On the genus *Vanikoropsis* Meek, 1876 (Gastropoda, Caenogastropoda) from the Paleocene of Denmark and West Greenland with descriptions of three new species

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The predominantly Cretaceous gastropod genus *Vanikoropsis* Meek, 1876 is represented in the Paleocene of Denmark and West Greenland by four species, of which three are established herein as new, *viz*. *Vanikoropsis mortenseni* n. sp., *Vanikoropsis* (s.l.) *jakobseni* n. sp. and *Vanikoropsis* (s.l.) *bashforthi* n. sp. The Danish species was found in a boulder of Kerteminde Marl (Selandian, middle Paleocene) from Gundstrup, while the species from West Greenland were found in the localities Sonja Lens and Qaarsutjægerdal on the Nuussuaq peninsula (late Danian, early Paleocene). The Danish species extends the stratigraphic range of the genus into the middle Paleocene and supports the affinities of the Kerteminde Marl fauna to the Paleocene fauna of West Greenland.

Keywords: Gastropoda, Vanikoridae, *Vanikoropsis*, Danian, Selandian, Paleocene, Kerteminde Marl, Denmark, Nuussuaq, West Greenland.

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The genus *Vanikoropsis* Meek, 1876 is represented in the Danish Kerteminde Marl Formation (Selandian, middle Paleocene) by a new species, which seems to represent the youngest occurrence of the genus. Stilwell *et al*. (2004) recorded *Vanikoropsis arktowskiana* (Wilckens, 1910) from the Sobral Formation of Antarctica and presumed it to be of Selandian age, but both Bowman *et al*. (2014) and Montes *et al*. (2019) suggested a Danian age.

The late Danian (early Paleocene) gastropod fauna from the Nuussuaq peninsula, West Greenland, contains three species of the genus *Vanikoropsis*, of which *Vanikoropsis skoui* was established by Rosenkrantz (1970). Two other representatives of the genus were mentioned in open nomenclature by Kollmann & Peel (1983) and illustrated. The gastropod fauna was recorded by Kollmann & Peel (1983) and contains at least 257 gastropod species, of which some families have already been revised (Merle & Pacaud 2004; Pacaud & Schnetler 1999; Schnetler & Petit 2010). The species from the Kerteminde Marl and the two undescribed species from West Greenland are established herein as new species. An overview of the stratigraphic record of *Vanikoropsis* is given.

Geological setting and stratigraphy

Denmark

The Danish Basin is situated between the Sorgenfrei–Tornquist Zone to the north and the Ringkøbing Fyn High to the south (Fig. 1). The Danian and Selandian deposits are thin over this high and thick in the Danish Basin (Sorgenfrei & Buch 1964; Clausen & Huuse 1999; Clemmensen & Thomsen 2005), having their maximum thickness of more than 350 m and 150 m, respectively (Gry 1935; Thomsen 1995).

The Danian deposits consist of carbonates, while the Selandian deposits are mainly clastic (Gry 1935; Heilmann-Clausen 1985, 1995; Clemmensen & Thom-

sen 2005). Three facies groups are recognised in the Danish Basin: the Lellinge Greensand, Kerteminde Marl and Ælebø Formations (Fig. 1). The Lellinge Greensand is strongly calcareous and glauconitic and is known from Sjælland and the margins of the Ringkøbing–Fyn High (Gry 1935; Foged *et al.* 1995; Clemmensen & Thomsen 2005). It has a thickness of less than 10 m and was presumably deposited in an inner shelf environment (Gry 1935; Schnetler 2001). Laterally towards the depocenter and upwards, the Lellinge Greensand grades into the fine-grained Kerteminde Marl Formation (Clemmensen & Thomsen 2005). The maximum thickness of this unit is controlled by Quaternary erosion and seems to have been more than 100 m. King (1994, 2015) presumed a deposition in a middle to outer neritic environment. The calcium carbonate content is composed of calcareous nannofossils and varies between 50 % and 70 % in the Lellinge Greensand and the Kerteminde Marl (Gry 1935; Foged *et al.* 1995). The overlying, slightly calcareous to non-calcareous Ælebø Formation was apparently deposited in the bathyal depth zone (King 1994, 2015).

Lithostratigraphical and biostratigraphical correlations

The Kerteminde Marl falls within the dinoflagellate zone 2 sensu Nøhr-Hansen & Heilmann-Clausen (2000). The age is early Selandian and the dinoflagellates indicate an open marine environment (Heilmann-Clausen pers. comm. 2003). Heilmann-Clausen (2006, p. 195) stated that the silicified boulders from the gravel-pit Gundstrup are coarser than the typical Kerteminde Marl and have a higher content of ben-

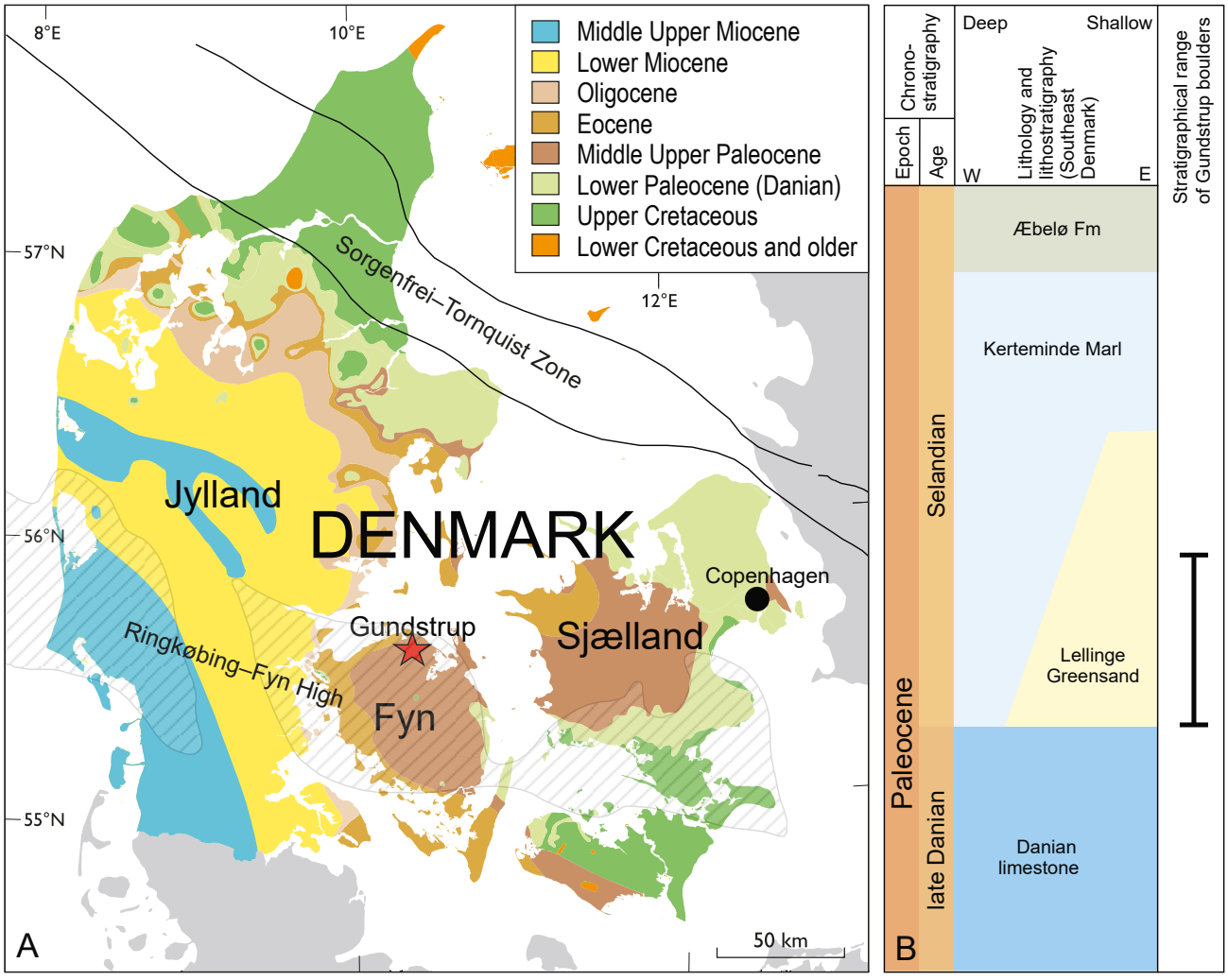

Fig. 1. A: Pre-Quaternary geological map of Denmark showing the location of the Gundstrup gravel pit on the island of Fyn (55.56°N, 10.35°E). Modified from Håkansson & Pedersen (1992). The gravel pit contains fossil-rich, glacially derived fragments of the Kerteminde Marl. **B:** Schematic representation of the Upper Danian – Selandian stratigraphy of south-eastern Denmark. Modified from Clemmensen & Thomsen (2005).

thic fossils. Thomsen (pers. comm., 2016) analysed the calcareous nannofossils in five Paleocene boulders retrieved from Quaternary deposits in the gravel pit at Gundstrup, north Fyn and found that the boulders could be correlated with the lowermost Selandian immediately above the Danian-Selandian boundary (Thomsen 1994; Clemmensen & Thomsen 2005). Thus, the samples could be correlated with the lower part of the Lellinge Greensand and the lowermost part of the Kerteminde Marl.

West Greenland

The geological setting of the West Greenland continental margin has been described by Rosenkrantz *et al.* (1974), Dam & Sønderholm (1994), Nøhr-Hansen & Dam (1997), Dam *et al.* (1998), Dam (2002), Nøhr-Hansen *et al.* (2002) and Dam *et al.* (2009). This margin was developed in connection with the extensional opening of the Labrador Sea during the late Mesozoic to early Cenozoic. Exposures of rocks and sediments from Cretaceous (Albian) to Paleocene (?Selandian) ages are found onshore on Baffin Island and in the Nuussuaq Basin, where they are overlain by Palaeogene basalts (Clarke & Pedersen 1976; Henderson *et al.* 1976; Burden & Langille 1990). The exposed succession of the Nuussuaq Basin consists of 2.5 km Albian to Paleocene sediments overlain by 3–5 km of Paleocene and Early Eocene hyaloclastites and basalts (Dam *et al.* 1998). From the late Albian, siliciclastic sandstones and shales were deposited in fluvial and deltaic settings on eastern Disko and central Nuussuaq, whereas the delta fanned into deeper marine, partly turbidic, environments towards the western and northern Nuussuaq. The Nuussuaq Basin underwent major rifting from the Albian to early Paleocene. At least three phases of rifting, major uplift and erosion and infilling of subaerial valleys and submarine canyons resulted in basin-wide unconformities in the late Maastrichtian to early Paleocene interval (Dam *et al.* 1998; Dam & Sønderholm 1998; Sørensen *et al.* 2017). The deposition of marine sediments of the Kangilia Formation was recorded by the first of these rifting events. The younger tectonic phases gave rise to the mudstone dominated Eqalulik and Agatdal Formations in deeper marine settings towards the northwest and the fluviatile incised valley fills of the Quikavsak Formation in the southern part of the basin (Dam 2002). The deposition of the marine sediments was followed by the extrusion of a thick succession of volcanic rocks of the Vaigat and Maligât Formations (Pedersen *et al.* 2006; Hjuler *et al.* 2016; Larsen *et al.* 2016; Fig. 2).

Lithostratigraphical and biostratigraphical correlations

Rosenkrantz (1970) referred the Agatdal Formation to the Upper Danian. The dinoflagellate cysts from the pre-volcanic Paleocene mudstone succession and the intrabasaltic Paleocene sediments at Nuussuaq were studied by Hansen (1980), Piacecki *et al.* (1992), Nøhr-Hansen (1996, 1997a, 1997b), Nøhr-Hansen & Dam (1997), Nøhr-Hansen & Heilmann-Clausen (2000) and Nøhr-Hansen *et al.* (2002). Nannoplankton assemblages have been studied by Perch-Nielsen (1973), Jürgensen & Mikkelsen (1974) and Nøhr-Hansen & Sheldon (2000). Perch-Nielsen (1973) dated samples from the Sonja Lens of the Sonja Member at Agatkløft as upper Zone NP3 based on nannofossils. Jürgensen & Mikkelsen (1974) dated samples from Marraat Killiit

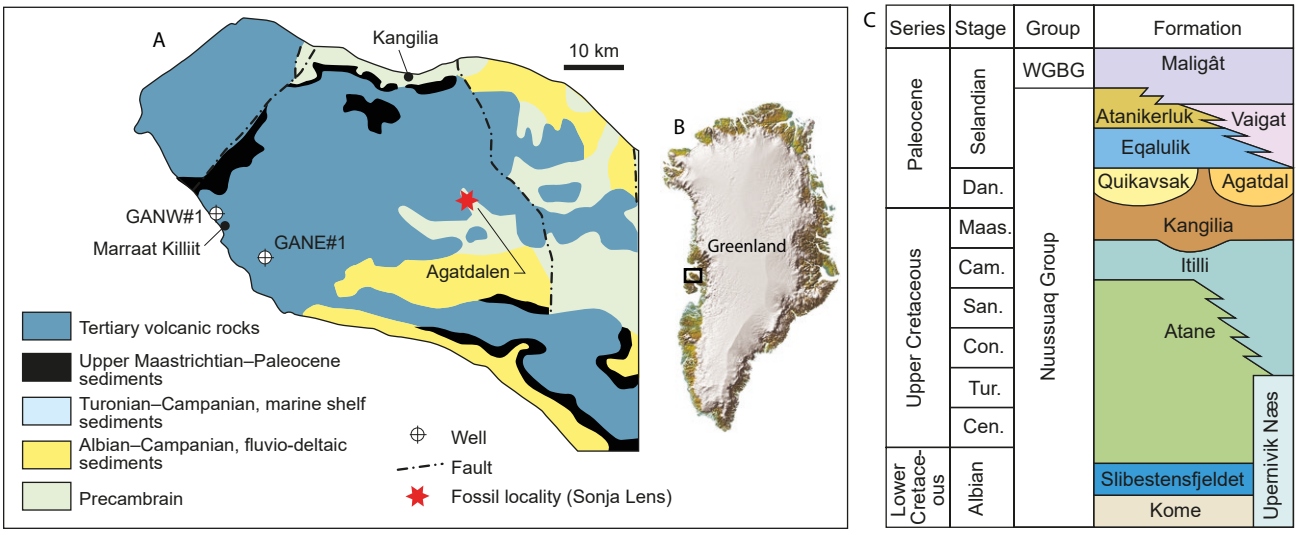

Fig. 2. A: Strongly simplified geological map of the western part of Nuussuaq. Modified from Sheldon (2003). **B:** Map of Greenland showing the location of Nuussuaq (rectangle). **C:** Lithostratigraphic scheme of the Nuussuaq Group and the lowermost part of the West Greenland Basalt Group (WGBG). Modified from Hjuler *et al.* (2017).

on the south-west coast of Nuussuaq and Kangilia on the north coast and placed them into Zone NP3, while Nøhr-Hansen & Sheldon (2000) referred the Equalik and Kangilia Formations to the upper NP3 to lower NP4 zones. Sheldon (2003) recorded an assemblage containing *Neochiastozygus perfectus* from the Eqalulik Formation of the GANE#1 and GANW#1 wells of western Nuussuaq, indicating correlation with the upper NP4 (Danian) or NP5 (Selandian) zones. Hansen (1980) dated the lower and upper part of the Paleocene mudstone succession at Nuussuaq as early and middle Paleocene, based upon dinoflagellate cysts, and correlated the lower part with nannoplankton zones NP3-NP4 and the upper part with NP5-NP6 (Martini, 1971). Jürgensen & Mikkelsen (1974), however, dated the upper part of the Kangilia Formation (now Eqalulik Formation) to NP3 (late Danian). Piasecki *et al*. (1992) suggested a late Danian to Thanetian age (NP zones 4-8). Nøhr-Hansen (1997a, 1997b) and Christiansen *et al*. (1997) dated dinoflagellate cyst assemblages from the Paleocene sediments in four wells and suggested a Selandian age (NP5-NP6) for the upper part of the succession. Nøhr-Hansen & Dam (1997) suggested an early Danian age (NP1-NP3?) for the oldest Paleocene on Nuussuaq. However, palaeomagnetic studies (Riisager & Abrahamsen 1999) correlated the lowermost volcanic Anaanaa Member with the late Danian. The correlation with NP5-NP6 suggested by Piasecki *et al*. (1992), Nøhr-Hansen (1997a, b) and Christiansen *et al*. (1997) was based on the presence of a dinoflagellate cyst species similar to the Selandian marker species *Isabelidinium viborgense*, previously only recorded from NP5 and NP6 in Denmark (Heilmann-Clausen 1985). Later examination, however, proved this species to be previously undescribed (Nøhr-Hansen & Heilmann-Clausen 2000), and its first occurrence was correlated with NP3 (middle Danian). Nøhr-Hansen *et al*. (2002) established a detailed zonation of the Lower Paleocene succession in the Nuussuaq Basin, based on dinoflagellate cyst and nannofossil data. They referred the Kangilia Formation in Central Nuussuaq to Danian (NP1-NP4) and the overlying Eqalulik Formation to NP4-NP5. Hjuler *et al*. (2017), Christiansen *et al*. (2020) and Nøhr-Hansen (pers. comm., 2020) referred the Agatdal Formation to the Danian (Fig. 1).

Material and methods

The gravel-pit of Alex Andersen A/S is situated near the village Gundstrup, *c*. 20 km north of Odense on Fyn and is remarkable by its very high content of glacially transported Paleocene boulders, which have yielded a rich and diverse molluscan fauna (Schnetler & Nielsen 2018). The bulk of the molluscs from the Kerteminde Marl is generally preserved as external impressions and internal moulds. As the boulders are consolidated, the making of silicone latex casts of fine quality is possible with SILASTIC® 9161 RTV Silicone Elastomer (product information sheet in the references). This process was described in detail by Schnetler & Nielsen (2018). The material has been collected by the junior author and Peter Tang Mortensen, who collected the boulder with the only *Vanikoropsis* specimen known from Denmark.

The mollusc material from Nuussuaq was collected by the late professor Alfred Rosenkrantz and his coworkers in the years between 1938 and 1968 (Kollmann & Peel 1983, Dam *et al*. 2009). In 1948 Sonja Hansen found fossiliferous sandstone in a riverbed in Agatdalen (Fig. 2) and four years later this rock type was found *in situ*. It was a sand lens with a length of 7 m and a thickness of only 0.7 m, according to Rosenkrantz (1970). The specimens of *Vanikoropsis* from the Nuussuaq have been collected at the localities Sonja Lens and Qaarsutjægerdal, east of Turritellakløft, Nuussuaq in 1953, 1956 and 1958 (Table 1). The locality Sonja Lens is a very loose sandstone and has yielded thousands of fossils, mainly gastropods, which have been found by washing and sieving the loose sediment (Rosenkrantz 1970, Kollmann & Peel 1983). The shells are

Table 1. West Greenland specimens of *Vanikoropsis* (*V.* in the table)

SNM no.[1]	Rkz no.[2]	Species Kollmann & Peel (1983)	Species this study	Locality	Year collected	Remarks
MGUH 10807	MS 144	*V. skoui* Rosenkrantz, 1970	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Sonja Lens	1958	Holotype
MGUH 15744	MS 322B	*V. skoui* Rosenkrantz, 1970	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Sonja Lens	1958	Paratype
MGUH 15745	MS 140	*V.* sp. 1	*V.* (s.l.) *jakobseni* n. sp.	Qaarsutjægerdal	1953	Holotype
MGUH 15746	MS 315	*V.* sp. 2	*V.* (s.l.) *bashforthi* n. sp.	Qaarsutjægerdal	1958	Holotype
GM 1977.1181/8	MS 228	cf. *Coptostoma*	*V.* (s.l.) *bashforthi* n. sp.	Sonja Lens	1956	Paratype
GM 1977.1296	MS 315	*V.* sp. 2	*V.* (s.l.) *bashforthi* n. sp.	Qaarsutjægerdal	1953	Paratype
GM 1977.1308	MS 322	*V. skoui* Rosenkrantz, 1970	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Sonja Lens	1958	Additional specimen

[1] SNM no.: number in the type collection of SNM, [2] Rkz no.: number in the Rosenkrantz collection of drawings

often somewhat worn, due to the transport by water. Stratigraphically, the lens is part of the Sonja Member at the base of the Agatdal Formation. The locality is the most significant in West Greenland for aragonitic molluscs preserved, but ammonites are found in the late Cretaceous Itilli Formation (Rasmussen, pers. comm. 2009).

Rosenkrantz organized the gastropods from Nuussuaq into species. The species were documented in many pencil drawings by artists, working under the supervision of Rosenkrantz, and some photos. All illustrations are stored in folders in the Rosenkrantz Collection in Natural History Museum of Denmark (SNM), Copenhagen. The bivalves were described by Petersen & Vedelsby (2000). The gastropods have been treated by Rosenkrantz (1970), Kollmann & Peel (1983), Pacaud & Schnetler (1999), Merle & Pacaud (2004), and Schnetler & Petit (2010). According to Kollmann & Peel (1983), the species from Nuussuaq were not arranged systematically, but were given current working numbers in a series from 1 to 340. However, a later revision of these species resulted in a lower number, as Kollmann & Peel (1983) documented only 254 taxa and concluded that Rosenkrantz had used a too narrow species concept. For their paper they selected numerous drawings from the Rosenkrantz files of drawings and arranged them in two folders. All illustrations are stored in folders in the Rosenkrantz Collection in Natural History Museum of Denmark (SNM), Copenhagen. Rosenkrantz used several numbers for species of *Vanikoropsis* in the drawings (Table 1), and we may conclude that he assumed a higher number of *Vanikoropsis* species. Kollmann & Peel (1983) recognized two further species of *Vanikoropsis* in Rosenkrantz' material.

Kollmann & Peel (1983) also discussed the gastropod fauna in detail and stated that the fauna of the Kangilia Formation was derived from a single environment, whereas the fauna of the overlying Agatdal Formation originated from a mixture of environments. Many specimens demonstrate signs of transport, and the composition of the gastropods indicates that they originate from different ecological niches. Kollmann & Peel (1983) concluded that the gastropods in the Agatdal Formation were transported to their present juxtaposition from different biocoenoses into a deeper part of the basin.

Abbreviations

SNM: Natural History Museum of Denmark, Copenhagen.
DK: Acronym for specimens housed in the Danekræ collection, SNM.
GM: Registered material housed in SNM.
ISL: Material housed in the collection of the senior author (only a silicone rubber cast of *Vanikoropsis mortenseni* n. sp., described herein).
MGUH: Type collection in SNM.
MNO: Material housed in the collection of the junior author (only a silicone rubber cast of *Vanikoropsis mortenseni* n. sp., described herein).
MS: Acronym for drawings in the folders of drawings in the Rosenkrantz collection in SNM.
Rkz no.: Number in the Rosenkrantz collection of drawings.

Systematic Palaeontology

Class Gastropoda Cuvier, 1797

Subclass Caenogastropoda Cox, 1960

Order Littorinimorpha Golikov & Starobogatov, 1975

Superfamily Vanikoroidea Gray, 1840

Family ? Vanikoridae Gray, 1840

[= Naricidae Récluz, 1845 = Merriidae Hedley, 1918].

Wenz (1941, p. 885, fig. 2694) gave a short diagnosis of the family Vanikoridae. According to this, species of this family have a depressed globose outline (like *Natica*) with a depressed, in rare cases a projecting spire. The protoconch is small, with a projecting tip. The last whorl is large, with an umbilicus and spiral ornament and more or less prominent prosocline axial folds. The aperture is large, oblique, and rounded. His diagnosis of *Vanikoro* Quoy & Gaimard, 1832, the type genus of the family, stated a medium-sized to small, rather thin-shelled shell with a depressed spherical outline, a short apex, convex whorls separated by a deep suture, prosocline axial ribs, spiral cords, a wide, rounded and obliquely placed aperture and a slightly concave columella. Cossmann (1925) described the protoconch of vanikorids as smooth, slender, and pointed. However, Bandel & Kowalke (1997, pl. 2, figs 1-9; pl. 3, figs 1-9) and Bandel (2006, pl. 2, figs. 8, 10) illustrated different types of protoconchs of Vanikoridae.

Genus *Vanikoropsis* Meek, 1876

Type species. Natica tuomeyana Meek & Hayden, 1856 by original designation. (1876, p. 270). Maastrichtian, USA.

Diagnosis. Sohl (1967, p. B 22) gave this diagnosis of the genus *Vanikoropsis*: Medium-sized thick naticiform shells. Sculpture dominated by strong broad spiral ribbons with transverse sculpture absent or as low and broad collabral rugosities. Umbilicus narrow.

Discussion. The genus *Vanikoropsis* was proposed by Meek (1876) for thick-walled unumbilicate shells with strong growth rugae. He provisionally placed the genus in the family Vanikoridae Gray, 1840 on the basis of the similarity with *Vanikoro* Quoy & Gaimard, 1832, the type genus of the family. Meek founded *Vanikoropsis* on the holotype of *Natica tuomeyana* Meek & Hayden, 1856. This holotype was illustrated by Wenz (1941, p. 1024, fig. 2935), who reproduced the illustration in Meek (1876), and it is a defective specimen with a worn spire and the body whorl broken back for about one half whorl. Wenz observed no umbilicus on this illustration, but a better illustration by Sohl (1967, pl. 5, figs. 15, 16) of the holotype showed its narrow umbilicus. Because of similarities in outline, sculpture, thickness of the shell and presence of an umbilicus Sohl (1967) included the type species, *Fossar? nebrascensis* (Meek & Hayden, 1860), *Natica haydeni* Cossmann, 1899 and *Natica praenominata* Cossmann,1920 in the genus *Vanikoropsis*.

The family Vanikoroidae was given a short diagnosis by Wenz (1940, p. 885): Shell white, more or less depressed spherical (*Natica*-like), mostly with a low spire, rarely with a raised spire. Protoconch small, smooth, somewhat projecting, last whorl large with umbilicus, with a spiral ornament and more or less distinct axial ribs. Aperture very large, rounded, and oblique. Species of the genus *Vanikoro* (type species *Vanikoro cancellata* (Lamarck, 1822)) are rather thin-shelled and have a stratigraphic range from late Jurassic (Portlandian = Tithonian) to Recent.

The taxonomic classification of the genus *Vanikoropsis* has been discussed since the establishing of the genus. The *Natica*-like outline for some species and the more or less visible umbilicus have caused assignments to Naticidae Guilding, 1834 or Ampullinidae Cossmann, 1918. Wenz (1941, p. 1024) placed *Vanikoropsis* next to *Ampullonatica* Sacco, 1890. Other authors suggesting this classification are White (1889), Cossmann (1907, 1925), Cossmann & Peyrot (1919), Pchelintsev (1927), Beisel (1983), and Caze *et al.* (2011). Cossmann (1907, 1925) and Cossmann & Peyrot (1919) found that the thick shell, broad aperture, inner-lip callus, and closed umbilicus do not match the diagnosis of Vanikoridae.

Sohl (1967) found *Vanikoropsis* and *Vanikoro cancellata* rather similar, as the former differed only in having a thicker shell, a lower spire, and a rounded aperture and placed *Vanikoropsis* in the Vanikoridae. This classification was followed by *e.g.* Thomson (1971), Erickson (1974), Kase (1984), Stilwell & Henderson (2002), and Kollmann (2005). Stilwell *et al.* (2004) referred *Vanikoropsis arktowskiana* (Wilckens, 1910) from the Paleocene of Antarctica to the family Vanikoridae. Crame *et al.* (2014) and Harper *et al.* (2019) however, revert to the original placement by Wilckens (1910), partly based on co-occurrence with drill holes, favored a naticid affinity and Crame *et al.* (2014) suggested that in the future the taxon could be placed in a new genus of the family Naticidae. However, there is no evidence of a similar association in the material from neither Denmark nor West Greenland. Beu (2009) assigned *Vanikoropsis arktowskiana* to the genus *Littorina* Férussac, 1822 (s.l.), because of similarities in outline and spiral ornament and the thickened lips meeting in a clearly defined angle at the top of the aperture.

Cataldo (2017) concluded that the shell outline and

Table 2. Measurements of West Greenland and Danish specimens of *Vanikoropsis (V.)*

SNM no.[1]	Rkz no.[2]	Species this study	Remarks	Height	Width	Height/ width ratio	Last whorl	LW/H ratio	Aperture	A/H ratio
MGUH 10807	MS 144	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Holotype	13.8	15.7	0.88	11.5	0.83	7.1	0.51
MGUH 15744	MS 322B	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Paratype	3.3	3.8	0.87	3.3	1.0	2.8	0.85
MGUH 15745	MS 140	*V.* (s.l.) *jakobseni* n. sp.	Holotype	11.9	11.4	1.04	11.0	0.92	7.7	0.65
MGUH 15746	MS 315	*V.* (s.l.) *bashforthi* n. sp.	Holotype	15.2	14.3	1.06	6.9	0.45	9.8	0.64
GM 1977.1181/8	MS 228	*V.* (s.l.) *bashforthi* n. sp.	Paratype	7.8	6.7	1.16	6.8	0.87	4.9	0.63
GM 1977.1296	MS 315	*V.* (s.l.) *bashforthi* n. sp.	Paratype	18.8	17.7	1.06	15.1	0.80	11.5	0.61
GM 1977.1308	MS 322	*V.* (s.l.) *skoui* Rosenkrantz, 1970	Additional specimen	3.9	4.2	0.67	3.4	0.87	2.9	0.74
MGUH 33950		*Vanikoropsis mortenseni* n. sp.	Holotype	24.1	22.8	1.06	21.5	0.89	13.7	0.61

[1] SNM no.: number in the type collection of SNM, [2] Rkz no.: number in the Rosenkrantz collection of drawings

sculpture in *Vanikoropsis* are evidently convergent with other gastropod taxa and emphasized further studies of the protoconch morphology for a safer suprageneric placement. The protoconch of *V. nebrascensis* from the Maastrichtian of Wyoming, USA was described by Sohl (1967) and Erickson (1974) as dome-shaped, paucispiral and smooth. Judging from the illustration of the holotype the protoconch of *V. demipleura* Stilwell & Henderson, 2002 (fig. 5-2) from the Cenomanian of Australia also is paucispiral.

The protoconchs of the West Greenland species, described herein, are all paucispiral and depressed, with 1¼ to 1½ planispiral, smooth whorls. As this protoconch type is not known from other *Vanikoropsis* species, we use the denomination *Vanikoropsis* (s.l.) for the West Greenland species. The species from the Kerteminde Marl apparently has a dome-like paucispiral protoconch, which is also known from other *Vanikoropsis* species, *e.g.*, *V.? leviplicata* Cataldo, 2017, *V. nebrascensis* (Meek & Hayden, 1860) and *V. demipleura* Stilwell & Henderson, 2002.

In our opinion especially the thick-walled shell, the strong varices and the undulating suture contradict an assignment of the species described herein to the families Naticidae and Ampullinidae. We agree with Sohl (1967) and Cataldo (2017) and tentatively include *Vanikoropsis* in the family Vanikoridae.

***Vanikoropsis mortenseni* n. sp.**
Fig. 3; Fig. 7i–j; Fig. 8a

Type material. Fig. 3a–f; Fig. 7i–j; Fig. 8a, MGUH 33950 (silicone latex cast of holotype MGUH 33950A and MGUH 33950B (ex DK 1133)). Casts in ISL and MNO.

Etymology. This species is named after Peter Tang Mortensen, who collected the only specimen found.

Type locality. Gravel-pit at Gundstrup, north of Odense, Fyn, Denmark.

Type strata. Kerteminde Marl, Selandian, middle Paleocene.

Diagnosis. A rather large, naticiform and moderately thick-walled *Vanikoropsis* with a H/W ratio at almost 1.1, a slightly undulating suture and numerous spiral ribbons. Secondary spirals are inserted from the first teleoconch whorl. Protoconch paucispiral and dome-like.

Measurements. See Table 2.

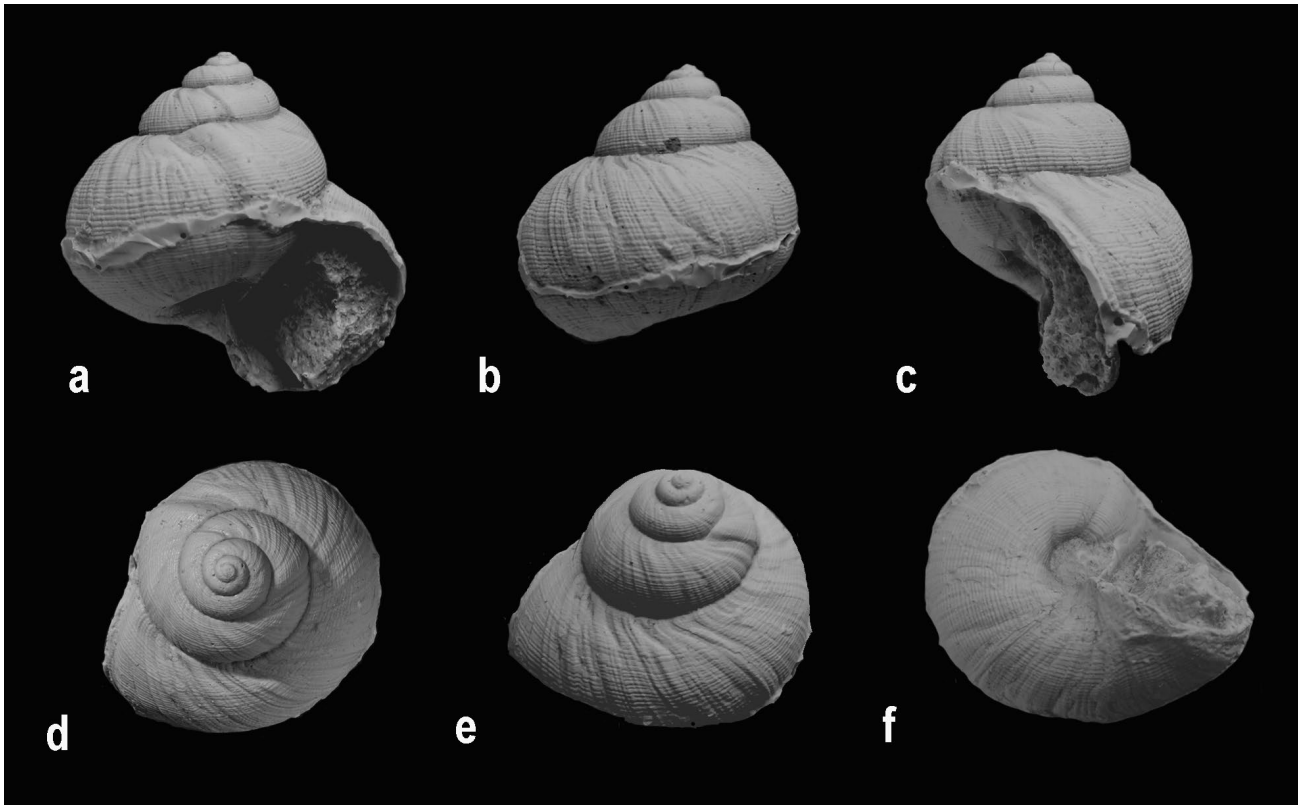

Fig. 3. a-f: *Vanikoropsis mortenseni* n. sp. Silicone latex cast of holotype MGUH 33950A and MGUH 33950B, ex DK 1133. Height 24.1 mm, width 22.8 mm. **a:** apertural view, **b:** rear view, **c:** lateral view, **d:** apical view, **e:** oblique apical view, **f:** umbilical view.

Description. The shell is medium sized, naticiform and moderately thick-walled, with a H/W ratio of 1.1. The only specimen has 5 whorls, of which the first 1¼ belongs to the protoconch. The whorls are medium convex and separated by a deep to slightly canaliculate and a slightly undulating suture. The body whorl equals 0.92 of the total shell height. The aperture equals 0.47 of the total shell height and is obliquely ovate, well rounded anteriorly, subangulate posteriorly. The labium is concave and partly covered by a thin callus, which also covers part of the parietal wall. The labrum is thickened and prosocline, inclined about 20° to the axis of coiling. There is a narrow, but rather deep umbilicus. The rather badly preserved protoconch is paucispiral and dome-like, consisting of 1¼ whorls. The teleoconch whorls are completely covered by numerous spiral ribbons, which are separated by narrow interspaces. The spiral ribbons on the abapical part of the whorls are wider than the adapical ribbons. Two spiral ribbons situated a little above the middle of the whorls are a little more prominent than the others. The number of spiral ribbons is 8 on the first teleoconch and secondary spirals are inserted from the first teleoconch whorl. On the penultimate whorl there are almost 30 spiral ribbons. The axial sculpture consists of prosocline growth lines or broad discontinuous swellings, which get more close-set before the aperture. Three old apertures are visible as indistinctively demarcated swellings. They have distances from 0.25 whorl to 0.75 whorl in abapical direction.

Discussion. We assign the new species to *Vanikoropsis* because of the general outline, the spiral ornament, the prosocline axial folds, and the rather thick-walled shell with varices. The apparently dome-like paucispiral protoconch is also known on other species of *Vanikoropsis*. *Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970 is considerably more thick-walled and has a coarser spiral ornament. The whorls have a narrow adapical ramp and more coarse axial folds and more prominent varices and the protoconch is planispiral and depressed. Kollmann & Peel (1983, p. 65, figs 131A-D) illustrated the holotype and an additional juvenile specimen, which is more low-spired. *Vanikoropsis* (s.l.) *jakobseni* n. sp. (Kollmann & Peel 1983, p. 65, figs 132A, B) has a lower spire and stronger and less numerous spiral cords. The suture is canaliculate and there is a narrow subsutural ramp. The protoconch is planispiral and depressed. *Vanikoropsis* (s.l.) *bashforthi* n. sp. (Kollmann & Peel 1983, p. 66, fig. 133) has an outline rather similar to the new species, but a lower number of spiral cords, which are wider and very weak on the body whorl. Furthermore, this species has a considerably more thick-walled shell, less convex whorls, and a more concave parietal wall. The axial folds are more prominent and cause a much more undulating suture. The protoconch is planispiral and depressed. *Vanikoropsis nebrascensis* (Meek & Hayden, 1860) from the Maastrichtian of Wyoming, USA has a higher spire and a lower number of spiral cords, which are wider. *Vanikoropsis? leviplicata* Cataldo, 2017 from the Lower Cretaceous of Argentina differs by having a closed umbilicus partially covered by the callus, a lower number of wider spiral ribbons and a subangular periphery. However, the protoconch is dome-like and is reminiscent of the protoconch of the Danish species.

***Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970**
Fig. 4a–e, f–h; Fig. 7f–h; Fig. 8b

1970 *Vanikoropsis skoui* Rosenkrantz, p. 438, text-figs 13, 14a-b.
1983 *Vanikoropsis skoui* Rosenkrantz – Kollmann & Peel, p. 65, figs 131A-D.

Type material. Holotype Fig. 4a–e, Fig. 8b, MGUH 10807, *Vanikoropsis skoui* Rosenkrantz (1970, p. 438, text-figs 13, 14a–b); Kollmann & Peel (1983, p. 65, figs 131A, B); additional specimen Fig. 4f–h, MGUH 15744 (Kollmann & Peel 1983, p. 65, figs 131C, D).

Additional material. Fig. 7f–h, MGUH 33953 (ex 1977.1308), Sonja Lens, 1 juvenile specimen.

Type locality. Sonja Lens, east of Turritellakløft, Nuussuaq peninsula, West Greenland.

Type strata. Agatdal Formation, late Danian, early Paleocene.

Measurements. See Table 2.

Description. The shell is small and naticiform, height/width ratio *c.* 0.9. The shell is rather thick-shelled with strongly convex whorls, which are regularly increasing in diameter. The whorls are separated by a deep to canaliculate, undulating suture. The protoconch is planispiral, consisting of *c.* 1¼ whorls, which are laying deeper than the following whorls. There are *c.* four teleoconch whorls. Last whorl equals 0.8 of the total shell height, the aperture *c.* 0.5 of the total shell height. The last whorl is large and swollen, wider than tall, with its maximum diameter at almost mid-whorl. The umbilicus is narrow, and the innerlip callus partly covers it. The aperture is holostomate and prosocline, with a deviation from the axis, the peristome round to slightly ovate, with an anterior spout near the columella, rounded abapically. The

labrum is strongly thickened and inclined about 15° to the axis of coiling. The inner lip is flat to slightly concave on parietal area and the callus thick and narrow. The columella is concave. The spiral ornament consists of low, band-like cords, which are separated by narrower spiral striae. The cords are twice as broad as the striae, nearly 20 on last whorl; the growth lines are prosocline and straight. There are growth rugae on last and penultimate whorl. They are irregular, parallel to growth lines, accentuated on adapical third of whorls. Old apertures are visible as swellings in distances of half a whorl. These swellings cause an undulating suture. The periphery is inconspicuous. The base is convex with spiral cords and growth lines.

Discussion. Rosenkrantz (1970, p. 438) gave no diagnosis and only a few descriptive remarks. He stated that the diagnosis given by Sohl (1967, p. 22) covers the thick-shelled naticiform new species completely and that the species in shape and height of the spire matches the holotype of *Vanikoropsis tuomeyana* (Meek & Hayden, 1860), the type species of *Vanikoropsis*. He stated that his new species has a finer spiral sculpture like *Vanikoropsis nebrascensis* (Meek & Hayden, 1860). However, he noted that this species has a much higher spire than the species from West Greenland. Rosenkrantz mentioned a few specimens of *V. skoui* but only illustrated the holotype. However, he obviously may have recognized further different *Vanikoropsis* species, as he supervised drawings of the specimens, by Kollmann & Peel (1983) interpreted as *Vanikoropsis* sp. 1 and sp. 2, and the additional specimens of *Vanikoropsis* (s.l.) *skoui* and *Vanikoropsis* (s.l.) *bashforthi* n. sp., illustrated herein.

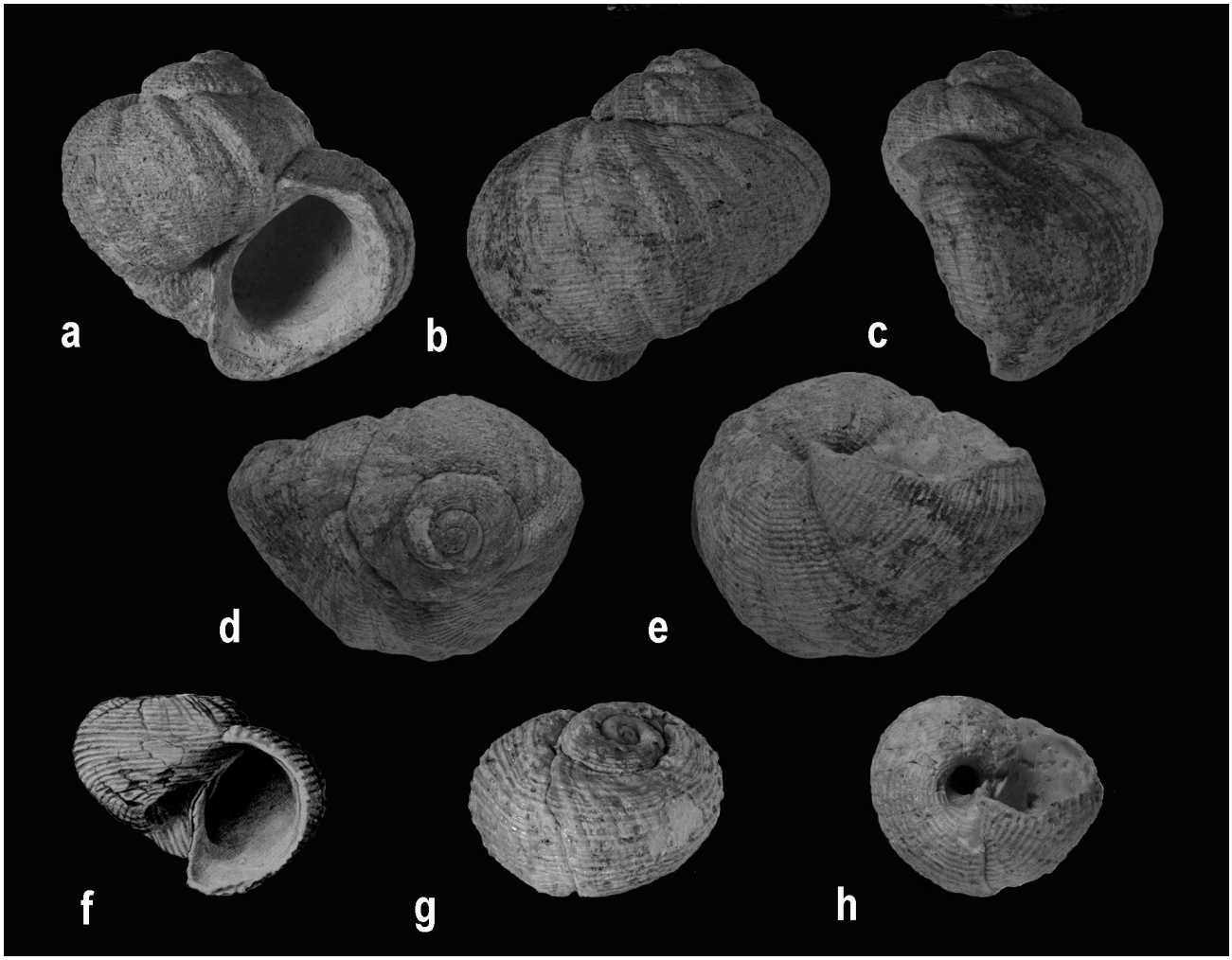

Fig. 4. a-e. *Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970. Holotype MGUH 10807. Height 13.8 mm, width 15.7 mm. **a:** apertural view, **b:** rear view, **c:** lateral view, **d:** apical view, **e:** umbilical view. **f-h.** *Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970. MGUH 15744. Height 3.3 mm, width 3.8 mm. **f:** apertural view (reproduced from Kollmann & Peel 1983, p. 65, fig. 131D), **g:** oblique apical view, **h:** umbilical view.

***Vanikoropsis* (s.l.) *jakobseni* n. sp.**
Fig. 5a–e; Fig. 8c

1983 *Vanikoropsis* sp. 1 – Kollmann & Peel, p. 65, figs 132A-B.

Type material. Holotype Fig. 5a–e, Fig. 8c, MGUH 15745.

Etymology. This species is named after Sten Lennart Jakobsen, Geomuseum Faxe, for his great help doing the greater part of the photographical work in SNM.

Type locality. Qaarsutjægerdal, east of Turritellakløft, Nuussuaq peninsula, West Greenland.

Type strata. Agatdal Formation, late Danian, early Paleocene.

Diagnosis. A low-spired *Vanikoropsis* with a rather coarse spiral ornament, a narrow umbilicus, and a narrow adapical ramp.

Measurements. See Table 2.

Description. The only specimen is naticiform and low-spired and provides three and a half whorls, which are separated by a canaliculate suture, and the protoconch. The whorls are medium convex and have a rather narrow adapical ramp. The last whorl equals 0.9 of the total shell height, the aperture 0.6. The aperture is ovate and oblique to the axis, with an anterior spout adaxially. The interior side of the thickened labrum is smooth. The labium is concave, and a thin callus partly covers the narrow umbilicus. The labrum is thickened and inclined *c.* 15° to the axis of coiling. The paucispiral protoconch is planispiral, consisting of *c.* 1½ whorls, which are laying deeper than the following teleoconch whorls. The protoconch whorls are more convex than on *Vanikoropsis* (s.l.) *skoui* and *Vanikoropsis* (s.l.) *bashforthi* n. sp. (described herein). On the first teleoconch whorl a keel appears near the adapical suture and is situated above the protoconch. This keel demarcates a narrow adapical ramp with indistinct spiral ribs. On the abapical part of the whorl there are 7-8 spiral cords of varying strength and on the body whorl weaker secondary spirals are inserted. There are irregularly placed axial rugae, which are most prominent adapically.

Discussion. The species especially differs from *Vanikoropsis* (s.l.) *skoui* by its lower apex and lower number of spiral cords. Kollmann & Peel interpreted it as a possible variation of *Vanikoropsis* (s.l.) *skoui*, but because of the mentioned differences in outline and spiral ornament we interpret it as not conspecific with *Vanikoropsis* (s.l.) *skoui*.

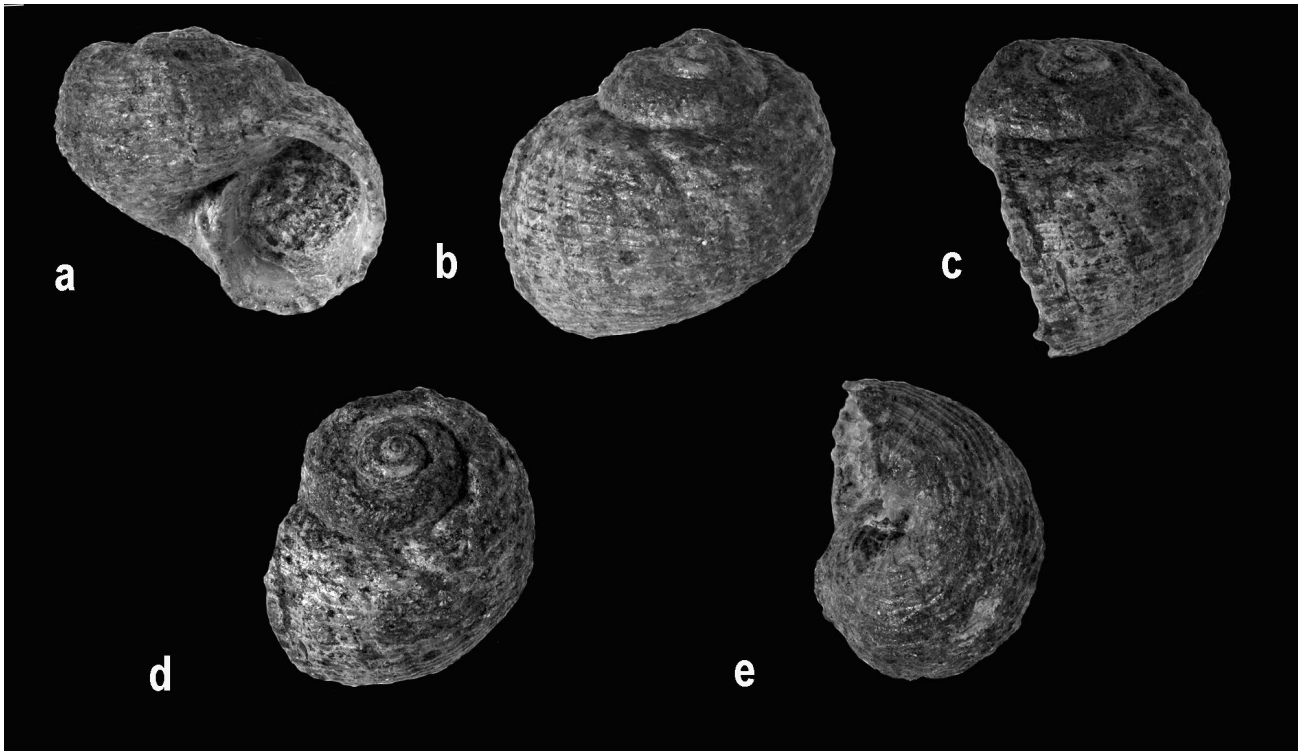

Fig. 5. *Vanikoropsis* (s.l.) *jakobseni* n. sp. Holotype MGUH 15745. Height 11.9 mm, width 11.4 mm. **a:** apertural view, **b:** rear view, **c:** lateral view, **d:** apical view, **e:** umbilical view.

***Vanikoropsis* (s.l.) *bashforthi* n. sp.**
Fig. 6a–e, f–j; Fig. 7a–e; Fig. 8d

1983 *Vanikoropsis* sp. 2 – Kollmann & Peel, p. 66, figs 133A-B.

Type material. Holotype Fig. 6a–e; Fig. 8d, MGUH 15746. Paratypes Fig. 6f–j, MGUH 33951 (ex GM 1977.1296); Fig. 7a–e, MGUH 33952 (ex GM 1977.1181/8).

Etymology. This species is named after Arden Roy Bashforth, SNM, Copenhagen, for his great help with locating of the material in the Rosenkrantz collection in SNM.

Type locality. Qaarsutjægerdal, east of Turritellakløft, Nuussuaq peninsula, West Greenland.

Type strata. Agatdal Formation, late Danian, early Paleocene.

Diagnosis. A relatively high-spired *Vanikoropsis* with a spiral ornament of delicate spiral threads, which cover the entire shell. The spiral ornament gradually becomes weaker on the body whorl. The whorls are slightly to medium convex, and the shell is thick-walled. The umbilicus is narrow. Old apertures are visible as swellings at intervals of half a whorl. The paucispiral protoconch is planispiral and depressed.

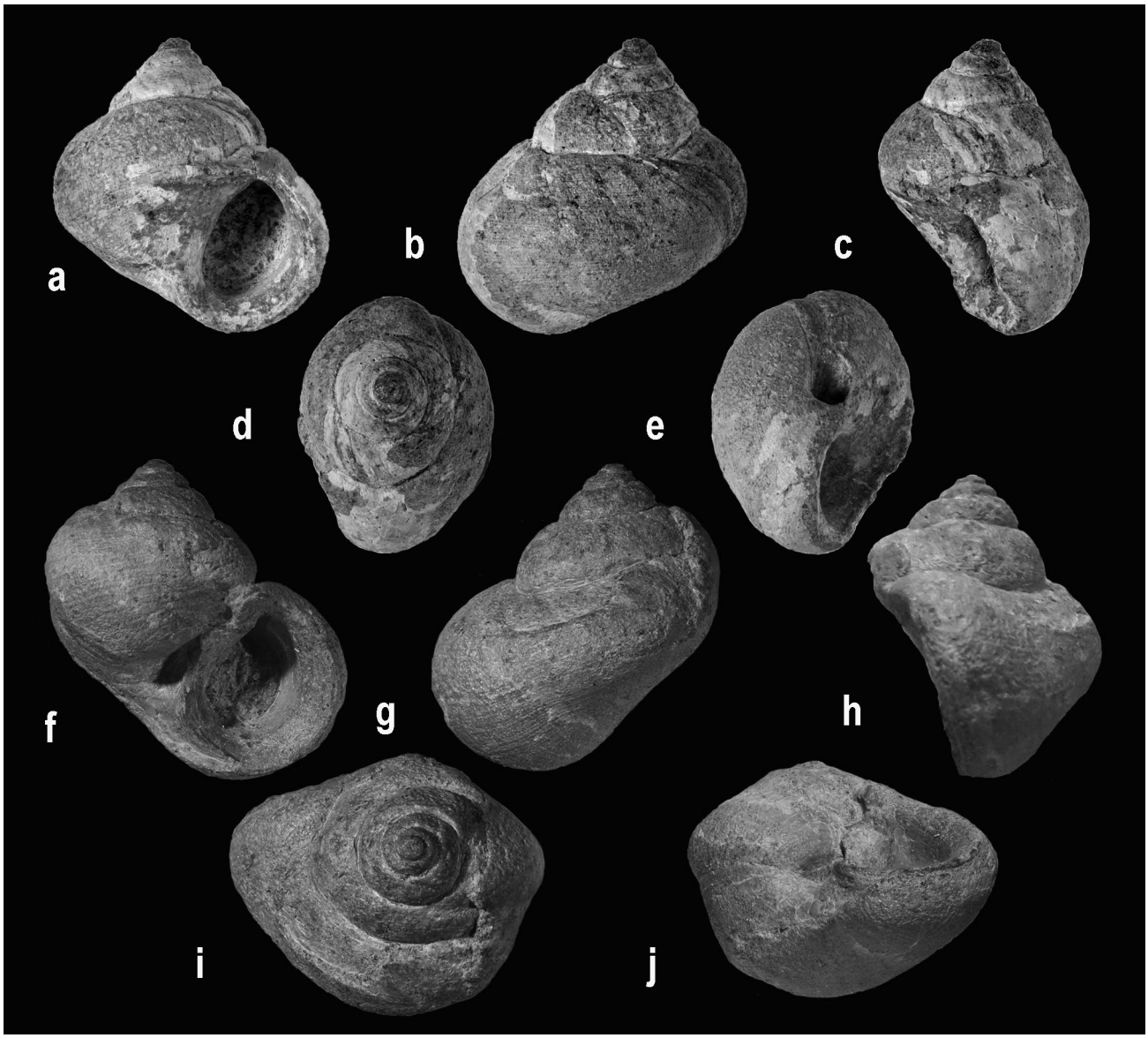

Fig. 6. a-e: *Vanikoropsis* (s.l.) *bashforthi* n. sp. Holotype MGUH 15746. Height 15.2 mm, width 14.3 mm. **a:** apertural view, **b:** rear view, **c:** lateral view, **d:** apical view, **e:** umbilical view. **f-j:** *Vanikoropsis* (s.l.) *bashforthi* n. sp. Paratype MGUH 33951, ex GM 1977.1296. Height 18.8 mm, width 17.7 mm. **f:** apertural view, **g:** rear view, **h:** lateral view, **i:** apical view, **j:** umbilical view.

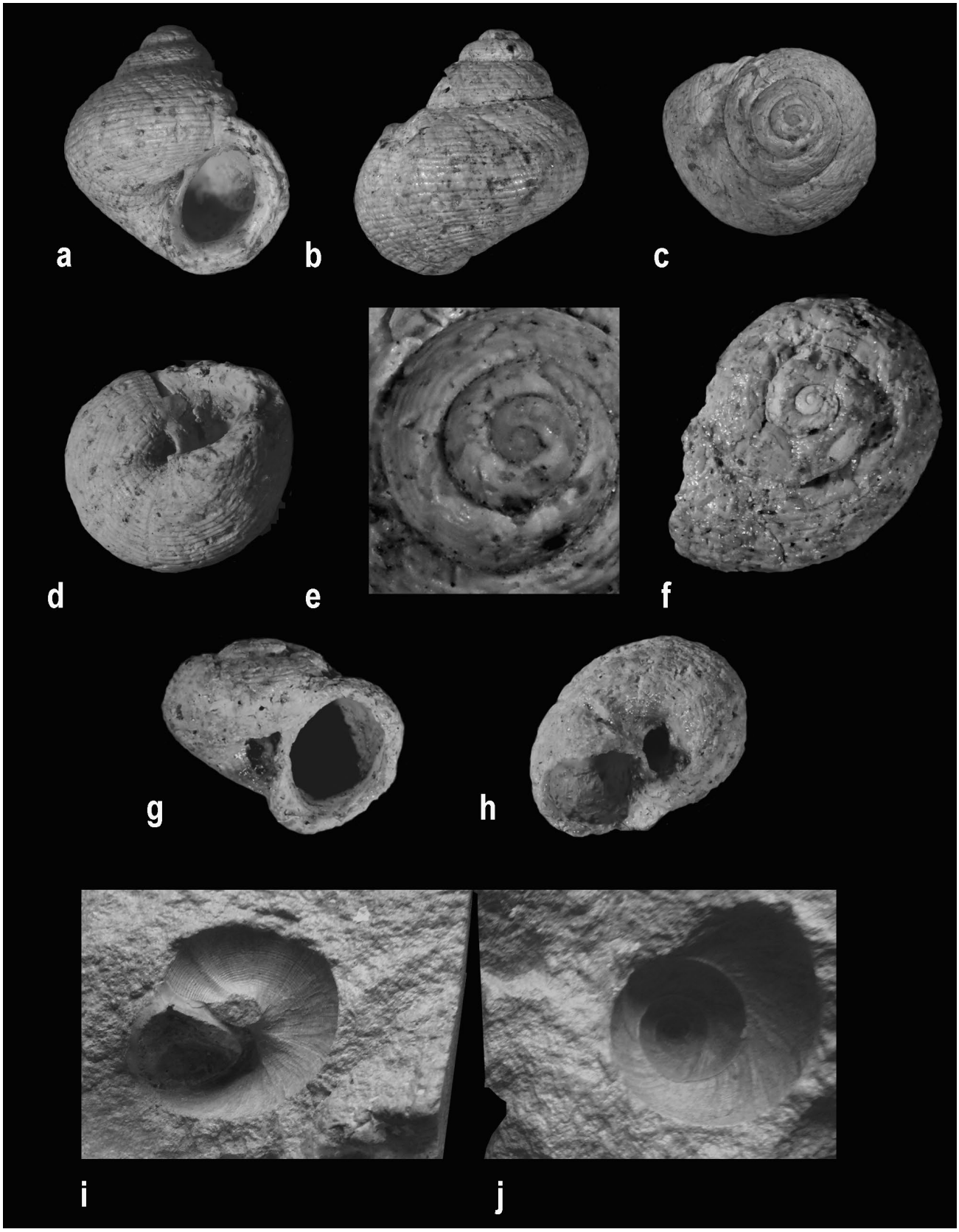

Fig. 7. a-e: *Vanikoropsis* (s.l.) *bashforthi* n. sp. Paratype MGUH 33952, ex GM 1977.1181/8. Height 7.8 mm, width 6.7 mm. **a:** apertural view, **b:** rear view, **c:** apical view, **d:** umbilical view, **e:** protoconch and first teleoconch whorls. **f-h:** *Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970. MGUH 33953, ex GM 1977.1308. Height 3.9 mm, width 4.2 mm. **f:** protoconch and first teleoconch whorls, **g:** apertural view, **h:** umbilical view. **i-j:** *Vanikoropsis mortenseni* n. sp. Holotype MGUH 33950A and MGUH 33950B (ex DK 1133). Impressions in slabs of Kerteminde Marl. Length 69 mm, height 27 mm.

Measurements. See Table 2.

Description. The material includes the three illustrated specimens only. The holotype was illustrated by Kollmann & Peel (1983). The paratype MGUH 33952 was found by the senior author (2005) in the sample GM 1977.1181, by Kollmann & Peel (1983, p. 94) labelled "cf. *Coptostoma* sp.". As a matter of fact, the senior author found eight different taxa in this sample, including a juvenile specimen, which he labelled "*Vanikoropsis* sp." and gave the number GM 1977.1181/8. The paratype MGUH 33951 (ex GM 1977.1296) is a larger specimen. The rather small turbiniform shell provides the protoconch and four slightly to medium convex whorls, which are separated by a distinct and highly undulating suture. The width/height ratio is *c.* 1.1. The body whorl equals 0.76-0.85 of the total shell height, the aperture 0.44-0.59. The aperture is rounded ovate, and the callus partly covers the narrow umbilicus. The shell is very thick-walled. The protoconch could be studied on the specimen 1977.1181/8. It consists of 1½ planispiral smooth whorls, which lay lower than the first teleoconch whorl. The transition into the teleoconch is indicated by a change in color. There are 10 fine spirals on the first teleoconch whorl, separated by fine furrows. The abapical spirals are stronger than the adapical spirals. On the following whorls secondary spirals are inserted and the entire shell is covered of these spirals, which are of slightly varying width. The aperture is rounded ovate and obliquely placed to the axis. The labrum is thickened and inclined about 30° to the axis of coiling. The thin callus partly covers the narrow umbilicus. Old apertures are visible as thickenings with intervals of half a whorl, which cause an undulating suture. In apical view the adult shell has a subovate outline.

Discussion. The species differs from the two other species from West Greenland by its spiral ornament of fine spirals and its more high-spired outline. It comes closer to the species from Denmark with regards to outline and ornament but has a different protoconch. *Vanikoropsis arktowskiana* (Wilckens, 1910) from the Danian of Antarctica has a similar outline, but a spiral ornament of fewer and coarser cords. Kollmann & Peel (1983) noted that *Littorina* sp. indet. in Krach (1963, p. 49; pl. 4, fig. 4; pl. 17, fig. 8) seemed to be related. This species has a rather similar outline, but a coarser spiral ornament.

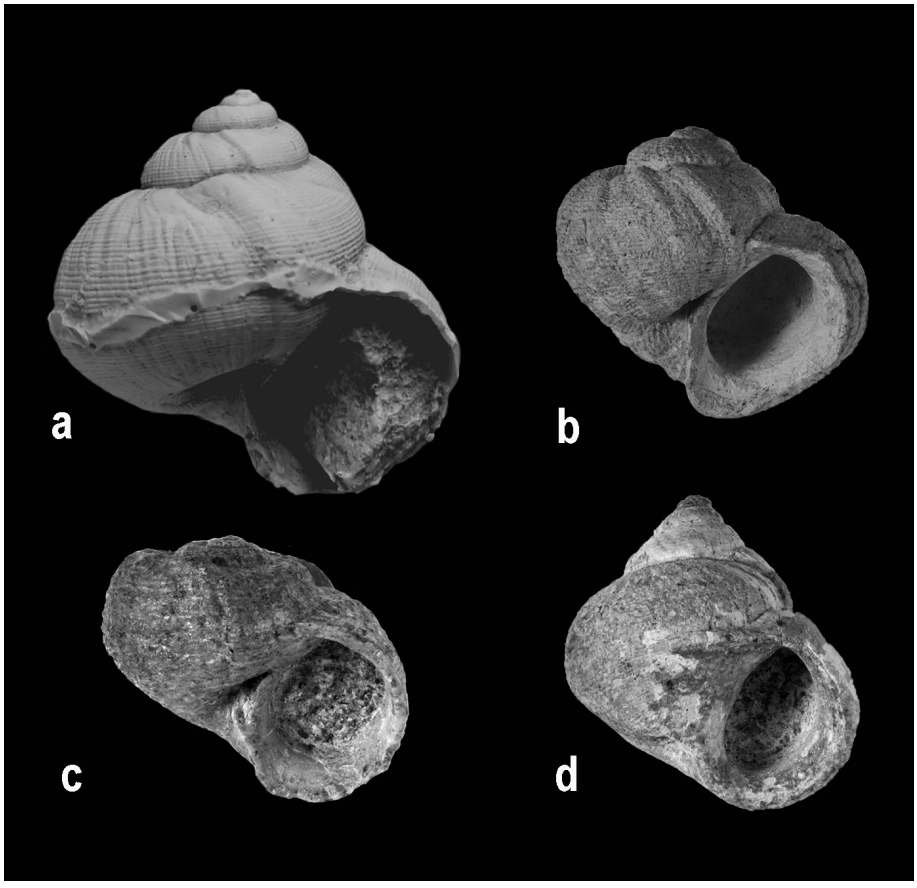

Fig. 8. a: *Vanikoropsis mortenseni* n. sp. Silicone latex cast of holotype MGUH 33950A and MGUH 33950B. Impressions in slabs of Kerteminde Marl. Height 24.1 mm, width 22.8 mm. **b:** *Vanikoropsis* (s.l.) *skoui* Rosenkrantz, 1970. Holotype MGUH 10807. Height 13.8 mm, width 15.7 mm. **c:** *Vanikoropsis* (s.l.) *jakobseni* n. sp. Holotype MGUH 15745. Height 11.9 mm, width 11.4 mm. **d:** *Vanikoropsis* (s.l.) *bashforthi* n. sp. Holotype MGUH 15746. Height 15.2 mm, width 14.3 mm.

Table 3. Stratigraphical records of *Vanikoropsis (V.)*, based on references in literature

Species	Country	Series/Epoch	Stage/Age	Reference
V. neritoides (Trautschold, 1866)	Russia	Upper Jurassic/ Lower Cretaceous		Gerasimov (1992)
V. minuta Pan, 1977	China	Middle Jurassic	Bajocian/Bathonian	Stilwell *et al.* (2004)
V. suciensis White, 1889	US	Cretaceous		Sohl (1967)
V. decussata (Deshayes in Leymerie, 1842)	France	Lower Cretaceous	Albian	Stilwell & Henderson (2002)
V. decussata (Deshayes in Leymerie, 1842)	Japan	Lower Cretaceous	Barremian	Stilwell & Henderson (2002)
V. exerta Cossmann, 1907	France	Lower Cretaceous	Barremian	Cossmann (1925)
V. houdardi Cossmann, 1925	France	Lower Cretaceous	Albian	Cossmann (1925)
V. borissjaki Pchelintsev, 1927	Ukraine	Lower Cretaceous	Albian	Pchelintsev (1927)
V. communis Pchelintsev, 1927	Ukraine	Lower Cretaceous	Albian	Pchelintsev (1927)
V. multistriata Pchelintsev, 1927	Ukraine	Lower Cretaceous	Albian	Pchelintsev (1927)
Vanikoropsis? sp.	Antarctica	Lower Cretaceous		Thomson (1971)
Vanikoro? sp.	Argentina	Lower Cretaceous	Barremian	Stanton (1901)
V? leviplicata Cataldo, 2017	Argentina	Lower Cretaceous	Upper Hauterivian	Cataldo (2017)
V. valanginensis Beisel, 1983	Sibiria	Lower Cretaceous	Valangian	Beisel (1983)
V. jackii Etheridge in Jack & Etheridge, 1892	Australia	Lower Cretaceous		Etheridge (1920)
V? stuarti Etheridge, 1902	Australia	Lower Cretaceous		Etheridge (1902)
V. decussata Etheridge, 1920 (non Deshayes in Leymerie, 1842)	Australia	Lower Cretaceous		Etheridge (1920)
V. demipleura Stilwell & Henderson, 2002	Australia	Upper Cretaceous	Cenomanian	Stilwell & Henderson (2002)
V. cassisiana (d'Orbigny, 1842)	Serbia	Upper Cretaceous	Lower Cenomanian	Ayoub-Hannaa *et al.* (2015)
V. nebrascensis (Meek & Hayden, 1860)	USA	Upper Cretaceous	Maastrichtian	Sohl (1967)
Vanikoro kiliani Wilckens, 1910	Antarctica	Upper Cretaceous		Wilckens (1910)
V. arktowskiana (Wilckens, 1910)	Antarctica	Lower Paleocene	Danian	Stilwell *et al.* (2004)
Vanikoropsis skoui Rosenkrantz, 1970	Greenland	Lower Paleocene	Danian	Rosenkrantz (1970)
Vanikoropsis? bashforthi n. sp.	Greenland	Lower Paleocene	Danian	Schnetler & Nielsen (this study)
Vanikoropsis? jakobsen n. sp.	Greenland	Lower Paleocene	Danian	Schnetler & Nielsen (this study)
Vanikoropsis mortenseni n. sp.	Denmark	Middle Paleocene	Selandian	Schnetler & Nielsen (this study)

Distribution of the genus *Vanikoropsis*

According to Wenz (1941, p. 1024) the genus has a stratigraphical range from upper Jurassic (Portlandian = Tithonian) to upper Cretaceous. Cataldo (2017, p. 428–429), in her discussion of the new species *Vanikoropsis? leviplicata*, discussed records of *Vanikoropsis* species in literature. We have checked the references but are not convinced that all these species in fact can be assigned to *Vanikoropsis*. In some cases, especially in older references, the illustrations and/or the material are rather poor, and the members of this group show a considerable variation in outline, sculpture, aperture and umbilicus. Thus, the group is most probably polyphyletic. As the present paper is not intended to be a revision of the genus *Vanikoropsis*, we prefer to list the records in Table 3, which is mainly based on Cataldo (2017).

Conclusions

The predominantly Cretaceous genus *Vanikoropsis* Meek, 1876 is represented by one species in the Danish Selandian (middle Paleocene) and three species in the Danian (early Paleocene) of West Greenland. Three new species are described, viz. *Vanikoropsis mortenseni* n. sp., *Vanikoropsis* (s.l.) *jakobseni* n. sp. and *Vanikoropsis* (s.l.) *bashforthi* n. sp. The protoconchs of the species from West Greenland are all paucispiral and depressed, whereas the species from Denmark apparently has a dome-like protoconch. The genus *Vanikoropsis* is tentatively included in the family Vanikoridae. The occurrences support the affinities between the Danish and the West Greenland Paleocene, which were discussed by Schnetler & Nielsen (2018). *Vanikoropsis mortenseni* n. sp. is probably the youngest record of *Vanikoropsis*.

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