Environmental impact on ectocochleate cephalopod reproductive strategies and the evolutionary significance of cephalopod egg size

Vladimir V. Laptikhovsky, Mikhail A. Rogov, Svetlana V. Nikolaeva & Alexander I. Arkhipkin

Published data on initial chamber (protoconch) diameter in 507 species, and embryonic shell (ammonitella) diameter in 231 species of Ammonoidea, and embryonic shell (nauta) diameters for 132 species of coiled Nautiloidea, were used to examine evolutionary change in ectocochleate cephalopod reproductive strategies. Palaeotemperatures were found to be a key factor influencing historical changes in the evolution of egg size in ammonoids and nautiloids. A negative relationship was found between egg size and warming of the Earth's climate. Factors related to habitat were also important; in general egg size was larger in cold-water cephalopods. Egg size in Lytoceratina and Phylloceratina in the deep waters of the upper continental slope was much larger than in epipelagic Scaphitidae, as in modern fish and squids. Small eggs and high evolutionary rates helped ammonoids to colonise new habitats and develop high biological diversity, but involved them in planktonic food webs making them more vulnerable to abiotic variability (*e.g.*, climatic changes), ultimately leading to their extinction. Large eggs helped nautiloids to persist through geological history, but at the cost of lower biological diversity, lower evolutionary rates and restricted options for colonising new habitats. Large-egged species such as nautiloids are more vulnerable to ecological, biotic disasters such as the appearance of new predators, including modern fishery. Independence from the planktonic food web is likely to be very important for a taxon's long-term survival over evolutionary history, as demonstrated also by Coelacanthiformes and Elasmobranchia. • Key words: Ammonoidea, Nautiloidea, reproductive strategy, mass extinction, climate change, egg.

Laptikhovsky, V.L., Rogov, M.A., Nikolaeva, S.E. & Arkhipkin, A.I. 2013. Environmental impact on ectocochleate cephalopod reproductive strategies and the evolutionary significance of cephalopod egg size. *Bulletin of Geosciences 88(1)*, 83–93 (4 figures, 1 table, online supplementary material – Appendices 1–3). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received February 2, 2012; accepted in revised form June 19, 2012; published online November 28, 2012; issued xxxxx xx, 201x.

Vladimir V. Laptikhovsky, Falkland Islands Government Fisheries Department, Stanley, FIQQ 1ZZ, Falkland Islands; vlaptikhovsky@fisheries.gov.fk • Mikhail A. Rogov, Geological Institute of Russian Academy of Sciences, Pyzhevskii Lane 7, Moscow, 119017, Russia; russianjurassic@gmail.com • Svetlana V. Nikolaeva, Paleontological Institute, Russian Academy of Sciences, Moscow, 117997, Russia; 44svnikov@mail.ru • Alexander I. Arkhipkin, Falkland Islands Government Fisheries Department, Stanley, FIQQ 1ZZ, Falkland Islands; aarkhipkin@fisheries.gov.fk

Reproductive strategy is an important choice that species face continuously during their evolutionary history. A trade-off exists between fecundity and egg size (numbers *vs* "quality" of hatchling) because generative production in every species is restricted by body size, available food and longevity (Kasyanov 1999). Understanding these competing strategies led to the idea of *r*- and *K*-selection in life histories (MacArthur & Wilson 1967, Pianka 1970). It involves a bet-hedging concept that assumes that maximizing strategies are more advantageous in stable and predictable environments where variance is minimal, while minimizing strategies can enhance long-term fitness in periodically variable environments. Because of this, *r*-populations tend to inhabit unpredictable or ephemeral habitats, whereas *K*-populations tend to inhabit environments that are relatively stable (Slatkin 1974, Frank & Slatkin 1990).

The *r*- and *K*-strategy model is no longer considered to be a satisfactory framework for the entire life history theory, because a species' life history also involves parameters such as longevity, growth rate, and body size to name but a few (Stearns 1992). However, it is still a useful tool to describe the relative position of a species' strategy within a taxon-specific *r-K* continuum, particularly in respect to egg size when other life history parameters are considered to be relatively equal.

The coiled ectocochleate cephalopods Ammonoidea and Nautiloidea were abundant and diverse in Late

Palaeozoic and Mesozoic seas. Both taxa co-existed and co-evolved over about 330 millions years. Ammonoidea appeared and instantly occupied the water column during the Devonian nekton revolution (Klug *et al*. 2010) and almost immediately displayed a variety of life styles (Klug 2001). Nautiloidea appeared in the Ordovician and persist to the present day. Ammonoidea produced smaller eggs with smaller offspring (Landman 1988), and can be considered *r*-strategists compared to Nautiloidea. They also had higher rates of origination of genera and families and higher biological diversity, as well as shorter average duration of genera compared to coiled nautiloidea (Teichert 1967, Ward 1980, Stephen & Stanton 2002, Wani 2011), though this still has to be demonstrated with respect to speciation and individual species longevity. Both ammonoids and nautiloids were active swimming marine non-herbivorous molluscs with external shell protection and a mechanism to maintain neutral buoyancy, though shell shape generally differed between the two groups (Ward 1980). Their evolutionary fate was also different; the Nautiloidea successfully survived all major extinctions despite lower biological diversity and slower recovery, *i.e.* fewer variants to meet drastic changes in environment. Conversely, the morphologically and ecologically diverse Ammonoidea narrowly passed through a number of mass extinction events before eventually becoming extinct at the end of the Cretaceous. As underlined by Wani (2011 and references within) this contradicts a generally accepted point of view that species with planktonic eggs and larvae – so wider dispersal – exhibit lower probability of speciation and extinction, and therefore lower species richness.

This paper aims to investigate the history of nautiloid and ammonoid reproductive strategies throughout their parallel evolution from the late Palaeozoic onwards, and to determine potential environmental factors influencing egg size (and hence offspring viability), which "is one character that can be used to estimate other life-history characters" (Jaeckle 2001). This is particularly true for ammonoids in which the strategy of early ontogenetic stages (expressed in protoconch and ammonitella size, shape, and ornament) was crucial for survival through extinction events and consequent quick radiation of survivors in contrast to slow recovery of nautiloid fauna (House 1996, Manda & Turek 2011).

Material and methods

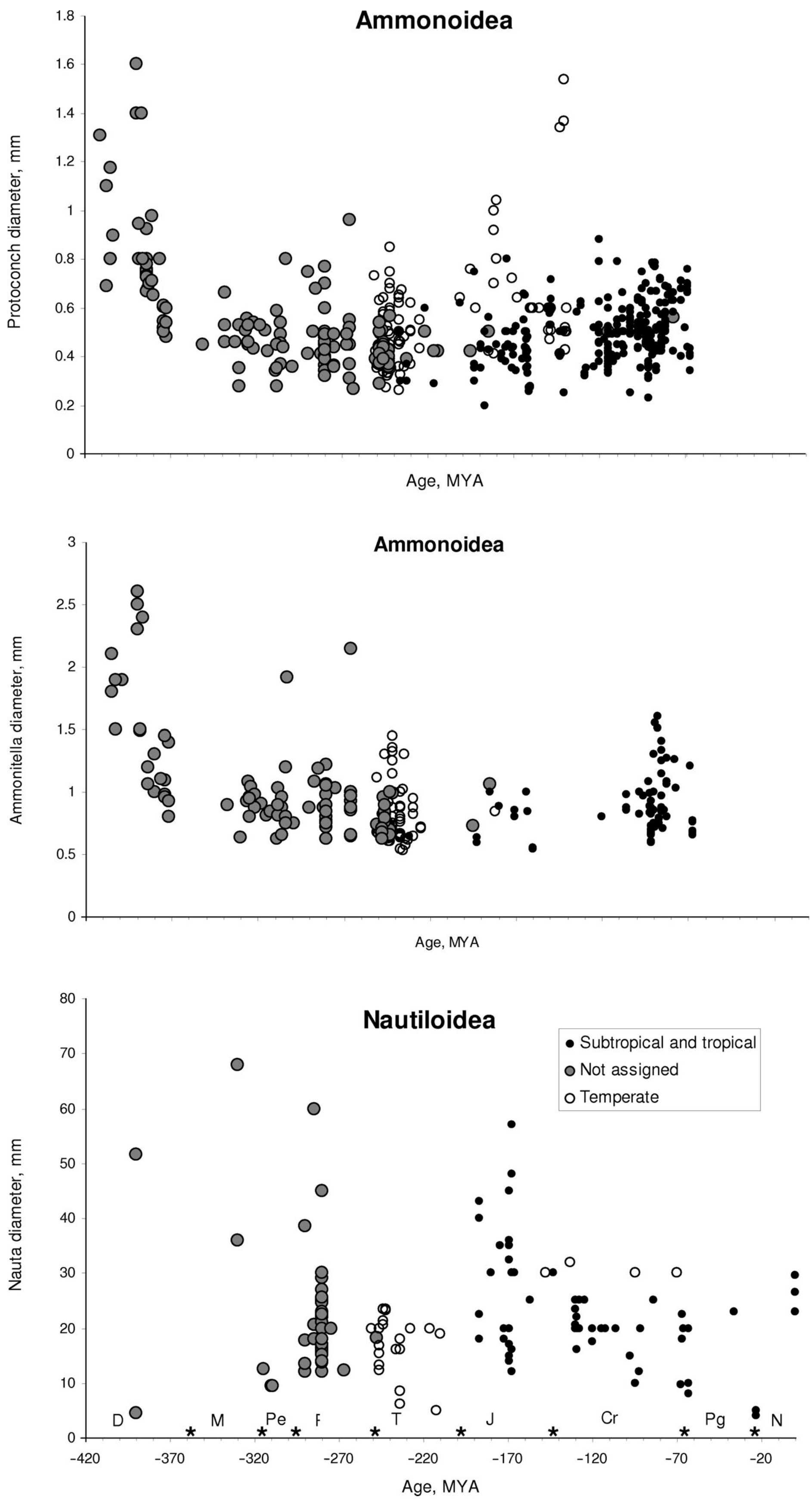
To describe evolutionary changes in ectocochleate cephalopod reproductive strategies we used published data on the diameter of initial chamber (so-called "protoconch", though not homologous to that of Gastropods) (PD, mm) in 508 species of Ammonoidea, and 231 measurements of embryonic shell (ammonitella) diameter (AD, mm) were also used (a total of 524 species; Appendix 1). The diameter of the nauta (the embryonic shell with a nepionic constriction at its aperture) (ND, mm) was found for 134 species of coiled Nautiloidea (Appendix 2). The dataset we compiled on extinct cephalopod reproductive features (Appendix 3) was about twice as large as the largest previous such dataset (267 ammonite species in De Baets *et al.* 2012). All sizes given were assumed to be the median between minimum and maximum values, which is how they have typically been reported. The size was taken as a single value when a single embryonic shell was measured. We assume that egg size of ammonoids was similar to that of the ammonitella, not of the protoconch (House 1996, Landman *et al*. 1996). However, we used PD because primary data were more abundant, and both AD and PD were closely related (AD = 1.63768 PD + 0.1063; Spearman r = 0.873, $P < 0.0001$ – our data set). Similarly, egg size of extinct nautiloids was assumed to be equal to the size of the nauta, as in extant *Nautilus* and *Allonautilus*. All statistical analyses were done using GraphPad Prism ver. 4.03 2005, and Brodgar Statistical Software ver. 2.5.1. Boundaries of chronostratigraphic units were taken from Gradstein *et al.* (2008). Jurassic and Cretaceous ammonites were arbitrarily divided into two major groups. 1) Tropical and subtropical species that included fossils collected well away from polar areas, and that lived at temperatures more or less similar to those in recent seas between latitudes 40°N and 40°S. 2) Temperate species that were collected in the polar areas of that time. Data on latitudinal variability of the Earth's climate were obtained from a range of publications (Kurushin & Zakharov 1995, Zakharov *et al*. 1999, Ross *et al*. 2002, Golonka 2007, Donnadieu *et al.* 2006, Takashima *et al.* 2006, Dera *et al*. 2011, Wierzbowski & Rogov 1911). Because of uncertainties related to ammonite ontogenetic latitudinal and bathymetric migrations, shell transport by currents, and short-term climate variability during individual geologic epochs, we did not attempt more precise species allocation to particular biogeographic ranges.

Results

Ammonoids

Both PD and AD varied significantly during the entire 330 million year history of ammonites: from 0.2 to 1.6 mm (Fig. 1) and from 0.54 to 2.6 mm respectively. The largest protoconchs were associated with the earliest ammonoids (Fig. 2) from the early and middle Devonian. Protoconch size began to decrease from middle to late Devonian, and in the Mississippian PD was mostly between 0.3 and 0.8 mm (AD mostly 0.6–1.4 mm). From the Mississippian to the Early Triassic mean PD was the lowest in the entire history of ammonoids (Kruskal–Wallis test, $P < 0.0001$; Dunn's

Figure 1. Historical changes in embryonic shell size in Ammonoidea (A) and Nautiloidea (B).



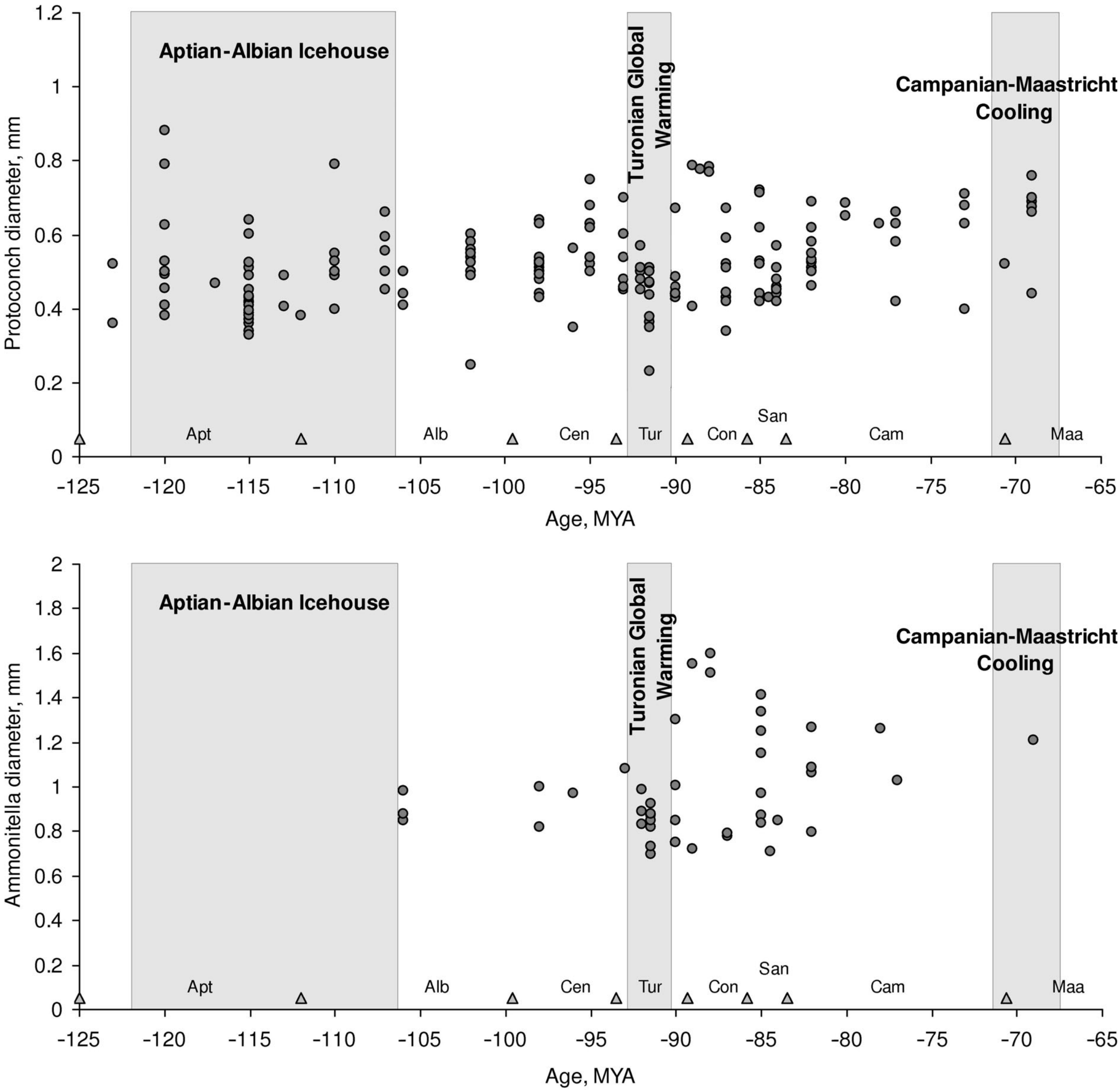


Figure 2. Temporal change of ammonoid protoconch size in Cretaceous.

multiple paired comparison post test, P from < 0.001 to < 0.01). From the Middle Triassic PD began to increase again until Early Cretaceous. This trend in change of initial shell size (PD) with geological age (MYA) is most evident in temperate ammonites (Pearson r = 0.51, $P < 0.0001$ at $\alpha = 0.05$), but was relatively weak in tropical and subtropical ammonites (Pearson r = 0.29, $P < 0.0001$ at $\alpha = 0.05$). For an entire combined sample of Mesozoic ammonites this correlation was also statistically significant (Pearson r = 0.20, $P < 0.0001$ at $\alpha = 0.05$) but less obvious because of climatic and taxonomic bias. In the Cretaceous, the average PD decreased from the Aptian–Albian (0.496 ± 0.027) to the Middle–Late Turonian (0.418 ± 0.040), and then increased again until the Maastrichtian (0.0569 ± 0.038), Kruskal–Wallis test ($P < 0.0001$) with Dunn's multiple comparison post-test (P from < 0.001 to < 0.05; Figs 2, 3).

Cold-water (temperate) ammonoids produced larger protoconchs than tropical-subtropical species [Mean PD 0.70 (confidence, interval, CI 0.61–0.78) *vs* 0.50 (CI 0.49–0.52), Mann Whitney U = 1726, $P < 0.0001$ in a combined Jurassic-Cretaceous sample]. The PD in Cretaceous ammonoids collected around Japan was also inversely related to historical changes in estimated paleotemperatures, Spearman r = –0.354, P = 0.002 (Fig. 4).

There were also differences between ammonites occurring in different habitats of the same area. Late Cretaceous Phylloceratina, and Lytoceratina from the North Pacific that lived in near-bottom layers over the continental slope (Moriya *et al.* 2003) produced relatively larger eggs (mean PD = 0.56 mm, AS = 1.06 mm, n = 82) than shelf and epipelagic Scaphitidae with an upward orientation of aperture that were adapted to live in upper layers of water column (Seilacher & Labarbera 1995, Landman *et al.* 2012) – mean PD = 0.41 mm, mean AD = 0.73 mm (n = 18). Differences were significant both between PD (Mann – Whitney, 185, P < 0.0001) and in AD (Mann – Whitney, 59, P < 0.0001).

Nautiloids

Nauta size in coiled nautiloids was very diverse throughout the Palaeozoic era (Fig. 1), but showed a decrease between the Permian and the Triassic. Further evolution of this feature in Mesozoic temperate seas followed the same pattern as in ammonoids: it increased from the Triassic to the Late Cretaceous (Pearson r = 0.63, P = 0.0009 at $\alpha = 0.05$). However, in tropical and subtropical seas it decreased with time (Fig. 1; Pearson r = –0.42, P = 0.0009 at $\alpha = 0.05$), with a particular drop in the Early Cretaceous. Where comparison was possible, cold-water species were found to produce larger eggs. For example, among the Cenomanian-Maastrichtian nautilids the largest nauta of about 30 mm was found in polar *Cymatoceras yabei* from Chukotka (Shimanski 1975) and *Eutrephoceras subplicatum* from Antarctica (Cichowolski *et al*. 2005), whereas the remaining tropical and subtropical nautiloids from Middle Asia, Caucasus, south USA and the Far East had embryonic shells of 10–25 (mean 16.9) mm. Even among this warm-water cohort, the largest nauta of 25 mm was found in a relatively cold-water species – *Cymatoceras* sp. from Sakhalin (Shimanski 1975). It is also noticeable that nauta size in modern *Nautilus* and *Allonautilus* (23–29 mm) that live in the relatively cold climate of the Holocene (as well as far away from surface waters) is larger than those in Cretaceous-Paleogene species that lived in a warmer epoch, even if we omit the unusual *r*-strategist *Aturia* spp. (8–23 mm in *Eutrephoceras*, *Hercoglossa*, *Cimomia*, *Teichertia*, and extinct species of *Nautilus*; Shimanski 1975, Wani *et al*. 2011).

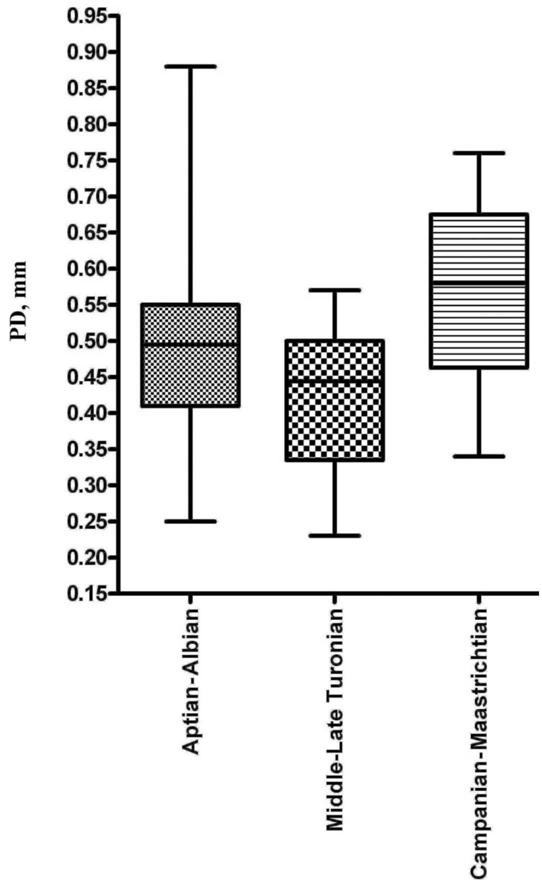


Figure 3. Box plot of Protoconch Diameter in Cretaceous ammonites (min., max., median; the box extends from 25 to 75 percentile).

Discussion

Climatic impact on egg size

Egg size in both nautiloids and ammonoids depended on latitudinal changes of climate. The negative relationship between egg size and environmental temperatures (so-called Thorson–Rass rule) is a well known phenomenon that exists at both interspecific and intraspecific levels and as phenotypic plasticity (Rass 1935, Thorson 1950, Marshall 1953, Laptikhovsky 2006) but is currently poorly understood. It has been described in extant invertebrates, fish, amphibians and insects, and it can be assumed that similar trends applied in the habitats of the past. Drushchits & Doguzhaeva (1981) were the first to demonstrate that the ammonitella of Late Mesozoic boreal ammonites were larger than those of warm-water species. Our data on both studied ectocochleate taxa support this suggestion.

However, egg size did not only vary with latitude, but also with global changes in climate. The general decrease in ammonite protoconch size between the Middle and Late Devonian could be explained by climatic change: during this period global temperatures increased (Joachimski *et al.* 2009) so production of progressively smaller eggs by invertebrates was to be expected. The early Triassic minimum in PD ended with a trend towards increased protoconch size that lasted until the Early Cretaceous. This evolutionary trend coincided with gradual cooling during this period (Barash 2008, Mutterlose *et al*. 2009; Föllmi 2012) and was particularly marked in high latitudes. During strong Turonian global warming (Takashima *et al*. 2006) ammonite protoconch size decreased, and started to increase again during the gradual Turonian-Maastrichtian cooling.

Egg size of nautiloids was also related to changes in environmental temperatures during geological history and, for example, decreased between the very cold early Permian and the very hot Triassic. However, nautiloid reproductive strategy was probably more dependent on the species' position in trophic webs and other biotic interactions and in contrast to that of ammonoids does not reveal important correlations with global climate changes.

Habitat impact on egg size

The ecological position of Ammonoidea was not fixed over its evolutionary history, particularly in the late Mesozoic when it was characterised by a gradual shift offshore and into deeper seas (Westermann 1996, Westermann & Tsujita 1999), possibly away from predatory marine reptiles (Ward 1996). By the end of the Cretaceous most adult stages of ammonites were oceanic to suboceanic (distal neritic), deep epipelagic to mesopelagic and only juveniles occurred in surface waters (Ward & Bandel 1987, Shigeta 1993, Landman *et al.* 1996, Moriya *et al.* 2003, Tajika & Wani 2011). Evolutionary rates were low, and cosmopolitanism was high – features characteristic of oceanic pelagic deep-water taxa (Ward & Signor 1983, Ward & Bandel 1987). This change of habitat during the ecological history of ammonites should obviously have had its impact on reproductive strategy. In Lytoceratina PD increased from Middle Jurassic to Late Cretaceous (Landman *et al.* 1996). This phenomenon is known but not explained. The same trend might be observed in another ammonite group – Phylloceratina. The general evolution of both taxa was directed to life in ocean depths (Westermann 1996, Westermann & Tsujita 1999) and in the end of the Cretaceous they inhabited demersal layers of continental slope (Moriya *et al.* 2003). The fact that these near-bottom ammonites produced much larger eggs than offshore pelagic vertical migrants, Scaphitidae (Westermann 1996, Westermann & Tsujita 1999) is in agreement with reproductive strategies of extant fish and cephalopods in which a similar trend in egg size exists. Small size of eggs in species reproducing in unstable and unpredictable sub-surface waters is due to increase of mortality at early stages, so – necessity to increase fecundity (Marshall 1953, Nigmatullin & Laptikhovsky 1994).

There are no indications that coiled nautiloids changed their life style, since post-Triassic nautilids evolved hypoxia tolerance and moved from neritic to slope habitats that is testified by their uncommon occurrence in shallow-water facies and abundance of rhyncholites in deep-water deposits (Riegraf & Shmidt-Riegraf 1995, Schlögl *et al.* 2011). Spawning style was not changed either except possibly *Aturia* in the Palaeocene, just after the extinction of ammonites left a wide range of ecological niches empty in the open ocean. That genus at that time possessed the smallest embryonic shells (4–5 mm) in the entire history of the coiled nautiloids. *Aturia* quickly became cosmopolitan, probably because of improved possibilities for juvenile dispersal. This genus was also characterised by the most complex sutures, and an ammonoid-shaped shell (Ward 1980), so it was an evolutionary attempt to restore not just the ammonoid reproductive strategy but the entire life style. However, Aturiacea appeared to not adopt small, ammonite-like eggs. Probably they were similar to the near-bottom shelf-slope predators and scavengers, with their distribution restricted by the need to lay large eggs on the bottom, like "normal" coiled nautiloids.

Ammonoids *vs* nautiloids – alternative cephalopod reproductive strategies in the past and present

Earliest evolution of ammonoid reproductive strategies in early – middle Devonian displayed evolutionary trends to decrease in egg size and increase fecundity because of tighter coiling and a size reduction in embryonic shells, ammonitellae (De Baets *et al.* 2012). Further shift to *r*-strategy in late Devonian was due to changes in protoconch and ammonitela sizes (Landman *et al.* 1996). Eventually egg dimensions of ammonites became closely resembling those of modern epi-mesopelagic coleoids: the squid families Ommastrephidae, Brachioteuthidae, Enoploteuthidae, Pyroteuthidae, Thysanoteuthidae, Heteroteuthinae, and octopods Argonautoidea, the hatchlings of which are epipelagic (Sweeney *et al.* 1992). Other extant cephalopods that live either at the bottom or in the meso-bathypelagic layers produce larger eggs (except some dwarfs like *Idiosepius*). This clearly indicates an epipelagic life style for ammonite juveniles, which is in accordance with suppositions of other authors (Landman 1988, Westermann 1996). Generally, adult ammonites might spawn anywhere, even in deep seas, whereas their hatchlings might quickly rise to surface waters to forage there as happens in the modern abundant and diverse squid families Onychoteuthidae Gonatidae, Cranchiidae and some others (Nesis 1985, 1995). Hypothetically, low positive buoyancy in deep-sea ammonite hatchlings might facilitate such ascension with juveniles automatically achieving neutral buoyancy at the border with the upper, less dense water layer – their natural habitat.

Throughout evolutionary history, nautiloids always produced much larger eggs than ammonoids, with no overlap between these taxa (Ward & Bandel 1987). Extinct coiled nautiloids normally produced eggs with nauta > 10 mm, and in tropical species nautas could sometimes be extremely large – up to 40–70 mm with the hatchling size similar to that of many adult ammonites. No vulnerable epipelagic

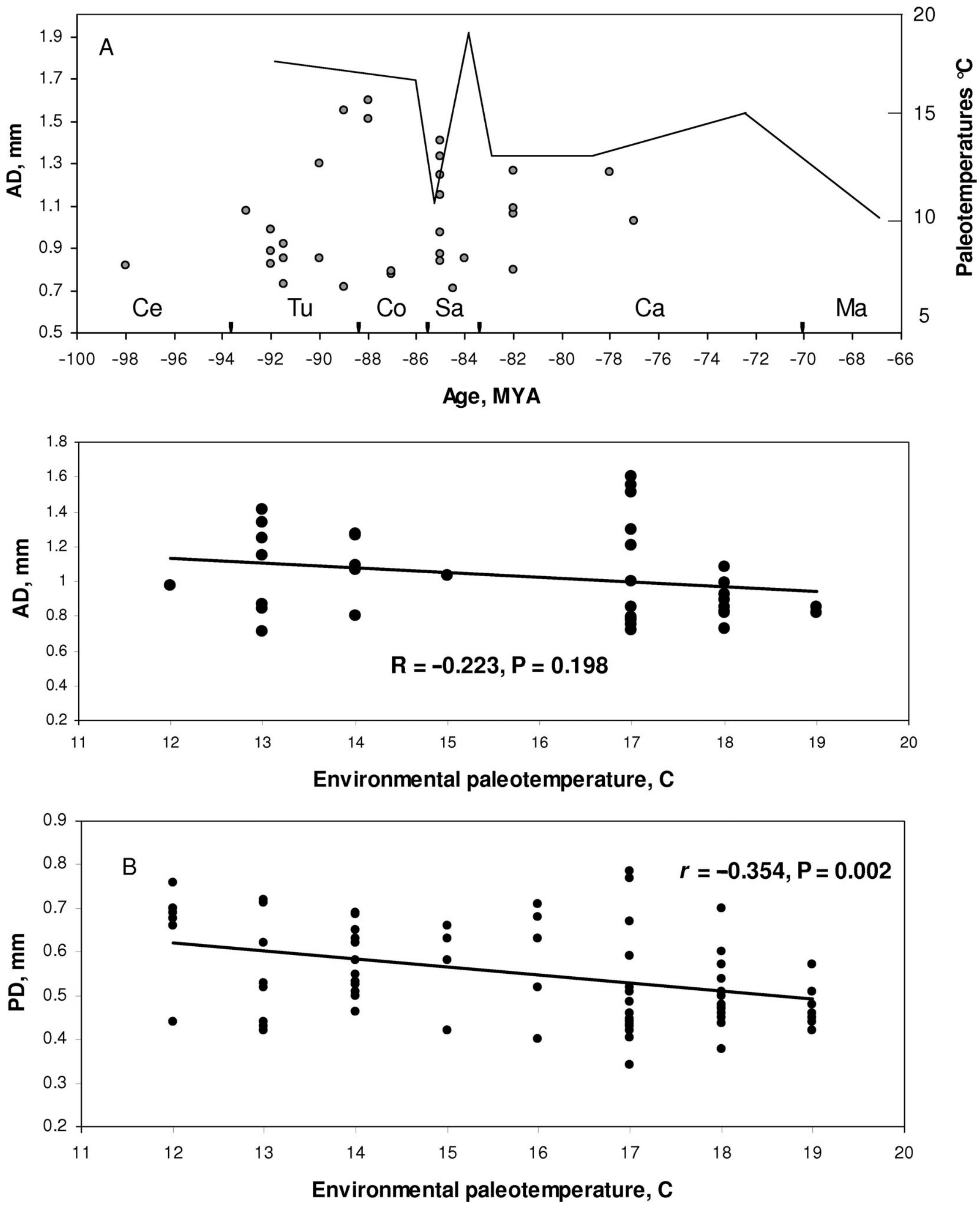


Figure 4. Temporal change of Protoconch Diameter (N = 76; dashed line) in Late Cretaceous ammonoids in North Pacific and paleotemperatures (solid line) in Sakhalin – Hokkaido area estimated from ammonoid shells (Zakharov *et al.* 1999). A – historical changes, B – correlation.

early stage ever existed, though fecundity was probably low, and juvenile dispersal was restricted. The absence of very large eggs in cold-water nautiloids throughout their evolutionary history seems surprising taking into account the Thorson–Rass rule. It may be explained by the excessive time that would be required for their embryonic development. In modern tropical *Nautilus* with eggs of moderate size (22–29 mm) embryonic development takes 269–362 days at temperatures 22–24 °C (Uchiyama & Tanabe 1999). The development time required for 40–70 mm cephalopod eggs in temperate seas would be unfeasibly long, and would involve too great a risk of predation or destruction.

Analysis of egg size variation within the *r-K* continuum in molluscs, echinoderms and fish revealed that there is usually not a taxon-specific modal size somewhere in between the minimum and the maximum, but rather two modes clustering around the extremes (Sewell & Young 1997, Laptikhovsky 1998, North 2001, Jaeckle 2001). This agrees with the mathematical model of Vance (1973a, b), which predicted that only the extremes in the possible range of egg size and method of nutrition (i.e. planktotrophy, lecitotrophy) are evolutionarily stable strategies. The evolution of reproductive strategies in ectocochleate cephalopods with two modal sizes of eggs (large in Nautiloidea and small in Ammonoidea) perfectly fits this theory.

Small egg size with pelagic offsprings (regardless adult life style and spawning habitat – just like in modern coleoids) allowed ammonoids to occupy surface waters at early ontogenetic stages making juveniles largely independent of near bottom anoxic events (Westermann 1996, Mapes & Nützel 2009, De Baets *et al*. 2012). Because of the small eggs, they obviously evolved high fecundity (Landman 1988) to compensate for increasing mortality of a long and vulnerable post-hatching pelagic stage, and high potential for dispersal of early stages by oceanic currents and consequent colonisation of new habitats. These epipelagic planktonic early ontogenetic stages were characteristic of the whole evolutionary history of ammonoids. Species with such a developmental type can maintain gene flow over wider geographic areas, and their populations are supposed to be less subjected to geographic isolation, thus – to allopatric speciation. Because of this it was supposed that sympatric speciation played the principal role in driving their macroevolutionary patterns (Wani 2011).

On the other hand, high fecundity also involves high mortality, thus high selective pressure of the environment and high evolutionary rate because of more intensive elimination of less successful variants. In modern coleoid cephalopods and fish with pelagic eggs and larvae most of this mortality (> 90%) occurs at early stages during the first days and weeks of life (Cushing 1974, Laptikhovsky *et al*. 1993 and references within). This means that the larval, rather than the adult morphotype, is most strongly subjected to natural selection, which at this stage might switch on such a powerful evolutionary tool as heterochronies (Minelli 2003). Paleozoic ammonoids that survived extinction events generally show novelty in external and internal morphology of the embryonic shell (House 1996) indicating some changes in larval development. An evolutionary increase in egg size could have been a mechanism providing a simple developmental basis for multiple heterochronic changes as an evolutionary response to selection on larval life history traits (Kligenberg 1998 and references within). These developmental changes probably became irreversible in coiled nautiloids that never evolved any small-egged species from late Paleozoic onwards. Natural selection in this group probably most strongly affected animals with adult body morphology.

Because of high evolutionary rates and wide larval dispersal, ammonites were quick to recover after major catastrophes. The entire evolutionary history of ammonoids is a series of major extinction and recovery events, generating a "boom and bust" pattern (McGowan 2004). During the Frasnian-Famennian, Devonian-Mississippian, Permo-Triassic, and end-Triassic mass extinctions the ammonoids were almost completely eliminated, but recovered very quickly. After the Permo-Triassic mass extinction it took less than 2 m.y. for a single surviving genus to surpass the biological diversity that had existed prior to the extinction (Brayard *et al*. 2009), while ammonite recovery after Triassic-Jurassic extinction was even faster (Guex *et al*. 2012). Eventually ammonites became extinct at the K/T boundary, with a very sudden, major catastrophe that affected oceanic plankton communities. Ammonoidea became extinct together with another dominant small-egged cephalopod group – the coleoid Belemnitida possibly because of oceanic acidification (Arkhipkin & Laptikhovsky 2012). The most prominent teleost fish that became extinct at the same time were five families that were ecological siblings of modern large-bodied predators like tuna and billfishes (Friedman 2009), which also are small-egged broadcast spawners.

Nautiloids had to lay eggs on the bottom (Chirat 2001, Mapes & Nützel 2009), and in contrast to ammonoids, had demersal life style from hatching, and did not depend so much on zooplankton (Westermann 1996). Because of demersal spawning nautiloids were restricted in their offshore distribution – ammonites can lay their eggs in pelagic waters above deep seas, whereas nautiloids can not reproduce there. Such an attachment to particular near-bottom habitats probably reduced the evolution of new life styles and it is the most important reason for their lower biological diversity in respect to ammonites. Thus, from the late Paleozoic, nautiloids never developed the morphological diversity seen in the ammonoids from the late Paleozoic to the end of the Cretaceous (Westermann 1996). However, the absence of a vulnerable paralarval stage related to planktonic food webs possibly saved them from extinction at the end of the Cretaceous period. This boundary was also crossed by Sepiida – another large-egged cephalopod group, as well as by squids and octopods. Among fish, the extremely large-egged Elasmobranchii and Coelacanthiformes persisted through K/T boundary unharmed as they did through many other extinction events (Laptikhovsky *et al*. 2010, Wani 2011). Independence of the planktonic food chain was indispensable for long-term survival of taxa.

There is one contradictory case from a "pre-ammonitic epoch" at the Silurian-Devonian boundary of Bohemia, when and where small-egged cephalopods with pelagic

Table 1. Distribution and occurrence (% of hauls) of cephalopods with different reproductive strategies over the shelf and slope of Namibia (50–500 m) (from Laptikhovsky 1990). Rare oceanic and deep-sea species removed. Large-egged demersal species are bolded. Upwelling area with intensive inflows of anoxic waters and sporadic occurrence of H_2S poisoned mud is shadowed.

Species	Latitude °S					
	17–19	19–21	21–23	23–25	25–27	27–29
Sepiella ornata	**3.4**					
Sepia bertheloti	**3.4**					
S. elegans	**3.4**					
S. orbygniana	**24.1**	**2.9**				
Rondeletiola minor	**17.2**	**2.9**				
***Alloteuthis* sp.**	**< 0.1**	**< 0.1**				
Loligo reynaudi	**6.8**	**5.8**				**6.6**
Illex coindeti	27.5	20.5	2.6			
Ornithoteuthis sp.	?	?	?	2.8	?	?
Argonauta nodosa	3.4	8.7	5.1			3.3
Todaropsis eblanae	24.1	26.4	33.3	2.8	2.3	10.0
Todarodes angolensis	31.0	64.7	61.5	38.1	50.0	23.3
Lycoteuthis diadema				22.2	31.0	26.6
Abraliopsis gilchristi				14.0	4.6	
Stoloteuthis leucoptera						**3.3**
Sepia australis						**30.0**

offspring performed much better than non-pelagic large-egged cephalopods (Manda 2008, Manda & Frýda 2010) because of upwelling of anoxic-hypoxic waters. Exactly the same situation exists now on the Namibian shelf and slope, where over a huge area of intensive upwelling between 21°S and 27°S outbreaks of toxic H_2S gas are a seasonally recurrent feature (Emeis *et al*. 2004). In this area only cephalopods with small pelagic eggs are able to reproduce, whereas to the north and to the south of this, large-egged bottom dwellers are very common (Table 1 – from Laptikhovsky 1990 MS). Therefore, such a phenomenon represents a geographical event that has the potential to become a true evolutionary event in the case of global change.

Conclusions

We may conclude that seawater temperatures were the key factor provoking historical changes in the evolution of ammonoids and nautiloids. Eggs were larger in temperate species with respect to inhabitants of equatorial areas. During global warming egg size decreased, and increased when the Earth's climate became colder. When taxa shifted into deeper and colder habitats during evolution it also provoked an increase in protoconch size: a phenomenon similar to that observed in modern fish and squids. However, in spite of all changes in egg size there were always two non-overlapping strategies in ectocochleate cephalopods. Ammonites never evolved large eggs even in the polar regions, and the smallest known nauta of coiled nautiloids were still 3–4 times bigger in volume than the largest known ammonitella.

Small eggs provide a relatively short-term (in the geological sense) ecological success with high evolutionary rates, biological diversity and the possibility of colonisation of new habitats. Large eggs help taxa to persist through geological history, but at the cost of lower biological diversity, lower evolutionary rates (as demonstrated also by Coelacanthiformes and Elasmobranchia) and less possibility to colonise new habitats, which would obviously be achieved first by small-egged species with a pelagic larval stage. Small-egged and highly fecund species are more vulnerable to disasters of a climatic, or abiotic character (extraterrestrial impact, volcanism, glaciation). Low fecundity, large-egged species are more vulnerable to disasters of ecological, biotic character such as the appearance of new predators. These conditions are still true today with the added impact of human activities.

Acknowledgements

The authors sincerely thank the Russian Academy of Sciences for RFBR grant No. 09-05-00456 , 10-05-00276, 12-05-00380, Program No. 1 of Earth Sciences division of RAS and Programs of the Presidium of RAS No. 18 and 24 for support, and colleagues at 8th International Symposium, Cephalopods – Present and Past (Dijon, 2010) for fruitful discussion. They are very grateful to K. Tanabe, N. Landman and K. Bandel for valuable and detailed comments on earlier version of the manuscript, and Paul Brewin and Max Barclay for editing the English language. Results of this paper were presented at the 8th International Symposium, Cephalopods – Present and Past, Dijon, August 30–September 3, 2010.

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Appendix 1.

Compilation of embryonic shell measurements of Paleozoic and Mesozoic ammonoid taxa, geographic areas and inferred climate.

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
"*Craspedites*" cf. *ivanovi*	0.53		?Craspeditidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Volgian, *Virgatus* Chron	Drushchits *et al.* (1985)
??*Cravenoceras incisum*	0.46	0.9	Cravenoceratidae	USA		Mississippian	Serpukhovian	Smith (1897)
??*Isohomoceras diadema*	0.66	0.9	Homoceratidae	USA		Mississippian	Bashkirian	Smith (1897)
Acanthohoplites sp.	0.39		Acanthohoplitidae	Caucasus/Mangyshlak	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Aconeceras trautscholdi	0.36		Aconeceratidae	Volga	Subtropical or Tropical	Cretaceous	Early Aptian, *Deschauesi* Chron	Drushchits & Doguzhaeva (1981)
Adrianites dunbari	0.55	1	Adrianitidae	Mexico		Permian	Middle	Tanabe *et al.* (1994)
Agathiceras applini	0.44	1.03	Agathiceratidae	USA		Permian	Admiral Formation	Miller & Unklesbay (1943)
Agathiceras uralicum	0.7		Agathiceratidae	Russia		Permian	Artinskian	Schoulga-Nesterenko (1926)
Agoniatites fulguralis	1.6	2.5	Agoniatitidae	Germany		Devonian	Givetian	Erben (1964)
Agoniatites holzapfeli	1.4	2.3	Agoniatitidae	Germany		Devonian	Givetian	Erben (1964)
Agoniatites obliquus	1.4	2.4	Agoniatitidae	Canada		Devonian	Middle Devonian (Dunedin – Besa river formations) – Givetian	Wissner & Norris (1991)
Agoniatites sp.		2.6	Agoniatitidae	Germany		Devonian	Givetian	Erben (1964)
Akmilleria electraensis	0.5	1.08	Medlicottiidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Amaltheus margaritatus	0.42		Eoderoceratoidea			Jurassic	Late Pliensbachian	Grandjean (1910)
Amauroceras ferrugineum	0.56	1	Eoderoceratoidea		Subtropical or Tropical	Jurassic	Late Pliensbachian	Landman *et al.* (1996)
Amoebites kitchini	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Kimmeridgian	Knyazev (1975)
Anagaudriceras buddha	0.68		Gaudryceratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Anagaudriceras limatum	0.67		Gaudryceratidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)
Anagaudriceras matsumotoi	0.69		Gaudryceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Anagaudriceras nanum	0.69		Gaudryceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Campanian	Shigeta (1993)
Anagaudriceras sp.	0.685		Gaudryceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Santonian–Campanian	Drushchits & Doguzhaeva (1981)
Anagaudriceras tetragonum	0.7		Gaudryceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Anagaudriceras yokomai	0.72	1.41	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Anahoplites intermedius	0.45		Hoplitaceae	Kopetdagh	Subtropical or Tropical	Cretaceous	Middle Albian, *A. intermedius* Chron	Mikhailova (1980)
Anahoplites michalskii	0.58		Hoplitaceae	Tuarkyr	Subtropical or Tropical	Cretaceous	Late Albian, *H. orbignyi*–*P. inflata* Chrons	Mikhailova (1980)
Anahoplites rossicus	0.54		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Albian, *A. rossicus* Chron	Mikhailova (1980)
Anahoplites solidus	0.5		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Albian, *A. rossicus* Chron	Mikhailova (1980)
Anahoplites uhligi	0.6		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Albian, *H. orbignyi*–*P. inflata* Chrons	Mikhailova (1980)
Anapachydiscus yezoensis	0.44		Pachydiscidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993)
Anarcestes (Anarcestes) simulans		1.9	Anarcestinae			Devonian	Emsian	Bogoslovskaya (1951)
Anarcestes (Latanarcestes) noeggerati		1.9	Anarcestinae			Devonian	Emsian	Bogoslovskaya (1951)
Anasibirites nevolini	0.445		Xenoceltitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Andidiscus behrendseni	0.15		Dubariceratidae	Argentina	Subtropical or Tropical	Jurassic	Early Pliensbachian	Hillebrandt 2006
Anthracoceras missouriense	0.28		Anthracoceratidae	USA		Pennsylvanian		Miller & Unklesbay (1943)
Arcestes	0.5		Arcestidae	Cosmopolite		Triassic	Anisian–Rhaetian	Spath (1950)
Arcestes sp.	0.37	0.65	Arcestidae	Timor	Subtropical or Tropical	Triassic	Carnian	Zakharov (1974)
Archoceras paeckelmanii		1	Anarcestidae	Morocco		Devonian	Frasnian	Landman *et al.* (1996)
Archoceras tataense		1	Anarcestidae	Morocco		Devonian	Frasnian	Landman *et al.* (1996)
Arctoceras septentrionale	0.51	0.96	Arctoceratidae	Far East		Triassic	Olenekian	Zakharov (1974)
Arctogymnites sonini	0.85	1.45	Beyrichitidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *nevadanus* Z.	Vavilov (1992)
Arctogymnites spectori	0.68	1.15	Beyrichitidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *spectori* Z.	Vavilov (1992)
Arctohungarites evolutus	0.39	0.735	Longobarditidae	Taymyr	Temperate	Triassic	Middle Anisian	Alekseyev *et al.* (1984)
Arctohungarites involutus	0.4	0.74	Longobarditidae	Taymyr	Temperate	Triassic	Early Anisian	Alekseyev *et al.* (1984)
Arctohungarites triformis	0.41	0.69	Longobarditidae	Taymyr	Temperate	Triassic	Middle Anisian	Alekseyev *et al.* (1984)
Arctohungatites kharaulakhensis	0.4	0.72	Longobarditidae	N Siberia/NE Asia	Temperate	Triassic	Middle Anisian, *kharaulakhensis* Z.	Vavilov (1992)
Arctomeekoceras rotundatum	0.37	0.82	Meekoceratidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Arctophyllites taimyrense	0.675	1.3	Discophyllitidae	N Siberia/NE Asia	Temperate	Triassic	Ladinian-Carnian boundary	Vavilov (1992)
Arctoprionites prontchischevi	0.39		Prionitidae	Far East		Triassic	Late Olenekian	Zakharov (1978)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Arctoptychites euglyphus	0.62	1	Ptychitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *omolojensis* Z.	Vavilov (1992)
Arctoptychites kruzini	0.65	0.885	Ptychitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *omolojensis* Z.	Vavilov (1992)
Arietites kridion	0.37		Psiloceratacea			Jurassic	Sinemurian	Grandjean 1910
Arietites sp.	0.35	0.64	Psiloceratacea	Germany (Lias)	Subtropical or Tropical	Jurassic	Sinemurian	Tanabe & Ohtsuka (1985)
Aristoceras sp.	0.36	0.75	Thalassoceratidae	USA		Late Pennsylvanian–Early Permian		Tanabe *et al.* (1994)
Aristoptychites kolymensis	0.64	0.785	Ptychitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *mcconnelli* Z.	Vavilov (1992)
Arkanites relictus	0.51	0.81	Reticuloceratidae	USA		Pennsylvanian	Bashkirian	Tanabe *et al.* (1994)
Artinskia artiensis	0.435	0.9	Medlicottiidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)
Baculites sp.	0.775		Baculitidae	USA	Subtropical or Tropical	Cretaceous	Turonian–Santonian	Landman (1982)
Berriasella (Hegaratella) jauberti	0.5		Berriasellidae	Crimea	Subtropical or Tropical	Cretaceous	Middle Berriasian	Bogdanova & Arkadiev (2005)
Beudanticeras laevigatum	0.49		Desmoceratidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Drushchits & Doguzhaeva (1981)
Bhimaites takahashii	0.5		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Turonian	Shigeta (1993)
Biasaloceras subsequens	0.33		Lytoceratidae	Crimea	Subtropical or Tropical	Cretaceous	Early Barremian	Drushchits (1956)
Binatisphinctes mosquensis	0.39		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian, *Coronatum* Chron	Sprey (2002)
Bisatoceras greenei	0.28		Bisatoceratidae	USA		Mississippian		Miller & Unklesbay (1943)
Bisatoceras sp.	0.34	0.62	Bisatoceratidae	USA		Pennsylvanian	Moscovian	Tanabe *et al.* (1994)
Boreomeekoceras keyserlingi	0.41	0.84	Meekoceratidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Boreophylloceras praeinfundibulum	1.54		Boreiophylloceratidae	NE Siberia	Temperate	Cretaceous	Late Berriasian, *Mesezhnikovi* Chron	Repin *et al.* 1998
Boreophylloceras sp.	1.365		Boreiophylloceratidae	Taimyr	Temperate	Cretaceous	Late Berriasian	Drushchits & Doguzhaeva (1981)
Brasilia bradfordensis	0.5		Graphoceratidae	Caucasus	Subtropical or Tropical	Jurassic	*Bradfordensis* Z., M. Aalenian	Kvantaliani *et al.* (1999)
Bredyia subinsignis [M]	0.5		Graphoceratidae	England	Subtropical or Tropical	Jurassic	E. Aalenian	Senior (1977)
Bredyia subinsignis [m]	0.38		Graphoceratidae	England	Subtropical or Tropical	Jurassic	E. Aalenian	Senior (1977)
Brightia canaliculata	0.39		Oppeliidae	France	Subtropical or Tropical	Jurassic	Late Callovian, *athleta* Z.	Rouget & Neige (2001)
Brightia glypta	0.329		Oppeliidae	England	Subtropical or Tropical	Jurassic	Late Callovian, *athleta* Z.	Palframan (1969)
Brightia sp.	0.35		Oppeliidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian (*Coronatum* Chron) – Late Callovian (Athleta Chron)	Sprey (2002)
Cadoceras elatmae	0.655	1	Cardioceraidae	Central Russia	Subtropical or Tropical	Jurassic	Early Callovian, *Elatmae* Chron	Bodylevsky (1925)
Cadoceras tchefkini	0.5		Cardioceraidae	Central Russia	Subtropical or Tropical	Jurassic	Early Callovian, *Calloviense* Chron	Drushchits *et al.* (1976)
Callihoplites sp.	0.525		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1974)
Calycoceras orientale	0.54		Acanthoceratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Canadoceras cossmati	0.51		Pachydiscidae	Japan	Subtropical or Tropical	Cretaceous	Early Campanian	Shigeta (1993)
Canadoceras mysticum	0.58		Pachydiscidae	Japan	Subtropical or Tropical	Cretaceous	Early Campanian	Shigeta (1993)
Cardioceras arcticum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron	Knyazev (1975)
Cardioceras cordatum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron	Knyazev (1975)
Cardioceras mountjoi	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron	Knyazev (1975)
Cardioceras percaelatum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron	Knyazev (1975)
Castanyiceras parvulum	0.43		Lytoceratidae	France	Subtropical or Tropical	Jurassic	Early Pliensbachian	Rakus & Guex (2002)
Catacoeloceras crassum	0.8		Dactylioceratidae	N Siberia/NE Russia	Temperate	Jurassic	Middle Toarcian	Knyazev *et al.* (1993)
Ceratites compressus	0.3		Ceratitidae	Germany	Subtropical or Tropical	Triassic	Latest Anisian, *Ceratites compressus* Chron	Rein (2006)
Ceratites sp.	0.5		Ceratitidae	Germany	Subtropical or Tropical	Triassic	Late Anisian, *Ceratites spinosus* Chron	Rein (2005)
Cheloniceras intermedium	0.51		Cheloniceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1960)
Choffania mutatus	0.44		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Early Callovian, *Enodatum* Chron	Kvantaliani *et al.* (1999)
Chondroceras sp.	0.5	0.8	Sphaeroceratidae	British Columbia	Subtropical or Tropical	Jurassic	Early Bajocian, late *Humpressianum* Chron	Hall & Westermann (1980)
Cladiscites sp.	0.42		Cladiscitidae	Cosmopolite		Triassic		Spath (1950)
Cleoniceras mangyschlakense	0.5		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973c)
Cleoniceras planum	0.55		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973c)
Cleoniceras renatae	0.5		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973c)
Cleoniceras tenuis	0.5		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973c)
Coeloceras crosbeyi	0.7		Dactylioceratidae	N Siberia/NE Russia	Temperate	Jurassic	Early Toarcian	Knyazev *et al.* (1993)
Collignoniceras woollgari	0.437	0.82	Collignoniceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian	Tanabe *et al.* (1979)
Colombiceras sinzovi	0.36		Acanthohoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1960)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Colombiceras sp.	0.38		Acanthohoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Drushchits & Doguzhaeva (1981)
Columbites ussuriensis	0.46	0.73	Columbitidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Convoluticeras lardeuxi	0.8	1.8	Mimoceratacea	France		Devonian	Emsian	Erben (1964)
Coroniceras reynsei	0.3	0.59	Psiloceratacea	USA	Subtropical or Tropical	Jurassic	Sinemurian	Landman *et al*. (1996)
Costelioceras sp.	0.8		Graphoceratidae	Caucasus	Subtropical or Tropical	Jurassic	Aalenian (early–middle)	Khvantaliani *et al*. 1999
Craspedites sp.	0.53		Craspeditidae	Central Russia	Subtropical or Tropical	Jurassic	Late Volgian?	Drushchits *et al*. 1985
Craspedodiscus discofalcatus	0.625		Simbirskitidae	Volga	Subtropical or Tropical	Cretaceous	Late Hauterivian, *Discofalcatus* Chron	Drushchits & Doguzhaeva (1981)
Creniceras renggeri	0.28	0.55	Oppeliidae	England	Subtropical or Tropical	Jurassic	Early Oxfordian, *Mariae* Chron	Palframan (1966)
Crimites elkoensis	0.37	0.65	Adrianitidae	USA		Permian	Middle	Tanabe *et al*. (1994)
Crimites krotowi	0.365	0.77	Adrianitidae	S. Ural		Permian	Artinskian	Bogoslovskaya (1951)
Cyrtoclymenia frechi	0.545	0.975	Cyrtoclymeniidae			Devonian	Famenian, *Prolobites delphinus* Z.	Bogoslovsky (1981)
Czekanovskites decipiens	0.345	0.6	Longobarditidae	Taymyr	Temperate	Triassic	Middle Anisian	Alekseyev *et al*. (1984)
Czekanovskites hayesi	0.33	0.6	Longobarditidae	Taymyr	Temperate	Triassic	Middle Anisian	Alekseyev *et al*. (1984)
Czekanowskites rieberi	0.39	0.8	Danubitidae		Temperate	Triassic	Lower Anisian	Landman *et al*. (1996)
Dactylioceras athleticum	1		Dactylioceratidae	N Siberia/NE Russia	Temperate	Jurassic	Early Toarcian	Knyazev *et al*. (1993)
Dactylioceras commune	1.04		Dactylioceratidae	Siberia	Temperate	Jurassic	Middle Toarcian	Kutygin (2009)
Damesites ainianum	0.365	0.7	Desmoceratidae		Subtropical or Tropical	Cretaceous	Turonian	Tanabe *et al*. (1979)
Damesites ainuanus	0.378	0.73	Desmoceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian	Tanabe *et al*. (1979)
Damesites damesi	0.46		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993)
Damesites damesi	0.44	0.87	Desmoceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe *et al*. (1979)
Damesites hetonaiensis	0.44		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Damesites latidorsatus	0.41	0.85	Desmoceratidae		Subtropical or Tropical	Cretaceous	Albian	Dauphin (1975)
Damesites semicostatus	0.42	0.84	Desmoceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe *et al*. (1979)
Damesites sugata	0.43		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)
Damesites sugata	0.47		Desmoceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Turonian	Zakharov (1978)
Daraelites elegans	0.45	1.06	Medlicottiidae	S. Ural		Permian	Artinskian	Bogoslovskaya (1951)
Darkaoceras meridionale	0.7		Taouzutidae	Morocco		Devonian	Givetian	Bockwinkel *et al*. (2009)
Deshayesites spp.	0.52		Deshayesitidae	Volga, N Caucasus	Subtropical or Tropical	Cretaceous	Early Aptian, *Deshauesi* Chron	Drushchits & Doguzhaeva (1981)
Desmoceras ezoanum	0.64		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Desmoceras japonicum	0.565	0.97	Desmoceratidae		Subtropical or Tropical	Cretaceous	Cenomanian	Landman *et al*. (1996)
Desmoceras kossmati	0.44		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Desmoceras sp.	0.66		Desmoceratidae	Crimea	Subtropical or Tropical	Cretaceous	Middle Albian, *Hoplites dentatus* Chron	Drushchits & Doguzhaeva (1981)
Desmophyllites	0.5		Desmoceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Campanian, Turonian	Zakharov (1978)
Desmophyllites diphilloides	0.4		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Late Campanian	Shigeta (1993)
Diadochoceras nodosocostatiforme	0.37		Acanthohoplitidae	Japan	Subtropical or Tropical	Cretaceous	Late Aptian	Shigeta (1993)
Diadochoceras sp. 1	0.525		Parahoplitidae	Turkmenia	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1976)
Diadochoceras sp. 2	0.415		Acanthohoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Dieneroceras chaoi	0.29		Dieneroceratidae	Far East		Triassic	Early Olenekian	Zakharov (1974)
Dieneroceras spathi	0.29	0.67	Dieneroceratidae	Nevada		Triassic	Early Olenekian	Zakharov (1974), Landman *et al*. (1996)
Dimorphoplites tethydis	0.58		Hoplitaceae	Turkmenia	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1975)
Discophyllites	0.42		Discophyllitidae	Cosmopolite		Triassic	Carnian–Norian	Spath (1950)
Discoscaphites conradi	0.4	0.76	Scaphitidae	USA, Dakota	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman & Waage (1993)
Discoscaphites rossi	0.34	0.69	Scaphitidae	USA, Dakota	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman & Waage (1993)
Distichoceras bicostatum	0.255		Oppeliidae	England	Subtropical or Tropical	Jurassic	Late Callovian, *lamberti* Z.	Palframan (1967)
Dombarites choctawensis	0.555	1.08	Goniatitidae	USA		Mississippian	Serpukhovian	Tanabe *et al*. (1994)
Dorsoplanites gracilis	0.47		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, *Ilovaiskii* Chron	Kvantaliani *et al*. (1999), Lominadze & Kvantaliani (1986)
Dorsoplanites sibirjakovi	0.6		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, *Maximus* Chron	Mikhailov (1966)
Edmooroceras plummeri		1.04	Girtyoceratidae	USA		Mississippian	Serpukhovian	Tanabe *et al*. (1994)
Eleganticeras elegantulum	0.41	0.84	Hildoceratacea	Germany		Jurassic	E. Toarcian	Tanabe & Ohtsuka (1985)
Eoamaltheus multicostatus	0.5		Dubariceratidae	Argentina	Subtropical or Tropical	Jurassic	Early Pliensbachian	Hillebrandt (2006)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Eogaudriceras aff. *aurarium*	0.51		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Eogunnarites unicus	0.52		Kossmaticeratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Eotetragonites balmensis	0.5	0.98	Tetragonitidae	USA	Subtropical or Tropical	Cretaceous	Albian	Landman *et al.* (1996)
Eothalassoceras inexpectans	0.37	0.66	Thalassoceratidae	USA		Pennsylvanian	Kasimovian–Gzhelian	Tanabe *et al.* (1994)
Epigoniceras glabrum	0.65		Tetragonitidae	Sakhalin	Subtropical or Tropical	Cretaceous	Santonian–Campanian	Drushchits & Doguzhaeva (1981)
Epihoplites	0.56		Hoplitaceae	Turkmenia	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1975)
Epilaugeites	0.6		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, *Vogulicus* Chron	Mikhailov (1966)
Epivirgatites s.l.	0.635		Dorsoplanitidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Volgian, *Nikitini* Chron	Druschiz *et al.* (1983)
Euhoplites ex gr. *trapezoidalis*	0.49		Hoplitaceae	Turkmenia	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1975)
Eupachydiscus haradai	0.525	1.065	Pachydiscidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Campanian	Tanabe *et al.* (1979)
Euphylloceras anthulai	0.495		Euphylloceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Drushchits & Doguzhaeva (1981)
Euphylloceras californicum	0.38		Euphylloceratidae	USA, California	Subtropical or Tropical	Cretaceous	Late Aptian–early Albian	Murphy & Rodda (2006)
Euphylloceras ponticuli	0.32		Euphylloceratidae	Crimea	Subtropical or Tropical	Cretaceous	Early Barremian	Drushchits 1956
Euphylloceras velledae	0.54		Euphylloceratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Eurycephalites gottschei	0.55		Sphaeroceratidae	Argentina	Subtropical or Tropical	Jurassic	lower Callowian	Parent (1997)
Eurystomiceras polyhelictum	0.405		Tetragonitidae	Caucasus	Subtropical or Tropical	Jurassic	Middle Bajocian	Drushchits & Doguzhaeva (1981)
Fagesia peroni	0.35		Acanthocerataceae	Tadzhikistan	Subtropical or Tropical	Cretaceous	Turonian	Mikhailova (1983b)
Fallotites costatus	0.23		Vascoceratidae	Tadzhikistan	Subtropical or Tropical	Cretaceous	Turonian	Mikhailova (1983b)
Flabellisphinctes lateralis	0.41		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian, *Coronatum* Chron	Kvantaliani *et al.* (1999)
Frechites humboldtensis	0.59		Beyrichitidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984a)
Frechites nevadanus	0.49	0.75	Beyrichitidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *Nevadanus* Z.	Vavilov (1992)
Frechites sp.	0.6	1.32	Beyrichitidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984a)
Gabbioceras angulatum	0.44	0.88	Tetragonitidae	USA	Subtropical or Tropical	Cretaceous	Albian	Landman *et al.* (1996)
Gabbioceras latericarinatum	0.49		Tetragonitidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Gabbioceras michelianum	0.52		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Gabbioceras sp.	0.555		Tetragonitidae	Kopetdagh	Subtropical or Tropical	Cretaceous	Middle Albian, *Hoplites dentatus* Chron	Drushchits & Doguzhaeva (1981)
Gaitherites morrowensis	0.42	0.84	Girtyoceratidae	USA		Pennsylvanian	Bashkirian	Tanabe *et al.* (1994)
Galaticeras aegoceroides	0.43		Lytoceratidae		Subtropical or Tropical	Jurassic	Early Pliensbachian	Rakus & Guex (2002)
Galaticeras subtriangulare	0.45		Lytoceratidae		Subtropical or Tropical	Jurassic	Early Pliensbachian	Rakus & Guex (2002)
Gaudriceras aff. *stefanii*	0.5		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Gaudriceras denseplicatum	0.48		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Middle Turonian	Shigeta (1993)
Gaudriceras striatum	0.71		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Late Campanian	Shigeta (1993)
Gaudriceras tombetsense	0.76		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Gaudryceras alamedense	0.56		Tetragonitidae	California		Cretaceous	Campanian	Smith (1898)
Gaudryceras denseplicatum	0.784	1.51	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian–Late Santonian	Tanabe *et al.* (1979)
Gaudryceras denseplicatum	0.62	1.25	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe & Ohtsuka (1985)
Gaudryceras striatum	0.67	1.3	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Cenomanian–Campanian	Tanabe & Ohtsuka (1985)
Gaudryceras tenuiliratum	0.63	1.26	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Campanian	Tanabe & Ohtsuka (1985)
Gaudryceras tenuiliratum	0.768	1.6	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian–Late Santonian	Tanabe et al. (1979)
Gaudryceras tenuiliratum var. *ornata*	0.714	1.337	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe *et al.* (1979)
Genuclymenia angelini	0.605	1.09	Cymaclimeniidae			Devonian	Famenian, *Prolobites delphinus* Z.	Bogoslovsky (1981)
Genuclymenia frechi	0.61		Cymaclimeniidae			Devonian	Famenian, *Prolobites delphinus* Z.	Bogoslovsky (1981)
Girtyoceras meslerianum	0.45	0.96	Girtyoceratidae	USA		Mississippian	Serpukhovian	Tanabe *et al.* (1994)
Glaphyrites jonesi	0.49		Glaphyritidae	USA		Pennsylvanian	Kasimovian–Gzhelian	Miller & Unklesbay (1943)
Glaphyrites clinei	0.455	0.83	Glaphyritidae	USA		Pennsylvanian	Kasimovian–Gzhelian	Tanabe *et al.* (1994)
Glaphyrites hyattianus	0.59	1.03	Glaphyritidae	USA		Pennsylvanian	Moscovian	Tanabe *et al.* (1994)
Glaphyrites jonesi	0.54	0.96	Glaphyritidae	USA		Pennsylvanian	Kasimovian-Gzhelian	Tanabe *et al.* (1994)
Glaphyrites warei	0.455	0.87	Glaphyritidae	USA		Pennsylvanian	Kasimovian-Gzhelian	Tanabe *et al.* (1994)
Glaphyrites welleri	0.35	0.81	Glaphyritidae	USA		Pennsylvanian	Moscovian	Tanabe *et al.* (1994)
Goniatites cf. *sphaericus*	0.53		Goniatitidae	USA		Mississippian	Viséan	Smith (1897)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Goniatites crenistria	0.46		Goniatitidae	USA		Mississippian	Viséan	Smith (1903)
Goniatites multiliratus	0.53	0.94	Goniatitidae	USA		Mississippian	Viséan	Tanabe *et al.* (1994)
Goniatites sp. aff. *G. crenistria*	0.54	0.98	Goniatitidae	USA		Mississippian	Chesterian/Serpukhovian	Tanabe *et al.* (1994)
Goniatites sphaericus	0.53		Goniatitidae	USA		Mississippian	Serpukhovian	Perrin-Smith (1903)
Gonioloboceras welleri	0.8	1.92	Gonioloboceratidae	Texas		Pennsylvanian	Gzhelian	Miller & Unklesbay (1943)
Gorgheiceras tuberculatum	0.35		Bouhamidoceratinae	Tunisia	Subtropical or Tropical	Jurassic	Early Pliensbachian	Rakus & Guex (2002)
Grambergia taymyrensis	0.525	0.915	Longobarditidae	Taymyr	Temperate	Triassic	Early Anisian	Alekseyev *et al.* (1984)
Gymnotoceras	0.35		Beyrichiidae			Triassic	Late Anisian	Spath (1950)
Gymnotoceras falciforme	0.38	0.69	Beyrichitidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984a)
Gymnotoceras meeki	0.42	0.725	Beyrichitidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984a)
Gymnotoceras rotelliforme	0.45		Beyrichitidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984a)
Gyroceratites gracilis	0.9	1.5	Mimoceratacea	Germany		Devonian	Emsian	Erben (1964)
Hauericeras angustum	0.42		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993)
Hauericeras gardeni	0.43	0.71	Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Santonian	Tanabe & Ohtsuka (1985), Tanabe *et al.* (1979)
Hedenstroemia hedenstroemi	0.63		Hedenstromeidae	NE Russia	Temperate	Triassic	Early Olenekian	Zakharov (1974)
Hedenstroemia mojsisovicsi	0.49		Hedenstromeidae	NE Russia	Temperate	Triassic	Early Olenekian	Zakharov (1974)
Hegaratia balkensis	0.25		Neocomitidae	Crimea	Subtropical or Tropical	Cretaceous	Late Berriasian	Khvantaliani (1999)
Hemiprionites contortus	0.5		Prionitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Hemiprionites dunajensis	0.54		Prionitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Holcophylloceras costisparsum	0.64		Holcophylloceratidae	NE Siberia	Temperate	Jurassic	Latest Bajocian/Earliest Bathonian, *Arctocephalites arcticus* Chron, *Oxycerites jugatus* SubChron	Repin (2005)
Holcophylloceras sp.	0.525		Holcophylloceratidae	Crimea-Caucasus	Subtropical or Tropical	Jurassic	Late Bajocian	Drushchits & Doguzhaeva (1981)
Homoceras sp.	0.35	0.64	Goniatitidae	U.K.		Mississippian		Tanabe & Ohtsuka (1985)
Hoplites benettianus	0.5		Hoplitidae	Turkmenia	Subtropical or Tropical	Cretaceous	Middle Albian, *Hoplites dentatus* Chron	Mikhailova (1973b)
Hoplites dentatus	0.66		Hoplitidae	Turkmenia	Subtropical or Tropical	Cretaceous	Middle Albian, *Hoplites dentatus* Chron	Mikhailova (1973b)
Hoploscaphites comprimus		0.66	Scaphitidae	Europe	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman & Waage (1993)
Hoploscaphites nicolettii	0.43	0.77	Scaphitidae	Europe	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman (1987)
Horioceras baugieri	0.27		Oppeliidae	England	Subtropical or Tropical	Jurassic	Late Callovian, *lamberti* Z.	Palframan (1967)
Hypacanthoplites sp. 1	0.64		Parahoplitidae	N. Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1976)
Hypacanthoplites sp. 2	0.405		Acanthohoplitidae	Caucasus/Mangyshlak	Subtropical or Tropical	Cretaceous	Latest Aptian	Drushchits & Doguzhaeva (1981)
Hypacanthoplites sp. 3	0.49		Acanthohoplitidae	Caucasus/Mangyshlak	Subtropical or Tropical	Cretaceous	Latest Aptian	Drushchits & Doguzhaeva (1981)
Hypacanthoplites subcornerianus	0.5		Acanthohoplitidae	Japan	Subtropical or Tropical	Cretaceous	Aptian	Shigeta (1993)
Hypophylloceras hetonaiense	0.52		Phylloceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Hypophylloceras ramosum	0.63	1.03	Phylloceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	?Campanian	Tanabe & Ohtsuka (1985)
Hypophylloceras sp.	0.66		Phylloceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Campanian	Drushchits & Doguzhaeva (1981)
Hypophylloceras subramosum	0.57	0.99	Phylloceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	MiddleTuronian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Hypoturrilites gravesianus	0.43	1	Turrilitidae	Kopetdagh	Subtropical or Tropical	Cretaceous	Early Cenomanian, *Mantelliceras mantelli* Chron	Atabekyan & Mikhailova (1976)
Hysteroceras orbignyi	0.25		Acanthocerataceae	Tuarkyr	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1983a)
Ilowaiskya schashkovae	0.6		Virgatitidae	Orenburg	Subtropical or Tropical	Jurassic	Early Volgian, *Pseudoscythica* Chron	Mikhailov (1964)
Indigirites constantis	0.45	0.67	Nathorstitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *omolojensis* Z.	Vavilov (1992)
Indigirites krugi	0.36	0.64	Nathorstitidae	N Siberia	Temperate	Triassic	Late Ladinian	Arkadiev & Vavilov (1984b)
Indigirites tozeri	0.325	0.535	Nathorstitidae	Hokkaido	Temperate	Triassic	Botneheia Formation	Landman *et al.* (1996)
Indigirophyllites bytschkovi	0.7	1.25	Ussuritidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *spectori* Z.	Vavilov (1992)
Indigirophyllites spitsbergensis	0.46	1.02	Ussuritidae		Temperate	Triassic	Botneheia Formation	Landman *et al.* (1996)
Indosphinctes nikitinoensis	0.43		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian	Kvantaliani *et al.* (1999)
Isohomoceras subglobosum	0.53	0.91	Homoceratidae	UK		Pennsylvanian	Lower Bashkirian	Tanabe *et al.* (1994)
Jeletzkytes nebrascensis	0.41	0.68	Scaphitidae	USA (Dacota)	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman & Waage (1993)
Jeletzkytes spedeni	0.41	0.76	Scaphitidae	USA (Dacota)	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman & Waage (1993)
Joannites	0.6		Joannitidae		Subtropical or Tropical	Triassic	Anisian–Carnian	Spath (1950)
Karangatites evolutus	0.27	0.76	Meekoceratidae	N Siberia/NE Asia	Temperate	Triassic	Earliest Anisian, *taimyrensis* Z.	Vavilov (1992)
Kargalites (Kargalites) typicus	0.41	0.88	Marathonitidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Karsteniceras obatai	0.35		n/a	Japan	Subtropical or Tropical	Cretaceous	Barremian	Shigeta (1993)
Kashpurites fulgens	0.715		Craspeditidae	Central Russia	Subtropical or Tropical	Jurassic	Late Volgian, *Fulgens* Chron	Drushchits *et al.* 1985
Keyserlingites middendorfi	0.64	1.3	Keyserlingitidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1978)
Keyserlingites sp.	0.58	1.3	Keyserlingitidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1970)
Kingites sp.	0.42	0.68	Paranoritidae	NE Russia, Far East	Temperate	Triassic	Induan	Zakharov (1974)
Kitchinites ishikawai	0.53	1.15	Desmoceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe *et al.* (1979), Shigeta (1993)
Koenenites styliophilus styliophilus	0.68		Koenenitidae	USA		Devonian	Frasnian	House & Kirchgasser (2008)
Kolymophylloceras turomchense	0.64		Yukagiritidae	NE Russia	Temperate	Jurassic	Hettangian, *Viligense* Chron	Repin *et al.* (1998)
Kosmoceras jason	0.42		Kosmoceratidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian, *jason* Z.?	Drushchits *et al.* (1976)
Kosmoceras spp.	0.42		Kosmoceratidae	Central Russia	Subtropical or Tropical	Jurassic	Late Callovian, *Athleta* Chron	Sprey (2002)
Kossmatella agassiziana	0.595		Tetragonitidae	Crimea	Subtropical or Tropical	Cretaceous	Middle Albian	Drushchits & Doguzhaeva (1981)
Latanarcestes noeegerati	0.69		Latanarcestidae			Devonian	Upper Emsian	De Baets *et al.* (2012)
Laugeites borealis	0.51		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, "*Groenlandicus*" Chron	Kvantaliani *et al.* (1999)
Leioceras opalinum	0.44		Graphoceratidae	Caucasus	Subtropical or Tropical	Jurassic	E. Aalenian, *opalinum* Z.	Kvantaliani *et al.* (1999)
Leiophylloceras calypso	0.4		Phylloceratidae	Crimea	Subtropical or Tropical	Cretaceous	Early–Middle Berriasian	Arkadiev (2002)
Lenotrophites solitarius	0.32	0.62	Longobarditidae	Taymyr	Temperate	Triassic	Early Anisian	Alekseyev *et al.* (1984)
Lenotrophites sp.	0.38	0.715	Longobarditidae	Taymyr	Temperate	Triassic	Early Anisian	Alekseyev *et al.* (1984)
Lenotrophites tardus	0.33	0.605	Longobarditidae	Taymyr	Temperate	Triassic	Early Anisian	Alekseyev *et al.* (1984)
Lenotropites boschoensis	0.38	0.725	Longobarditidae	N Siberia/NE Asia	Temperate	Triassic	Early Anisian, *tardus* Z.	Vavilov (1992)
Leymeriella andrussovi	0.4		Hoplitaceae	Kopetdagh	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973a)
Leymeriella ex gr. *pseudoregularis*	0.4		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973a)
Leymeriella tardefurcata	0.4		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1973a)
Lomonossovella s.l.	0.59		Dorsoplanitidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Volgian, *Nikitini* Chron	Druschiz *et al.* (1983)
Longobardites nevadanus	0.43	0.88	Longobarditidae	Taymyr	Temperate	Triassic	Late Anisian	Alekseyev *et al.* (1984)
Ludwigia sp.	0.45		Graphoceratidae	Caucasus	Subtropical or Tropical	Jurassic	Aalenian	Kvantaliani *et al.* (1999)
Luppovia dotshamensis	0.46	0.8	Ancyloceratidae	Turkmenia	Subtropical or Tropical	Cretaceous	Middle Aptian	Kakabadze *et al.* (1978)
Luppovia sp.	0.5		Ancyloceratidae	Turkmenia	Subtropical or Tropical	Cretaceous	Middle Aptian	Doguzhaeva & Mikhailova (1982)
Mantelliceras japonicum	0.48		Acanthoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Mantelliceras mantelli	0.35		Acanthocerataceae	Tuarkyr	Subtropical or Tropical	Cretaceous	Cenomanian	Mikhailova (1983a)
Manticoceras adorfense	0.74		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras affine	0.925		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras bullatum	0.76	1.2	Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras cordatum	0.755		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras crassum	0.755		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras drevermanni	0.73		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras galeatum	0.8		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras intumescens	0.725		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras orbiculum	0.78		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras serratum	0.665		Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Manticoceras sp.		1.3	Gephuroceratidae			Devonian	Frasnian	Ruzhencev & Shimansky (1954)
Manticoceras sp. 2	0.65		Gephuroceratidae	France		Devonian	Frasnian	Korn & Klug (2007)
Marschallites compressus	0.5		Kossmaticeratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Masonoceras kentuckiensis	0.45		Goniatitidae	USA		Mississippian	Upper Tournaisian–lower Viséan	Miller & Unklesbay (1943)
Medlicottia orbignyana	0.34	0.72	Medlicottiidae			Permian	Artinskian	Bogoslovskaya (1951)
Meekoceras subcristatum	0.44		Meekoceratidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Megaphyllites prometheus	0.565	0.99	Megaphyllitidae			Triassic	Late Anisian	Landman *et al.* (1996)
Melchiorites sp.	0.34		Desmoceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Menuites pusillus	0.5	0.87	Desmoceratidae		Subtropical or Tropical	Cretaceous	Turonian	Tanabe *et al.* (1979)
Mesopuzosia pacifica	0.451	0.829	Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Middle Turonian	Shigeta (1993), Tanabe *et al.* (1979)
Mesopuzosia yubarensis	0.34		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Metalegoceras baylorense	0.45	0.85	Metalegoceratidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Metaplacenticeras (?) *pacificum*	0.56		Hoplitaceae	California		Cretaceous	Campanian	Smith (1900)
Metaplacenticeras subtilistriatum	0.63		Placenticeratidae	Japan	Subtropical or Tropical	Cretaceous	Late Campanian	Shigeta (1993)
Metaplacenticeras subtilistriatum	0.532	1.088	Placenticeratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Campanian	Tanabe *et al.* (1979)
Mexicoceras guadalupense	0.52	0.93	Cyclolobidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Microdesmoceras tetragonum	0.53		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Mimagoniatites fecundus	1.175	2.1	Mimagoniatitidae	France		Devonian	Emsian	Erben (1964)
Mimosphinctes zlichovensis	1.31		Mimosphinctidae			Devonian	Emsian–early	De Baets *et al.* (2012)
Monophyllites sp.	0.425		Ussuritidae	Far East		Triassic	Anisian	Zakharov (1974)
Nannites simplex	0.38		Nannitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Nathorstites agratassensis	0.36	0.66	Nathorstitidae	N Siberia	Temperate	Triassic	Late Ladinian	Arkadiev & Vavilov (1984b)
Nathorstites gibbosus	0.39	0.615	Nathorstitidae	Taymyr	Temperate	Triassic	Early Carnian	Alekseyev *et al.* (1984)
Nathorstites lenticulatis	0.26	0.54	Nathorstitidae	N Siberia	Temperate	Triassic	Late Ladinian	Arkadiev & Vavilov (1984b)
Nathorstites mcconnelli	0.465	0.765	Nathorstitidae	Taymyr	Temperate	Triassic	Late Ladinian	Alekseyev *et al.* (1984)
Neoasteria reliqua	0.38		Desmoceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Kvantaliani *et al.* (1999)
Neoglyphioceras abramovi	0.51	0.93	Neoglyphiceratidae	Russia		Mississippian	Upper Viséan–Lower Serphukhovian	Zakharov (1978)
Neopronorites permicus	0.5	0.98	Pronoritidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)
Neoprotrachyceras sp.	0.48	0.57	Trachiceratidae	N Siberia/NE Asia	Temperate	Triassic	Early Carnian, *omkutchanikum* Z.	Vavilov (1992)
Neopuzosia ishikawai	0.42		Desmoceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Campanian	Zakharov (1978)
Neosirenites irregularis	0.37	0.65	Trachiceratidae	N Siberia/NE Asia	Temperate	Triassic	Late Carnian, *penlastichus* Z.	Vavilov (1992)
Nevadisculites smithi	0.36	0.7	Proarcestidae	Nevada		Triassic	Middle Anisian	Arkadiev *et al.* (1993)
Nevadisculites taylori	0.4	1	Proarcestidae	Nevada		Triassic	Middle Anisian	Arkadiev *et al.* (1993)
Nikitinoceras (Costamenjaites) jucundus	0.5		Craspeditidae	NE Siberia	Temperate	Cretaceous	Early Valanginian	Klimova (1987)
Nodosohoplites sinuocostatus	0.395		Acanthohoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Nolaniceras sp.	0.42		Acanthohoplitidae	Caucasus, Mangyshlak	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Nordophiceras schmidti	0.38	0.78	Meekoceratidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Obrutchevites prodigialis	0.51	0.82	Trachiceratidae	N Siberia/NE Asia	Temperate	Triassic	Late Carnian, *yakutensis* Z.	Vavilov (1992)
Olenekites sp.	0.335	0.72	Sibiritidae	N Siberia/NE Asia	Temperate	Triassic	Late Olenekian	Zakharov (1970)
Olenekites spiniplicatus	0.37	0.67	Sibiritidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1978)
Ophiceras sp.	0.39	0.74	Ophiceratidae	Jakutia		Triassic	Induan	Zakharov (1974)
Osperleioceras lapparenti	0.39		Hildoceratidae	France	Subtropical or Tropical	Jurassic	Reynesi S/z (L. Toarcian)	Morard & Guex (2003)
Osperleioceras reinesi	0.41		Hildoceratidae	France	Subtropical or Tropical	Jurassic	Reynesi S/z (L. Toarcian)	Morard & Guex (2003)
Otoceras boreale	0.73	1.11	Otoceratidae	NE Russia	Temperate	Triassic	Early Induan, *Otoceras boreale* Chron	Zakharov (1978)
Otoscaphites clamathensis	0.42	0.78	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Coniacian	Tanabe & Ohtsuka (1985), Shigeta (1993), Tanabe *et al.* (1979)
Otoscaphites matsumotoi	0.52		Scaphitidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)
Otoscaphites puerculus	0.51	0.85	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian	Tanabe *et al.* (1979), Shigeta (1993)
Owenites koeneni	0.37		Owenitidae	Far East, Timor		Triassic	Early Olenekian	Zakharov (1978)
Owenoceras bellilineatum	0.435	0.87	Gastrioceratidae	USA		Pennsylvanian	Moscovian	Tanabe *et al.* (1994)
Pachyclymenia intermedia	0.48	0.8	Myroclymeniidae			Devonian	Famenian	Bogoslovsky (1981)
Pachydiscid, young, gen. et sp. indet.	0.463	0.798	Pachydiscidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Campanian	Tanabe *et al.* (1979)
Palaeokazachstanites ussuriensis	0.45	0.76	Sibiritidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Paracladiscites sp.	0.5	0.87	Cladiscitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *macconnelli* Z.	Vavilov (1992)
Parafrechites meeki	0.42	0.73	Beyrichitidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *nevadanus* Z.	Vavilov (1992)
Paragastrioceras sp.	0.48	0.84	Paragastrioceratidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)
Paragastrioceras sp. 2		0.9	Paragastrioceratidae			Permian	Artinskian	Ruzhencev & Shimansky (1954)
Parahedenstroemia nevolini	0.44		Aspenitidae	Far East		Triassic	Early Olenekian, *Anasibirites nevolini* Chron	Zakharov (1978)
Parahoplites melchioris	0.53		Parahoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian, *Parahoplites melchioris* Chron	Mikhailova 1962
Parahoplites melchioris 1	0.88		Parahoplitidae	N Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Mikhailova (1976)
Parahoplites melchioris 2	0.625		Parahoplitidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian, *Parahoplites melchioris* Chron	Drushchits & Doguzhaeva (1981)
Parahoplites schmidti	0.79		Parahoplitidae	N Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Mikhailova (1976)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Parajaubertella sp.	0.63		Tetragonitidae	Sakhalin	Subtropical or Tropical	Cretaceous	Cenomanian	Drushchits & Doguzhaeva (1981)
Parajaubetelle kawakitana	0.63		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Paranannites spathi	0.35	0.67	Paranannitidae	Spitzbergen	Temperate	Triassic	Olenekian	Landman *et al.* (1996)
Parannites aspenensis	0.37	0.65	Nannitidae	Nevada		Triassic	Early Olenekian	Zakharov (1974)
Paranorites? *kolymensis*	0.44	0.82	Paranoritidae	NE Russia	Temperate	Triassic	Early Olenekian	Zakharov (1978)
Parapatoceras calloviense	0.47	0.84	Spiroceratidae	USA (Dacota)	Subtropical or Tropical	Jurassic	Early–Middle Callovian	Landman *et al.* (1996)
Parapatoceras distans	0.65		Spiroceratidae	England	Subtropical or Tropical	Jurassic	Early Callovian, ?*koenigi* Z.	Dietl (1978)
Parapopanoceras asseretoi	0.365	0.68	Parapopanoceratidae	N Siberia	Temperate	Triassic	Late Anisian	Arkadiev & Vavilov (1984b)
Parapopanoceras janaense	0.5		Parapopanoceratidae	N Siberia	Temperate	Triassic	Middle Anisian	Arkadiev & Vavilov (1984b)
Parapopanoceras medium	0.375		Parapopanoceratidae	N Siberia	Temperate	Triassic	Early Anisian	Arkadiev & Vavilov (1984b)
Parapopanoceras paniculatum	0.39	0.66	Parapopanoceratidae	NE Russia	Temperate	Triassic	Anisian	Zakharov (1974)
Parapopanoceras paniculatum	0.39	0.64	Parapopanoceratidae	N Siberia	Temperate	Triassic	Middle Anisian	Arkadiev & Vavilov (1984b)
Paraschistoceras sp.		1.2	Schistoceratidae			Pennsylvanian		Ruzhencev & Shimansky (1954)
Parasibirites grambergi	0.4	0.71	Sibiritidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1978)
Paravirgatites aff. *boldini*	0.6		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Early Volgian, "*Pectinatus*" Chron	Mikhailov (1964)
Partschiceras sp.	0.44		Phylloceratidae	Caucasus	Subtropical or Tropical	Jurassic	Middle Bajocian	Drushchits & Doguzhaeva (1981)
Partschiceras striatocostatum	0.75		Phylloceratidae	Austria	Subtropical or Tropical	Jurassic	Sinemurian	Rakus (1999)
Parussuria semenovi	0.43		Ussuritidae			Triassic	Early Olenekian	Zakharov (1978)
Pavlovia iatrensis	0.51		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, *Iatriensis* Chron	Kvantaliani *et al.* (1999)
Pavloviceras	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Obliteratum* Chron	Knyazev (1975)
Peritrochia erebus	0.45	0.88	Popanoceratidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Peritrochia typicus	0.41	0.88	Popanoceratidae			Permian	Sakmarian	Landman *et al.* (1996)
Peronoceras fibulatum	0.45	0.89	Eoderoceratoidea		Subtropical or Tropical	Jurassic	Middle Toarcian	Landman *et al.* (1996)
Perrinites sp.	0.96	2.15	Perrinitidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Pharciceras tridens	0.7		Pharciceratidae	Morocco		Devonian	Givetian	Bockwinkel *et al.* (2009)
Philocladisites basaginensis	0.37	0.66	Cladiscidae	Far East		Triassic	Anisian	Zakharov (1974)
Phylloceras omkuchanicum	0.76		Phylloceratidae	NE Russia	Temperate	Jurassic	Early Sinemurian, *Libratus (Bucklandi)* Chron	Repin *et al.* (1998)
Phyllopachyceras ezoense	0.51	0.85	Phyllopachyceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Late Santonian	Tanabe & Ohtsuka (1985)
Phyllopachyceras ezoense	0.58		Phyllopachyceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Campanian	Zacharov (1974)
Phyllopachyceras japonicum	0.54		Phyllopachyceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Cenomanian	Shigeta (1993)
Phyllopachyceras sp.	0.455		Phyllopachyceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Drushchits & Doguzhaeva (1981)
Placenticeras	0.75		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Cenomanian	Mikhailova (1974b)
Placites polydactylus	0.39		Pinacoceratidae	Timor		Triassic	Carnian	Zakharov (1978)
Plasmatoceras bodylevskii	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Middle Oxfordian	Knyazev (1975)
Platyclymenia richteri	0.52	0.96				Devonian	Famenian, *Platyclymenia annulata* Z.	Bogoslovsky (1981)
Platyphylloceras lebedevi	0.72		Phylloceratidae	NE Siberia	Temperate	Jurassic	Late Aalenian	Repin (2005)
Pleuroceras sp.	0.5	1.06	Eoderoceratoidea			Jurassic	Late Pliensbachian	Tanabe & Ohtsuka (1985)
Pleurohoplites studeri	0.55		Hoplitaceae	Turkmenia	Subtropical or Tropical	Cretaceous	Late Albian	Mikhailova (1975)
Politoceras politum	0.45	0.9	Dimorphoceratidae	USA		Pennsylvanian	Moscovian	Miller & Unklesbay (1943)
Polyptychites beani	0.52		Polyptychitidae	N Siberia	Temperate	Cretaceous	Valanginian – early	Klimova (1987)
Polyptychites mikhalskii	0.5		Polyptychitidae	N Siberia	Temperate	Cretaceous	Valanginian – early	Klimova (1987)
Polyptychites pumilio	0.425		Polyptychitidae	Germany	Temperate	Cretaceous	Valanginian – early	Vogel (1959)
Polyptychites sp.	0.5		Polyptychitidae	N Siberia	Temperate	Cretaceous	Valanginian – early	Klimova (1987)
Popanoceras annae	0.308	0.66	Popanoceratidae	Russia		Permian	Middle	Miller & Unklesbay (1943), Tanabe *et al*. (1994)
Proarcestes korchinskajae	0.5	0.875	Proarcestidae	Nsiberia	Temperate	Triassic	Late Carnian	Arkadiev *et al.* (1993)
Proarcestes verchojanicus	0.62	0.95	Proarcestidae	NE Russia	Temperate	Triassic	Late Carnian	Arkadiev et al. (1993)
Probeloceras lutheri		1.06	Gephuroceratidae	Germany		Devonian	Frasnian	Clausen (1969)
Promicroceras sp.	0.42	0.73	Eoderoceratoidea			Jurassic	Early Sinemurian	Landman *et al.* (1996)
Pronorites praepermicus	0.6	1.22	Pronoritidae	Russia		Permian	Artinskian	Miller & Unklesbay (1943), Tanabe *et al*. (1994)
Pronorites vulgaris	0.49	1.05	Pronoritidae			Permian	Artinskian	Bogoslovskaya (1959)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Properisphinctes pseudobernensis	0.48		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Late Callovian	Kvantaliani *et al.* (1999)
Properrinites bakeri	0.68	1.19	Perrinitidae	USA		Permian	Early	Miller & Unklesbay (1943), Tanabe *et al.* (1994)
Prosphingites czekanowskii	0.44	0.79	Nannitidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Prosphingites hexagonalis	0.41	0.71	Nannitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Prosphingites ovalis	0.41	0.68	Nannitidae	Far East		Triassic	Early Olenekian	Zakharov (1978)
Protexanites minimus	0.45		Collignoniceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993)
Pseudocadoceras sp.	0.5		Cardioceraidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian, *jason* Z.?	Drushchits *et al.* (1976)
Pseudogastrioceras suessi	0.46		Paragastrioceratidae	USA		Permian	Artinskian	Miller & Unklesbay (1943)
Pseudogastrioceras fedorowi	0.39	0.75	Gastrioceratidae			Permian	Artinskian	Bogoslovskaya (1959)
Pseudogastrioceras simulator	0.4	0.8	Paragastrioceratidae	USA		Permian	Early	Tanabe *et al.* (1994)
Pseudohaploceras nipponicus	0.41		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Late Aptian	Shigeta (1993)
Pseudophillites indra	0.71		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Late Campanian	Shigeta (1993)
Pseudosageceras borealis	0.57	0.96	Sageceratidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1978)
Pseudosilesites akushensis	0.43		Desmoceratidae	N. Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1972)
Pseudosilesites seranonifirmis	0.45		Desmoceratidae	N. Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Mikhailova (1972)
Psiloceras spellae	0.62		Psiloceratidae	Austria	Subtropical or Tropical	Jurassic	basal Hettangian	Hillebrandt & Krystin (2009)
Pterosirenites nelgechensis	0.55	0.72	Trachiceratidae	N Siberia/NE Asia	Temperate	Triassic	Early Norian, *obrucevi* Z.	Vavilov (1992)
Ptychoceras renngarteni	0.395		Ptychoceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Ptychophylloceras ptychoticus	0.41		Phylloceratidae	Crimea	Subtropical or Tropical	Cretaceous	Berriasian	Drushchits & Doguzhaeva (1981)
Puzosia orientalis	0.48		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Turonian	Shigeta (1993)
Reesidites minimus	0.458	1.004	Collignoniceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Late Turonian	Tanabe *et al.* (1979)
Rhacophyllites	0.29		Discophyllitidae		Subtropical or Tropical	Triassic	Carnian–Norian	Spath (1950)
Richardonites richardsonianus	0.46	0.8	Glaphyritidae	USA		Mississippian	Serpukhovian	Tanabe *et al.* (1994)
Saghalinites teshioensis	0.68		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Late Campanian	Shigeta (1993)
Sakmarites vulgaris	0.49	1.05	Gephuroceratidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)
Salfeldiella spp.	0.47		Phylloceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle–Late Aptian	Drushchits & Doguzhaeva (1981)
Sanmartinoceras sp.	0.435		Aconeceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Doguzhaeva (1981)
Scaphites carlilensis		0.6	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Turonian	Landman (1987)
Scaphites corvensis	0.31	0.67	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Turonian	Landman (1987)
Scaphites depressus	0.36	0.75	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Coniacian	Landman (1987)
Scaphites larvaeformis	0.32	0.59	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Turonian	Landman (1987)
Scaphites nigricollensis	0.37	0.68	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Turonian	Landman (1987)
Scaphites planus	0.51	0.89	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Scaphites planus	0.487	0.85	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Late Turonian	Tanabe *et al.* (1979)
Scaphites pseudoequalis	0.445	0.79	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Scaphites pseudoequalis	0.405	0.72	Scaphitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Coniacian	Tanabe *et al.* (1979)
Scaphites warreni	0.32	0.66	Scaphitidae	USA	Subtropical or Tropical	Cretaceous	Turonian	Landman (1987)
Scaphites yonekurai	0.51		Scaphitidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)
Scarburgiceras alphacordatum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Gloriosum* Chron	Knyazev (1975)
Scarburgiceras obliteratum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Obliteratum* Chron	Knyazev (1975)
Scarburgiceras praecordatum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Gloriosum* Chron	Knyazev (1975)
Schloenbachia	0.525		Hoplitaceae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Cenomanian	Mikhailova (1974b)
Scoticardioceras excavatum	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron – M. Oxfordian	Knyazev (1975)
Sellanarcestes neglectus	1.1		Anarcestidae			Devonian	Emsian upper	De Baets *et al.* (2012)
Siberites sp.	0.6		Craspeditidae	NE Siberia	Temperate	Cretaceous	Early Valanginian	Klimova (1983)
Sibirites eichwaldi	0.36	0.635	Sibiritidae	N Siberia	Temperate	Triassic	Late Olenekian	Zakharov (1978)
Simbirskites spp.	0.61		Simbirskitidae	Volga	Subtropical or Tropical	Cretaceous	Late Hauterivian, *Discofalcatus* Chron	Drushchits & Doguzhaeva (1981)
Sokolovites subdragunovi	0.45		Hoplitidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1975)
Sonneratia luppovi	0.53		Hoplitidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Early Albian	Mikhailova (1974a)
Speetoniceras versicolor	0.58		Simbirskitidae	Volga	Subtropical or Tropical	Cretaceous	Late Hauterivian, *Versicolor* Chron	Drushchits & Doguzhaeva (1981)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Sphaerocladiscites omolonensis	0.55	0.8	Cladiscitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *macconnelli* Z.	Vavilov (1992)
Sphaeromanticoceras rhynchostomum	0.8	1.1	Gephuroceratidae	USA		Devonian	Frasnian	House & Kirchgasser (2008)
Spheroceras brongniarti	0.34		Stephanocerataceа	Europe	Subtropical or Tropical	Jurassic	Bajocian	Grandjean (1910)
Stacheoceras subinterruptom	0.425	0.84	Popanoceratidae			Permian	Artinskian	Bogoslovskaya (1959)
Stacheoceras toumanskyae	0.266		Popanoceratidae	Mexico		Permian	Capitanian	Miller & Unklesbay (1943)
Stenoglaphyrites incisus	0.53	0.95	Stenoglaphyritidae	USA		Mississippian	Serpukhovian	Tanabe *et al.* (1994)
Stenopopanoceras mirabile	0.44		Parapopanoceratidae	N Siberia	Temperate	Triassic	Early Anisian	Arkadiev & Vavilov (1984b)
Stephanoceras itinsae	0.43	0.8	Stephanoceratidae	British Columbia	Subtropical or Tropical	Jurassic	Early Bajocian, *Humpressianum* Chron	Hall & Westermann (1980)
Stolleyites tenuis	0.36	0.62	Nathorstitidae	Spitzbergen	Temperate	Triassic	Early Carnian	Landman *et al.* (1996)
Strajevskya strajevskyi	0.6		Dorsoplanitidae	Subpolar Ural	Temperate	Jurassic	Middle Volgian, *Iatriensis* Chron	Mikhailov (1966)
Subcolumbites multiformis	0.375	0.63	Columbitidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Sublunoceras virguloides	0.36		Hecticoceratidae	France	Subtropical or Tropical	Jurassic	Late Callovian, *athleta* Z.	Rouget & Neige (2001)
Subprionocyclus neptuni	0.432	0.75	Collignoniceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Late Turonian	Tanabe *et al.* (1979)
Subpryonocyclus minimus	0.44		Collignoniceratidae	Japan	Subtropical or Tropical	Cretaceous	Late Turonian	Shigeta (1993)
Subpryonocyclus neptuni	0.45		Collignoniceratidae	Japan	Subtropical or Tropical	Cretaceous	EarlyTuronian	Shigeta (1993)
Sulcohoplites altifurcatus	0.5		Hoplitidae	Mangyshlak		Cretaceous	Late Albian	Mikhailova & Saveliev (1994)
Surites subanalogus	0.41		Craspeditidae	N Siberia	Temperate	Cretaceous	Middle Berriasian, *Analogus* Chron	Shulgina (1985)
Svalbardiceras sibiricum	0.39	0.9	Meekoceratidae	Far East		Triassic	Late Olenekian	Zakharov (1978)
Svalbardiceras spitzbergensis	0.37	0.7	Olenekitidae	Spitzbergen	Temperate	Triassic	Olenekian	Zakharov (1971)
Taramelliceras richei	0.275	0.54	Oppeliidae	England	Subtropical or Tropical	Jurassic	Early Oxfordian, *Mariae* Chron	Palframan (1966)
Tauricoceras crassicostatum	0.5		Neocomitidae	Crimea	Subtropical or Tropical	Cretaceous	Late Berriasian	Khvantaliani (1999)
Tauricoceras lyssenkoi	0.51		Neocomitidae	Crimea	Subtropical or Tropical	Cretaceous	Late Berriasian	Khvantaliani (1999)
Teshioites sp.	0.55		Pachydiscidae	Japan	Subtropical or Tropical	Cretaceous	Early Campanian	Shigeta (1993)
Tetragonites aff. *kitchini*	0.62		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Middle Cenomanian	Shigeta (1993)
Tetragonites depressus	0.6		Tetragonitidae	Caucasus	Subtropical or Tropical	Cretaceous	Late Aptian	Drushchits & Mikhailova (1973)
Tetragonites glabrus	0.6	1.08	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Turonian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Tetragonites glabrus	0.786	1.55	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian–Early Santonian	Tanabe *et al.* (1979)
Tetragonites minimus	0.54		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Turonian	Shigeta (1993)
Tetragonites popetensis	0.62	1.27	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Campanian	Tanabe & Ohtsuka (1985)
Tetrahoplites dragunovi	0.79		Hoplitaceae	Mangyshlak		Cretaceous	Early Albian	Mikhailova (1974)
Texanites kawasaki	0.57		Collignoniceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993)
Texoceras sp.		0.97	Adrianitidae	USA		Permian	Middle	Tanabe *et al.* (1994)
Thalassoceras gemmellaroi	0.32	0.62	Thalassoceratidae	USA		Permian	Artinskian	Bogoslovskaya (1951)
Tiltoniceras antiquum	0.92		Hildoceratidae	Siberia	Temperate	Jurassic	Early Toarcian	Kutygin (2009)
Tornoceras arkonense	0.8	1.5	Tornoceratidae	Canada		Devonian	Givetian	House (1965)
Tornoceras arquatum	0.71		Tornoceratidae	USA		Devonian	Frasnian	House (1965)
Tornoceras concentricum	0.55	1.4	Tornoceratidae	USA		Devonian	Famennian	House (1965)
Tornoceras uniangulare aldenense	0.945	1.49	Tornoceratidae	USA		Devonian	Givetian	House (1965)
Tornoceras uniangulare obesum	0.98		Tornoceratidae	USA		Devonian	Middle Frasnian	House (1965)
Tornoceras uniangulare uniangulare	0.8		Tornoceratidae	Canada		Devonian	Uppermost Givetian	House (1965)
Tornoceras uniangulare widderi		1.5	Tornoceratidae	Canada		Devonian	Givetian	House (1965)
Trachyceras aonoides	0.3		Trachiceratidae	Alps	Subtropical or Tropical	Triassic	Middle Carnian	Spath (1950)
Tragodesmoceras subcostatum	0.46		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Early Turonian	Shigeta (1993)
Tragodesmoceroides subcostatus	0.7		Desmoceratidae	Sakhalin	Subtropical or Tropical	Cretaceous	Early Turonian	Nishimura *et al.* (2006)
Tragodesmoceroides subcostatus	0.472	0.924	Desmoceratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Middle Turonian	Tanabe *et al.* (1979)
Tragophylloceras loscombi	0.425		Juraphyllitidae	England	Subtropical or Tropical	Jurassic	Late Pliensbachian	Spath (1914)
Tropidoceras cf. *zitteli*	0.2		Acanthopleuroceratidae	Argentina	Subtropical or Tropical	Jurassic	Early Pliensbachian	Hillebrandt (2006)
Truyolsoceras bicostatum	0.5	1.45	Tornoceratidae	USA		Devonian	Famennian	House (1965)
Tsvetkovites dolioliformis	0.36	0.65	Nathorstitidae	N Siberia/NE Asia	Temperate	Triassic	Late Ladinian, *omolojensis* Z.	Vavilov (1992)
Uraloceras fedorowi	0.39	0.75	Paragastrioceratidae	USA		Permian	Artinskian	Bogoslovskaya (1951)

Species	Protoconch, mm	Ammonitella, mm	Family or Superfamily	Location	Climate (if known)	Period	Age (stage)	Source
Uraloceras subsimense	0.75		Paragastrioceratidae	Russia		Permian	Sakmarian	Kutygin (2004)
Uraloclymenia kazakhstanica	0.54	0.925	Myroclymeniidae			Devonian	Famenian	Bogoslovsky (1981)
Ussurites sp.	0.75	1.35	Ussuritidae	N Siberia/NE Asia	Temperate	Triassic	Late Anisian, *nevadanus* Z.	Vavilov (1992)
Valdedorsella akuschaensis	0.33		Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Late Aptian	Shigeta (1993)
Vertebriceras vertebrale	0.6		Cardioceraidae	N Siberia	Temperate	Jurassic	Early Oxfordian, *Cordatum* Chron	Knyazev (1975)
Vidrioceras sp.	0.44	0.8	Vidrioceratidae			Pennsylvanian		Tanabe *et al.* (1994)
Vidrioceras sp. 2		0.75	Vidrioceratidae	USA		Pennsylvanian		Tanabe *et al.* (2001)
Virgatites virgatus	0.575		Virgatitidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Volgian, *Virgatus* Chron	Druschiz *et al.* (1983)
Volgaites elatmaensis	0.435		Perisphinctidae	Central Russia	Subtropical or Tropical	Jurassic	Middle Callovian, *jason* Z.?	Kvantaliani *et al.* (1999)
Waagenina sp.	0.365		Vidrioceratidae			Permian		Ruzhencev & Shimansky (1954)
Waagenina subinterrupta	0.425	0.84	Vidrioceratidae	Russia		Permian	Artinskian	Bogoslovskaya (1951)
Waagenoceras dieneri girtyi	0.448		Cyclolobidae	Mexico		Permian	Wordian	Miller & Unklesbay (1943)
Waagenoceras guadalupense	0.49		Cyclolobidae	USA		Permian	Wordian	Miller & Unklesbay (1943)
Wangoceras berissense	0.435	0.71	Trachiceratidae	N Siberia/NE Asia	Temperate	Triassic	Early Norian, *obrucevi* Z.	Vavilov (1992)
Xenodiscus subleptodiscus	0.38	0.73	Xenodiscidae	NE Russia	Temperate	Triassic	Early Olenekian	Zakharov (1978)
Yinoceras lenticulare	0.49		Pseudohaloritidae			Permian	Middle	Zhou *et al.* (2002)
Yokoyamaoceras ishikawai	0.5	0.88	Desmoceratidae	Japan	Subtropical or Tropical	Cretaceous	Turonian	Tanabe *et al.* (1979)
Yokoyamaoceras jimboi	0.52	0.972	Kossmaticeratidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Santonian	Tanabe *et al.* (1979), Shigeta (1993)
Yukagirites kinasovi	0.6		Yukagiritidae	NE Russia	Temperate	Jurassic	Late Sinemurian, *Kolymicum* Chron	Repin *et al.* (1998)
Zelandites inflatus	0.495	0.82	Tetragonitidae	Hokkaido	Subtropical or Tropical	Cretaceous	Early Cenomanian	Tanabe & Ohtsuka (1985)
Zelandites japonicus	0.675	1.21	Tetragonitidae	Sakhalin	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Zakharov & Grabovskaya (1984)
Zelandites kawanoi	0.48		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Santonian	Shigeta (1993), Tanabe & Ohtsuka (1985)
Zelandites mihoensis	0.59		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Coniacian	Shigeta (1993)
Zelandites varuna	0.66		Tetragonitidae	Japan	Subtropical or Tropical	Cretaceous	Early Maastrichtian	Shigeta (1993)
Zemistephanus crickmayi		0.85	Stephanoceratidae	Alaska, British Columbia	Subtropical or Tropical	Jurassic	Early Bajocian, *Humpressianum* Chron	Hall & Westermann (1980)
Zemistephanus richardsoni	0.35	0.8	Stephanoceratidae	Alaska	Subtropical or Tropical	Jurassic	Early Bajocian, *Humpressianum* Chron	Hall & Westermann (1980)
Zugodactylites braunianus	0.8		Dactylioceratidae	N Siberia/NE Russia	Temperate	Jurassic	Middle Toarcian	Knyazev *et al.* (1993)
Zulcherella falcistriata	0.41		Desmoceratidae	Caucasus	Subtropical or Tropical	Cretaceous	Middle Aptian	Drushchits & Doguzhaeva (1981)
Boreophylloceras densicostatum	1.34		Boreiophylloceratidae	NE Siberia	Temperate	Cretaceous	Early–Middle Berriasian, *Hectoroceras kochi* Chron	Igolnikov (2007)
Metalegoceras sp.	0.36		Metalegoceratidae	Russia		Permian		Ruzhencev & Shimansky (1954)
Parapronorites biformis	0.77		Medlicottiidae	Russia		Permian	Artinskian	Schoulga-Nesterenko (1926)

Appendix 2.

Compilation of embryonic shell measurements of Paleozoic–recent coiled nautiloids, geographic areas and inferred climate.

Species	Nauta size, mm	Family	Location	Climate (if known)	Period	Age (Stage)	Source
?*Germanonautilus willeyi*	22.5	Tainoceratidae	France, Calvados	Subtropical or Tropical	Jurassic	Early Pliensbachian, *Ibex* Chron	Chirat (1997)
?*Cenoceras pseudotruncatum*	18	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Early Pliensbachian, *Ibex* Chron	Chirat & Rioult (1998)
?*Cymatoceras bifurcatum*	25	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Barremian–Aptian	Shimansky (1975)
Aktubonautilus cruciformis	22	Aktubonautilidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Allonautilus perforatus	26	Nautilidae	Indonesia	Subtropical or Tropical	Cenozoic Era	Recent	Ward & Saunders (1997)
Anglonautilus japonicus	15	Nautilidae	Japan	Subtropical or Tropical	Cretaceous	late Early Cenomanian, *Mantelliceras japonicum* Chron	Matsumoto *et al.* (1984)
Anglonautilus subalbensis	20	Nautilidae	Cacasus, Mangyshlak	Subtropical or Tropical	Cretaceous	Aptian–Early Albian	Shimansky (1975)
Aphelaeceras arcansasum	5.5	Trigonoceratidae	USA		Missisipian	Chesterian	Stephen & Staton (2002)
Apogonoceras remotum	25	Thrincoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Arctonautilus dolganensis	23.5	Tainoceratidae	N Siberia	Temperate	Triassic	Early Anisian, *Grambergia taimyrensis* and *Lenotropites tardus* Chrons	Sobolev (1989)
Arctonautilus egorovi	23.4	Tainoceratidae	N Siberia	Temperate	Triassic	Late Anisian, *Frechites nevadanus* Chron	Sobolev (1989)
Arctonautilus ljubovae	20.55	Tainoceratidae	N Siberia	Temperate	Triassic	Early Anisian, *Grambergia taimyrensis* Chron	Sobolev (1989)
Arctonautilus spatiosus	21.3	Tainoceratidae	N Siberia	Temperate	Triassic	Early Anisian, *Grambergia taimyrensis* Chron, *Karangatites evolutus* SubChron	Sobolev (1989)
Articheilus luxuriosum	27	Mosquioceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Aturia cubaensis	4	Hercoglossidae	Chile	Subtropical or Tropical	Cenozoic Era	Eocene–Miocene	Nielsen *et al.* (2009)
Aturia sp.	5	Hercoglossidae	Cosmopolite	Subtropical or Tropical	Cenozoic Era	Paleocene–Miocene	Ruzhencev & Shimansky (1954)
Basleonautilus sp.	20	Aktubonautilidae	Timor		Permian	Basleo beds (~Artinskian)	Ruzhencev & Shimansky (1954)
Cenoceras obesum	20	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Niortense* Chron	Chirat & Rioult (1998)
Cenoceras aff. *bradfordensis*	14	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Garantiana* Chron	Chirat & Rioult (1998)
Cenoceras aff. *clausum*	20	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Aalenian, *Concavum* Chron	Chirat & Rioult (1998)
Cenoceras aff. *fuscum*	12	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Parkinsoni* Chron	Chirat & Rioult (1998)
Cenoceras boreale	18.1	Nautilidae	NE Russia, N Siberia	Temperate	Triassic	Early Carnian	Sobolev (1989)
Cenoceras fuscum	48	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Parkinsoni* Chron	Chirat (1997)
Cenoceras gr. *obesum*	17	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Niortense* or *Garantiana* Chron	Chirat & Rioult (1998)
Cenoceras sp. 1	18	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Aalenian, *Concavum* Chron	Chirat & Rioult (1998)
Cenoceras sp. 2	15	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Garantiana* Chron	Chirat & Rioult (1998)
Cenoceras sp. 3	16	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Parkinsoni* Chron	Chirat & Rioult (1998)
Cimomia angustus	20.4	Hercoglossidae	India		Cretaceous	Albian–Cenomanian	Wani *et al.* (2011)
Condraoceras ellipsoidale	16	Liroceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Cooperoceras sp.	60	Tainoceratidae	N America		Permian	Lower Permian	Ruzhencev & Shimansky (1954)
Cosmonautilus polaris	8.6	Clydonautilidae	NE Russia, N Siberia	Temperate	Triassic	Early Carnian, *Neosirenites pentastichus* Chron	Sobolev (1989)
Cymatoceras karakaschi	20	Nautilidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Aptian	Shimansky (1975)
Cymatoceras paralibanoticum	22.5	Nautilidae	Crimea, Donbass	Subtropical or Tropical	Cretaceous	Maastrichtian	Shimansky (1975)
Cymatoceras patagonicum	30	Nautilidae	Argentina	Temperate	Jurassic	Tithonian	Cichowolski (2003)
Cymatoceras perstriatum	32	Nautilidae	Argentina	Temperate	Cretaceous	Hauterivian	Cichowolski (2003)
Cymatoceras pseudoelegans	25	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Hauterivian–Early Barremian	Shimansky (1975)
Cymatoceras pulchrum	20.5	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Hauterivian–Early Barremian	Shimansky (1975)
Cymatoceras radiatum	17.5	Nautilidae	Caucasus	Subtropical or Tropical	Cretaceous	Aptian	Shimansky (1975)
Cymatoceras renngarteni	23.5	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Hauterivian–Early Barremian	Shimansky (1975)
Cymatoceras sarysuense	30	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Berriasian	Shimansky (1975)
Cymatoceras sp.	20	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Barremian	Shimansky (1975)
Cymatoceras sp. 2	25	Nautilidae	Sakhalin	Subtropical or Tropical	Cretaceous	Late Santonian–Early Campanian	Shimansky (1975)
Cymatoceras yabei	30	Nautilidae	NE Russia, Chukotka	Temperate	Cretaceous	Cenomanian	Shimansky (1975)
Digonioceras arnoldi	30	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Middle Toarcian, *Bifrons* Chron	Chirat (1997)
Digonioceras carlsoni	30	Nautilidae	France, Normandy	Subtropical or Tropical	Jurassic	Middle Bathonian, *Progracilis* Chron	Chirat (1997)
Digonioceras excavatum	36	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian	Chirat (1997)
Digonioceras gr. *landmani*	45	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian	Chirat (1997)
Digonioceras landmanni	32.5	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Niortense-Garantiana* Chron	Chirat (1997)

Species	Nauta size, mm	Family	Location	Climate (if known)	Period	Age (Stage)	Source
Digonioceras sp. 1	57	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Parkinsoni* Chron	Chirat (1997, 2001), Chirat & Rioult (1998)
Digonioceras zittelii	35	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Early Aalenian, *Opalinum* Chron	Chirat (1997)
Epicymatoceras monstrum	20	Nautilidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Late Maastrichtian	Shimansky (1975)
Eucymatoceras plicatum	25	Nautilidae	Crimea, Caucasus	Subtropical or Tropical	Cretaceous	Barremian	Shimansky (1975)
Eutrephoceras bouchardianum	12	Nautilidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Cenomanian–Coniacian	Shimansky (1975)
Eutrephoceras burundukkajense	8	Nautilidae	Crimea	Subtropical or Tropical	Cenozoic Era	Danian	Shimansky (1975)
Eutrephoceras clementinum	20	Nautilidae	S India	Subtropical or Tropical	Cretaceous	Middle Turonian	Wani & Ayyasamib (2009)
Eutrephoceras dekayi	9.8	Nautilidae	UAS, S. Dakota	Subtropical or Tropical	Cretaceous	Maastrichtian	Landman *et al.* (1983)
Eutrephoceras moskvini	22	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Early Barremian	Shimansky (1975)
Eutrephoceras municeps	20	Nautilidae	Crimea	Subtropical or Tropical	Cretaceous	Early Barremian	Shimansky (1975)
Eutrephoceras subplicatum	30	Nautilidae	Antarctica	Temperate	Cretaceous	Campanian–Maastrichtian	Cichowolski *et al.* (2005)
Eutrephoceras uzense	18	Nautilidae	Mangyshlak	Subtropical or Tropical	Cretaceous	Maastrichtian	Shimansky (1975)
Gen. nov.? *A. austriacus*	43	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Early Pliensbachian, *Ibex* Chron	Chirat (1997)
Germanonautilus kyotanii	19	Tainoceratidae	N Siberia, NE Russia	Temperate	Triassic	Norian	Sobolev (1989)
Germanonautilus popowi	20	Tainoceratidae	N Siberia, NE Russia	Temperate	Triassic	Late Carnian–Early Norian	Sobolev (1989)
Germanonautilus sibiricus	16.2	Tainoceratidae	N Siberia, NE Russia	Temperate	Triassic	Early Carnian, *Neosirenites pentastichus* Chron	Sobolev (1989)
Gyronautilus praevolutum	18.2	Grypoceratidae	Far East		Triassic	Early Olenekian	Zakharov & Shigeta (2000)
Gzheloceras biangulare	16	Gzheloceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Gzheloceras ellipsoidale	15.5	Gzheloceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Gzheloceras sholakense	17.7	Gzheloceratidae	South Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Gzheloceras uralense	16.5	Gzheloceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Hemiliroceras inflatum	15.8	Liroceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Hemiliroceras zhiltauense	15.2	Liroceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Heminautilus lallieri	20	Nautilidae	Suez	Subtropical or Tropical	Cretaceous	Aptian	Chirat & Bucher (2006)
Hercoceras mirum	4.5	Hercoceratidae	Czech		Devonian	Upper Emsian	Turek (2007)
Hercoglossa danica	10	Hercoglossidae	Crimea, Caucasus, Mangyshlak	Subtropical or Tropical	Cenozoic Era	Danian	Shimansky (1975)
Hercoglossa obesianus	22.2	Hercoglossidae	India		Cretaceous	Albian–Cenomanian	Wani *et al.* (2011)
Heurekoceras notabile	14	Gzheloceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Koninckioceras sp.	36	Koninckioceratidae	N America, Europe		Missisipian	Kungurian	Ruzhencev & Shimansky (1954)
Leonardocheilus sp.	45	Mosquioceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Liroceras (?) *korulkense*	18	Liroceratidae	N America, Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Liroceras sp.	9.5	Liroceratidae	South Ural		Pensylvanian	Pendleian	Ruzhencev & Shimansky (1954)
Metacoceras altilobatum	20	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras artiense	24.5	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras kruglovi	23	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras mcchesneyi	9.5	Tainoceratidae	USA, Ohio		Pensylvanian	Pennsylvanian	Wani & Mapes (2010)
Metacoceras orthogonium	17	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras parartiense	21	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras subpiszovi	29	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras subquadratum	27	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Metacoceras vagans	8.5	Tainoceratidae	USA		Pensylvanian	Morrowan–Missourian	Stephen & Staton (2002)
Mosquoceras jakowlewi	30	Mosquioceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Mosquoceras simense	38.5	Mosquioceratidae	South Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Nautilus belauensis	29.5	Nautilidae	Philippines	Subtropical or Tropical	Cenozoic Era	Recent	Saunders & Landman (2010)
Nautilus macromphalus	26.4	Nautilidae	Philippines	Subtropical or Tropical	Cenozoic Era	Recent	Chirat (2001)
Nautilus pompilius	23	Nautilidae	Philippines	Subtropical or Tropical	Cenozoic Era	Recent	Saunders & Landman (2010)
Nautilus praepompilius	23	Nautilidae	Kazakhstan	Subtropical or Tropical	Cenozoic Era	Late Eocene	Saunders & Landman (2010)
Neothrincoceras soshkinae	25.5	Thrincoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Neothrincoceras uralicum	20.5	Thrincoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Ophionautilus burtonensis	35	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Niortense-Garantiana* Chron	Chirat (1997)

Species	Nauta size, mm	Family	Location	Climate (if known)	Period	Age (Stage)	Source
Ophionautilus ex gr. *catonis*	30	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Late Bajocian, *Parkinsoni* Chron	Chirat (1997)
Ophionautilus sp. aff. *schwalmi*	40	Nautilidae	France, Calvados	Subtropical or Tropical	Jurassic	Early Pliensbachian, *Ibex* Chron	Chirat (1997)
Palelialia karpinskyi	16	Pseudonautilidae	Crimea	Subtropical or Tropical	Cretaceous	Early Barremian	Shimansky (1975)
Paracenoceras hexagonum	25	Paracenoceratidae	France	Subtropical or Tropical	Jurassic	Middle–Late Oxfordian	Chirat (1997)
Parametacoceras sp.	12.5	Gzheloceratidae	N America		Pensylvanian	Cherokee shales	Ruzhencev & Shimansky (1954)
Paranautilus asiaticus	20	Liroceratidae	NE Russia	Temperate	Triassic	Late Carnian–Early Norian	Sobolev (1989)
Paranautilus smithi	23.3	Liroceratidae	N Siberia	Temperate	Triassic	Late Anisian, *Frechites nevadanus* Chron	Sobolev (1989)
Pararhiphaeoceras aktastense	14	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Pararhiphaeoceras incallidum	14	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Pararhiphaeoceras tastubense	18	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Parastenopoceras khvorovae	15.2	Domatoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Peripetoceras asselense	12	Liroceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Phaedrysmoheilus evolutus	16.7	Tainoceratidae	N Siberia	Temperate	Triassic	Late Olenekian, *Dieneroceras demokidovi* Chron, *Nordophiceras contrarium* SubChron	Sobolev (1989)
Phaedrysmoheilus involutus	13.15	Tainoceratidae	N Siberia	Temperate	Triassic	Late Olenekian, *Olenekites spiniplicatus* Chron, *Keyserlingites subrobustus* SubChron	Sobolev (1989)
Phaedrysmoheilus nestori	20	Tainoceratidae	N Siberia	Temperate	Triassic	Late Olenekian, *Olenekites spiniplicatus* Chron	Sobolev (1989)
Phaedrysmoheilus ornatus	15.5	Tainoceratidae	N Siberia	Temperate	Triassic	Late Olenekian, *Dieneroceras demokidovi* Chron, *Bajarunia euomphalus* SubChron	Sobolev (1989)
Phaedrysmoheilus subaratus	12.3	Tainoceratidae	N Siberia	Temperate	Triassic	Late Olenekian, *Olenekites spiniplicatus* Chron	Sobolev (1989)
Proclydonautilus pseudoseimkanensis	6.2	Clydonautilidae	NE Russia, N Siberia	Temperate	Triassic	Early Carnian, *Neosirenites pentastichus* Chron / *Sirenites yakutensis* Chron	Sobolev (1989)
Proclydonautilus seimkanensis	5	Clydonautilidae	NE Russia, N Siberia	Temperate	Triassic	Norian, *Pterosirenites obrucevi–Otapiria ussuriensis* Chrons	Sobolev (1989)
Pseudocenoceras archiacianum	10	Nautilidae	Moldavia	Subtropical or Tropical	Cretaceous	Cenomanian	Shimansky (1975)
Pseudocenoceras? *supervacuum*	20	Nautilidae	Gissar Range	Subtropical or Tropical	Cretaceous	Albian	Shimansky (1975)
Pseudotemnocheilus kosswae	20	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Pseudotemnocheilus posttuberculatum	22.5	Tainoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Rhiphaeoceras humile	12	Rhiphaeoceratidae	South Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Rhiphaeoceras venustum	18	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Rhiphaeonautilus curticostatus	13.7	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Rutoceras sp.	51.5	Rutoceratidae	N America, Europe		Devonian		Ruzhencev & Shimansky (1954)
Sholakoceras bisulcatum	12	Rhiphaeoceratidae	South Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Sholakoceras cf. *S. pleuronautiloides*	12.2	Rhiphaeoceratidae	Italy		Permian	Wordian	Mapes *et al.* (2007)
Sholakoceras privum	14	Rhiphaeoceratidae	South Ural		Permian	Artinskian	Ruzhencev & Shimansky (1954)
Sholakoceras transforme	13.5	Rhiphaeoceratidae	South Ural		Permian	Sakmarian	Ruzhencev & Shimansky (1954)
Sibyllonautilus artus	16	Tainoceratidae	N Siberia	Temperate	Triassic	Ladinian	Sobolev (1989)
Teichertia similis	20	Hercoglossidae	Crimea, Turkmenia, Kazakhstan	Subtropical or Tropical	Cenozoic Era	Danian	Shimansky (1975)
Titanoceras sp.	68	Domatoceratidae	N. America, Europe		End Missisipian		Ruzhencev & Shimansky (1954)
Tomponautilus setorymi	20	Liroceratidae	NE Russia	Temperate	Triassic	Induan, *Concavum–Nielseni* Chrons	Sobolev (1989)
Xenocheilus ulixis	20	Pseudonautilidae	Crimea	Subtropical or Tropical	Cretaceous	Hauterivian–Early Barremian	Shimansky (1975)

Appendix 3

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