De Groene Poort, Boxtel, the Netherlands) for preparation of photographs and the journal reviewers, Wolfgang Stinnesbeck (Geologisch-Paläontologisches Institut, Universität Heidelberg, Germany) and Stijn Goolaerts (Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussels, Belgium) for insightful comments on an earlier typescript. ASA is grateful to Mikhail A. Nazarov, Larisa D. Barsukova, Dmitriy D. Badyukov (all Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Russia) and to Kosarbay Khodzhakhmedov (Aktau, western Kazakhstan) for help during the field work in southwestern Turkmenia.

References

Alekseev, A.S., Nazarov, M.A., Barsukova, L.D., Kolesov, G.M., Nuzhegorodova, I.V. [Nužegorodova, I.V.], and Amanniyazov, K.N. [Amanniâzov, K.N.] 1988. The Cretaceous–Paleogene boundary in southern Turkmenia and its geochemical characteristics [in Russian]. *Bûelleten' Moskovskgo Obŝestva Ispytatelej Prirody, Otdel Geologičeskij* 63 (2): 55–69.

Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, H.V. 1980. Extraterrestrial cause for the Cretaceous–Tertiary extinction. *Science* 208: 1095–1108.

Arkadiev, V.V. and Bogdanova, T.N. 1997 (eds.). *Atlas melovoj fauny ûgo-zapadnogo Kryma*, 356 + i pp. Pangeia, Sankt-Peterburg.

Arkadiev, V.V., Atabekian, A.A., Baraboshkin, E.Yu., and Bodganova, T.N. 2000. Stratigraphy and ammonites of Cretaceous deposits of south-west Crimea. *Palaeontographica A* 255: 85–128.

Atabekian, A.A. [Atabekân, A.A.] and Likhacheva, A.A. [Lihačeva, A.A.] 1961. Stratigraphy of the Upper Cretaceous deposits of the western Kopet-Dag [in Russian]. *Trudy VSEGEI*, new series 62: 1–242.

Birkelund, T. 1993. Ammonites from the Maastrichtian White Chalk of Denmark. *Bulletin of the Geological Society of Denmark* 40: 33–81.

Claeys, P., Kiessling, W., and Alvarez, W. 2002. Distribution of Chicxulub ejecta at the Cretaceous–Tertiary boundary. *In*: C. Koeberl and K.G. MacLeod (eds.), Catastrophic Events and Mass Extinctions: Impacts and Beyond. *Geological Society of America, Special Paper* 356: 55–68.

Gill, T. 1871. Arrangement of the families of mollusks. *Smithsonian Miscellaneous Collections* 227: 1–49.

Goolaerts, S. 2010. Late Cretaceous ammonites from Tunisia: chronology and causes of their extinction and extrapolation to other areas. *Aardkundige Mededelingen* 21: 1–220.

Goolaerts, S., Kennedy, W.J., Dupuis, C., and Steurbaut, E. 2004. Terminal Maastrichtian ammonites from the Cretaceous–Paleogene Global Stratotype Section and Point, El Kef, Tunisia. *Cretaceous Research* 25: 313–328.

Heymann, D., Korochantsev, A., Nazarov, M.A., and Smit, J. 1996. Search for fullerenes C_{60} and C_{70} in Cretaceous–Tertiary boundary sediments from Turkmenistan, Kazakhstan, Georgia, Austria, and Denmark. *Cretaceous Research* 17: 367–380.

Jagt, J.W.M. 2012. Ammonieten uit het Laat-Krijt en Vroeg-Paleogeen van Limburg. *Staringia* 13: 154–183.

Keller, G. and Stinnesbeck, W. 1996. Sea-level changes, clastic deposits, and megatsunamis across the Cretaceous–Tertiary boundary: 415–450. *In*: N. MacLeod and G. Keller (eds.), *The Cretaceous–Tertiary Mass Extinction: Biotic and Environmental Events*, 415–450. Norton Press, New York.

Kennedy, W.J. 1986. The ammonite fauna of the Calcaire à *Baculites* (Upper Maastrichtian) of the Cotentin Peninsula (Manche, France). *Palaeontology* 29: 25–83.

Kennedy, W.J. 1987. The ammonite fauna of the type Maastrichtian with a revision of *Ammonites colligatus* Binkhorst, 1861. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Sciences de la Terre* 86 (for 1986): 151–267.

Krymgol'ts, G.Ya. [Krymgol'ts, G.Â.] 1974 (ed.) *Atlas verhnemelovoj fauny Donbassa*. 640 pp. Izdatel'stvo Nauka, Moskva.

Lamarck, J.P.B. de M. de 1799. Prodrome d'une nouvelle classification des coquilles. *Mémoires de la Société d'Histoire naturelle de Paris* 1: 63–91.

Lamarck, J.P.B. de M. de 1801. *Système des animaux sans vertèbres*, vii + 432 pp. Déterville, Paris.

Landman, N.H., Johnson, R.O., Garb, M.P., Edwards, L.E., and Kyte, F.T. 2007. Cephalopods from the Cretaceous/Tertiary boundary interval on the Atlantic coastal plain, with a description of the highest ammonite zones in North America. Part III. Manasquan River Basin, Monmouth County, New Jersey. *Bulletin of the American Museum of Natural History* 303: 1–122.

Machalski, M. 2005a. Late Maastrichtian and earliest Danian scaphitid ammonites from central Europe: taxonomy, evolution, and extinction. *Acta Palaeontologica Polonica* 50: 653–696.

Machalski, M. 2005b. The youngest Maastrichtian ammonite faunas in Poland and their dating by scaphitids. *Cretaceous Research* 26: 813–836.

Machalski, M. and Heinberg, C. 2005. Evidence for ammonite survival into the Danian (Paleogene) from the Cerithium Limestone at Stevns Klint, Denmark. *Bulletin of the Geological Society of Denmark* 52: 97–111.

Machalski, M., Jagt, J.W.M., Heinberg, C., Landman, N.H., and Håkansson, E. 2009. Duńskie amonity – obecny stan wiedzy i perspektywy badań. *Przegląd Geologiczny* 57: 486–493.

Machalski, M. and Walaszczyk, I. 1988. The youngest (uppermost Maastrichtian) ammonites in the Middle Vistula Valley, Central Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 36: 67–70.

Mahboubi, A., Moussavi-Harami, R., Mansouri-Daneshvar, P., Nadjafi, M., and Brenner, R.L. 2006. Upper Maastrichtian depositional environments and sea-level history of the Kopet-Dagh Intracontinental Basin, Kalat Formation, NE Iran. *Facies* 52: 237–248.

Meek, F.B. 1876. A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country. *Report of the United States Geological Survey of the Territories* 9: 1–629.

Meisel, T., Krähenbühl, U., and Nazarov, M.A. 1995. Combined osmium and strontium isotopic study of the Cretaceous–Tertiary boundary at Sumbar, Turkmenistan: a test for an impact vs. a volcanic hypothesis. *Geology* 22: 313–316.

Molina, E., Alegret, L., Arenillas, I., Arz, J.A., Gallala, N., Hardenbol, J., von Salis, K., Steurbaut, E., Vandenberghe, N., and Zaghbib-Turki, D. 2006. The Global Boundary Stratotype Section and Point for the base of the Danian Stage (Paleocene, Paleogene, "Tertiary", Cenozoic) at El Kef, Tunisia—original definition and revision. *Episodes* 29: 263–273.

Moskvin, M.M. (ed.) 1959. *Atlas verhnemelovoj fauny severnogo Kavkaza i Kryma*. 499 pp. Moskva, Gostoptekhizdat.

Nowak, J. 1911. Untersuchungen über die Cephalopoden der oberen Kreide in Polen. II. Teil. Die Skaphiten. *Bulletin international de l'Académie des Sciences de Cracovie, Classe des Sciences mathématiques et naturelles, Série B, Sciences naturelles* 1911: 547–589.

Racki, G., Machalski, M., Koeberl, C., and Harasimiuk, M. 2011. The weathering-modified iridium record of a new Cretaceous–Paleogene site at Lechówka near Chełm, SE Poland, and its palaeobiologic implications. *Acta Palaeontologica Polonica* 56: 205–215.

Schulte, P., Alegret, L., Arenillas, I., Arz, J.A., Barton, P.J., Bown, P.R., Bralower, T.J., Christeson, G.L., Claeys, P., Cockell, C.S., Collins, G.S., Deutsch, A., Goldin, T.J., Goto, K., Grajales-Nishimura, J.M., Grieve, R.A., Gulick, S.P., Johnson, K.R., Kiessling, W., Koeberl, C., Kring, D.A., MacLeod, K.G., Matsui, T., Melosh, J., Montanari, A., Morgan, J.V., Neal, C.R., Nichols, D.J., Norris, R.D., Pierazzo, E., Ravizza, G., Rebolledo-Vieyra, M., Reimold, W.U., Robin, E., Salge, T., Speijer, R.P., Sweet, A.R., Urrutia-Fucugauchi, J., Vajda, V., Whalen, M.T., and Willumsen, P.S. 2010. The Chicxulub asteroid impact and mass extinction at the Cretaceous–Paleogene boundary. *Science* 327: 1214–1218.

Smit, J. 1997. Predictive elements of large-body impacts in geologic history. *Geologische Rundschau* 86: 464–470.

Smit, J. 1999. The global stratigraphy of the Cretaceous–Tertiary boundary impact ejecta. *Annual Review of Earth and Planetary Sciences* 27: 75–113.

Sowerby, J. 1817. *The Mineral Conchology of Great Britain, Vol. 2*, 151–186. Published by the author, London.

Surlyk, F. 1997. A cool-water carbonate ramp with bryozoan mounds: Late Cretaceous–Danian of the Danish Basin. *In*: N.P. James and J.D.A. Clarke (eds.), Cool-water Carbonates. *SEPM Special Publication* 56: 293–307.

Wiedmann, J. 1966. Stammesgeschichte und System der posttriadischen Ammonoideen; ein Überblick. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 125: 49–79; 127: 13–81.

Wolbach, W.S., Anders, E., and Nazarov, M.A. 1990. Fires at the K/T boundary: Carbon at Sumbar, Turkmenia, site. *Geochemica et Cosmochimica Acta* 54: 1133–1146.

Zittel, K.A. von. 1884. *Handbuch der Palaeontologie, 1–3, Cephalopoda*, 329–522. R. Oldenburg, München.

http://dx.doi.org/10.4202/app.2011.0110