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Scientific Editor:

Dr. Godtfred Høpner Petersen, University of Copenhagen, Zoological Museum, Universitetsparken 15, DK 2100 Copenhagen Ø. Phone + 45 3532 1082, fax + 45 3532 1010

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The Commission for Scientific Research in Greenland
Danish Polar Center
Strandgade 100 H
DK-1401 Copenhagen
Denmark
tel +45 3288 0100
fax +45 3288 0101
e-mail dpc@dpc.dk

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ABSTRACT

Símonarson, L.A., Petersen, K.S. & Funder, S. 1998. Molluscan palaeontology of the Pliocene-Pleistocene Kap København Formation, North Greenland.
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The sediments of the Pliocene-Pleistocene Kap København Formation reflect a succession from isostatic conditioned regression (Member A) to transgression (Member B). Transgression rates were first slow (unit B1), then faster (unit B2), and then again slower (unit B3). The fragmented molluscan death assemblage of Member A reflects moderately deep water and arctic temperatures. Unit B1 was deposited mainly in foreshore, backshore, and shoreface environments, and the mollusc fauna was most probably washed up from slightly greater depths. Temperatures had now risen to subarctic. In unit B2 the mollusc fauna is a death assemblage of the parautochthonous type. Temperatures had risen to even milder subarctic conditions with higher sea temperatures. Unit B3 contains a fragmented low diverse molluscan death assemblage from an estuarine environment and with no temperature indication. However, all the faunas lived in waters with reduced salinity.

The 15 gastropod, 27 bivalve, and one brachiopod species from the Kap København Formation are amphiatlantic in character, but five species are new to the Greenland fossil fauna and four species are not known to live in Greenland today. All species are extant, but ten have not been found in older deposits and apparently have their FAD - their first appearance datums - in the Kap København Formation.

The mollusc fauna in the Kap København Formation is considered to be the oldest arctic fauna from marine, shallow water environments known so far. Biostratigraphical correlations indicate that the boundary between Member A and Member B is close to 2.45 Ma, i.e. the transition between the Praetiglian and Tiglian in northern Europe. This dates the formation to the uppermost Pliocene (allochthonous fauna assemblage) and the lowermost Pleistocene (Members A and B). It is suggested that the fauna evolved in response to the new and harsher environments following the Praetiglian glaciation, most probably during migration into shallow water environments. When the Polar Basin became ice covered the molluscs were attracted to the ice margin where food conditions were more favourable, and then to the shallow water shelves with seasonally ice free areas close to the coasts.

Grab-samples with contemporary benthic fauna featuring 21 molluscan species from the fjord off Kap København are described.

Keywords: Plio-Pleistocene; molluscs; Greenland.

Leifur A. Símonarson, Science Institute, Jardfrædahús Háskólans v/Hringbraut, 101 Reykjavík, Iceland;
Kaj Strand Petersen, The Geological Survey of Denmark and Greenland (GEUS), Thoravej 8, DK-2400, Copenhagen NV, Denmark;
Svend Funder, Geological Museum, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark.

Introduction

Located less than 800 km from the North Pole (Fig. 1), the sediments of the Kap København Formation is one of very few occurrences around the Arctic Ocean to give a picture, unsurpassed in detail, of terrestrial and nearshore ecosystems of the present High Arctic at the time when the large continental ice sheets had just made their debut in the Northern Hemisphere.

The sediments' surprisingly rich land-floras and insect faunas have been monographed previously. In contrast to them, the nearshore marine mollusc faunas which are the subject of this contribution have great similarities with the present day faunas of the High Arctic. Thus, while terrestrial biota differed greatly from today's, the arctic nearshore benthic communities were nearly ready-made already at this early time.

In the present survey the marine macro-invertebrates, i.e. molluscs and a brachiopod, altogether 43 species, from the expeditions in 1979, 1980 and 1983 have been treated. The work also deals with a few species from the last expedition to the area in 1986, collected by Ole Bennike. The identified species are all extant and only four are not found in Greenland waters today. Considering the high latitude and the few occurrences of this type that are known, it is not surprising that ten arctic species, including such a well known indicator of cold water as *Portlandia arctica*, seem to have their FAD - their first appearance datums - in the Kap København Formation.

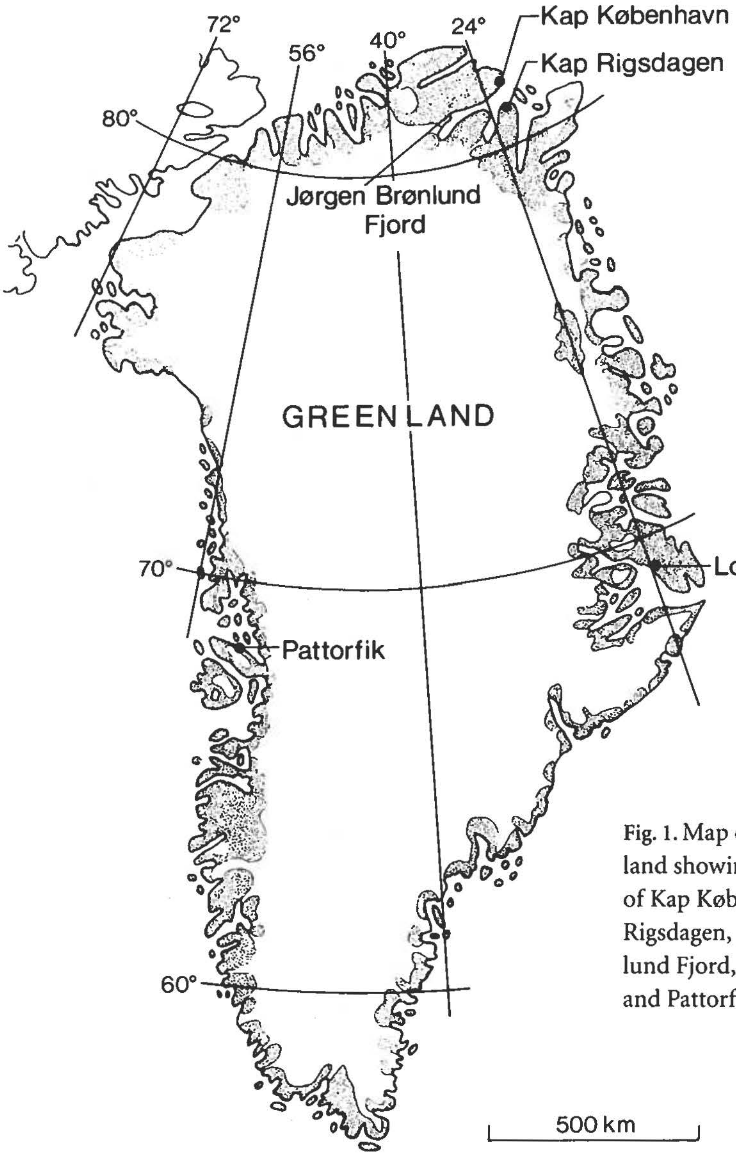

Fig. 1. Map of Greenland showing the location of Kap København, Kap Rigsdagen, Jørgen Brønlund Fjord, Lodin Elv, and Pattorfik.

The faunas are discussed in relation to their physical environment and compared and correlated with other Late Tertiary/Early Quaternary mollusc faunas from the Arctic Ocean borderlands.

Table 1. Proposed chronostratigraphy, lithostratigraphy, foraminiferal and ostracode zones of the Kap København Formation according to Feyling-Hanssen 1990 and Penney 1993

Epoch	Lithostratigraphy		Foraminiferal zones	Ostracode zones
Lower Pleistocene	Member B	Unit B3	▨	▨
		Unit B2	*Elphidiella gorbunovi*	*Rabilimis paramirabilis* & *Pterygocythereis vannieuwenhuisei*
			Elphidium excavatum	
			Elphidium cf. *excavatum*	
Pliocene			*Elphidiella rolfi*	
		Unit B1	▨	▨
	Member A		*Cassidulina laevigata*	*Rabilimis mirabilis*
			Elphidium funderi	

Finally, as a basis for comparison with present conditions, grab-sampling of benthos on the fjord bottom off Kap København was carried out; and the results are included here.

In previous publications the Kap København Formation has been referred to „the Plio/Pleistocene“ (c. 2.5- c. 1.8 Ma) - acknowledging the schisma in opinions on where the Pliocene-Pleistocene boundary should best be drawn (e.g. Zagwijn 1992, Berggren *et al.* 1995; Table 1).

In this paper we use the boundary between the Reuverian and Praetiglian Stages in the Netherlands, at the beginning of the first major glaciation in the Northern Hemisphere, since this is commonly used in northern and western Europe (e.g. Zagwijn 1992). The age of this boundary is close to 2.55 Ma (Funnell 1995, 1996) and in this terminology the Kap København Formation is Early Pleistocene, whereas the allochthonous fauna assemblage is Late Pliocene. In North American literature the boundary is often drawn at c. 1.8 Ma (Berggren *et al.* 1995). which would make the Kap København Formation Pliocene. To avoid misunderstanding we have as far as possible mentioned absolute ages for stratigraphical units, and where these were not available we have attempted to be consistent in our use of terminology, so that some North American Pliocene deposits, such as the Fishcreekian (Fish Creek Fauna) of northern Alaska, are here Early Pleistocene.

History of previous research

The Kap København Formation was discovered during the Geological Survey of Greenland's regional geological mapping in North Greenland in 1979 and the lithology of the area at the type section, locality 50 (Fig. 2), was established (Funder & Hjort 1980). Subsequent analyses of organic remains showed that conditions had been considerably warmer than at the present and it was assumed that the sedi-

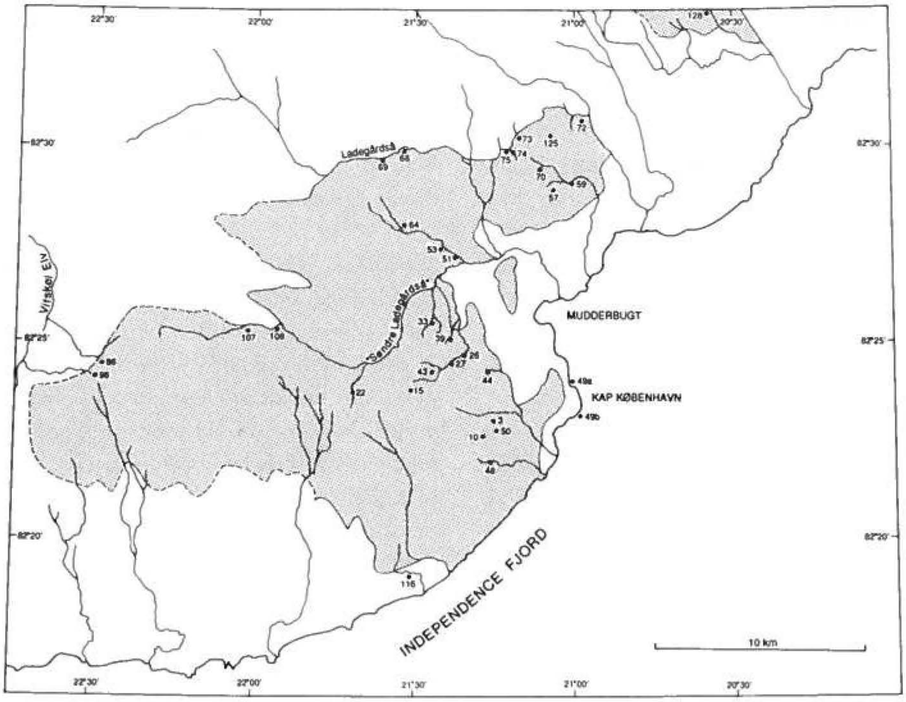

Fig. 2. The Kap København area showing field localities and the boundary of the Kap København Formation.

ments belonged to the last interglaciation (Fredskild & Røen 1982). In 1980 the area was again visited by a team and samples for palaeomagnetic analyses were collected (Abrahamsen & Marcussen 1986). The third and most extensive field season came in 1983. This time a group of six scientists worked in the area in the entire four week field season. Most of the material treated in this monograph was collected during this field season, which resulted in formalisation of the stratigraphy and an age estimate at the Pliocene-Pleistocene boundary, both of which have been retained in all later publications (Funder *et al.* 1984, 1985). The fourth, and to this time last visit, was in 1986, when one team again spent a whole field season in the area. Since then there has been no field work on the Kap København Formation. Based on collections made during this field work monographs have been published on the foraminifera (Feyling-Hanssen 1990), plants (Bennike 1990), ostracodes (Brouwers *et al.* 1991), and insects (Böcher 1995). In addition, some mosses have been treated by Mogensen (1984) and the few mammals by Repenning *et al.* (1987). Preliminary notes on amino acid analyses were published by Funder *et al.* (1987) and some molluscs were treated by Bennike (1989). A preliminary account of the insect fauna was published by Böcher (1989) and a survey of the terrestrial biotopes by Bennike & Böcher (1990). Additional ostracodes were described by Penney (1993), who also gave a detailed discussion of the age. Preliminary correlations with the orbitally tuned isotope record have been made by Funder (1995) and Funder *et al.* (1996).

Various models for correlation between the Kap København Formation and terrestrial as well as marine sediments in Arctic Canada and Alaska have been published by Brigham-Grette & Carter (1992), Repenning & Brouwers (1992), Matthews & Ovenden (1990), and Kaufman & Brigham-Grette (1993).

Stratigraphy and mollusc fauna collections

During the first field season a lithologic division of the Kap København Formation was established (Funder & Hjort 1980). Later this was formalised as the Kap København Formation with two members and the youngest of these was subdivided into three units (Funder *et al.* 1984). This division has been retained in all later publications on the Kap København Formation (Fig. 3 and Table 1).

The lithological criteria can with a high degree of certainty be used for correlation within a radius of c. 15 km from the type section. However, in the far west (localities 86 and 96) and east (locality 128) the facies are different and correlations uncertain (Fig. 2). Therefore at some sites the individual units of Member B cannot be distinguished (localities 57 and 128). Detailed logs and sediment descriptions, including grain size analyses, have been published from a number of localities by Bennike (1990). Individual localities are briefly described in the next section.

Member A. - At the base of the section it has a visible maximum thickness of 35 m, but the lower contact is nowhere exposed. At two localities, 7 and 39, the base is composed of boulder-rich diamicton, interpreted here as till. Overlying this is a sequence of finely laminated silty clay with scattered stones. The surface of this sediment forms extensive plains sloping from c. 30 m a.s.l. at the coast to c. 125 m a.s.l. at its inland margin. The sediments apparently drape a sloping bedrock surface

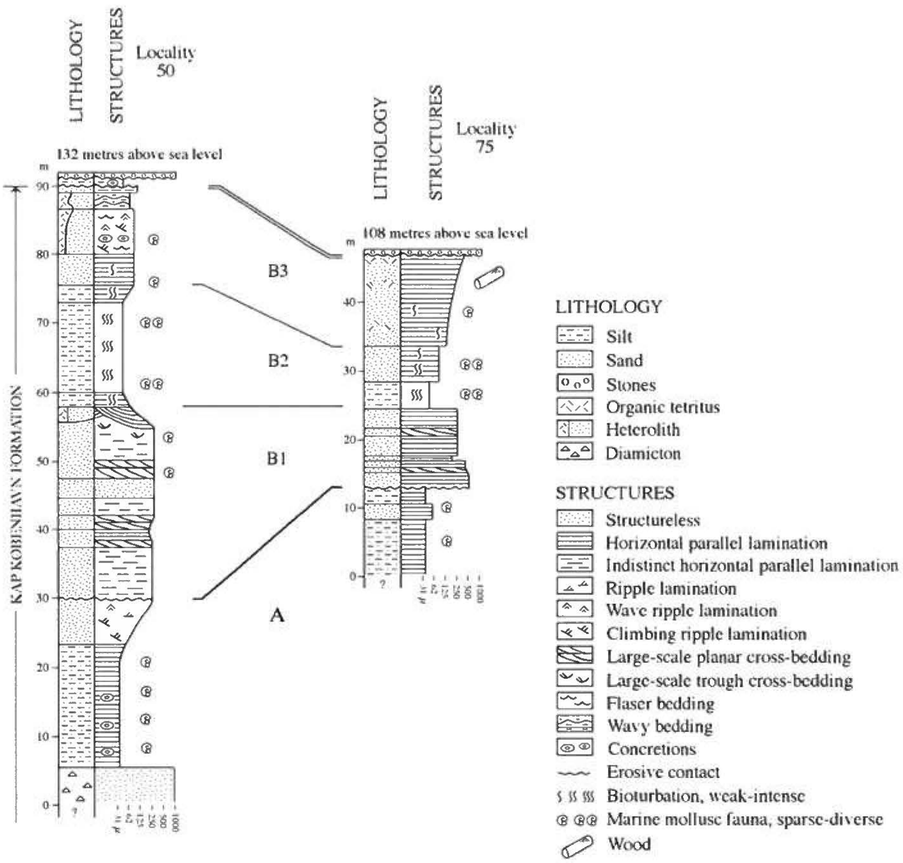

Fig. 3. Lithology and sedimentary structures of the Kap København Formation.

Table 2. Molluscs of the Kap København Formation

Species	Member A		Member B									
			unit B1		unit B2		unit B3		Locality 57.2		Locality 128	
	F	P	F	P	F	P	F	P	F	P	F	P
Margarites sp.					1.0	0.23						
Pseudosetia turgida (Jeffreys, 1870)					2.0	0.46						
Boreocingula globula (Møller, 1842)			29.0	7.86	51.0	11.66						
Alvania sp.					1.0	0.23						
Rissoa parva (da Costa, 1778)					1.0	0.23						
Trichotropis bicarinata (Sowerby, 1825)											+	
Lunatia pallida (Broderip & Sowerby, 1829)			2.0	0.54	1.0	0.23					2.0	1.61
Lunatia sp.					3.0	0.69						
Natica affinis (Gmelin, 1790)			2.0	0.54							+	
Natica sp.			1.0	0.27	6.0	1.37						
Trophonopsis truncatus (Strom, 1767)											+	
Colus sp.											+	
Buccinum cf. *undatum* Linné, 1758					3.0	0.69					2.0	1.61
Buccinum spp.					2.0	0.46						
Admete couthouyi (Jay, 1839)					1.0	0.23						
Oenopota decussata (Couthouy, 1839)			13.0	3.52	51.0	11.66					2.0	1.61
Propebela reticulata (Brown, 1827)			3.0	0.81	6.0	1.37						
Propebela nobilis (Møller, 1842)			1.0	0.27								
Oenopota & *Propebela* spp.			3.0	0.81	18.0	4.11						
Retusa obtusa (Montagu, 1803)			1.0	0.27	3.0	0.69						
Cylichna alba (Brown, 1827)					4.0	0.91						
Cylichna occulta (Mighels & Adams, 1841)			8.0	2.17	23.0	5.26						
Cylichna sp.			1.0	0.27	3.0	0.69						
Nucula nucleus (Linné, 1758)			1.5	0.41	2.0	0.46						
Nucula tenuis (Montagu, 1808)			0.5	0.14	0.5	0.11						
Nuculana pernula (Müller, 1779)											+	
Portlandia arctica (Gray, 1824)	1.0	40.00	25.5	6.91	1.0	0.23			27.0	21.60		
Yoldiella fraterna Verrill & Bush, 1898			2.0	0.54	4.5	1.03						
Yoldiella intermedia (M. Sars, 1865)					2.0	0.46					+	
Bathyarca glacialis (Gray, 1824)			1.0	0.27	0.5	0.11						
Mytilus edulis Linné, 1758					1.0	0.23						
Musculus niger (Gray, 1824)	0.5	20.00			1.0	0.23			1.0	0.80		
Arctinula greenlandica (Sowerby, 1842)											+	
Tridonta borealis Schumacher, 1817			45.5	12.33	42.5	9.71	1.0	18.18	27.0	21.60	1.0	0.80
Tridonta elliptica (Brown, 1827)			0.5	0.14	10.5	2.40			1.5	1.20		
Tridonta soror (Dall, 1903)					0.5	0.11						
Tridonta montagui (Dillwyn, 1817)	1.0	40.00	2.0	0.54							+	
Axinopsida orbiculata (G.O. Sars, 1878)					3.0	0.69			0.5	0.40		
Thyasira gouldi (Philippi, 1845)					1.0	0.23						
Montacuta dawsoni Jeffreys, 1863					0.5	0.11						
Serripes groenlandicus (Mohr, 1786)			1.5	0.41	4.0	0.91			6.5	5.20	11.0	8.84
Clinocardium ciliatum (Fabricius, 1780)			1.0	0.27	2.5	0.57					1.0	0.80
Macoma calcarea (Gmelin, 1790)			11.5	3.12	30.5	6.97					40.5	32.53
Macoma balthica (Linné, 1758)			2.0	0.54	117.5	26.86					46.5	37.35
Macoma moesta (Deshayes, 1855)					0.5	0.11						
Cyrtodaria kurriana Dunker, 1862			87.5	23.71	30.0	6.86	4.5	81.82	1.0	0.80	10.5	8.43
Hiatella arctica (Linné, 1767)			122.5	33.20	0.5	0.11			60.5	48.40	0.5	0.40
Mya truncata Linné, 1758					0.5	0.11					7.5	6.02
Pandora glacialis Leach, 1819			0.5	0.14	0.5	0.11						
Cochlodesma sp.					0.5	0.11						
	2.5	100.00	369.0	100.00	437.5	100.00	5.5	100.00	125.0	100.00	124.5	100.00

F: Frequency - number of individuals, P: Percentage, + from Bennike (1989) which, however, is nowhere seen. The top of Member A is usually truncated, and the fine sediments are overlain by the sandy Member B with an erosional hiatus. However, as noted by Bennike (1990), at the type section of locality 50, the fine grained sediments coarsen gradually upwards into sand, possibly unit 4 in Bennike's logs, and is bounded upwards by an unconformity.

Scattered mollusc shells in the clay-silt sediment show that it is marine and Member A is interpreted as glacigenic and glaciomarine from the end of a major glaciation of the area. The marine sediments were probably sedimentated during the isostatically conditioned regression that followed the glaciation. Two distinct fauna assemblages are associated with Member A: sparse faunas collected in the sediments at four localities (summarised in Table 2), while allochthonous, worn shell fragments occur on the eroded surface of Member A sediments in all parts of the area and have been sampled at 15 localities (summarised in Table 3). For reasons stated below this latter assemblage is considered to be older than the Member A glaciation.

Member B. - Is composed mainly of sandy sediments with a maximum thickness of c. 90 m, and divided into three lithological units, representing three stages in a transgression.

The lowermost unit, B1, is dominated by parallel-laminated sandy sediments, up to 35 m thick. The upper contact to unit B2 is gradational. Mollusc shells are sparsely present and at least the upper part of the unit is marine. Bennike (1990) interpreted the unit as representing back- and foreshore and shoreface environments. Mollusc faunas have been collected

Table 3. Molluscs from the Kap Rigsdagen deposits and the allochthonous fauna assemblage

Species	Kap Rigsdagen		The allochthonous fauna assemblage	
	F	P	F	P
Natica sp.	1.0	4.08		
Portlandia arctica (Gray, 1824)	1.0	4.08		
Bathyarca glacialis (Gray, 1824)	0.5	2.04		
Arctinula greenlandica (Sowerby, 1842)	0.5	2.04		
Tridonta borealis Schumacher, 1817	12.0	48.98	9.0	20.00
Tridonta montagui (Dillwyn, 1817)			1.0	2.22
Arctica islandica (Linné, 1767)			9.0	20.00
Serripes groenlandicus (Mohr, 1786)			1.0	2.22
Cyrtodaria kurriana Dunker, 1862	1.0	4.08	1.0	2.22
Hiatella arctica (Linné, 1767)	8.5	34.69	17.5	38.89
Mya truncata Linné, 1758			6.5	14.44
	24.5	99.99	45.0	99.99

F: Frequency - number of individuals, P: Percentage at four localities (summarised in Table 2), the richest at locality 74, but all the shells are crushed and fragmented, in agreement with the sedimentological evidence for a turbulent environment. The sediments were deposited during a transgression where sedimentation and sea level kept pace.

Unit B2 is composed of silty sand which may occur as a massive bioturbated bed or finely laminated with discrete silt beds. The thickness varies from c. 20 m to a few metres. Both the lower and upper contacts are gradational. This unit, and especially the gradational upper and lower parts, contain the richest marine faunas in the Kap København Formation and is interpreted to mark an increase in transgression rate or decrease in sediment supply. Faunas from this unit have been collected at eight localities (summarised in Table 2), the most diverse is locality 75.

Unit B3 consists of horizontally laminated medium sand with organic remains of terrestrial flora and fauna washed out from nearby land. The maximum visible thickness is 35 m. The lower boundary is gradational, whereas the upper one is an erosional unconformity. Bennike (1990) noted that some sites show a general coarsening upwards tendency and logs of small trees characterise this unit, and reflects beach environments. The shallow water sediments are rich in burrows (Bennike 1990), but poor in shells. Only one site (locality 50) has yielded shells and the fauna is extremely poor and composed of fragmented shells (summarised in Table 2). This contrasts with the rich and diverse plant and insect assemblages (Bennike 1990, Böcher 1995). The unit is interpreted to show decreasing rates of sea level rise and progradation.

Marginal areas. - The sediments in the eastern and western parts of the area (localities 86, 96 and 128) are sandy and the fine grained sediments of Member A and Member B, unit B2, have not been recognised. In the eastern part, at locality 128, correlation with Member B is provided by the rich fauna (summarised in Table 2). The ostracode fauna and the amino acid analyses on mollusc shells indicate a high age within the Kap København Formation (Table 4).

The western part of the area (localities 86 and 96) has been studied only during a short reconnaissance in 1983 and future field work should attempt to correlate these sediments with the central areas. The thick sandy sediments lack *in situ* fauna, but contain the allochtounous fauna assemblage which is associated with Member A in other parts of the area (Table 3; see also below). On this basis we provisionally consider these sediments as a fluvial age-correlative of the glaciomarine Member A.

Kap Rigsdagen.- On the other side of the Independence Fjord at Kap Rigsdagen (locality 200; Fig. 1), a sedimentary sequence is correlated with the Kap København Formation because the mollusc fauna has some similarities with the Kap København fauna, e.g. abundant *Tridonta borealis* and sparse *Cyrtodaria kurriana* (Table 3). Also the amino acid data (Table 4) indicate that the age could be similar (Funder *et al.* 1984).

The allochthonous fauna assemblage. - As a residual lag together with stones and scattered boulders, fragments of mollusc shells occur on the terrain surface where this is composed of Member A sediments in patches throughout the area. Shell fragments of the same type are found also in the sandy sediments in the western part of the area, and provide the only link between the two areas. At all sites the fragment fauna is distinguished by the presence of *Arctica islandica* and high frequency of *Mya truncata* (Table 3), which are absent or rare in the Kap København Formation, suggesting that they come from a common source. This is also indicated by the similarity of amino acid ratios in the shells, which further imply that the fauna is slightly older than the Kap København

Table 4. Amino acid results from the Kap København Formation and Kap Rigsdagen

Locality and unit 1)		Lab # AAL-	Species 2)	Total fraction			Free fraction		
				mean	±	n	mean	±	n
72	B2?	3147	*Poar*	0.097	0.002	2			
72	B2?	4029	*Trbo*	0.065	0.001	3	0.679	0.007	3
75	B2	4020	*Hiar*	0.130		1			
75	B2	4021	*Trbo*	0.083	0.002	3	0.739	0.100	3
50	B2	4030	*Trbo*	0.069	0.016	3	0.643	0.017	3
59	B1	4032	*Hiar*	0.138	0.043	3	0.698	0.038	3
59	B1	4033	*Trbo*	0.115	0.020	3	0.657	0.120	3
128	B	5072 3)	*Hiar*	0.155	0.023	3	0.833	0.012	3
128	B	3146	*Hiar*	0.140	0.015	3	0.727	0.026	3
57	B	4031	*Trbo*	0.091	0.021	3	0.732	0.052	3
33	AF	3993	*Hiar*	0.250		1	1.040		1
64	AF	4017	*Aris*	0.208		1	0.845		1
43	AF	4019	*Hiar*	0.197	0.019	3	0.953	0.064	3
33	AF	3991	*Mytr*	0.179	0.005	2	0.981	0.040	2
15	AF	3990	*Hiar*	0.176	0.009	2	0.935	0.015	2
64	AF	4018	*Hiar*	0.173	0.016	3	0.796	0.094	3
57	AF	4028	*Hiar*	0.165		1	0.959		1
33	AF	3992	*Aris*	0.163	0.009	2	0.917	0.049	2
107	AF	3997	*Mytr*	0.159		1	0.917		1
108	AF	3998	*Mytr*	0.158	0.009	3	0.860	0.012	3
107	AF	3996	*Hiar*	0.143	0.005	2	0.790	0.049	2
96	AF	3995	*Trbo*	0.103		1	0.855		1
86	AF	3994	*Trbo*	0.095	0.016	3	0.833	0.052	3
33	AF	3991	*Trbo*	0.074		1	0.768		1
200	KR	3149	*Hiar*	0.118		1	0.790		1

1) AF: Allochthonous fauna assemblage. KR: Kap Rigsdagen

2) *Aris: Arctica islandica, Hiar: Hiatella arctica, Mytr: Mya truncata, Poar: Portlandia arctica,* and *Trbo: Tridonta borealis*

3) From Bennike (1989)

Formation (Table 4 and discussion below). The roundedness and heavy wear of the fragments as well as the bias towards heavy umbonal parts show that before they were embedded in the fine grained suspension sediment of Member A they had undergone crushing and selective transport by waves, rivers or glacier ice. Their occurrence in association with Member A and absence in sediments of Member B, suggests that their source was no longer available after the cessation of Member A sedimentation. Based on these premises, we propose that they are glacially reworked from marine sediments that predate the glaciation of Member A.

The presence of *Arctica islandica* in the assemblage indicates distinctly higher sea temperatures than implied by the mollusc fauna of Member A. Probably the other thermophilic species which have been encountered in these sediments, such as the foraminifer *Cibicides grossa*, also belong to the allochthonous fauna assemblage. This has consequences for both the age and the climatic assessments of the Kap København Formation, because this species played a part in the correlation scheme presented by Feyling-Hanssen (1990). He suggested that Member A marked peak warmth in the sequence contrary to our estimates which mark it as the coldest.

Age

Our age estimate for the Kap København Formation and its correlation with the marine isotope stratigraphy is shown on Fig. 4.

In comparison with Upper Pliocene and Pleistocene faunas in other parts of Greenland, Iceland, Northwest Europe, Alaska, and Siberia, the Pleistocene character of the mollusc faunal assemblages in the Kap København Formation and correlatives is strongly indicated. This is manifested by the high frequency of recent, arctic and subarctic bivalve species such as *Portlandia arctica, Macoma balthica*, and *Cyrtodaria kurriana*, and also the fact that all the *Tridonta* species found in the Kap København Formation are living today (Hopkins *et al.* 1972). Lower Pliocene mollusc faunas of the North Atlantic as well as the North Pacific include 22-30% extinct species (Norton 1975, Gladenkov 1979), whereas all the species found in the Kap København Formation are extant. Therefore, based on the mollusc fauna, the Kap København Formation postdates the Lower Pliocene, which is further stressed by the presence of species such as *Portlandia arctica* and *Cyrtodaria kurriana* reflecting cold Pleistocene environments.

Feyling-Hanssen was the first to state that the Kap København Formation was deposited at „the Pliocene-Pleistocene transition“, which according to his interpretation lay in Member B, unit B2 (Table 1 and Funder *et al.* 1985, Feyling-Hanssen 1990). Later estimates have in part confirmed this, but attempted to add absolute ages. Thus, by biostratigraphical correlation with North American occurrences Repenning *et al.* (1987) suggested a duration between 2.0 and 1.8 Ma, Repenning & Brouwers (1992) an age between 2.2 and 1.9 Ma, and Brigham-Grette & Carter (1992) an age within the interval from 2.48-2.14 Ma. Penney (1993) discussed several alternatives ranging from either 2.6-2.5 Ma or 2.5-2.1 Ma. Recently Cronin *et al.* (1993) suggested an age in the interval from 3.5 to 2.0 Ma.

These estimates were based mainly on first and last appearance datums (FAD and LAD) for species found in the sediments. Thus, the ostracodes *Rabilimis paramirabilis* and *Pterygocythereis vannieuwenhuisei* and the rodent genus *Hypolagus* which occur in Member B had their last appearance around the Gauss/Matuyama boundary at 2.6 Ma (Repenning *et al.* 1987, Brouwers *et al.* 1991), while the ostracodes *Rabilimis mirabilis* and *Rabilimis septentrionalis,* and the rodent genus *Lepus* which also occur in Member B, have their first appearance shortly after the Gauss/Matuyama boundary (Repenning *et al.* 1987, Brigham-Grette & Carter 1992, Penney 1993). To the latter group we can add the bivalve mollusc *Macoma balthica.*

The precision of the LAD and FAD estimates for these species and genera may be questioned, since their history is not always well known. However, it should be noted that both the LAD and FAD group contain species which today belong in subarctic environments, and it is unlikely that they should have lived longer or appeared earlier in the arctic-high arctic Kap København area than in more southerly localities. Also, the agreement between evidence from very different types of animals give credibility to the age estimate. Therefore this evidence points to an age shortly after the Gauss/Matuyama boundary. The foraminifer *Cibicides grossa* has earlier been cited by Feyling-Hanssen (1990) as an argument for a pre-Gauss/Matuyama age and warm climate in Member A where it occurs sparsely. However, it is now considered to be reworked and part of „the allochthonous fauna assemblage“.

The palaeontological evidence is supported also by the palaeomagnetic analyses by Abrahamsen & Marcussen (1986) who showed that the upper Member B is reversely magnetised. Finally, the age estimate is not in conflict with the amino acid composition of the bivalve shells (see below).

Given these restraints Funder (1995) and Funder *et al.* (1996) proposed that it was not unreasonable to correlate the glaciation which caused the formation of the lowermost diamicton of Member A (Fig. 3) of the Kap København Formation with the Praetiglian of northern Europe (isotope stages 100-96; Fig. 4). Since there is no further evidence for significant cooling in the sequence, the sediments can hardly be younger than the next phase of major cooling at c. 2.15 Ma (isotope stage 82). From this it follows that Member A of the Kap København Formation represents the last phases of the Praetiglian glaciation, and Member B one or possibly several of the warm periods in the early Tiglian, since it cannot be excluded that marine incision has taken place. The sequence at the type section (locality 50), which is the longest continuous section in the area, may be interpreted as reflecting the isostatic/eustatic response to the Praetiglian glaciation, and therefore Member B correlates well with the first warm stages following this glaciation (isotope stages 95-91; Fig. 4). The age of the boundary between Member A and Member B is therefore considered close to 2.45 Ma (e.g. Chen *et al.* 1995; Fig. 4).

The allochthonous fauna assemblage, which is reworked into the glacial deposits of Member A is, based on its fauna and amino acid diagenesis (see below), correlated with the warm phase that preceded the Praetiglian, the Reuverian Stage of the uppermost Pliocene.

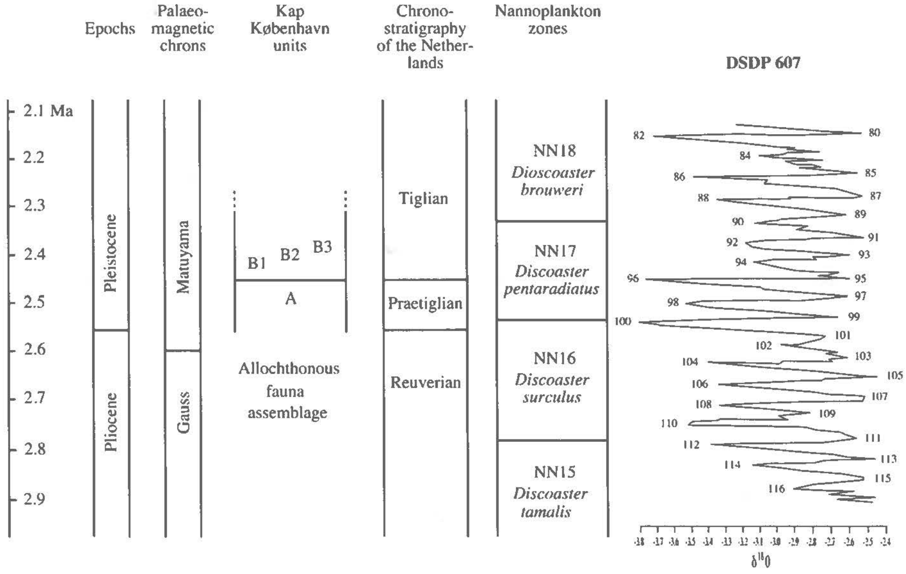

Fig. 4. Correlation of the Kap København Formation with the palaeomagnetic chrons, the chronostratigraphy of the Netherlands, nannoplankton zones, and the oxygen isotope curve with isotope chrons (data from Raymo *et al.* 1989, 1992, Wei 1993, Tiedemann *et al.* 1994, Funnell 1995, 1996).

Amino acid correlation

The ratio of the amino acid pair alloisoleucine:isoleucine (aile:ile) has been measured in mollusc shells from the whole area, in the hope that they would provide a means for correlation between sites, and an indication of age. An important issue was also to indicate or disprove contemporaneity of the widely scattered reworked faunas („the allochthonous fauna assemblage"). The results are shown in Table 4. In addition to these results a number of analyses were made during the experimental stage of this method before 1982, and these results, which are considered unreliable, are not included in the table, but briefly mentioned in the site-descriptions below.

The ratios were measured both in the bulk hydrolysate (total) and in the free and peptide bound fractions (free). The methodology and many potential errors have been described by Kaufman & Brigham-Grette (1993). The rate of amino acid diagenesis in mollusc shells is species-dependent, and best known in *Mya truncata* and *Hiatella arctica*. Unfortunately these species are rare in the Kap København Formation. The data has therefore been supplemented with measurements on *Tridonta borealis*, *Arctica islandica*, and *Portlandia arctica*, which however are not directly comparable with each other. Thus, in Member B the total aile:ile ratios in 12 shells of *Mya* and *Hiatella* gave an average of 0.135±0.032, while 12 shells of *Tridonta borealis* only gave 0.083±0.024. Even considering the large spread in both populations this is an indication of considerable inter-specific differences in the rate of diagenesis.

The large and unsystematic spread in the results makes the age resolution too low to distinguish units within Member B, or to indicate its duration. But they do in a general way support the age estimate of c. 2.3 Ma for this member (see below). Thus, based on this age, the calculated EDT (effective diagenetic temperature over the time span since the animal's death) for *Mya/Hiatella* would be -14°C, which is not unreasonable when compared with the present mean annual temperature of -16°C.

For the allochthonous fauna assemblage the ratios are higher and have a larger spread. These shells have had a different temperature history, since they have been reworked at least once, and they occur as a residual on the terrain surface where they must have spent a long but varying time, and therefore should not be compared directly with those of Member B. However, we consider the ratios to be sufficiently well delimited to indicate that the shell fragments originate in a marine episode, somewhat older than Member B. The variable temperature regime, with occasionally high temperatures, experienced by the allochthonous shell fragments, has inevitably sped up the amino acid diagenesis, and produced higher ratios than in constantly buried shells. Therefore, in the allochthonous fauna assemblage the lowest ratios may be the most significant. The lowest sample average for allochthonous *Mya/Hiatella* fragments is 0.143±0.005, and the lowest single valve measurement is 0.138 (sample AAL-3996; Table 4).

At Kap Rigsdagen, locality 200, a single *Hiatella arctica* in the position of growth gave a total ratio of 0.118, which together with fauna and flora evidence, is taken as an indication that this deposit correlates with the Kap København Formation across the fjord. An early analysis from this fauna gave values for both *Hiatella* and *Portlandia arctica* of 0.13-0.24 in the total and c. 0.8 in the free fractions. However, these results were made during the laboratory's experimental stage and are not considered reliable.

Description of localities

This section is a list of localities where molluscs have been collected. The numbering is the same as used in other publications on the Kap København Formation, and shown on Fig. 2.

The samples have been collected by several field workers during four field seasons (1979, 1980, 1983, 1986), but the main part comes from the expedition in 1983. The collections fall into four different categories; 1) shells procured from bulk (3-10 kg) sediment samples by sieving in the laboratory, 2) shells picked from their sediment in the field, 3) shells collected on the surface of their sedimentary unit, and 4) fragments picked from the terrain surface (the allochthonous fauna assemblage). Because of the heterogeneity of the material we have chosen to lump all collections from one site according to their stratigraphical position. Thus, sample 50.1 contains shells which have been collected from the lowermost unit on locality 50, sample 50.2 is from the next unit above on the same locality (see chapter on palaeontology).

Besides the Kap København area, also shells collected on the other side of Independence Fjord, at Kap Rigsdagen, are included (locality 200), because they are considered to correlate with the Kap København Formation.

The worn fragments found on the terrain surface scattered over the whole area are treated as a category of their own, „the allochthonous fauna assemblage“, because they include taxa, notably *Arctica islandica* and a brachiopod, which are not known from *in situ* collections (see discussion p. 13). The list also contains brief summaries of previous results from each locality.

Locality 3. - A 40 m high section, 450 m to the north of the type section for the Kap København Formation (locality 50), and showing the same stratigraphy. The locality was visited and sampled in 1979 and again in 1983. The five samples all come from unit B2, about 105 m a.s.l. Pre-1982 amino acid analyses of *Portlandia* shells from this locality gave total ratios of 1.5.

Locality 10. - Two areas on the surface of silt-clay plain c. 1 and 2 km west of the type section. The silt is Member A. Two samples of worn shell fragments have been collected from the surface. The collections contain *Arctica islandica* and brachiopod fragments, both taxa have been analysed for amino acids and ^{14}C dated. The pre-1982 amino acid ratios were 0.190 and 0.46.

Locality 15. - A 60 m high section on the south slope of „Søndre Ladegårdså“, 9 km west of Kap København. Worn shell fragments were collected from the surface of the clay-silt plain (Member A), at the foot of the section, 102 m a.s.l. Amino acid analysis has been made on *Hiatella arctica* (Table 4). A sample from the section above yielded extremely well preserved leaves of *Dryas octopetala* and *Vaccinium uliginosum* (Bennike 1990).

Locality 22. - A 15 m high section at the junction between two small streams on the south slope of „Søndre Ladegårdså“, 10.6 km west of Kap København (Fig. 5). The section is composed of laminated sand with 10-90 cm beds of massive, bioturbated silt with scattered individuals of *Cyrtodaria kurriana*. From its lithology the sediment is correlated with unit B2 (Fig. 5). The shell sample comes from a 1 m thick silt bed 7 m above the base of the section, 163 m a.s.l.

Locality 26. - A 2 m high section showing massive, bioturbated fine sand with lenses and laminae of coarse sand, overlying poorly exposed coarse laminated sand, with scattered *Cyrtodaria kurriana*. A sample was collected under the hill top, 90 m a.s.l., 6 km northwest of Kap København. The fine grained sediment is correlated with unit B2.

Locality 27. - A 20 m high and 300 m long northward facing section along a stream 5.5 km northwest of Kap København. The section comprises Member A and Member B, units B1 and B2, and a detailed log of the sediments has been published by Bennike (1990, Figs. 5, 6). A series of five samples have been collected from unit B2. *Macoma balthica* is not present here, although so stated by Bennike (1990, Fig. 32). This unit has yielded a sparse flora of macrofossils, and pollen spectra rich in *Betula* and with some conifers (Bennike 1990). The insect fauna from unit B2 also has low diversity (Böcher 1995). In this unit, the sparse ostracod fauna contains a single specimen of *Pterygocythereis vannieuwenhuisei*, considered to have become extinct at the Pliocene-Pleistocene boundary (Penney 1993).

Fig. 5. View of locality 22 showing Member B.

Locality 33. - Surface of clay-silt (Member A) in 37 m high section on the south slope of „Søndre Ladegårdså", 8 km northwest of Kap København. Worn shell fragments were collected between 51 and 71 m a.s.l. The fauna contains *Arctica islandica*. Amino acid analysis has been made on *Tridonta borealis, Arctica islandica, Hiatella arctica*, and *Mya truncata* (Table 4).

Locality 39. - Stream bed 7 km northwest of Kap København. Among the carbonate concretions found at 42 m a.s.l. along the stream one contained the hinge of an *Arctica islandica*. Small sections in Member A are exposed along the stream.

Locality 41. - Small section under hill top 4.7 km northwest of Kap København. The poorly exposed section shows massive sand at 103 m a.s.l. One fragmentary specimen and several fragments of *Buccinum* spp. were found in the sediment.

Locality 43. - Surface of silt-clay plain (Member A) 5.5 km westnorthwest of Kap København on the slopes of „Søndre Ladegårdså". Worn shell fragments collected 143 m a.s.l. The sample contains *Arctica islandica*. Three *Hiatella arctica* fragments have been amino acid analysed (Table 4).

Locality 48. - A 15 m high and 300 m long section along a small stream, exposing Member B, unit B1, and massive bioturbated silt of unit B2, glaciotectonically folded and faulted. The site was first visited and sampled in 1979 and in 1983 one bulk sediment sample and three samples of shells picked from the sediment were collected, all from unit B2 or the boundary between units B1 and B2 (sample 56820). The fauna from this locality has yielded only gastropods.

Locality 50. - This is the type section of the Kap København Formation, c. 4 km west-northwest of Kap København, and the most intensely investigated site in the area (Fig. 6). The sediments are exposed in a system of snow corries eroded into north-south runnning hill, and in the small snow-melt canyons draining the corries.

Detailed sedimentary logging was carried out by Bennike (1990, Figs 5, 8, 9), but the sequence is here shown in a simplified version (Fig. 3). It comprises a 65 m thick sequence of slightly tilted sand and silt,

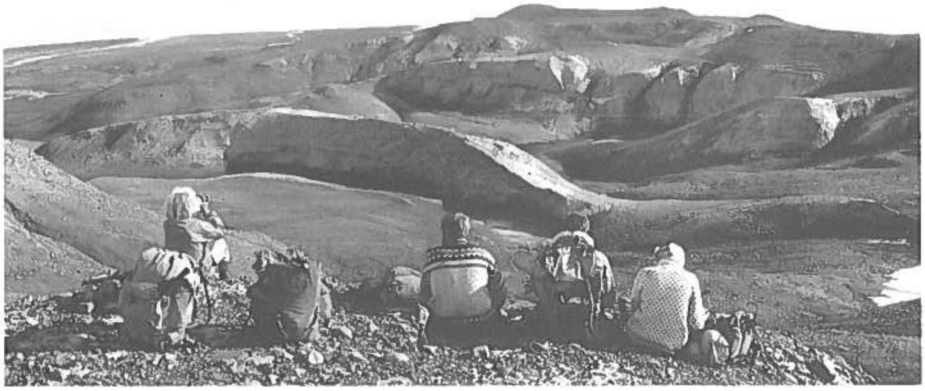

Fig. 6. View of locality 50 showing the top of Member A and units B1, B2 and B3 of Member B.

rich in organic detritus, representing Member B of the Kap København Formation. Although sampled intensely, the fauna list remains somewhat monotonous, dominated in all units by *Cyrtodaria kurriana* and *Tridonta borealis*. Farther down the snow-melt streams, and in direct contact with Member B, the clay-silt sediments of Member A are exposed from 65 to c. 40 m a.s.l. No molluscs have, however, been found in these deposits which contain rather rich foraminifer faunas.

The 21 collections of shells range from bulk sediment to single shells picked from the sediments, and from different places within the area. They are here grouped according to their stratigraphical setting and comprise Member B, unit B1 (locality 50.2), lower and upper unit B2 (localities 50.1, 50.3) and unit B3 (locality 50.4).

The foraminifer faunas have, at least in some intervals, proved to be much richer and more diverse than the mollusc faunas, and with 40 analysed samples contain the longest record known from the area (Feyling-Hanssen 1990), extending over three assemblage zones; the *Elphidium funderi* Zone (Member A) and the *Elphidiella rolfi* Zone (lower Member B, unit B2). Both these assemblages were referred to the Upper Pliocene, and are followed by the *Elphidium* cf. *excavatum* Zone (in upper Member B, unit B2) considered to house within it the Pliocene-Pleistocene boundary (Feyling-Hanssen 1990). Diamicton at the base of Member A, interpreted as till, contains two specimens of *Cibicides grossa*, considered to have become extinct at the Pliocene-Pleistocene boundary (Table 1).

This is in agreement with ostracode identifications from 18 samples from unit B2 by Brouwers *et al.* (1991) and Penney (1993). The assemblages are less diverse than other sites, but contain the species *Rabilimis paramirabilis* and *Pterygocythereis vannieuwenhuisei*, which are considered by Brouwers *et al.* (1991) to have become extinct at c. 2.5 Ma. These species are now interpreted as reworked from older marine sediments.

A large number of samples from Member B have been analysed for macroscopic plant remains and pollen, and reflect an arctic tundra rich in grasses and sedges and dwarf shrubs as *Betula nana, Vaccinium uliginosum, Empetrum nigrum*, and *Dryas*. Contrary to other sites to the north, there are a few tree remains and little tree pollen in these sediments (Bennike 1990), also the insect fauna from Member B is both poorer in total numbers and has a lower diversity than sites to the north. This is especially the case for unit B3, which has very low diversity and lacks the forest-dwelling insects, which play a prominent role in the faunas from other unit B3 sites (Böcher 1995).

Analyses of the diatom flora reflect oligotrophic fresh water in unit B1, possibly with a change to deeper water in unit B2 (U. Miller, personal communication 1984).

Shells of *Tridonta borealis* from unit B2 have been amino acid analysed (Table 4).

Locality 51. - Clay-silt plain (Member A) 4 km northwest of Mudderbugt. Shell concretions were collected from the surface 65 m a.s.l.

Locality 53. - A 20 m high and 100 m long section in clay-silt (Member A), 5.3 km northwest of Mudderbugt. Shells were collected from the surface c. 48 m a.s.l.

Locality 57. - A slightly tilted sequence of stratified sand (Member B, unit B3) is poorly exposed in the side of a distinct north-south running hill c. 6 km north of Mudderbugt (Fig. 7). The hill extends from 145 to 60 m a.s.l. and rests on a clay-silt pediment (Member A). Shells occur scattered on the hill side between 70 and 80 m a.s.l., and are characteristically coated by cemented sand grains. The fauna is rather rich. On the surface of the underlying clay-silt sediment a sample of worn shell fragments has been collected. Amino acid analysis has been performed on *Tridonta borealis* and *Hiatella arctica* fragments (Table 4). The sample from 57.2 is referred to unspecific Member B (see also Table 2), and this from 57.1 to the allochthonous fauna assemblage.

In the top twenty meters of the hill side pieces of wood occur scattered and this sediment is correlated with unit B3.

Locality 59. - A 20 m high and 400 m long section in a sequence of clay-silt (Member A) reaching 55 m a.s.l., overlain in places by patches of stratified sand with organic detritus (Member B, unit B1). The whole sequence is folded and dips towards west-southwest (Fig. 8). The fine grained sediments of Member A (locality 59.1) are very poor in molluscs, only one valve of *Musculus niger* was picked from the sediment. The overlying unit B1 (locality 59.2) has a richer fauna, and in some areas worn shell fragments are found on the eroded surface of Member A, including brachiopod fragments (locality 59.3).

The ostracode fauna on this and the nearby locality 58 contains a few speci-

Fig. 7. View of locality 57 showing Member B resting on Member A (foreground). Notice persons for scale.

Fig. 8. View of locality 59 showing the upper part of Member A.

mens of the modern *Rabilimis mirabilis* (Penney 1993).

Amino acid analyses have been made on *Tridonta borealis* and *Hiatella arctica* shells (Table 4).

Locality 64. - Clay-silt plain (Member A) between the hills 7.2 km northwest of Mudderbugt. Worn shell fragments were collected 148 m a.s.l.

Shells of *Arctica islandica* and *Hiatella arctica* from the allochthonous fauna assemblage have been amino acid analysed (Table 4).

Locality 68. - A 70 m high and 500 m long section south of Ladegårdså. The sediments range from Member A at the river bed to Member B, unit B3 at 150 m a.s.l. (corresponding to localities 120 and 119 in Bennike 1990). A thin bed of mud in the middle of Member B serves as correlation with unit B2 in the type section (locality 50). Unit B3 in this section has yielded spectacular remains of terrestrial flora (cones, needles, and twigs of *Thuja*, *Larix*, and *Picea*) and mammalian (arctic hares) faunas (Bennike 1990), as well as beetle remains (Böcher 1995). No attempt has been made to interpret the very low diversity ostracode assemblages from unit B3 (Penney 1993; see also Table 1), but ecological analyses of the ostracodes from this unit indicate a nearshore estuarine environment with reduced salinities (Brouwers *et al.* 1991), in agreement with the geological interpretation (p. 13 and Bennike 1990). In Member A the ostracodes at the nearby locality 120 suggest frigid to subfrigid inner shelf environments and normal salinity (Penney 1993).

Mollusc shells occur abundantly in unit B2, and the four samples are bulk samples, shells picked from the sediment and surface collections. The fauna is especially noteworthy for its abundance of *Macoma balthica*.

Amino acid analyses of *Portlandia arctica* from Member A gave an indication of high age, whereas the ostracode fauna at the nearby locality 120 contains the modern *Rabilimis mirabilis* (Penney 1993).

Locality 69. - A 50 m high and 300 m long section on the south slope of Ladegårdså, 1 km southwest of locality 68, showing the same sequence of sediments. The three shell collections are from Member B, unit B1.

The macroscopic plant remains from this site are not quite as rich as those from locality 68, and have yielded mainly fruits of arctic dwarf shrubs, although conifer pollen is rather abundant (Bennike 1990). The insect remains in unit B3 show changing subarctic and northern boreal temperatures (Böcher 1995).

Locality 70. - A 20 m high and 400 m long section showing clay-silt (Member A) overlain by stratified sand with organic detritus (Member B, unit B1). The base is 75 m a.s.l., 7 km north of Mudderbugt. Worn and some fresh shell fragments have been collected on the surface of Member A, including brachiopod fragments.

Locality 72. - Section in an isolated hill, 10 km northnortheast of Mudderbugt. The sandy sediments rest on a pediment of clay-silt at 60 m a.s.l. (Member A), and reach 115 m. Between 96 and 100 m there is a bed of massive, bioturbated silt which is correlated with Member B, unit B2 at the type section 15 km away (locality 50), although both the mollusc, foraminifer and ostracode faunas are richer here. The silt bed is overlain by laminated sand and silt, which again is overlain by 13 m of fluvial or glaciofluvial stratified pebbles, gravel and sand.

The locality was visited during helicopter reconnaissance in 1979 (Funder & Hjort 1980), and in 1983 there were two short visits to this remote site. Finally, it was visited again in 1986. The mollusc fauna includes *Macoma balthica*.

Amino acid analyses on shells of *Portlandia arctica* and *Tridonta borealis* indicate a slightly younger age than unit B2 at locality 50 (Table 4).

Foraminifer analyses of 11 samples from unit B2 has yielded a rich foraminifer fauna from shallow water environment. The fauna is referred to the *Elphidium excavatum* Zone of Lower Pleistocene age, with a transition to the *Elphidiella gorbunovi* Zone at the top (Feyling-Hanssen 1990).

The ostracode fauna is richer and more diverse than that of the type locality and contains a number of thermophilic species, which are not found at other localities in the Kap København area. Besides the extinct species found at the type locality, there are also some of the modern *Rabilimis septentrionalis*, which is supposed to have its first appearance at c. 2.5 Ma (Brouwers *et al.* 1991).

Pollen analysis in the upper part of unit B2 reflects a terrestrial environment that was slightly richer than unit B2 in the type section, with more conifers and bushes (Bennike 1990).

Some of the differences between locality 50 and locality 72, 15 km away, may owe to the fact that the sediments at locality 72 were deposited in shallower water closer to the coast, as indicated by Bennike (1990) and Brouwers *et al.* (1991). However, there is also the possibility that in spite of its lithology the silt bed at locality 72 should be correlated with the sand unit B3 in the type section. Such readjustment needs more field work.

Locality 73. - A 10 m high and 100 m long poorly exposed section along a small stream 8.5 km north of Mudderbugt, showing stratified sand with organic detritus, driftwood and mollusc shells, tentatively correlated with Member B, unit B2. One sample of shells was picked from the sediment 88 m a.s.l. The sample contains the small and rare bivalve *Montacuta dawsoni.*

Locality 74. - A 20 m high and 200 m long section at a small stream 8 km north of Mudderbugt. The sediments have been logged in detail by Bennike (1990). Especially noteworthy is the giant-scale cross bedding, 3 m high, which underlies the laminated silt and sand that is correlated with Member B, unit B2. The cross bedding is interpreted as a migrating sandwave. The section ranges from unit B1 to B2.

The two mollusc samples represent bulk and shells picked from the sediment immediately under the lower boundary of unit B2. The fauna is rich and contains the rare *Yoldiella fraterna*.

The plant macrofossils in this unit are

dominated by swamp plants (Bennike 1990). A single sample from unit B1, analysed for ostracodes contains the extinct *Rabilimis paramirabilis* as well as the rare *Heterocyprideis fascis* (Brouwers *et al.* 1991).

Locality 75. - About 40 m high section in Member A and Member B, units B1, B2 and B3 up to 108 m a.s.l. The sediments have been logged in detail by Bennike (1990). This sequence has a 4 m thick bed of massive, bioturbated silt correlated with unit B2, and the lithology has a great resemblance to that in the type section (locality 50; Fig. 3).

Five bulk samples and one of shells picked from the sediment have been collected. There is a rich mollusc fauna with the rare *Nucula nucleus* and *Mytilus edulis*.

Unit B2 is characterised by fruits of *Empetrum*, *Menyanthes*, and sedges, whereas unit B3 also contains needles of *Picea* and *Larix* (Bennike 1990). The ostracode faunas from unit B2 have great similarity to those from the type section (Brouwers *et al.* 1991, Penney 1993), as does the amino acid ratios measured in samples of *Tridonta borealis* and *Hiatella arctica* (Table 4). The nearby locality 77 has yielded very rich insect faunas from a lens of organic detritus in unit B3. Within the lens, several climatic faunal types are registered. Boreal insects indicate summer temperatures as high as 15°C (Böcher 1995).

Locality 86. - Worn shell fragments were collected from the surface of a small exposure of stratified sand in a small valley 3 km east of Vitskøl Elv. Like the other samples from the eastern part of the area this one contains *Arctica islandica*. A sample of *Tridonta borealis* has been amino acid analysed (Table 4).

Locality 96. - Worn shell fragments were picked from the surface of a 20 m high section in poorly exposed, stratified sand. A fragment of *Tridonta borealis* has been amino acid analysed (Table 4).

Locality 107. - A 60 m high, poorly exposed section in laminated sand and silt with large scour and fill structures, tectonically disturbed. On the south slope of „Søndre Ladegårdså" 16 km westnorthwest of Kap København. Worn fragments were picked from the sediment surface c. 110 m a.s.l. The fauna contains a fragment of *Arctica islandica*.

Amino acid analyses has been made on shells of *Hiatella arctica* and *Mya truncata* (Table 4).

Locality 108. - A 30 m high section in glaciotectonically disturbed, stratified silt and sand with organic detritus and driftwood (Member B, unit B2? and B3) c. 130 m a.s.l. On the south slope of „Søndre Ladegårdså", 14 km westnorthwest of Kap København. Worn shell fragments were collected from diamicton on top of the section c. 125 m a.s.l. The fauna contains fragments of *Arctica islandica*.

Amino acid analyses have been made on shells of *Mya truncata* (Table 4).

Locality 116. - The top of a coastal ridge 11 km southwest of Kap København. Worn shell fragments were collected from a till covered surface c. 90 m a.s.l. The fauna may have no relation to the Kap København Formation.

Locality 125. - Brachiopod fragments were collected from the terrain surface, 8 km north of Mudderbugt.

Locality 128. - An isolated, poorly exposed stream-cut section 21 km northnortheast of Kap København (Fig. 9). The site was first visited and sampled in 1979 (Funder & Hjort 1980). It was visited again in 1986 by Ole Bennike, who published a description of his findings in 1989 (Bennike 1989). The section is composed of shell-rich laminated sand and silt from 50 to 58 m a.s.l., overlain by stratified coarse sand and gravel, which forms a Late Pleistocene

Fig. 9. Locality 128, Member B is exposed in the river bank below the helicopter.

or Holocene delta terrace at c. 70 m a.s.l. Bennike (1990) correlated the shell-rich sediments with Member B, unit B2, using the occurrence of *Macoma balthica* as a stratigraphical marker. However, *Macoma balthica* is not restricted to unit B2 at other sites and the sediments cannot be correlated with any specific unit in Member B.

The mollusc fauna is both similar and dissimilar to the faunas of the other units in the Kap København Formation. The similarities are the high frequency of *Macoma balthica* and *Cyrtodaria kurriana*. The dissimilarities are mainly the high frequency of *Mya truncata*, rare in other units, and the occurrence as minor constituents of *Trichotropis bicarinata*, *Trophonopsis truncatus*, *Nuculana pernula*, and *Arctinula greenlandica*, which are absent or rare in other units, as noted by Bennike (1989).

Also the foraminifer fauna is different from other sites and referred to the *Elphidiella gorbunovi* assemblage of Lower Pleistocene age, considered to be the youngest foraminifer assemblage in the Kap København Formation (Feyling-Hanssen 1990). However, the age-significance of this species was questioned by Penney (1993), who found the two Pliocene ostracodes *Rabilimis paramirabilis* and *Pterygocythereis vannieuwenhuisei* in samples from this locality, suggesting a high age within the Kap København Formation. He also noted species indicative of shallow low-saline water. Amino acid analyses on *Hiatella arctica* also indicate a high age within the Kap København Formation (Table 4). The palaeontological evidence from this locality therefore shows significant differences from other sites within the Kap København Formation, and we tentatively correlate it with an unspecific stage of Member B.

Locality 200. - A 10 m high and 100 m long, partly snow-covered section along a small stream, 5 km west of Kap Rigsdagen (Fig. 10). The site was visited during brief reconnaissance in 1979 (Funder & Hjort 1980). The sequence is composed of stratified sand and gravel, rich in shells and organic detritus, overlying massive marine silt with scattered mollusc shells. The beds are dipping towards east, and covered discordantly by a thin till bed. Even though it is situated far away on the other side of the fjord (Fig. 1) and the lithology is different, the occurrence is included in this treat-

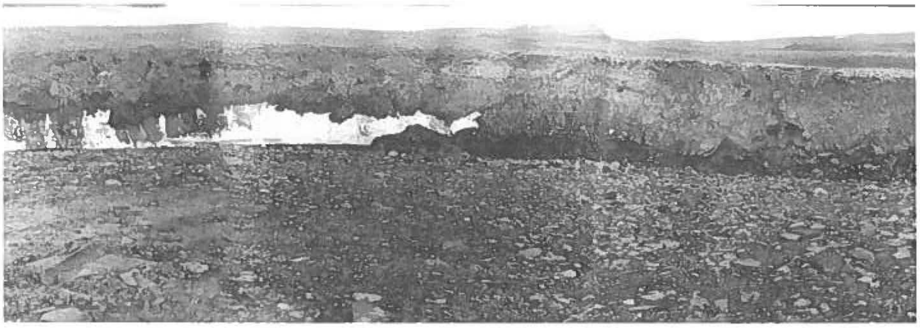

Fig. 10. View of locality 200 at Kap Rigsdagen. The section is 10 m high and 100 m long. The upper stratified sand over the snow dips towards the southeast, and overlies marine silt to the right in the picture.

ment of the Kap København Formation, because the mollusc fauna has some similarities with the Kap København fauna, e.g. abundant *Tridonta borealis* and sparse *Cyrtodaria kurriana*. Also the amino acid data from *Hiatella arctica* and an older measurement on *Portlandia arctica* indicate that the age could be similar (Table 4; Funder *et al.* 1984). Among the organic remains two seeds of *Menyanthes trifoliata*, a thermophilic plant which occurs abundantly in the Kap København Formation, have been identified by Bennike (1990).

Palaeontology

The nomenclature used in this paper partly follows that of the „Treatise on Invertebrate Paleontology" (Moore 1960, 1969) with the addition of Bogdanov (1990), Høisæter (1986), Símonarson (1981), Sneli & Stokland (1986), and Warén (1996a, 1996b) for the prosobranchs, and Lemche (1948) and Høisæter (1986) for the opisthobranchs. The total fauna is listed on Tables 2 and 3. The shell material is deposited in the Geological Museum, University of Copenhagen (MGUH), and all the originals in this paper have MGUH numbers (see fig. captions). The samples taken in the field are labelled with numbers from the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse or GGU) and the Geological Central Institute of the University of Copenhagen (GCI) (see also fig. captions).

In dealing with gastropods the term „diameter" always means the maximum outer diameter of the conispiral shell (cf. Cox *et al.* in Moore 1960). The following abbrevations are used: d=diameter, h=height, l=length, b=breadth, h/d=height/diameter ratio, h/l=height/length ratio and b/l=breadth/length ratio.

When dealing with bivalves the term „paired" always means that the valves were found articulated (united) in the sediment, whereas „single" means that they were disarticulated (not united) when collected. „Plate fragment" refers to shell fragment without umbo preserved.

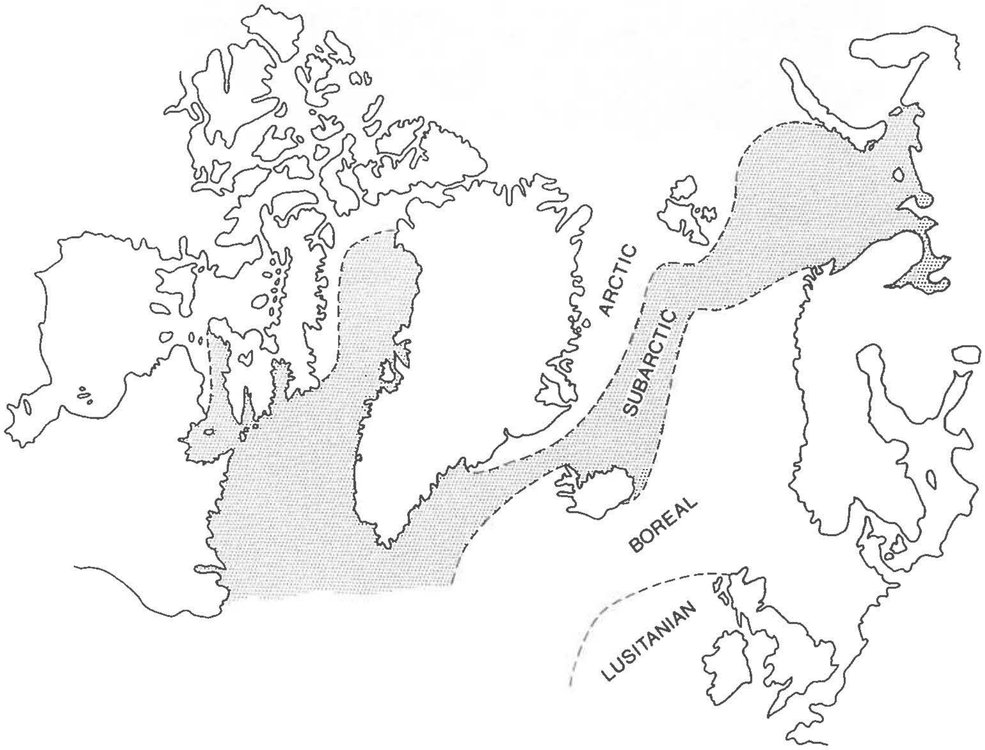

Fig. 11. Regional division of the northern European seas (based on data from Thorson 1944, 1951, Feyling-Hanssen 1955, Ockelmann 1958, Lubinsky 1980, and Peacock 1989).

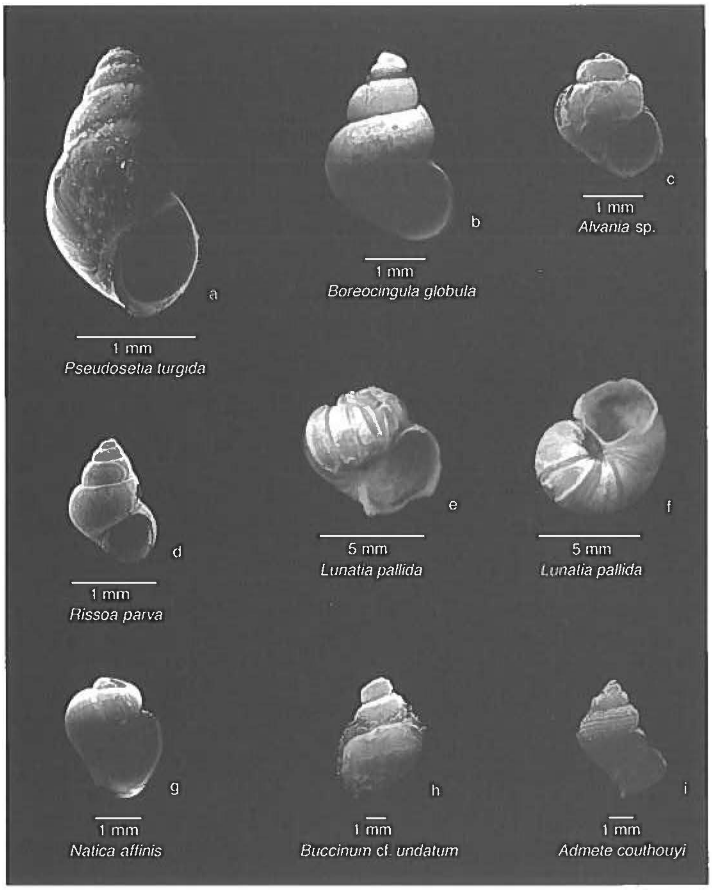

Fig. 12. *a: Pseudosetia turgida* (Jeffreys) from locality 48.1, MGUH 22289, GGU/GCI 56822. b: *Boreocingula globula* (Møller) from locality 72.1, MGUH 22290, GGU/GCI 56862. c: *Alvania* sp. from locality 72.1, MGUH 22291, GGU/GCI 56862. d: *Rissoa parva* (da Costa) from locality 48.1, MGUH 22292, GGU/GCI 56822. e-f: *Lunatia pallida* Broderip & Sowerby from locality 74.1, MGUH 22293, GGU/GCI 56875. g: *Natica affinis* (Gmelin) from locality 74.1, MGUH 22294, GGU/GCI 56875. h: *Buccinum* cf. *undatum* Linné from locality 41.1, MGUH 22295, GGU/GCI 56865. i: *Admete couthouyi* (Jay) from locality 75.1, MGUH 22296, GGU/GCI 56868.

The zoogeographical division of the North Atlantic is shown on Fig. 11. The Canadian Arctic and Northwest Atlantic is in accordance with Lubinsky (1980). The division of the Greenland coasts into areas is that of Thorson (1944, 1951) and Ockelmann (1958). The zoogeographical division of the eastern North Atlantic is modified from Feyling-Hanssen (1955) and Peacock (1989). The term „panarctic“ means that the species in case lives both in the arctic and subarctic fauna regions.

The stratigraphical terms are as far as possible adjusted to the North European Tertiary/Quaternary boundary at 2.55 Ma.

Mollusca

Gastropoda, Prosobranchia

Class Gastropoda Cuvier, 1797. Subclass Prosobranchia Milne Edwards, 1848. Order Archaeogastropoda Thiele, 1925. Family Trochidae d'Orbigny, 1837. Genus *Margarites* Gray, 1847.

Margarites sp.

Material: Member B, unit B2, 27.1: one fragmentary and worn specimen.

Remarks: Species identification is impossible, because of the imperfect state of preservation.

Order Mesogastropoda Thiele, 1925. Family Rissoidae Adams & Adams, 1854. Genus *Pseudosetia* Monterosato, 1884.

Pseudosetia turgida (Jeffreys, 1870)

Figs 12a, 13.

1870 *Rissoa turgida* Jeffreys, p. 445.

Material: Member B, unit B2, 48.1: two complete specimens.

Remarks: Height of shells (h) and diameter (d) were measured for the specimens and the h/d ratios caculated:

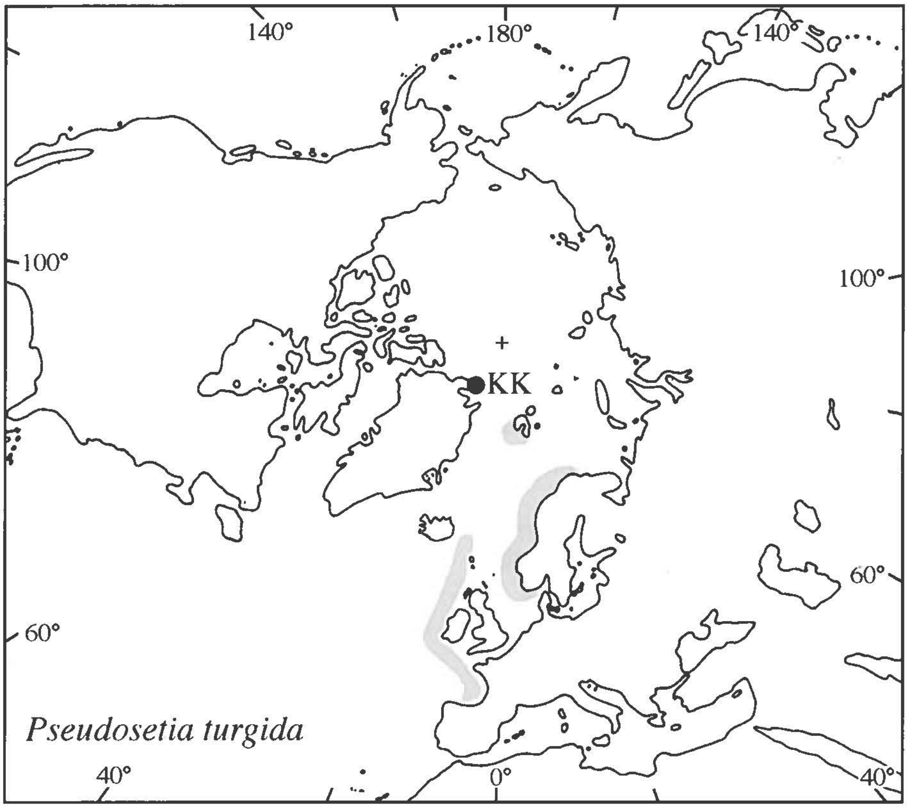

Fig. 13. Recent known geographical distribution of *Pseudosetia turgida* (Jeffreys). KK: Kap København.

h in mm	d in mm	h/d
2.3	1.2	1.92
1.4	0.9	1.56

The thin semitransparent and holostomat shells consist of 5.5 and 4.4 whorls, respectively. The whorls are flattened with distinct but shallow sutures. The smooth protoconch is flat. The teleoconch whorls are smooth, encircled by a faint line just below the sutures. The aperture is roundly oval with a thin outer lip. There is a very narrow umbilicus at the base.

Recent distribution: Subarctic, boreal, ?lusitanian, only in the eastern part of the Atlantic (Fig. 13). *Pseudosetia turgida* occurs from ?west of Svalbard and Finnmark (Norway) in the north to Kattegat in the south (G.O. Sars 1878, Warén 1973, 1996a, Fretter & Graham 1978). The species is not known living in Greenland, the Faeroe Islands or the British Isles. It has recently been recorded from southeast of Iceland and it seems distributed along the European continental slopes to northern Spain (Warén 1996a). Vertical range: From ?67 m in Norway (G.O. Sars 1878) to 2438 m in the North Atlantic at 77°58' N, 05°10' E (Warén 1973). The figures cited for the vertical range are uncertain as it does not appear from all the records whether the specimens in the individual cases were living or dead, and also because of some misidentifications. According to G.O. Sars (1878) the species prefers depths of several hundreds of metres.

Ecology: Most common at depths between 100 and 600 m on slightly current swept muddy to silty bottom (Warén 1996a).

Fossil occurrence: Lower Pleistocene: Sicilian, ?Santernian, and ?Emilian (Malatesta & Zarlenga 1986). The species has apparently its origin in the Atlantic. It is new to the Greenland fossil fauna, and the occurrence in the Kap København Formation seems to be the earliest known appearance of the species.

Genus *Boreocingula* Golikov & Kussakin, 1974.

Boreocingula globula (Møller, 1842)
Figs 12b, 14.
1842 *Rissoa globulus* Møller, p. 82.

Material: Member B, unit B1, 59.2: two fragmentary specimens, 74.1: 24 complete and three fragmentary specimens. Unit B2, 72.1: four complete and five fragmentary specimens, 75.1: 23 complete and 19 fragmentary specimens.

This is the most common gastropod in the samples from the Kap København Formation.

Remarks: Height of shell (h) and diameter (d) were measured for the five largest specimens and the h/d ratios calculated:

h in mm	d in mm	h/d
3.3	2.3	1.43
3.1	2.1	1.48
3.0	2.1	1.43
2.9	2.3	1.26
2.9	2.0	1.45

Recent distribution: ?Panarctic (Fig. 14). *Boreocingula globula* has been recorded from the eastern part of the Atlantic from Svalbard and Finnmark and is also mentioned from Newfoundland (Jeffreys 1877, Verrill 1882). According to Warén (1972) all these records are uncertain. A few specimens have been recorded (?living) in deep water southwest of the Faeroe Islands, but they most probably belong to *Benthonella tenella* (Jeffreys, 1867) (Warén 1996a). In West Greenland the species has been recorded from Qeqertarsuaq/Godhavn in the north to Qaqortoq/Julianehåb in the south (Posselt & Jensen 1898). It is not known from East Greenland. Vertical

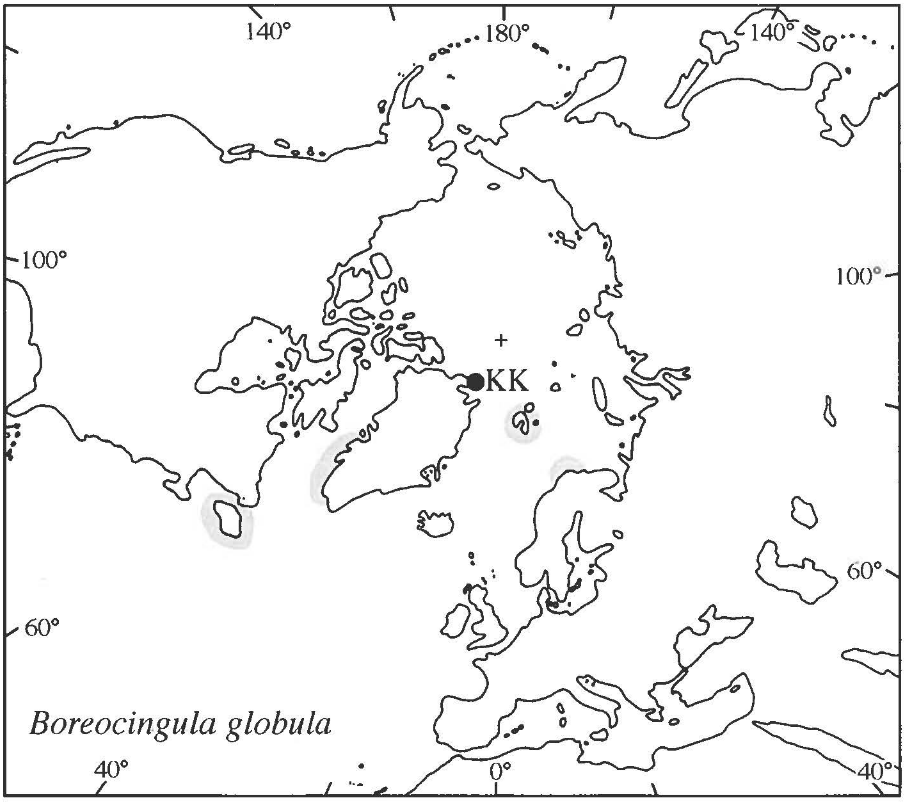

Fig. 14. Recent known geographical distribution of *Boreocingula globula* (Møller). KK: Kap København.

range: From ?5 m in West Greenland (Posselt & Jensen 1898) to 450 m in West Greenland (Warén 1996a). The figures cited for the minimal vertical range are uncertain as it does not appear from the records whether the specimens in the individual cases were living or dead.

Ecology: The species seems to prefer a bottom of clay, sand, shells, and algae (Posselt & Jensen 1898).

Fossil occurrence: Lower Pleistocene: Pattorfik beds (Símonarson 1981). The occurrence in the Kap København Formation seems to be the earliest known appearance of the species.

Genus *Alvania* Risso, 1826.
Alvania sp.
Fig. 12c.

Material: Member B, unit B2, 72.1: one fragmentary specimen.

Remarks: The height of shell is 2.1 mm and the diameter is 1.7 mm. It consists of 2.5 whorls but the protoconch is damaged and for the most part missing. The specimen is worn, but a fine reticulate surface pattern is visible on the last convex whorl. No tubercles are found on the crossing points of the prominent radial ribs and the numerous, rather fine axial ribs. The sutures are rather deep. The aperture is roundly oval and there seems to be a narrow umbilicus at the base.

The shell at hand is somewhat similar to *A. wyvillethomsoni* (Friele, 1877), but the poor state of preservation prevents a closer identification.

Genus *Rissoa* Fréminville, 1814.
Rissoa parva (da Costa, 1778)
Figs 12d, 15.
1778 *Turbo parvus* da Costa, p. 104-105.

Material: Member B, unit B2, 48.1: one almost complete specimen.

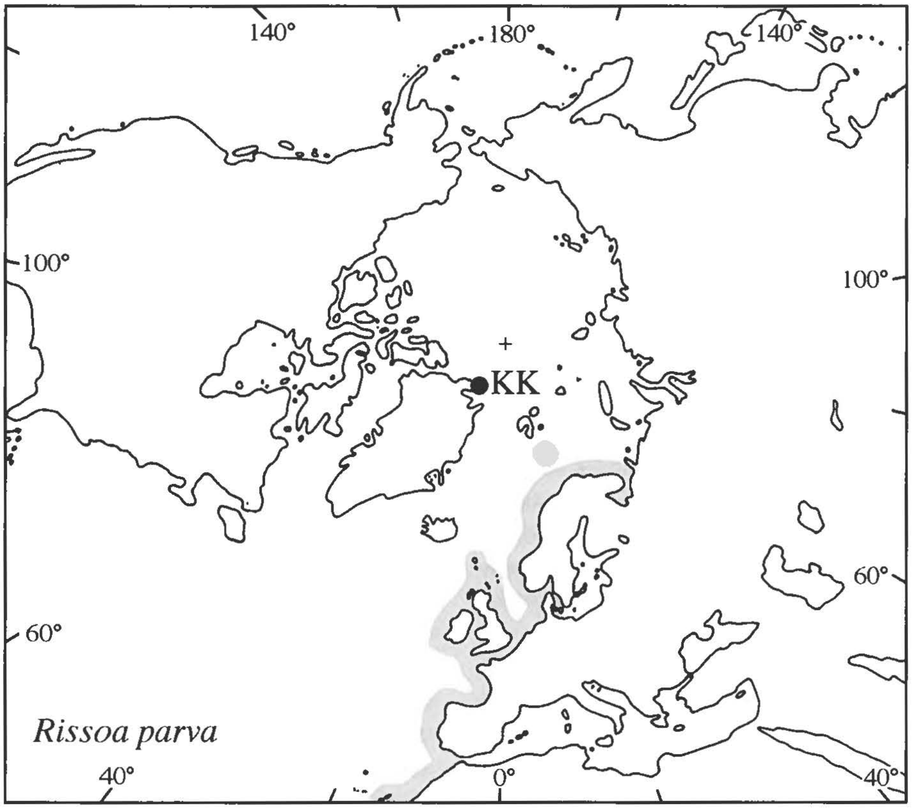

Fig. 15. Recent known geographical distribution of *Rissoa parva* (da Costa). KK: Kap København.

Remarks: The rather thick holostomat shell is 1.4 mm high and 1.0 mm in diameter. It consists of 1.6-1.7 protoconch whorls and 3.5 teleoconch whorls. The teleoconch has low and broad, brown coloured axial ribs and some fine spiral ribs, most prominent near the base. The sutures are rather deep. The aperture is roundly oval with a thickened outer lip. There is a narrow umbilicus at the base.

Discussion: G.O. Sars (1878) recorded *Rissoa interrupta* (Adams, 1798) from Norway, but emphasized the difficulties in separating it from *Rissoa parva*. Actually he was of the opinion that there is hybridization between them. According to Warén (1973) the specimens G.O. Sars recorded should be referred to *R. parva*. The specimen from the Kap København Formation has low axial ribs and is therefore referred to *R. parva*. It has been questioned (e.g. Warén 1996b) if smooth specimens should be referred to distinct species, *R. interrupta* (see K.S. Petersen 1976).

Recent distribution: Subarctic, boreal, lusitanian, only in the Atlantic (Fig. 15). *Rissoa parva* is distributed from Bjørnøya, the White Sea, and northern Norway southward to the Canary Islands and the Moroccan west coast (G.O. Sars 1878, Warén 1973, 1996b). It is unknown from the Mediterranean (Warén 1996b), Greenland, and Iceland, but recorded from the Faeroe Islands (Spärck & Thorson 1933). Vertical range: From 0 m in England (Graham 1971) to 84 m in West Norway (G.O. Sars 1878).

Ecology: The species is abundant in the British Isles amongst corallines and fine weeds in pools, also under stones and in rocks crevices (Graham 1971). In Norway it is mainly in rather shallow water together with algae (G.O. Sars 1878). It prefers intertidal areas with good water circulation, but lives slightly deeper where the surface water is more brackish (Warén 1996b).

Fossil occurrence: Pliocene: Coralline Crag, Altavilla (Harmer 1920). Middle Pleistocene: Bridlington (Harmer 1920). The species apparently originated in the Atlantic. The species is new to the Greenland fossil fauna.

Family Naticidae Forbes, 1838. Genus *Lunatia* Gray, 1847.

Lunatia pallida (Broderip & Sowerby, 1829)

Fig. 12e-f.

1829 *Natica pallida* Broderip & Sowerby, p. 372.

Material: Member B, unit B1, 74.1: one complete and one fragmentary specimen. Unit B2, 72.1: one complete specimen. Member B, locality 128: two complete specimens.

Remarks: The best preserved specimen is 5.0 mm high and 3.5 mm in diameter.

Recent distribution: Panartic, boreal, circumpolar. *Lunatia pallida* inhabits the eastern part of the Atlantic from Franz Josef Land and Svalbard southward to Denmark, Holland, and Belgium (Thorson 1944). Furthermore, it is found in the Siberian Arctic Sea, Alaska (Point Barrow), the Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay (Posselt & Jensen 1898, MacGinitie 1959, Macpherson 1971). The southern boundary in the western part of the Atlantic seems to be at New England and it extends into the Pacific southward to Japan and Puget Sound (MacGinitie 1959). The species is distributed along the coast of West Greenland from Dundas in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In East Greenland the northernmost occurrence is at Danmarkshavn and it reaches to south of Lindenow Fjord (Qeqertatsiaq) (Thorson 1944). Vertical range: From 0 m in Norway to 2430 m off Cape Hatteras (Thorson 1944).

Ecology and biology: The species belongs to the infauna and in East Greenland it is common in the Arctic *Macoma* community, but it lives also in the *Astarte crenata* community, and the *Gomphina fluctuosa* community (Thorson 1944). The larval development is non-pelagic (Thorson 1935).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Red Crag (Harmer 1921), San Joaquin beds (Hopkins & MacNeil 1960). Lower Pleistocene: Baventian (West *et al.* 1980), Olkhov Suite (Petrov 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Kresta, Kolvin, and Padymeiskii Suites (Petrov 1966, 1982, Merklin *et al.* 1979), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972).

The species most probably has its origin in the Pacific (Durham & MacNeil 1967) and migrated towards the North Atlantic during the Upper Pliocene (Malatesta & Zarlenga 1986).

Lunatia sp.
Material: Member B, unit B2, 27.1: one fragmentary specimen, 72.1: one fragmentary specimen, 75.1: one fragmentary specimen.
Remarks: One of the fragments is of a juvenile shell. Obviously they all belong to a Naticidae with an open umbilicus i.e. the genus *Lunatia*, but they are too poorly preserved for further identification.

Genus *Natica* Scopoli, 1777.
Natica affinis (Gmelin, 1790)
Fig. 12g.
1790 *Nerita affinis* Gmelin, p. 3675.
Material: Member B, unit B1, 74.1: two fragmentary specimens.
Remarks: The more complete specimen is 5.3 mm high and 4.0 mm in diameter, but these figures are rather uncertain because of the imperfect state of preservation. The protoconch is missing and the last whorl is damaged. The surface pattern is worn, especially in the upper part of the shell, but it is smooth except for fine growth lines and faint spiral lines. The holostomat shell has a large aperture with a rather thin, smoothly curved outer lip. The inner lip is thick and the umbilicus is filled up with callosity. The fragmentary shells can best be referred to *Natica affinis*.
Discussion: Since Collin (1887) came to the conclusion that *Natica clausa* and *N. affinis* could not be kept separate as two distinct species, many authors have treated them as one and the same species, e.g. Thorson (1941, 1944, 1951), Feyling-Hanssen (1955), and Macpherson (1971), using the name *N. clausa* Broderip & Sowerby, 1829, whereas Nordsieck (1968) as well as Malatesta & Zarlenga (1986) termed it *N. affinis* (Gmelin, 1790). In this paper we regard *N. clausa* and *N. affinis* as one species. However, as the name *N. affinis* is older and is not found used before 1790 for any other species of *Natica* it seems to have priority to *N. clausa*, and is therefore considered the valid species name (Símonarson 1981, Malatesta & Zarlenga 1986).

The species is referred to the Genus *Natica* Scopoli, 1777 which differs from the Genus *Lunatia* Gray, 1847 in having the umbilicus filled up with callosity.
Recent distribution: Panarctic, boreal, lusitanian, circumpolar. *Natica affinis* occurs in the area from Franz Josef Land, Novaya Zemlya, the Kara Sea, the Siberian Arctic Sea, Alaska (Point Barrow), and Ellesmere Island southward to Japan, Vancouver, Cape Hatteras, and the Mediterranean (Thorson 1944, MacGinitie 1959, Macpherson 1971). In West Greenland it has been found along the coast from Iita in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In East Greenland the species occurs commonly along the outer coast from Shannon as the northernmost locality and southward to Lindenow Fjord (Thorson 1944). Vertical range: From 0 m in Norway to 2660 m in Algeria (Thorson 1944).
Ecology and biology: The species belongs to the infauna and in Iceland it is found in the Arctic *Macoma* community, in shallow water on clay or mud bottom, as well as in the *Yoldia hyberborea* community at depths of 45-160 m on clay bottom (Spärck 1937). The larval development is non-pelagic (Thorson 1935).
Fossil occurrence: Miocene: Burdigalian, Arnum Formation (Sorgenfrei 1958). Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et*

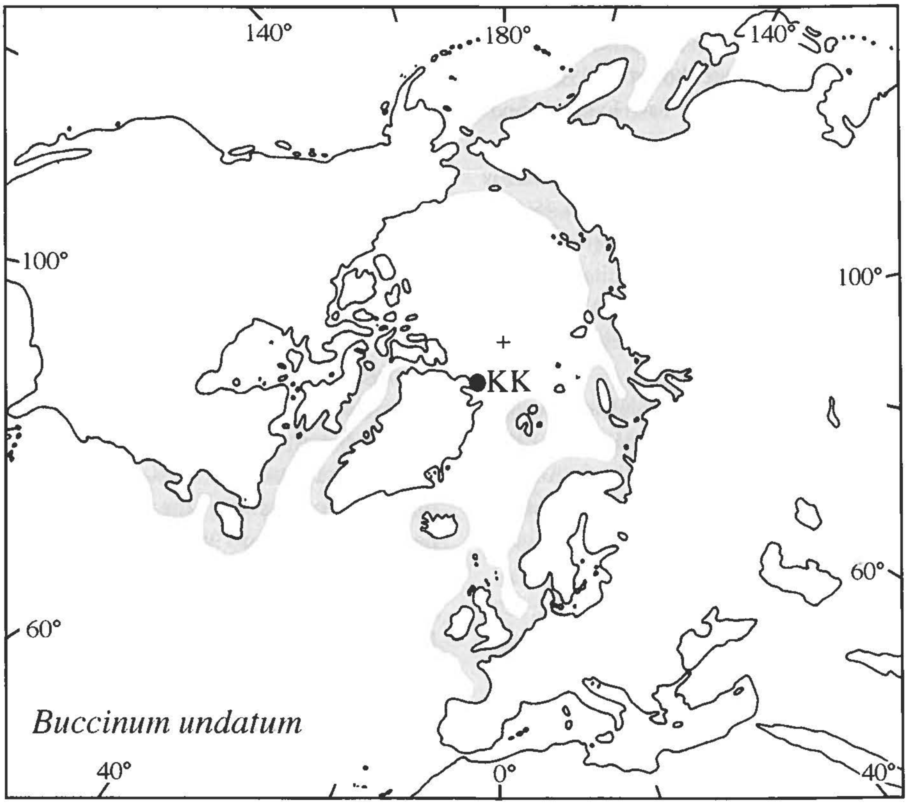

Fig. 16. Recent known geographical distribution of *Buccinum undatum* Linné. KK: Kap København.

al. 1980), Red Crag (Harmer 1921), San Joaquin beds (Durham & MacNeil 1967). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Santernian (Malatesta & Zarlenga 1986), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Kresta, Kolvin, and Padymeiskii Suites (Petrov 1966, 1982, Merklin *et al.* 1979), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972).

Natica sp.

Material: Member B, unit B1, 74.1: one fragmentary specimen. Unit B2, 48.1: one fragmentary specimen, 50.3: two fragmentary specimens, 72.1: one fragmentary specimen, 75.1: two fragmentary specimens.

Kap Rigsdagen, 200.3: one fragmentary specimen.

Remarks: One of the fragmentary shells is juvenile, but it is not possible to decide whether the fragments belong to one or more species of *Natica*.

Order Neogastropoda Wenz, 1838. Family Buccinidae Latreille, 1825. Genus *Buccinum* Linné, 1758.

Buccinum cf. ***undatum*** Linné, 1758

Figs 12h, 16.

1758 *Buccinum undatum* Linné, p. 740.

Material: Member B, unit B2, 50.3: one fragmentary and worn specimen, 41.1: a few worn fragments from at least two specimens, Member B, locality 128: a few fragments from at least two specimens.

Remarks: Only three whorls are preserved in the fragmentary specimen, the protoconch is missing and the last whorl is damaged. The height is about 6 mm. Although the surface pattern is more or less damaged, the curved axial folds so characteristic for *B. undatum* are clearly visible.

Recent distribution: Panarctic, boreal, lusitanian, ?circumpolar (Fig. 16). *Buccinum undatum* has been found in the eastern part of the Atlantic from Svalbard and Novaya Zemlya in the north to the Bay of Biscay in the south (Thorson 1944). In

North America the species is known from Jones Sound in the north southward to New England and from Alaska (Point Barrow) (MacGinitie 1959, Macpherson 1971). The occurrence in the Siberian Arctic Sea, the Bering Sea, and northern Pacific is somewhat uncertain. In West Greenland it has been found in the following areas: Qeqertarsuaq/Godhavn, Aasiaat/Egedesminde, and Nuuk/Godthåb (Thorson 1951). Thorson (1944) has excluded the species from the East Greenland fauna. Vertical range: From 0 m in Iceland (Óskarsson 1962) to 624 m in Norway (Thorson 1941).

Ecology and biology: In Iceland the species has been found on a bottom of sand, gravel, stones, shells, and algae (Thorson 1941). On Svalbard (Isfjorden) it almost exclusively occurs on muddy bottom (Odhner 1915). The larval development is non-pelagic (Thorson 1941).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Coralline Crag and Red Crag (Harmer 1914). Lower Pleistocene: Threngingar and Máná Formations (J. Eiríksson 1981), Baventian (West *et al.* 1980), Emilian and Sicilian (Malatesta & Zarlenga 1986), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Padymeiskii Suite (Merklin *et al.* 1979, Petrov 1982). Although Durham & MacNeil (1967) mentioned *B. undatum* among immigrants from the Pacific to the North Atlantic, the species seems to have originated in the Atlantic.

Buccinum spp.

Material: Member B, unit B2, 41.1: one fragmentary specimen and several fragments.

Remarks: Species identification is impossible because of the imperfect state of preservation. Most likely the fragments belong to more than one species of *Buccinum.*

Family Cancellariidae Adams & Adams, 1853. Genus *Admete* Krøyer, 1842.

Admete couthouyi (Jay, 1839)

Fig. 12i.

1839 *Cancellaria couthouyi* Jay, p. 77.

Material: Member B, unit B2, 75.1: one almost complete specimen.

Remarks: The outer lip is slightly damaged, but height of shell is 3.9 mm and the diameter is close to 3.0 mm.

Discussion: This is the „*Admete viridula* (Fabricius, 1780)“ of many authors. Dall (1887) examined the type specimen of Fabricius' species and stated that it was a *Bela*, i.e. an *Oeonopota* or *Propebela*, and not an *Admete* at all. Therefore the species name *viridula* is considered as invalid (see also Macpherson 1971, Gladenkov *et al.* 1980, Sneli & Stokland 1986).

Recent distribution: Panarctic, boreal, circumpolar. *Admete couthouyi* is of common occurrence from Svalbard, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea in the north to west of the English Channel and Japan in the south (Thorson 1944). In North America it is known from Jones Sound and Point Barrow in the north and extends south to California and New England (MacGinitie 1959, Macpherson 1971). In West Greenland it has been found along the coast from Iita in the north and southward to Qaqortoq/Julianehåb (Thorson 1951). In North and East Greenland it was found in the outer part of the Jørgen Brønlund Fjord area at 45 m depth (Schiøtte 1989), and reaches to south of Lindenow Fjord (Qeqertatsiaq) (Thorson 1944). Vertical range: From 3 m in Novaya Zemlya to 1010 m west of the English Channel (Thorson 1944).

Ecology and biology: The adults apparently belong to the epifauna on algae as well as that of the level sea bottom (Thorson 1944). In East Greenland *A. couthouyi* penetrates into the inner parts of the larger fjords and is mainly found associated with the Polar water with its maximum occurrence at negative temperatures (Thorson 1944). The larval development is non-pelagic (Thorson 1935).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Coralline Crag and Red Crag (Harmer 1918). Lower Pleistocene: Sicilian (Malatesta &

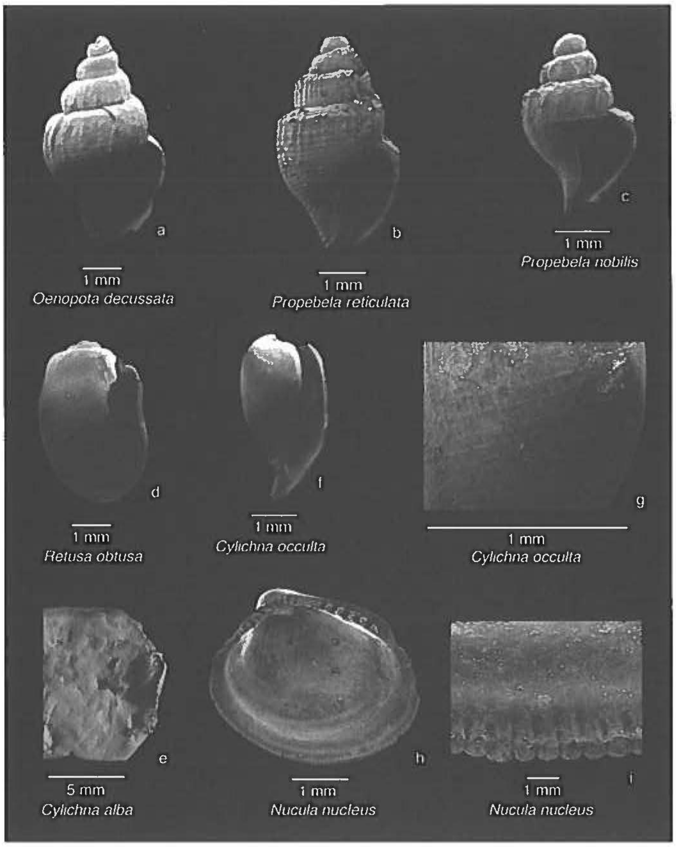

Fig. 17. a: *Oenopota decussata* (Couthouy) from locality 74.1, MGUH 22297, GGU/GCI 56875. b: *Propebela reticulata* (Brown) from locality 75.1, MGUH 22298, GGU/GCI 56868. c: *Propebela nobilis* (Møller) from locality 50.2, MGUH 22299, GGU/GCI 56814. d: *Retusa obtusa* (Montagu) from locality 74.1, MGUH 22300, GGU/GCI 56875. e: *Cylichna alba* (Brown) from locality 50.3, MGUH 22301, GGU/GCI 197165. f-g: *Cylichna occulta* (Mighels & Adams) from locality 74.1, MGUH 22302, GGU/GCI 56875. h-i: *Nucula nucleus* (Linné) from locality 74.1, MGUH 22303, GGU/GCI 56875. h: left valve. i: the crenulated inner margin of the same valve.

Zerlenga (1986), Lower San Pedro Series (Grant & Gale 1931). Middle Pleistocene: Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Kotzebuan (Hopkins *et al.* 1972). Durham & MacNeil (1967) include the species among immigrants from the Pacific to the North Atlantic.

Family Turridae Melville, 1917. Genus *Oenopota* Mörch, 1852.

Oenopota decussata (Couthouy, 1839)

Fig. 17a.

1839 *Pleurotoma decussata* Couthouy, p. 183, pl. 4, fig. 8.

Material: Member B, unit B1, 50.2: two complete specimens, 74.1: five complete and six fragmentary specimens. Unit B2, 3.1: five complete specimens, 48.1: two complete specimens, 50.3: 10 complete and five fragmentary specimens, 72.1: one complete specimen, 75.1: 13 complete and 15 fragmentary specimens. Member B, locality 128: one complete and one fragmentary specimen.

Remarks: Height of shell (h) and diameter (d) were measured for the five largest complete specimens and the h/d ratios calculated:

h in mm	d in mm	h/d
6.0	3.5	1.71
5.8	3.3	1.76
5.8	3.1	1.87
5.0	2.8	1.79
5.0	3.5	1.43

Recent distribution: Panarctic, mid boreal, circumpolar. *Oenopota decussata* occurs from Svalbard, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to New England, north of Scotland (at great depths) and west of Norway to 60° N (Bouchet & Warén 1979). In North America it is known from the Foxe Basin and Hudson Bay to Alaska (Point Barrow) in the west (MacGinitie 1959, Macpherson 1971). The species has been found along

the West Greenland coast from Upernavik in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In East Greenland the typical form has been met with in the Kejser Franz Joseph Fjord area and the Scoresby Sund area (Thorson 1944). Vertical range: From 3.5 m in East Greenland to 1008 m north of Scotland (Thorson 1944).
Ecology: The species seems to prefer muddy or clayey bottom in the Arctic *Macoma* community (Thorson 1941).
Fossil occurrence: Pliocene: Red Crag (Harmer 1915). Lower Pleistocene: Pattorfik beds (Símonarson 1981). Schlesch (1924) described a new subspecies *Oenopota decussata tjoernesensis* from the Pliocene *Serripes* Zone of the Tjörnes beds. The species is apparently of an Atlantic origin.

Genus *Propebela* Iredale, 1918.
Propebela reticulata (Brown, 1827)
Fig. 17b.
1827 *Pleurotoma reticulata* Brown pl. 48, figs. 29-30.
Material: Member B, unit B1, 74.1: three complete specimens. Unit B2, 50.3: one complete and one fragmentary specimen, 75.1: three complete and one fragmentary specimen.
Remarks: Height (h) and diameter (d) were measured for the five largest complete specimens and the h/d ratios calculated:

h in mm	d in mm	h/d
4.6	2.6	1.77
4.0	2.2	1.82
3.6	2.3	1.57
3.3	2.0	1.65
3.0	1.9	1.58

Discussion: The species is mainly referred to as *P. trevelliana* of Turton 1834. However, as the species name *reticulata* is older it has priority to *trevelliana* and is therefore considered the valid species name (see also Harmer 1915, Macpherson 1971).
Recent distribution: Panarctic, boreal, lusitanian. *Propebela reticulata* is widely distributed in arctic, subarctic, boreal, and lusitanian waters and extends from Svalbard, Bjørnøya, the Barents Sea, the Kara Sea, and Baffin Bay southward to ?British Columbia (only empty shells), Cape Cod, and the Bay of Biscay (Thorson 1944). In the Canadian Arctic Archipelago it is known to Dease Strait in the west (Macpherson 1971). In West Greenland it has been taken in the following areas: Qimusseriarsuaq/Melville Bugt, Uummannaq, Qeqertarsuaq/Godhavn, Aasiaat/Egedesminde, Nuuk/Godthåb, and Paamiut/Frederikshåb (Thorson 1951). In North and East Greenland it has been found in the Jørgen Brønlund Fjord area where it is most common in the outer fjord at depths between 3 and 50 m (Schiøtte 1989), and from Store Koldewey in the north to the Lindenow Fjord in the south (Thorson 1944). Vertical range: From 9 m in Svalbard to 1447 m in the North Greenland Sea (Golikov 1964).
Ecology and biology: In East Greenland the species is particularly collected from mud and clay bottom in the Arctic *Macoma* community (Thorson 1944). In East Greenland the pelagic larval stage was found to be very short (Thorson 1944).
Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Red Crag (Harmer 1915). Lower Pleistocene: Pattorfik beds (Símonarson 1981). Middle Pleistocene: Padymeiskii Suite (Merklin *et al.* 1979). The species apparently originated in the Atlantic.

Propebela nobilis (Møller 1842)
Fig. 17c.
1842 *Defrancia nobilis* Møller, p. 85.
Material: Member B, unit B1, 50.2: one juvenile specimen.
Remarks: The shell height (h) is 3.9 mm, the diameter (d) is 1.8 mm and height of aperture is 1.7 mm. The h/d ratio is 2.17 which is considerably higher than in the other *Propebela* species found in the Kap København Formation. A part of the siphonal canal broke off when the shell was measured before it was photographed.

Recent distribution: Panarctic, boreal, circumpolar. *Propebela nobilis* extends from Svalbard, the Barents Sea, the Kara Sea, the north coast of Russia, the Siberian Arctic Sea, and the Bering Strait southward to North Japan, Cape Cod, the Faeroe Islands, and West Norway at 68° N (Posselt & Jensen 1898, Thorson 1951, Høisæter 1986). In West Greenland the species has been found along the coast from Dundas in the north to Nanortalik in the south (Thorson 1944). In East Greenland it has been taken at Danmarkshavn as the northernmost locality whence it reaches southward to Lindenow Fjord (Thorson 1944). Vertical range: From 5 m in Svalbard to 995 m in the Siberian Arctic Sea (Thorson 1944).

Ecology and biology: In Iceland the species is especially frequent on a bottom of mud (Thorson 1941), but in East Greenland it seems to prefer a bottom of clay (Thorson 1944). The larval development is nonpelagic (Thorson 1935).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Coralline Crag and Red Crag (Harmer 1915). Lower Pleistocene: Pattorfik beds (Símonarson 1981). Middle Pleistocene: Padymeiskii Suite (Merklin *et al.* 1979). The species apparently originated in the Atlantic.

Oenopota & Propebela spp.

Material: Member B, unit B1, 50.2: two fragmentary specimens, 74.1: one fragmentary specimen. Unit B2, 27.1: two fragmentary specimens, 50.3: eight fragmentary specimens, 75.1: eight fragmentary specimens.

Remarks: The fragments are too poorly preserved for any closer identification, but they apparently belong to more than one species.

Gastropoda, Opisthobranchia

Subclass Opisthobranchia Milne Edwards, 1848. Order Pleurocoela Thiele, 1925. Family Retusiidae Thiele, 1931. Genus *Retusa* Brown, 1827.

Retusa obtusa (Montagu, 1803)

Fig. 17d.

1803 *Bulla obtusa* Montagu, p. 223, pl. 7, fig. 3.

Material: Member B, unit B1, 74.1: one almost complete specimen. Unit B2, 50.3: three complete specimens.

Remarks: Height of shell (h) and diameter (d) were measured for the complete specimens and the h/d ratios calculated:

h in mm	d in mm	h/d
3.4	2.1	1.62
2.4	1.6	1.50
2.1	1.4	1.50

Discussion: Lemche (1948) examined thoroughly the genus *Retusa* from the North Atlantic. He arrived at the conclusion that *R. pertenuis* is not a distinct species. Quoting Lemche (1948, p. 51): „The southern, larger and stronger *obtusa* is replaced by the smaller *pertenuis* in northern latitudes and in brackish waters, etc.“. Lemche also wrote (p. 53): „It is concluded that *obtusa* is widely distributed in the North Atlantic; under optimal conditions it develops into typical *obtusa* with a shell length of 5-6 mm, whereas under less favourable circumstances (lower salinity - or difficulties in feeding?) it occurs as the dwarf varity *pertenuis*“. We refer the specimens from the Kap København Formation to *R. obtusa*, but obviously they are all closer to the shell variety *pertenuis* than the typical one.

Recent distribution: Panarctic, boreal, lusitanian, circumpolar. *Retusa obtusa* is distributed from Svalbard, Bjørnøya, the northern coasts of Europe and Asia, the Bering Sea, and Parry Islands southward to the Aleutians, Nova Scotia, the Bay of Biscay, and the Mediterranean (Lemche 1941a, 1941b). It occurs along the West Greenland coast northward to 72°38' N (near Kangersuatsiaq) (Lemche 1941a). In North Greenland it is common in the Jørgen Brønlund Fjord area at depths between 5 and 190 m (Schiøtte 1989). In East Greenland the species has been found from Sabine Ø in the north to Lindenow Fjord in the south (Lemche 1941b). Vertical range: From 5 m in East Greenland to 1300 m in the North Atlantic at 63°36' N, 7°30' W (Lemche 1948).

Ecology: In East Greenland the species seems exclusively bound to the Arctic *Macoma* community, especially the lower *Ophiocten* Zone (Lemche 1941b).

Fossil occurrence: Miocene: Arnum Formation (Sorgenfrei 1958). Pliocene: Coralline Crag (Harmer, 1923), Astiano and Monte Mario (Sorgenfrei 1958) Lower Pleistocene: Icenian (Harmer 1923, Norton 1967), Pattorfik beds (Símonarson 1981). Middle Pleistocene: ?Padymeiskii Suite (Merklin *et al.* 1979), Kotzebuan (Hopkins *et al.* 1972). The occurrence in the Kap København Formation seems to be the earliest known appearance of the shell variety *pertenuis*.

Family Scaphandridae Fischer, 1883.
Genus *Cylichna* Lovén, 1846.
Cylichna alba (Brown, 1827)
Fig. 17e.
1827 *Volvaria alba* Brown, p. 3, pl. 19, figs 43-44.

Material: Member B, unit B2, 3.1: one fragmentary specimen, 50.3: three fragmentary specimens.

Remarks: The most complete specimen at hand, reaching 5.4 mm in height (h) and 3.0 mm in diameter (d), has a h/d ratio of 1.80. Another measurable specimen has h/d ratio close to 1.95. Thus, the species is distinctly more slender than *Cylichna occulta* (Mighels & Adams, 1841).

Recent distribution: Panarctic, boreal, circumpolar. *Cylichna alba* occurs from Svalbard, the north coast of Russia, the Siberian Arctic Sea, and the Canadian Arctic Archipelago in the north to San Diego, North Carolina, and the Bay of Biscay (at greater depths) in the south (Grant & Gale 1931, Lemche 1941a). It has been found in West Greenland northward to 81°41' N and is the most abundant of all tectibranchs in West Greenland (Lemche 1941a). In North Greenland it is common in the Jørgen Brønlund Fjord area at depths between 5 and 190 m (Schiøtte 1989). It is very common in East Greenland where it is distributed from Sabine Ø in the north to Lindenow Fjord in the south (Lemche 1941b). Vertical range: From 4 m in East Greenland to 2500 m west of Ireland (Lemche 1948). Abyssal in the southern part of the area of distribution.

Ecology: In East Greenland *Cylichna alba* almost exclusively occurs at depths of more than 9 m and it is the dominating species at depths of 20-35 m on all kinds of bottom except rocks (Lemche 1941b). The temperature at 9 m depth in East Greenland during the summer will hardly exceed 3-4°C in the large fjords (Lemche 1941b). In West Greenland the species is bound to the infauna and in East Greenland it is not limited to any specific benthic community as it has been found in the Arctic *Macoma* community, the *Gomphina fluctuosa* community, as well as the *Arca glacialis-Astarte crenata* community (Lemche 1941a, 1941b).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Norton 1975), San Joaquin beds (Durham & MacNeil 1967). Lower Pleistocene: Icenian (Harmer 1923), Emilian (Malatesta & Zarlenga 1986). Middle Pleistocene: Padymeiskii Suite (Merklin *et al.* 1979, Petrov 1982). The species is considered to have originated in the Pacific and immigrated to the North Atlantic (Malatesta & Zarlenga 1986).

Cylichna occulta (Mighels & Adams, 1841)
Fig. 17f-g.
1841 *Bulla occulta* Mighels & Adams, p. 50.

Material: Member B, unit B1, 50.2: five fragmentary specimens, 74.1: two complete and one fragmentary specimen. Unit B2, 3.1: one complete and five fragmentary specimens, 27.1: one fragmentary specimen, 50.3: three complete and four fragmentary specimens, 72.1: two fragmentary specimens, 75.1: seven fragmentary specimens.

Remarks: Height of shell (h) and diameter (d) were measured for the complete specimens and the h/d ratios calculated:

h in mm	d in mm	h/d
7.8	5.3	1.47
4.1	2.5	1.64
2.9	2.1	1.38
2.6	2.0	1.30
2.4	1.8	1.33
2.3	1.5	1.53

Discussion: It is evident from comparison with recent material that the shells at hand have somewhat lower h/d ratios than the typical form. Therefore they may be referred to the shell variety *scalpta* (Reeve, 1855) in accordance with Lemche (1948) and Óskarsson (1962).

Recent distribution: Panarctic, circumpolar. *Cylichna occulta* has been recorded from Svalbard, Bjørnøya, North and East Iceland, Finnmark, the north coast of Russia, the White Sea, Novaya Zemlya, the Kara Sea, the Siberian Arctic Sea, Alaska from Point Barrow to the Aleutians, and the east coast of North America southward to Cape Cod (Lemche 1941a, 1941b). In West Greenland it has been met with alive at 71°40' N and 66°35' N, but records from several other localities do not distinguish between empty shells or living animals (Lemche 1941a). In North Greenland it is common in the Jørgen Brønlund Fjord area at depths between 3 and 80 m (Schiøtte 1989). In East Greenland the species has been found at Danmarkshavn in the north whence it reaches to Lindenow Fjord in the south (Lemche 1941b). Vertical range: From 0 m in East Greenland to ?600 m in West Greenland (Lemche 1948).

Ecology: In East Greenland and Iceland *C. occulta* is especially found in the Arctic *Macoma* community, but in Iceland it probably also occurs in the *Yoldia hyperborea* community (Lemche 1938, 1941b).

Fossil occurrence: Lower Pleistocene: Olkhov Suite (Petrov 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Bridlington (Harmer 1923), Kotzebuan (Hopkins *et al.* 1972 as *Cylichna propinqua* Sars, 1858). The occurrence in the Kap København Formation seems to be the earliest known appearance of the typical form as well as the shell variety *scalpta*.

***Cylichna* sp.**

Material: Member B, unit B1, 50.2: one fragmentary specimen. Unit B2, 48.1: one fragmentary specimen, 50.3: one fragmentary specimen. 75.1: one fragmentary specimen.

Remarks: The fragmentary specimens are too poorly preserved for any closer identification, but they certainly belong to *Cylichna*.

Bivalvia

Class Bivalvia Linné, 1758. Subclass Palaeotaxodonta Korobkov, 1954. Order Nuculoidea Dall, 1889. Family Nuculidae Gray, 1824. Genus *Nucula* Lamarck, 1799.

Nucula nucleus (Linné, 1758)

Figs 17h-i, 18.

1758 *Arca nucleus* Linné p. 1143.

Material: Member B, unit B1, 74.1: two left and one right valves. Unit B2, 75.1: four umbonal fragments.

Remarks: All valves are very small (?juvenile) less than 4 mm.

Recent distribution: Subarctic, boreal, lusitanian (Fig. 18). *Nucula nucleus* is known in the Atlantic from 68° N (north of Bodø, Norway) in the north to the Mediterranean and South Africa in the south (G.O. Sars 1878, Posselt & Jensen 1898, G.H. Petersen 1968, Høisæter 1986). In West Greenland it has been found in the Aasiaat/Egedesminde area down to 219 m (Posselt & Jensen 1898). The species is not living in East Greenland or Iceland today, but of common occurrence in the Faeroe Islands (G.H. Petersen 1968). Vertical range: From 1 m in West Greenland to ?219 m in West Greenland (Posselt & Jensen 1898).

Ecology: In the British Isles the species lives offshore on rather coarse bottom of

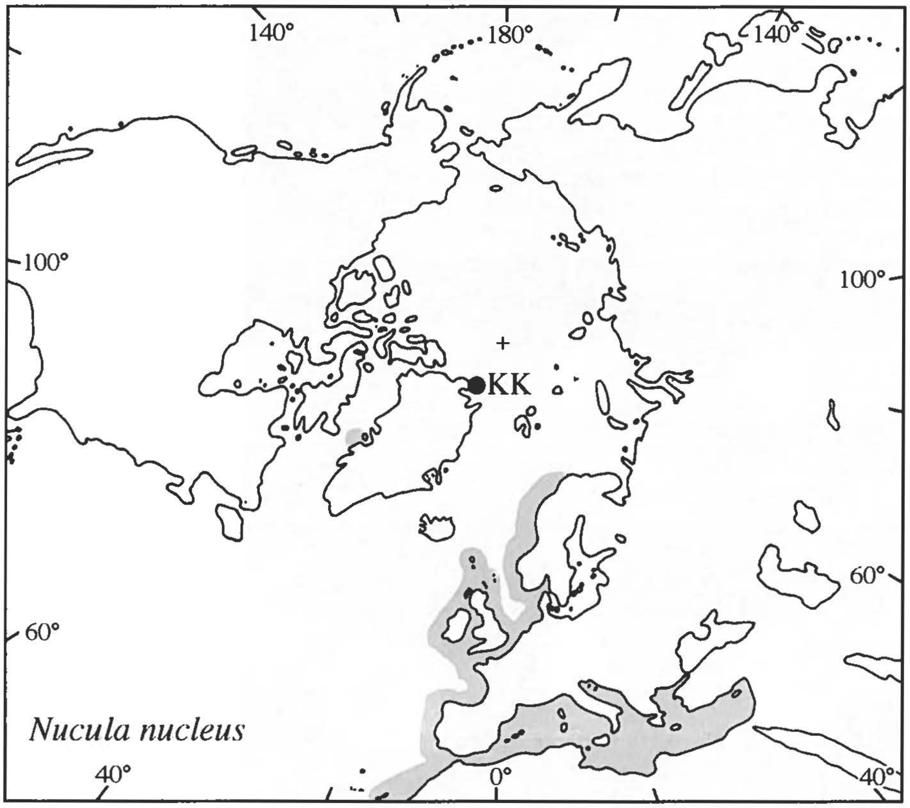

Fig. 18. Recent known geographical distribution of *Nucula nucleus* (Linné). KK: Kap København.

muddy gravel and coarse sand (Tebble 1966). The species is a deposit feeder as are the other members of this family (Ockelmann 1958).

Fossil occurrence: Oligocene: North Sea Basin (Heering 1950). Miocene: Arnum Formation (*N. nucleus* var. *hanleyi* Winckworth, 1931), Aquitanian, Burdigalian, Anversian, Hemmoor Stage, (Sorgenfrei 1958). Pliocene: Tjörnes *Mactra* and *Serripes* Zones (Gladenkov *et al.* 1980), Coralline Crag (Heering 1950), Scaldisian (Heering 1950, Glibert 1957a), Piacenziano, Astiano, and Monte Mario (Sorgenfrei 1958).

The geologically long-lived *Nucula nucleus* has not previously been known as a fossil in Greenland, and from a zoogeographical point of view it is a very peculiar addition to the mainly arctic fauna of the Kap København Formation. It is tempting to regard its occurrence here as a relic from a milder period. However, the species has recently been identified by S. Funder in samples collected by J. Landvik in Late Pliocene-Early Pleistocene sediments on Île de France, c. 400 km south of Kap København (Landvik 1994).

Nucula tenuis (Montagu, 1808)
Fig. 19a.
1808 *Arca tenuis* Montagu p. 56, pl. 29, fig. 1.

Material: Member B, unit B1, 74.1: one umbonal fragment. Unit B2, 75.1: one umbonal fragment.

Recent distribution: Panarctic, boreal, circumpolar. *Nucula tenuis* occurs from Svalbard, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to ? Gibraltar and ?the Mediterranean (Filatova 1957, Ockelmann 1958). In North America and the Pacific it is mainly recorded as *N. belloti* Adams, 1856 from the Beaufort Sea and Ellesmere Island south to Florida, California (Baja), and Japan (Bernard 1979, Lubinsky 1980). In West Greenland it has been found along the whole coast north to 78° N (Posselt & Jensen 1898, Vibe 1950). In North Green-

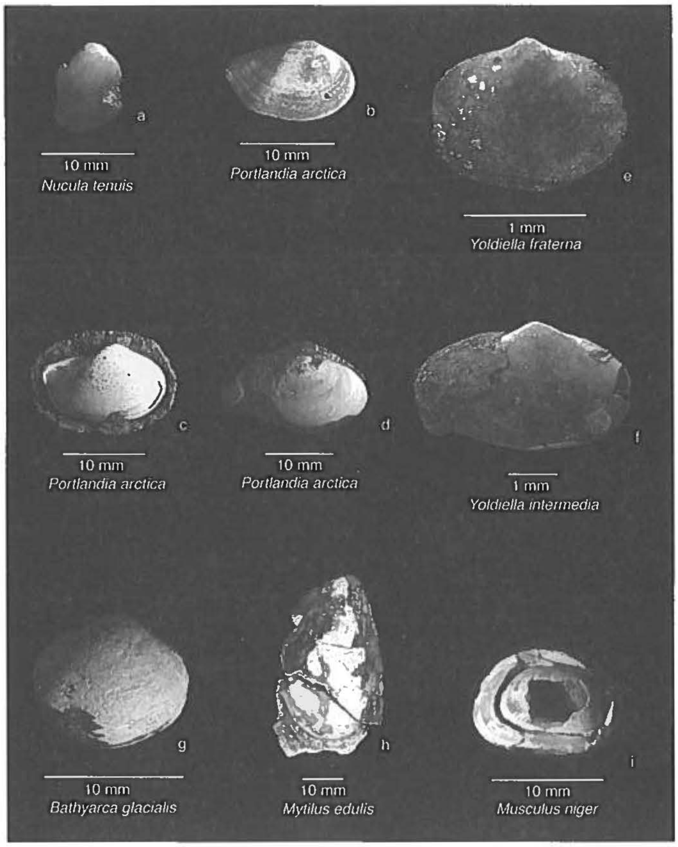

Fig. 19. a: *Nucula tenuis* (Montagu), right valve from locality 74.1, MGUH 22304, GGU/GCI 56875. b-d: *Portlandia arctica* (Gray). b: right valve from locality 57.2, MGUH 22305, GGU/GCI 56856. c: right valve in a concretion from locality 59.2, MGUH 22306, GGU/GCI 56661. d: right view of fragmentary specimen with paired valves from locality 59.2, MGUH 22307, GGU/GCI 56661. e: *Yoldiella fraterna* (Verrill & Bush), right valve from locality 74.1, MGUH 22308, GGU/GCI 56874. f: *Yoldiella intermedia* (M. Sars), right view of specimen with paired valves from locality 75.1, MGUH 22309, GGU/GCI 56868. g: *Bathyarca glacialis* (Gray), right view of a specimen with paired valves on stone core from locality 59.2, MGUH 22310, GGU/GCI 56661. h: *Mytilus edulis* Linné, right view of fragmentary specimen with paired valves from locality 75.1, MGUH 22311, GGU/GCI 56868. i: *Musculus niger* (Gray), right view of fragmentary specimen with paired valves from locality 57.2, MGUH 22312, GGU/GCI 56856.

land Schiøtte (1989) found it between 6 and 85 m in Jørgen Brønlund Fjord. In East Greenland it is distributed along the entire coast (Ockelmann 1958). Vertical range: From 2 m in Svalbard to 2560 m in the Beaufort Sea (Ockelmann 1958, Bernard 1979).

Ecology and biology: In East Greenland this deposit feeder inhabits a bottom of mud, clay, silt, and gravel in the Arctic *Macoma* community and the *Astarte crenata* community as well as in transitional zones (Thorson 1934, Ockelmann 1958). The larval development is lecitotrophic and the pelagic stage is very short or entirely lacking (Thorson 1936).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Coralline Crag (Heering 1950), San Joaquin beds (Durham & MacNeil 1967). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Baventian (West *et al.* 1980), *Serripes groenlandicus-Yoldia lanceolata* Zone of the Netherlands (Spaink 1975), Olkhov Suite (Petrov 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Pinakul, Kresta, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982).

From the available information *N. tenuis* dates back to the Pliocene both in the Pacific and the Atlantic. The occurrence in the Kap København Formation are among the oldest known. Bernard (1979) considered the species to have originated in the Atlantic.

Family Nuculanidae Adams & Adams, 1858. Genus *Portlandia* Mörch. 1857.

Portlandia arctica (Gray, 1824)
Figs 19b-d, 20.
1824 *Nucula arctica* Gray p. 251.

Material: Member A, 51.1: one umbonal fragment in concretion, 68.1: a few plate fragments.

Member B, unit B1, 59.2: 18 left and 22 right valves, 11 umbonal fragments. Unit B2, 3.1: a few plate fragments, 72.1: one

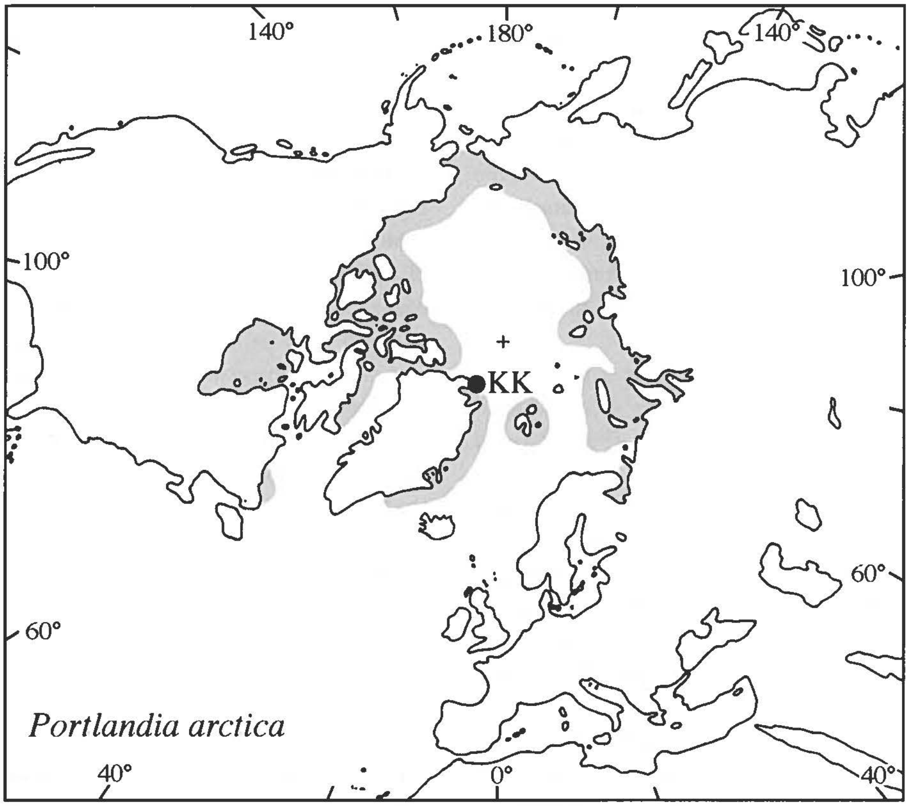

Fig. 20. Recent known geographical distribution of *Portlandia arctica* (Gray). KK: Kap København.

umbonal fragment and some plate fragments. Member B, 57.2: 23 left and 17 right valves, 14 umbonal fragments.

Kap Rigsdagen, 200.1: one specimen with paired valves.

Remarks: The length (l) and height (h) were measured for the five largest valves and the h/l ratios calculated:

l in mm	h in mm	h/l
15.5	10.8	0.70
15.5	10.7	0.69
15.0	11.1	0.74
15.0	9.4	0.63
13.8	9.2	0.67

The valves are somewhat smaller than those in the recent East Greenland populations where the maximum length is 24-25 mm.

Recent distribution: Arctic with subarctic outposts, circumpolar (Fig. 20). *Portlandia arctica* is pronouncedly arctic and its southern limit coincides closely with the southern boundary for polar water mass domination (Lubinsky 1980). The species has been found living in Eurasia from Svalbard, the White Sea (in deep water), the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea to Chuckchi Sea, including Arctic Islands except Franz Josef Land (Ockelmann 1958, Scarlato 1981). In North America it is distributed from the Bering Strait, with isolated southern outposts off the mouth of the Yukon river (Hopkins *et al.* 1974), the Beaufort Sea, Ellesmere Island, Hudson Bay, Baffin Bay, and the Labrador Sea to southern Labrador (Bernard 1979, Lubinsky 1980). In West Greenland the species has only been found living north of 77° N (Jensen 1942). In North Greenland it is common in Jørgen Brønlund Fjord at depths from 3 to 18 m and at Kap København where 851 individuals have been taken in one dredge at 6.5 m depth (K.S. Petersen 1986). In East Greenland it is frequent at shallow depths in the fjords south to 68°10' N (Ockelmann 1958). Vertical range: From 2 m in East Greenland to 339 m in East Greenland (Ockelmann 1958) or 2560 m in the Beaufort Sea (Bernard 1979, 1983). Bernard (1979) reported the species in the Beaufort Sea from depths between 0 and 2560 m, although he considered it as a member of the shallow water fauna. Furthermore, he pointed out that the specimens from the deep water stations are slightly different from the typical shallow water *Portlandia arctica*, but concluded that he had not sufficient reason to separate them.

Ecology and biology: The species is almost exclusively a deposit feeder and belongs to the infauna (Ockelmann 1958, Bernard 1979). In East Greenland it lives mainly accociated with the Polar Current water in a muddy or clayey bottom and forms monospecific community in front of calving glaciers and melt water outlets at depths between 10 and 50 m and sea temperatures from 0°C to -1.7°C (Ussing 1934, Ockelmann 1958). It is adapted to oligohaline environment with rapid sedimentation and temperatures lower than 4°C (Jensen 1942, Bernard 1983). The larval development is lecithotrophic with a short pelagic stage (Ockelmann 1958).

Fossil occurrence: Lower Pleistocene: Hörgi and Threngingar Formations (J. Eiríksson 1981), *Serripes groenlandicus-Yoldia lanceolata* Zone of the Netherlands (Spaink 1975), Icenian of the Netherlands (Heering 1950), Yakataga Formation, Middleton Island (Allison 1978). Middle Pleistocene: Karagin, Pinakul, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972), Pre-Cape Christian sediments (Andrews *et al.* 1981). *Portlandia arctica* is considered to have originated in the Atlantic (Durham & MacNeil 1967).

The fossil occurrence of *P. arctica* demonstrates the southward expansion of cold Polar water along the North Atlantic and Pacific coasts during glaciations, as much as 2000 km to the south of its present southern boundary. The finds from Kap København appear to be the oldest record of the species and it is hardly surprising that this expert of arctic survival should have its first appearance at extreme northern latitudes.

Genus *Yoldiella* Verrill & Bush, 1897.
Yoldiella fraterna Verrill & Bush, 1898
Fig. 19e.
1898 *Yoldiella fraterna* Verrill & Bush p. 867, pl. 80, fig. 5, pl. 82, fig. 8.

Material: Member B, unit B1, 74.1: two left and two right valves. Unit B2, 72.1: three umbonal fragments, 75.1: six umbonal fragments.

Remarks: Length (l) and height (h) were measured for the four complete valves and the h/l ratios calculated:

l in mm	h in mm	h/l
3.1	1.9	0.61
3.0	1.9	0.63
1.9	1.2	0.63
1.8	1.2	0.67

The maximum lengths for recent Svalbard and East Greenland shells were 3.0 to 3.7 mm (Odhner 1915, Ockelmann 1958).

Recent distribution: Panarctic, boreal. *Yoldiella fraterna* is known from Svalbard, the Kara Sea, Matotschkin Schar, North and East Iceland, the whole coast of Norway, the Faeroe Islands, and the area between Scotland and the Hebrides (Ockelmann 1958, Høisæter 1986). Also known from Novaya Zemlya and the Siberian Islands to Chukotka (Scarlato 1981). In North America it lives in the Beaufort Sea, Hudson Bay, the Canadian Arctic Archipelago, and along the east coast of North America to Georgia (Bernard 1979, Lubinsky 1980). In West Greenland the species has been found near Sisimiut/Holsteinsborg and Maniitsoq/Sukkertoppen (Odhner 1915, Ockelmann 1958). In East Greenland it is somewhat scattered along the coast at depths of 5 to 460 m from Moskusoksefjord in the north (Ockelmann 1958). Vertical range: From 5.5 m in East Greenland to 2900 m in New England (Ockelmann 1958). The species lives in littoral or sublittoral environments in the north, but is abyssal in the south, associated with cold Polar water.

Ecology and biology: In East Greenland this deposit feeder seems to prefer clayey bottom (Ockelmann 1958). The larval development is probably lecitothrophic with short lasting pelagic stage (Ockelmann 1958).

Fossil occurrence: Lower Pleistocene: Pattorfik beds (Símonarson 1981). Middle Pleistocene: Kolvin, Padymeiskii, and Middle to Upper Kresta Suites (Merklin *et al.* 1979, Petrov 1966). The species is considered to have originated in the Atlantic (Bernard 1979). The occurrence in the Kap København Formation is the earliest known appearance of this small animal.

Yoldiella intermedia (M. Sars, 1865)

Fig. 19f.

1865 *Yoldia intermedia* M. Sars p. 38, fig. 92-96.

Material: Member B, unit B2, 75.1: one specimen with paired valves, one right valve, and one umbonal fragment.

Remarks: Length (l) and height (h) were measured for the specimen with paired valves and the single right valve and the h/l ratios calculated:

l in mm	h in mm	h/l
4.9	3.0	0.61
4.9	2.9	0.59

The valves are considerably smaller than those recorded in present day East Greenland populations where the maximum length is 13-16 mm (Ockelmann 1958).

Recent distribution: Panarctic, boreal, circumpolar. *Yoldiella intermedia* occurs from Svalbard, Novaya Zemlya, the Barents Sea, the Kara Sea, and the Siberian Arctic Sea in the north southward to the Shetland Islands and Bohuslän (Sweden) (Odhner 1915, Filatova 1957, Ockelmann 1958). In North America from the Beaufort Sea, the Canadian Arctic Archipelago, Hudson Bay, and Baffin Bay south to 68° N (Ellis 1960, Bernard 1979, Lubinsky 1980). In West Greenland it has been found scattered along the coast northward to 78° N at depths between 680 and 850 m (Thorson 1951). In North Greenland it was found common in Jørgen Brønlund Fjord at 45-190 m depth (Schiøtte 1989). In East Greenland the species lives along the entire coast at depths between 11 and 600 m (Ockelmann 1958). Vertical range: From 7 m in the Siberian Arctic Sea (Odhner 1915) to 2250 in the East Siberian Sea (Clarke 1963). The species is sublittoral-bathyal and most common at depths between 50 and 600 m.

Ecology: In East Greenland the species was almost always found living in a bottom of clay or mud, here and there mixed with sand and gravel and it seems to replace *Portlandia arctica* at greater depths (Ockelmann 1958). It is a deposit feeder (Ockelmann 1958).

Fossil occurrence: Lower Pleistocene: Hörgi Formation (J. Eiríksson 1981). Middle Pleistocene: Ossor and Kresta Suites (Merklin *et al.* 1962, Petrov 1966, 1982), Kotzebuan (Hopkins *et al.* 1972). *Y. intermedia* is considered to be of Atlantic origin (Bernard 1979), and the material from Kap København is the earliest record of this species.

Subclass Pteriomorphia Beurlen, 1944. Order Arcoida Stoliczka, 1871. Family Arcidae Lamarck, 1809. Genus *Bathyarca* Kobelt, 1891.

Bathyarca glacialis (Gray, 1824)

Fig. 19g.

1824 *Arca glacialis* Gray p. 224.

Material: Member B, unit B1, 59.2: one specimen with paired valves on stone core. Unit B2, 50.3: one right valve in concretion.

Kap Rigsdagen, 220.1: two umbonal fragments.

Recent distribution: Panarctic, bathyal in boreal areas. *Bathyarca glacialis* extends from Svalbard, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to Iceland and the eastern Finnmark (Ockelmann 1958). Empty shells have been reported south to the Bay of Biscay and in the Mediterranean (Jensen & Spärck 1934). In North

America it is reported living from the Beaufort Sea, the Canadian Arctic Archipelago, Hudson Bay, Baffin Bay, and the Labrador Sea to the Gulf of St. Lawrence (Bernard 1979, Lubinsky 1980). In West Greenland it is known from the Upernavik-Uummannaq area and the Qaqortoq/Julianehåb area (Thorson 1951). In North Greenland it is common in Jørgen Brønlund Fjord at 30-50 m depth (Schiøtte 1989) and sparsely present at 14.6 m depth off Kap København (Table 9). The species is of common occurrence along the whole East Greenland coast (Ockelmann 1958). Vertical range: From 5 m in Svalbard and East Greenland (Ockelmann 1958) to 916 m in the Baffin Bay (Clarke 1974), most common at depths from 40 to 400 m.

Ecology and biology: In East Greenland this epifaunal species is most abundant below 40 m connected with the *Astarte crenata* community (Thorson 1933, 1934). It is generally found on a bottom of clay with gravel and stones where it lives as a suspension feeder (Ockelmann 1958). The species has most probably lecitotrophic eggs and non-pelagic larval development (Ockelmann 1958).

Fossil occurrence: Middle Pleistocene: Middle Kresta Suite, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982), Pre-Cape Christian beds (Andrews *et al.* 1981). *B. glacialis* is considered to have originated in the Atlantic, and the sparse material from the Kap København Formation is the earliest record of this arctic species.

Order Mytiloidea Férussac, 1822. Family Mytilidae Rafinesque, 1815. Genus *Mytilus* Linné, 1758.

Mytilus edulis Linné, 1758

Figs 19h, 21-22.

1758 *Mytilus edulis* Linné p. 705.

Material: Member B, unit B2, 75.1: one fragmentary specimen with paired valves.

Remarks: The compressed specimen mea-

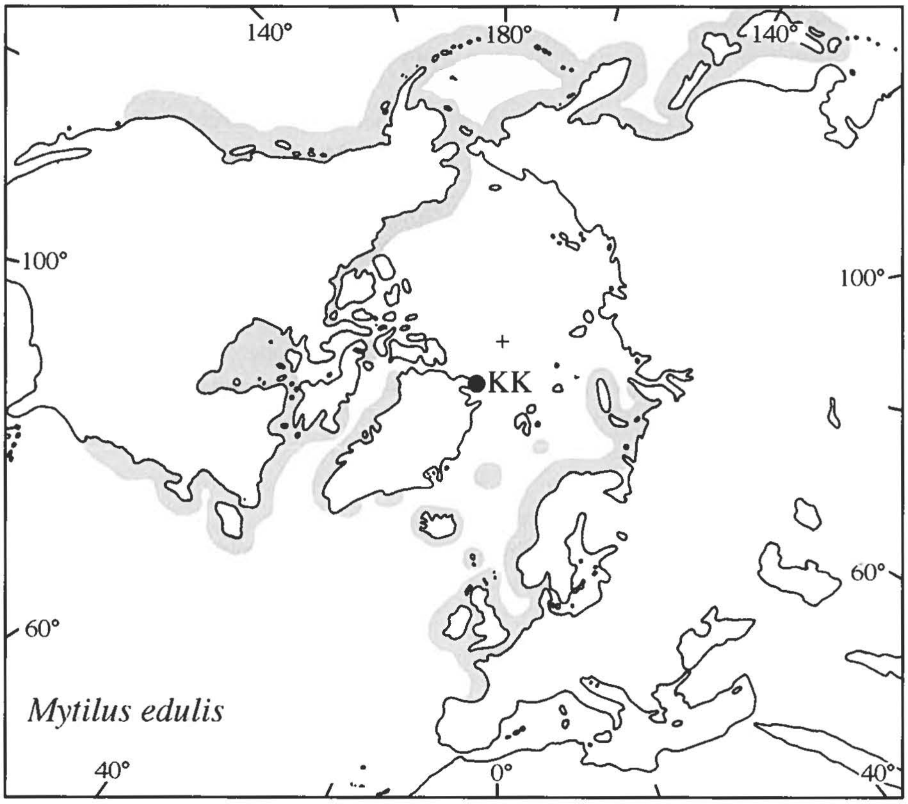

Fig. 21. Recent known geographical distribution of *Mytilus edulis* Linné. KK: Kap København.

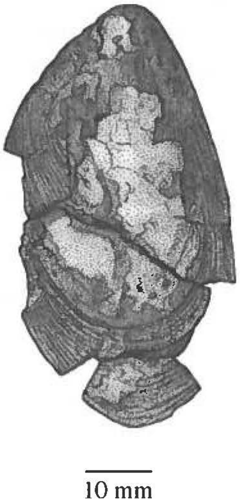

Fig. 22. *Mytilus edulis* Linné, right view of a fragmentary specimen from locality 75.1, MGUH 22311, GGU/GCI 56868. The same specimen is photographed Fig. 19h, but more incomplete.

sures (l x h): 62.7 x 34.5 mm. It is fractured, but with the fragments lying *in situ*. Remnants of periostracum are retained.

Recent distribution: Subarctic, boreal, lusitanian (Fig. 21). *Mytilus edulis* occurs from Jan Mayen, Iceland, Novaya Zemlya, and the western Kara Sea and Chuckchi Sea, where it is rare, south to the Bay of Biscay and Japan (Malatesta & Zarlenga 1986, Filatova 1957, Scarlato 1981). In North America it is known living from the Beaufort Sea, north to Victoria Island, Hudson Bay, Baffin Bay from Pond Inlet (isolated outpost), and Padloping Island south to Cape Hatteras and California (Ellis 1960, Bernard 1979, Lubinsky 1980). It is lacking from Svalbard, Franz Josef Land, and the Siberian Arctic Sea, however, it apparently lives again around Bjørnøya (J.M. Weslawski, personal communication 1997). In West Greenland the species has been collected from Dundas and Siorapaluk (close to 78° N) (Theisen 1973) and it extends along the West Greenland coast south to Qaqortoq/Julianehåb (H. Madsen 1940, Hjort & Funder 1974). In East Greenland it is known in the Ammassalik district and again further south near 61° N (Ockelmann 1958). Vertical range: 0 m (several localities) to 180 m (Jan Mayen) (Ockelmann 1958), most frequent at depths less than 10 m.

Ecology and biology: In East Greenland the young animals probably belong to the algal epifauna, whereas the adults belong to the epifauna associated with gravel, stones, and rocks (Ockelmann 1958). The species is mainly littoral-intertidal, attached to the substratum with byssus (Jensen & Spärck 1934). It belongs to the suspension feeders (Ockelmann 1958). Reproduction by pelagic larvae (Thorson 1936).

Fossil occurrence: ?Miocene: Blakeley Formation (Grant & Gale 1931). Pliocene: Tjörnes *Tapes*, *Mactra*, and *Serripes* Zones (Gladenkov *et al.* 1980), Red Crag (Wood 1872), Dienstian, Scaldisian (Heering 1950, Glibert 1957a). *Nassarius reticosus-Chlamys opercularis* Subzone of the Netherlands (Spaink 1975). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Ludhamnian (Norton 1967), Baventian (West *et al.* 1980), Merksenian (Heering 1950, Glibert 1957a), Emilian and Sicilian (Malatesta & Zarlenga 1986), Olkhov Suite (Petrov 1967, 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Anvilian (Hopkins *et al.* 1974).

M. edulis is considered to have originated in the Pacific (Durham & MacNeil 1967). The find of a single specimen of this gregarious animal in the Kap København Formation is indeed odd. However, since the general composition of the fauna indicates that the species could have lived in the area, we regard the species as synchronous with the rest of the fauna, although the specimen could have been washed to the site from adjacent areas.

Genus *Musculus* Röding, 1798.

Musculus niger (Gray, 1824)

Fig. 19i.

1824 *Modiola nigra* Gray p. 244.

Material: Member A, 59.1: one right valve.

Member B, unit B2, 75.1: 10 plate fragments with prismatic structure. Member B, 57.2: one specimen with paired valves in a concretion.

Recent distribution: Panarctic, boreal, circumpolar. *Musculus niger* extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to the western Baltic, the North Sea, and Japan (Ockelmann 1958). In North America it is distributed from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, and the Labrador Sea south to California and Cap Hatteras (Ockelmann 1958, Bernard 1979). In West Greenland it lives scattered along the coast north to 71°21' N (Thorson 1951). In North Greenland it was found here and there in Jørgen Brønlund Fjord at depths between 9 and 19 m (Schiøtte 1989). It is common along the East Greenland coast from Danmarkshavn in the north, however, it is rarely met with at depths exceeding 40 m (Ockelmann 1958). Vertical range: From 3 m in Novaya Zemlya to 376 m in West Greenland (Ockelmann 1958).

Ecology and biology: In East Greenland the species is epifaunal, generally occurring where the vegetation is scarce (Ockelmann 1958). It is probably a suspension feeder. The larval development is without any pelagic stage (Thorson 1935, 1936).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980). Lower Pleistocene: Hörgi Formation (J. Eiríksson 1981), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Alaska Unga Island (Grant & Gale 1931). Middle Pleistocene: Pinakul, Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982).

The species is considered to have originated in the Pacific (Durham & MacNeil 1967). Its appearance in the Kap København Formation seems to be slightly older than the Lower Pleistocene occurrences in the North Pacific and the North Atlantic, where they probably signify the earliest penetration of cold water southward to mid-latitudes.

Order Pterioida Newell, 1965. Family Pectinidae Rafinesque, 1815. Genus *Arctinula* Friele, 1935.

Arctinula greenlandica (Sowerby, 1842)

1842 *Pecten greenlandicus* Sowerby p. 57, pl. 3, fig. 40.

Material: Kap Rigsdagen, 200.2: two plate fragments (without umbo).

Reported also from Member B, locality 128 (Bennike 1989).

Recent distribution: Panarctic, circumpolar (except Beringia). *Arctinula greenlandica* is known from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, Laptev Sea, and the Siberian Arctic Sea south to North and East Iceland and the North Atlantic near 63° N (at great depth) (Filatova 1957, Ockelmann 1958). In North America it is known living from the Beaufort Sea, Ellesmere Island, Jones Sound, Baffin Bay, Hudson Bay, and the Labrador Sea south to Cape Cod (Bernard 1979, Lubinsky 1980). In West Greenland it has been found from Kap York in the north to Uummannaq in the south (Thorson 1951). In North Greenland it has been met with in Jørgen Brønlund Fjord and it is very common along the entire East Greenland coast especially at depths between 20 and 60-70 m (Ockelmann 1958). Vertical range: 1 m in North Greenland (Schiøtte 1989) to 2560 m in the Beaufort Sea (Bernard 1979).

Ecology and biology: In East Greenland this suspension feeder prefers a clayey bottom with gravel, stones, and shells, especially in the lower *Ophiocten* Zone of the Arctic *Macoma* community (Thorson 1933, Ockelmann 1958). The pelagic larval stage is very short or lacking (Thorson 1936).

Fossil occurrence: Miocene/Pliocene: Sagavanirktok Formation, Nuwok Member (MacNeil 1957, Repenning *et al.* 1987). Plio/Pleistocene: Lodin Elv Formation (Feyling-Hanssen *et al.* 1983). Lower Pleistocene: Hörgi Formation (J. Eiríksson 1981), *Hyalinea baltica* deposits of the Emilian (Malatesta & Zarlenga 1986), Pattorfik beds (Símonarson 1981). Middle

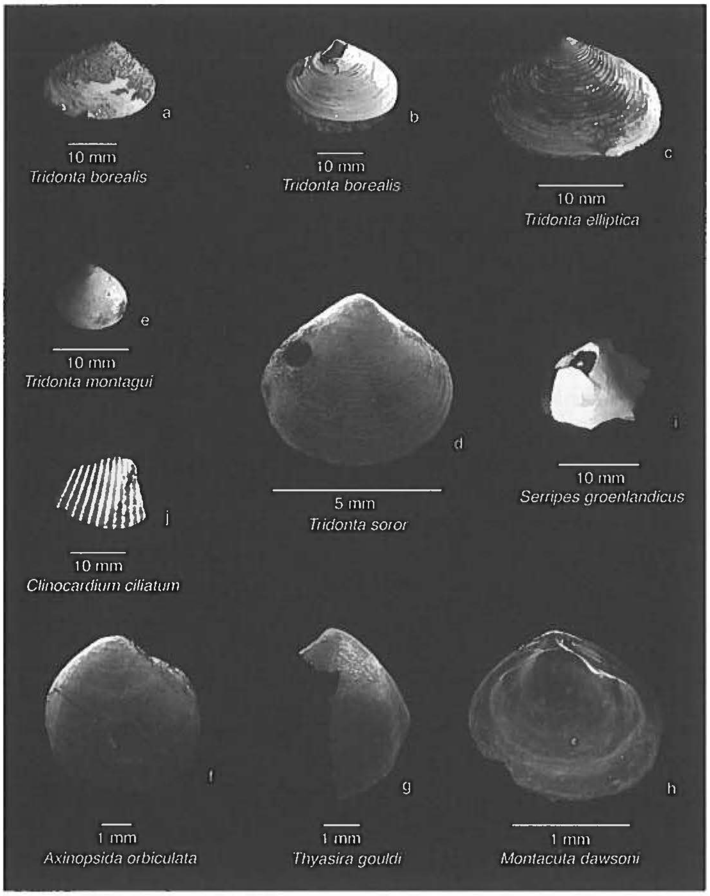

Fig. 23. a-b: *Tridonta borealis* Schumacher. a: right valve from locality 75.1, MGUH 22313, GGU/GCI 56868. b: left valve from locality 50.3, MGUH 22314, GGU/GCI 197151. c: *Tridonta elliptica* (Brown), left valve from locality 27.1, MGUH 22315, GGU/GCI 56832. d: *Tridonta soror* (Dall), right valve from locality 72.1, MGUH 22316, GGU/GCI 56859. e: *Tridonta montagui* (Dillwyn), left valve from locality 74.1, MGUH 22317, GGU/GCI 56874. f: *Axinopsida orbiculata* (G.O. Sars), right valve from locality 27.1, MGUH 22320, GGU/GCI 56831. g: *Thyasira gouldi* (Philippi), fragmentary left valve from locality 27.1, MGUH 22321, GGU/GCI 56831. h: *Montacuta dawsoni* Jeffreys, left valve from locality 73.1, MGUH 22322, GGU/GCI 56863. i: *Serripes groenlandicus* (Mohr), umbonal fragment of right valve from locality 59.2, MGUH 22323, GGU/GCI 56661. j: *Clinocardium ciliatum* (Fabricius), plate fragment from locality 75.1, MGUH 22324, GGU/GCI 56868.

Pleistocene: Kolvin and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Pre-Cape Christian beds (Andrews *et al.* 1981). The species is considered to have originated in the Atlantic (Durham & MacNeil 1967) and apart from its early appearance in Alaska, its evolutionary history took place in the Atlantic.

Subclass Heterodonta Neumayr, 1884. Order Veneroida Adams & Adams, 1856. Family Astartidae d'Orbigny, 1844. Genus *Tridonta* Schumacher, 1817.
Tridonta borealis Schumacher, 1817
Fig. 23a-b.
1817 *Tridonta borealis* Schumacher p. 47, pl. 17, fig. 1.
Material: Member B, unit B1, 50.2: one umbonal fragment and several plate fragments, 59.2: 29 left valves, 30 right valves, and 15 umbonal fragments, 69.1: one left valve, one right valve, four umbonal and many plate fragments, 74.1: one specimen with paired valves, one left and seven right valves. Unit B2, 3.1: one left valve and two umbonal fragments, 27.1: one specimen with paired valves (juvenile), two umbonal and many plate fragments with periostracum, 48.1: five umbonal and several plate fragments, 50.3: two specimens with paired valves, one left valve, one right valve, and 24 umbonal fragments, 72.1: four umbonal fragments, 73.1: one umbonal fragment and several plate fragments, 73.2: one umbonal fragment, 75.1: seven left valves, five right valves, and 25 umbonal fragments. Unit B3, 50.4: two umbonal and several plate fragments. Member B, 57.2: 27 left valves, 21 right valves, and six umbonal fragments, locality 128: one specimen with paired valves (juvenile).
The allochthonous fauna assemblage, 10.1: two specimens with paired valves, 33.1: two umbonal and many plate fragments

with periostracum, 43.1: one umbonal fragment, 53.1: one umbonal fragment, 57.1: two umbonal and several plate fragments, 59.3: one left valve and several plate fragments, 64.1: one umbonal fragment, 70.1: three plate fragments, 86.1: two umbonal and many plate fragments, 96.1: one umbonal and many plate fragments, 107.1: one umbonal and several plate fragments, 108.1: some plate fragments. Samples 10.1, 43.1, 70.1, 86.1, 96.1, 107.1, and 108.1 contain several thick plate fragments without umbo, but they cannot with certainty be distinguished from those of *Arctica islandica.*

Kap Rigsdagen, 200.1: four left valves, five right valves, and 15 umbonal fragments.

Remarks: Length (l) and height (h) were measured for the five largest valves and the h/l ratios calculated:

l in mm	h in mm	h/l
32.5	24.0	0.74
31.6	24.1	0.76
29.8	20.9	0.70
28.9	20.0	0.69
28.8	20.9	0.73

The maximum sizes are smaller than those measured on present-day East Greenland populations which grow to between 40 and 50 mm, whereas the h/l ratios are the same (Ockelmann 1958). Juvenile shells occur frequently. Shells bored by carnivorous gastropods were found in all units.

Recent distribution: Panarctic, boreal, circumpolar. *Tridonta borealis* extends from Franz Josef Land, Novaya Zemlya, the Kara Sea, the Siberian Arctic Sea, the Beaufort Sea, the Bering Strait, Parry Islands, and Ellesmere Island southward to northern Japan, the Gulf of Alaska, Massachusetts, Iceland, and the Baltic (Ockelmann 1958). In West Greenland the species is known from Iita in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In North Greenland it is common in Jørgen Brønlund Fjord at depths between 6 and 16 m (Schiøtte 1989) and it was frequently found at 14.6 m depth off Kap København (Table 9). It is common along the East Greenland coast south to Lindenow Fjord, especially at depths of less than 30 m (Ockelmann 1958). Vertical range: From 0 m in East Finnmark to 463 m north of Svalbard, but empty shells have been found down to 2710 m in the North Atlantic (Ockelmann 1958).

Ecology and biology: In East Greenland it lives as a suspension feeder on a substratum that varies from clayey to stony bottom and is abundant in the *Gomphina fluctuosa* and the Arctic *Macoma* communities (Thorson 1933, 1934, Ockelmann 1958). The larval development is probably lecithotrophic with a very short pelagic stage (Thorson 1936).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980). Plio/Pleistocene: Lodin Elv Formation (Feyling-Hanssen *et al.* 1983), Omma-Manganji Fauna, Honshu (Chinzei 1978). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Pre-Pastonian (Funnell *et al.* 1979), Icenian of the Netherlands (*Astarte semisulcata*; Heering 1950), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982, 1986), Pattorfik beds (Símonarson 1981), Gubik Formation, Fishcreekian (Repenning *et al.* 1987). Middle Pleistocene: Pinakul, Kresta, Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972).

T. borealis is as the majority of Astartidae considered to have originated in the Atlantic (Durham & MacNeil 1967, Bernard 1979). The records from Japan and the Fish Creek Fauna of the Fishcreekian show that it belongs to the early immigrants in the North Pacific.

Tridonta elliptica (Brown, 1827)

Fig. 23c.

1827 *Crassina elliptica* Brown pl. 18, fig. 3.

Material: Member B, unit B1, 74.1: one right valve. Unit B2, 27.1: two specimens with paired valves, two left valves, two right valves, and seven umbonal fragments, 50.3: one specimen with paired valves, 72.1: four umbonal fragments. Member B, 57.2: one left and two right valves.

Remarks: Length (l), height (h), and breadth (b) were measured for the three largest valves and the h/l ratios calculated:

l in mm	h in mm	b in mm	h/l
20.9	15.0	3.5	0.72
7.2	5.4	1.2	0.75
4.8	3.7		0.77

The average length in the present day East Greenland populations is betweem 30 and 35 mm (Ockelmann 1958).

Recent distribution: Panarctic, boreal. *Tridonta elliptica* occurs from Svalbard, Franz Josef Land, Novaya Zemlya, and the Kara Sea southward to the British Isles and the western Baltic (Ockelmann 1958). In eastern North America it is known from Smith Sund and Baffin Bay south to Massachusetts (Lubinsky 1980). In West Greenland the species has been found from Qimusseriarsuaq/Melville Bugt in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In North Greenland it was not found in Jørgen Brønlund Fjord (Schiøtte 1989), but dredged at 6.5 and 14.6 m depths off Kap København (Table 9). It is known in East Greenland from Île de France in the north southward to Lindenow Fjord where it is most abundant at depths below 50 m along the southernmost coast (Ockelmann 1958). Vertical range: From 2 m in East Greenland to 442 m in West Greenland (Ockelmann 1958).

Ecology and biology: In East Greenland it lives as a suspension feeder where the substratum is mainly mud, clay, and sand in the Arctic *Macoma* community (Thorson 1933, Ockelmann 1958). The larval development is lecithotropic, the pelagic larval stage either very short or lacking (Thorson 1936).

Fossil occurrence: Plio/Pleistocene: Tugidak Formation (Allison 1978). Lower Pleistocene: Hörgi Formation (J. Eiríksson 1981), Pre-Pastonian (Funnell *et al.* 1979), Pattorfik beds (Símonarson 1981), Yakataga Formation, Middleton Island (Allison 1978). Middle Pleistocene: Kolvin and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Pre-Cape Christian beds (Andrews *et al.* 1981).

The species was reported from the Pliocene of Belgium, the Netherlands, ?France, and Italy by Heering (1950) as *Astarte sulcata* (da Costa, 1778) var. *elliptica*, but this was contested by Glibert (1957b), who referred the specimens to the related but extinct *Astarte basterotti* Jonkaire, 1823, which is known also from the Pliocene *Serripes* Zone of the Tjörnes beds in Iceland (Gladenkov *et al.* 1980). In the Bering Sea region the closely related *A. alaskensis* Dall, 1903 is known from the Tusatuva-Yamsk and Kresta Suites (Petrov 1982, Merklin *et al.* 1962). *T. elliptica* apparently originated in the Atlantic, but migrated to the North Pacific, during an early opening of the Bering Strait (Durham & MacNeil 1967).

Tridonta soror (Dall, 1903)

Figs 23d, 24.

1903 *Astarte soror* Dall p. 947, pl. 62, fig. 11.

Material: Member B, unit B2, 72.1: one right valve.

Remarks: The valve is bored by a carnivorous gastropod. It measures 5.8 mm in length and 5.0 mm in height.

Recent distribution: ?Panarctic (Fig. 24). *Tridonta soror* seems to be endemic in the Baffin Bay-Labrador Sea region (Lubinsky 1980). In Greenland it is known from Smith Sund and it was originally described by Dall (1903) from Disko Bugt. Vertical range: 8-150 m (La Rocque 1953).

Fossil occurrence: Middle Pleistocene: Einahnuhtan (*Astarte* sp. cf. *A. soror*; Hopkins 1967). The species is new to the fossil fauna of Greenland, and the valve is the earliest known.

Tridonta montagui (Dillwyn, 1817)

Fig. 23e.

1817 *Venus montagui* Dillwyn p. 167

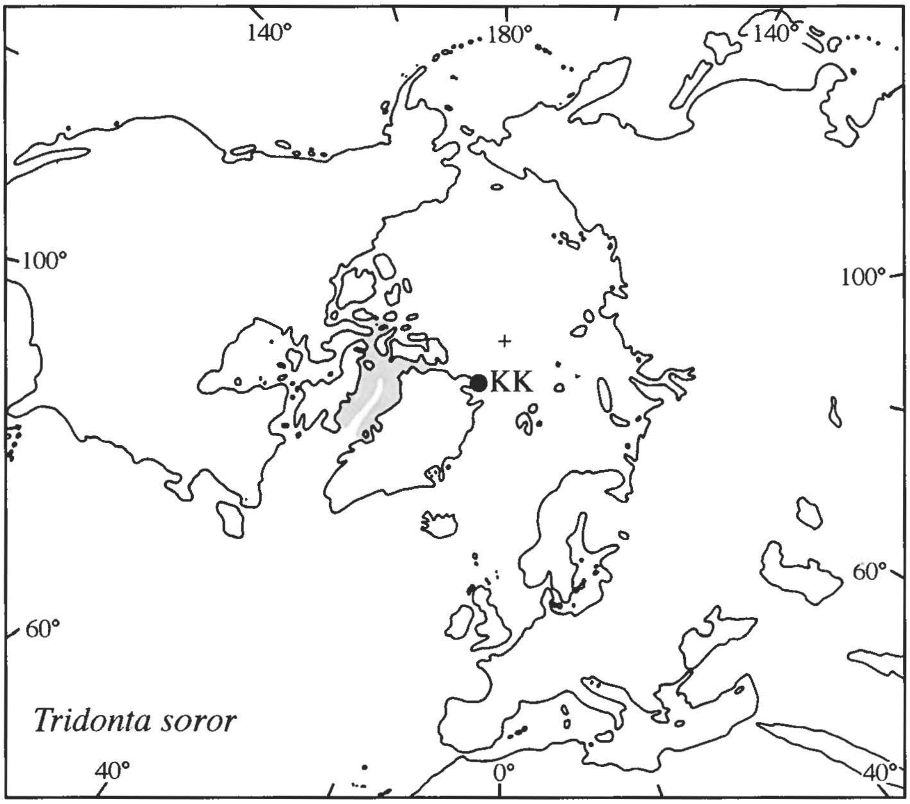

Fig. 24. Recent known geographical distribution of *Tridonta soror* (Dall). KK: Kap København.

Material: Member A, 51.1: one fragmentary specimen with paired valves.
Member B, unit B1, 74.1: four left valves.
The allochthonous fauna assemblage, 116.1: one right valve and one umbonal fragment.
Remarks: Length (l), height (h), and breadth (b) were measured for the specimen from Member A and the five valves from Member B and the h/l and b/l ratios calculated:

l in mm	h in mm	b in mm	h/l	b/l
21.6	15.9	9.9	0.74	0.46
14.5	11.9		0.82	
8.0	7.6		0.95	
7.8	7.1		0.91	
7.1	6.8		0.96	
7.0	6.8		0.97	

The size is considerably smaller than the maximum sizes recorded elsewhere with lengths between 20 and 30 mm (Odhner 1915). The h/l and b/l ratios for the specimen from Member A (the first in the list) are comparable to those for the recent shell variety *warhami* (Hancock, 1846), whereas these ratios for the valves from Member B are closer to those for the recent variety *striata* (Leach, 1819) in East Greenland (Ockelmann 1958).

The species is variable and from the shape of the shell it has been divided into a number of forms or shell varieties (Ockelmann 1958), subspecies (Filatova 1957, Scarlato 1981), or even species (Lubinsky, 1980). The material from Kap København is not large enough to allow further differentiation.

Recent distribution: Panarctic, boreal, circumpolar. *Tridonta montagui* occurs from Franz Josef Land, Novaya Zemlya, the Kara Sea, the Siberian Arctic Sea, the Beaufort Sea, and Ellesmere Island southward to the Aleutians, northern Japan, Massachusetts, the British Isles, Denmark, and the western Baltic (Ockelmann 1958, Bernard 1979). In West Greenland it has been found from

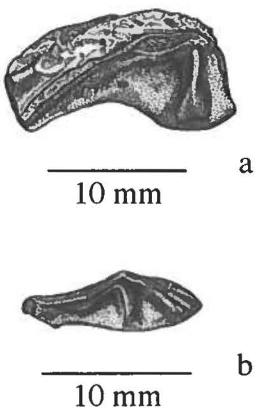

Fig. 25 a-b.: *Arctica islandica* (Linné). a: umbonal fragment from locality 10.1, MGUH 22318, GGU/GCI 223267. b: umbonal fragment from locality 33.1, MGUH 22319, GGU/GCI 56513.

Foulke Fjord in the north to Qaqortoq/Julianehåb in the south (Thorson 1951). In North Greenland the shell variety *warhami* (Hancock, 1846) is common in Jørgen Brønlund Fjord at depths between 6 and 16 m (Schiøtte 1989) and is also present at 14.6 m depth off Kap København (Table 9). It is common along the East Greenland coast south to Lindenow Fjord (Ockelmann 1958). Vertical range: From 0 m in the western Baltic (Ockelmann 1958) to 455 m in the Beaufort Sea (Bernard 1979).

Ecology and biology: In East Greenland this suspension feeder lives on a bottom varying from mud to rocks and is common in the Arctic *Macoma* community, as well as in the *Gomphina fluctuosa* community, and may also occur in the *Astarte crenata* community (Thorson 1933, 1934, Ockelmann 1958). The larval development is lecithotropic with a very short or lacking pelagic stage (Thorson 1936).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980). Plio/Pleistocene: Tugidak Formation (Allison 1978). Lower Pleistocene: Hörgi Formation (J. Eiríksson 1981), Baventian (West *et al.* 1980), Pre-Pastonian (Funnell *et al.* 1979), Icenian of the Netherlands (Heering 1950), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981), Yakataga Formation, Middleton Island (Allison 1978). Middle Pleistocene: Pinakul, Kresta, Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982), Pre-Cape Christian beds (Andrews *et al.* 1981), Kotzebuan (Hopkins *et al.* 1972).

The fossil record shows that together with many other northern mollusc species, it became widespread both in the North Atlantic and the North Pacific in the Upper Pliocene and Lower Pleistocene.

Family Arcticidae Newton, 1891. Genus *Arctica* Schumacher, 1817.

Arctica islandica (Linné, 1767)

Figs 25a-b, 26.

1767 *Venus islandica* Linné p. 1131.

Material: The allochthonous fauna assemblage, 10.1: four umbonal fragments, 33.1: three umbonal fragments, 39.1: one specimen with stone core, 43.1: three umbonal fragments, 57.1: one umbonal fragment and several plate fragments, 64.1: one umbonal fragment and several plate fragments, 86.1: one umbonal fragment and several plate fragments, 107.1: one umbonal fragment, 108.1: two umbonal fragments.

The material consists only of worn fragments and identification is only possible with certainty when the umbonal part is preserved. Plate fragments, i.e. shell fragments without umbo, are difficult to separate from those of *Tridonta borealis.*

Recent distribution: Subarctic, boreal, lusitanian (Fig. 26). *Arctica islandica* is amphiatlantic and extends from Newfoundland, the southeastern Barents Sea, and the Spitsbergen Bank in the north to North Carolina and Portugal in the south (F.J. Madsen 1949, Zenkevitch 1963, Funder & Weidick 1991). The occurrence on the Spitsbergen Bank is controlled by the warm Gulf Stream and in the Barents Sea the species occurs in areas with summer temperatures above 6°C (Zenkevitch 1963, Funder & Weidick 1991). In North America its concentration peak is in the Rhode Island area and in Europe it is rare in the lusitanian region (Malatesta & Zarlenga 1986). The species is absent from Greenland waters today, but has lived in West Greenland during milder Holocene time

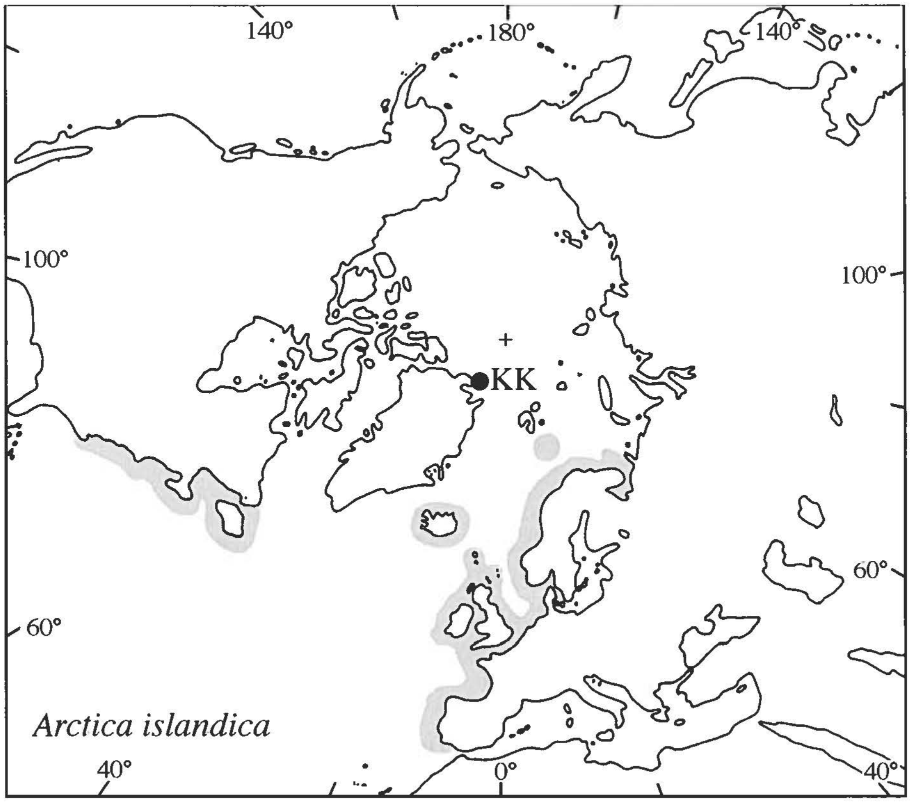

Fig. 26. Recent known geographical distribution of *Arctica islandica* (Linné). KK: Kap København.

from c. 7.500 yr to slightly after 5.000 yr (Kelly 1986, Funder 1989). Vertical range: From 0 m in the British Isles (Tebble 1966) to 2000 m, juvenile specimens west of Ireland (F.J. Madsen 1949). In Iceland it is most abundant at depths between 10 and 90 m (H. Eiríksson 1988).

Ecology and biology: In the British Isles the species lives on firm bottom of sand and muddy sand from low in the intertidal zone to considerable depths (Tebble 1966). In Iceland the belongs to the infauna in sandy bottom from a depth of 3-5 m to about 100 m in the *Spisula elliptica* community (Spärck 1937, F.J. Madsen 1949). However, in Iceland this suspension feeder prefers depths just below the low water mark, in the winter it burrows shallow in the bottom, but in the summer it is lying in abundance on the bottom ground (F.J. Madsen 1949, H. Eiríksson 1988). The planktotrophic larvae have a rather long pelagic stage (Jørgensen 1946).

Fossil occurrence: ?Oligocene: Hungary (Malatesta & Zarlenga 1986). Miocene: Lenham beds (Harmer 1900), Anversian (Glibert 1957a). Miocene/Pliocene: *Arcoperna sericea-Chlamys tigerinus* Zone of the Netherlands (Spaink 1975). Pliocene: Tjörnes *Tapes*, *Mactra*, and *Serripes* Zones (Gladenkov *et al.* 1980), Coralline Crag (Harmer 1900), Scaldisian (Heering 1950). Lower Pleistocene: Threngingar and Máná Formations (J. Eiríksson 1981), Ludhamnian (Norton 1967), Baventian (West *et al.* 1980), *Serripes groenlandicus-Yoldia lanceolata* Zone of the Netherlands (Spaink 1975), Santernian, Emilian, and Sicilian (Malatesta & Zarlenga 1986), Yakataga Formation, Middleton Island (Allison 1978). Middle Pleistocene: Kolvin and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982).

Family Thyasiridae Dall, 1901. Genus *Axinopsida* Kenn & Chavan, 1951.

Axinopsida orbiculata (G.O. Sars, 1878) Fig. 23f.

1878 *Axinopsis orbiculata* G.O. Sars p. 63, pl. 19, fig. 11.

Material: Member B, unit B2, 3.1: one

right valve and one umbonal fragment, 27.1: one specimen with paired valves and one umbonal fragment, 75.1: one umbonal fragment. Member B, 57.2: one right valve.
Remarks: Length (l), height (h), and breadth (b) were measured for the two largest valves and the h/l ratios calculated:

l in mm	h in mm	b in mm	h/l
4.8	5.0	1.7	1.04
4.2	4.5	1.3	1.07

The shells are of similar size as the largest ones in the present East Greenland populations (Ockelmann 1958).
Recent distribution: Panarctic, boreal. *Axinopsida orbiculata* extends from Svalbard, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to north of the Hebrides and Bodø (Norway) (Ockelmann 1958, Høisæter 1986). In North America it is known from the Beaufort Sea, the Canadian Arctic Archipelago, Hudson Bay, and the Labrador Sea south to Cape Cod (Bernard 1979, Lubinsky 1980). In West Greenland the species occurs from Uummannaq in the north to Paamiut/Frederikshåb in the south (Thorson 1951). In North Greenland it is common in Jørgen Brønlund Fjord at depths of 9-12 m (Schiøtte 1989). It is distributed along the entire coast of East Greenland especially at depths not exceeding 50-70 m (Ockelmann 1958). Vertical range: From 2 m at several localities in the Arctic to 944 m north of the Hebrides (Ockelmann 1958).
Ecology and biology: In East Greenland this suspension feeder prefers a bottom of silt in the Arctic *Macoma* and the *Gomphina fluctuosa* communities or the *Yoldia hyperborea* community in Lindenow Fjord (45-48 m on clay bottom) (Ockelmann 1958). The larval stage of the lecithotrophic larvae is very short or lacking (Ockelmann 1958).
Fossil occurrence: Pliocene: Plio/Pleistocene: Tugidak Formation (*A.* cf. *A. orbiculata* (Allison 1978)). Lower Pleistocene: Olkhov Suite (Petrov 1982), Pattorfik beds (Símonarson 1981), Fishcreekian (Repenning *et al.* 1987).

A. orbiculata is considered to have originated in the Pacific (Bernard 1979). Its occurrence in the Kap København Formation is the earliest in the Atlantic, showing that it is an early immigrant there.

Genus *Thyasira* Leach, 1818.
Thyasira gouldi (Philippi, 1845)
Fig. 23g.
1845 *Lucina gouldii* Philippi p. 74, pl. 2, fig. 7.
Material: Member B, unit B2, 27.1: one umbonal fragment of a left valve, 50.3: stone core with shell fragments attached.
Recent distribution: Panarctic, boreal, ?circumpolar. *Thyasira gouldi* occurs from the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea (to about 184° E) southward to the Faeroe Islands and western Norway near Bodø (Ockelmann 1958, Høisæter 1986). In North America it is known from the Beaufort Sea, the southern part of the Canadian Arctic Archipelago, Hudson Bay, and the Labrador Sea south to Massachusetts and southern California (Bernard 1979, Lubinsky 1980). In West Greenland it is living along the coast to Qaanaaq/Thule in the north at depths exceeding 10-15 m (Ockelmann 1958). In North Greenland it is common in Jørgen Brønlund Fjord at depths of 8-16 m (Schiøtte 1989). It is common in East Greenland south to Lindenow Fjord (Ockelmann 1958). Vertical range: From 2 m in East Greenland to 1590 m in British Columbia (Nordsieck 1969).
Ecology and biology: In East Greenland the species lives as a suspension feeder on various types of bottom, but most frequently it was found in a bottom of clay or mud in the Arctic *Macoma* community (Ockelmann 1958). The larval development is lecithotrophic with a very short or lacking pelagic stage (Ockelmann 1958)
Fossil occurrence: Pliocene: San Diego Formation (Grant & Gale 1931). Lower Pleistocene: Olkhov Suite (Petrov 1982). Middle Pleistocene: Kresta Suite (Petrov 1966).

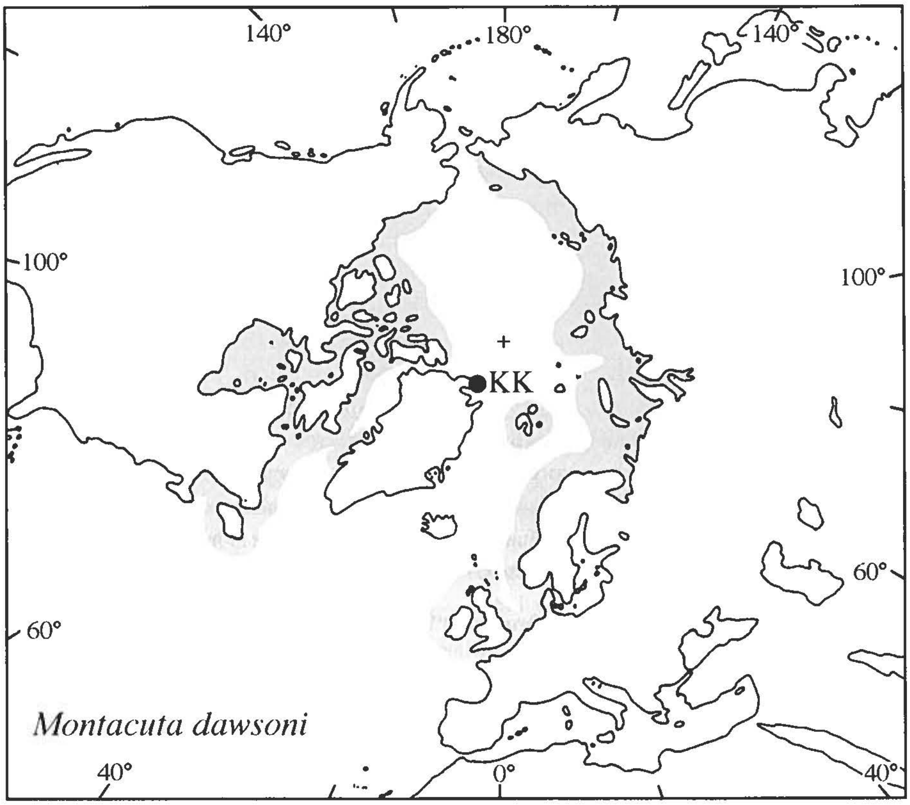

Fig. 27. Recent known geographical distribution of *Montacuta dawsoni* Jeffreys. KK: Kap København.

Bernard (1979) considered *T. tokunagai* Kuroda & Habe, 1951 and *T. wajampolkana* Krishtofovich, 1936 from the Tertiary of Japan and the Pliocene of Kamchatka as synonym with *T. gouldi*. Although the early records of this small bivalve apparently come from the Pacific, it has generally been considered to have originated in the Atlantic (Durham & MacNeil 1967, Bernard 1979).

Family Montacutidae Clark, 1855. Genus *Montacuta* Turton 1822.

Montacuta dawsoni Jeffreys, 1863

Figs 23h, 27.

1863 *Montacuta dawsoni* Jeffreys p. 216.

Material: Member B, unit B2, 73.1: one left valve.

Remarks: The valve is 1.7 mm long and 1.4 mm high.

Discussion: Most probably *Montacuta maltzani* Verkrüzen, 1876 is a synonym (see also Bernard 1979). Although it has not been possible to confirm this, *M. dawsoni* and *M. maltzani* will be treated here as one and the same species.

Recent distribution: Panarctic, boreal, circumpolar (Fig. 27). *Montacuta dawsoni* extends from Svalbard, the Barents Sea, Novaya Zemlya, and the Siberian Arctic Sea southward to the British Isles (F.J. Madsen 1949, Bernard 1979). In North America it is known from the Arctic Canadian Archipelago and Baffin Bay south to Point Barrow and New Brunswick (Bernard 1979). It is lacking from the Pacific and Bering Sea. In West Greenland it is known from the Qeqertarsuaq/Godhavn, Aasiaat/Egedesminde, Sisimiut/Holsteinsborg, and Nuuk/Godthåb areas (Thorson 1951). The species is not known from East Greenland. Vertical range: From 5 m in West Greenland (Posselt & Jensen 1898) to 3150 m in Svalbard (Odhner 1915).

Ecology: In West Greenland the species is mainly found in sandy bottom (Posselt & Jensen 1898). This small bivalve is sometimes attached to echinoderms (Nordsieck 1969).

Fossil occurrence: The species has recently been recorded in deposits from the last interglacialation at Langelandselv, Jameson

Land, East Greenland (Vosgerau *et al.* 1994). The occurrence in the Kap København Formation seems to be the earliest known appearance of the species.

Family Cardiidae Lamarck, 1809. Genus *Serripes* Gould, 1841.
Serripes groenlandicus (Mohr, 1786)
Fig. 23i.
1786 *Cardium grönlandicum* Mohr p. 129.
Material: Member B, unit B1, 59.2: one umbonal fragment, 74.1: two umbonal fragments. Unit B2, 73.2: two umbonal fragments, 75.1: six umbonal fragments. Member B, 57.2: 13 umbonal fragments, locality 128: 22 umbonal and several plate fragments.
The allochthonous fauna assemblage, 70.1: one umbonal and several plate fragments, 96.1: one umbonal and several plate fragments.
Remarks: The shell material is very fragmented and almost exclusively of umbonal and plate fragments.
Discussion: Warén (1993) has pointed out that the original binominal description of the species is that of Mohr (1786) and not the almost always cited decription of Bruguière (1789). The still older description of Chemnitz (1782) is not binominal.
Recent distribution: Panarctic, high boreal, circumpolar. *Serripes groenlandicus* occurs from Svalbard, Frans Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea south to South Iceland, Finnmark, and Japan (Ockelmann 1958). In North America it is known from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, Hudson Bay, and the Labrador Sea southward to Cape Cod and Oregon (Bernard 1979, Lubinsky 1980). In West Greenland the species is known along the coast to Iita in the north (Thorson 1951). It lives in East Greenland from Danmarkshavn in the north south to Lindenow Fjord at depts less than 70 m (Ockelmann 1958). Vertical range: From 0 m in Iceland (F.J. Madsen 1949) to 303 m in West Greenland (Ockelmann 1958).
Ecology and biology: In East Greenland this suspension feeder has been found in a bottom of mud, clay, silt, sand, and gravel, but it seems to prefer silt or sand. Here it lives mainly in the *Gomphina fluctuosa* community as well as in the transitional zones between this and the Arctic *Macoma* community (Thorson 1933, 1934, Ockelmann 1958). The larval development is apparently planktotrophic with a pelagic stage (Thorson 1936, Ockelmann 1958).
Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Red Crag (Harmer 1925), Amstelian (Heering 1950). Plio/Pleistocene: Omma-Manganji Fauna (Chinzei 1978). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Baventian (West *et al.* 1980), *Serripes groenlandicus-Yoldia lanceolata* Zone of the Netherlands (Spaink 1975), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981), Gubik Formation, Fishcreekian (Repenning *et al.* 1987). Middle Pleistocene: Pinakul, Kresta, Karagin, Kolvin, and Padymenskii Suites (Merklin *et al.* 1962, 1979), Pre-Cape Christian beds (Andrews *et al.* 1981), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972). It is considered to have originated in the Pacific and migrated into the North Atlantic about 3.5 Ma ago (Durham & MacNeil 1967). In the Atlantic it occurs in great abundance in deposits from the Upper Pliocene and Lower Pleistocene and has given name to the *Serripes* Zones in Iceland, Britain, and Holland.

Genus *Clinocardium* Keen, 1936.
Clinocardium ciliatum (Fabricius, 1780)
Fig. 23j.
1780 *Cardium ciliatum* Fabricius p. 410.
Material: Member B, unit B1, 74.1: two umbonal fragments. Unit B2, 72.1: three umbonal fragments, 75.1: two umbonal fragments. Member B, locality 128: two umbonal and several plate fragments.
Remarks: The shell material is very fragmented, exclusively consisting of umbonal and plate fragments.
Recent distribution: Panarctic, high boreal,

?circumpolar. *Clinocardium ciliatum* extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to South Iceland, East Finnmark, and northern Japan (Ockelmann 1958). In North America it is known from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, Hudson Bay, and the Labrador Sea south to Cape Cod and the Gulf of Alaska (Bernard 1979, Lubinsky 1980). In West Greenland the species is living along the coast to Iita in the north (Thorson 1951). It is common in East Greenland from Clavering Ø in the north to Lindenow Fjord in the south (Ockelmann 1958). Vertical range: From 0 m in Iceland (Óskarsson 1964) to 677 m in West Greenland (Ockelmann 1958).

Ecology and biology: In East Greenland the species prefers more clayey bottom than *S. groenlandicus*, and here this suspension feeder is mainly found in the Arctic *Macoma* community and the transitional zones between this and the adjoining communities (Thorson 1933, 1934, Ockelmann 1958). The larval development is apparently lecithotrophic with a very short or lacking pelagic stage (Thorson 1936).

Fossil occurrence: Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980). Plio/Pleistocene: Lodin Elv Formation (Feyling-Hanssen *et al.* 1983). Lower Pleistocene: Threngingar and Máná Formations (J. Eiríksson 1981), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981), Gubik Formation, Fishcreekian (Repenning *et al.* 1987). Middle Pleistocene: Pinakul, Kolvin, Kresta, Karagin, and Padymeiskii Suites (Petrov 1982, Merklin *et al.* 1962, 1979), Pre-Cape Christian beds (Andrews *et al.* 1981), Kotzebuan (Hopkins *et al.* 1972).

Family Tellinidae de Blainville, 1814.
Genus *Macoma* Leach, 1819.
Macoma calcarea (Gmelin, 1790)
Fig. 28a-b.

1790 *Tellina calcarea* Gmelin p. 3236.

Material: Member B, unit B1, 74.1: two right valves and 21 umbonal fragments. Unit B2, 27.1: 28 umbonal fragments, 50.3: two umbonal fragments, 72.1: 16 umbonal fragments, 75.1: 15 umbonal fragments. Member B, locality 128: three right valves and 78 umbonal fragments.

Remarks: The shell material is very fragmented, mainly consisting of umbonal and plate fragments. Length (l) and height (h) were measured for the three largest undamaged valves and the h/l ratios calculated:

l in mm	h in mm	h/l
22.9	16.0	0.70
21.0	16.0	0.76
20.5	14.9	0.73

The valves have considerably smaller maximum lengths than recent populations of *M. calcarea* in East Greenland, which are up to 40-44 mm (Ockelmann 1958).

Recent distribution: Panarctic, boreal, circumpolar. *Macoma calcarea* is known from all arctic seas and extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to the Faeroe Islands and northern Japan. (Ockelmann 1958, G.H. Petersen 1968). The occurrence in the Oslofjord, Kattegat, and the Baltic seems isolated and has been considered a relic by some authors (C.G.J. Petersen 1888, Jensen 1905). In North America it occurs in the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, Hudson Bay, and the Labrador Sea south to New Jersey and Washington (Bernard 1979, Lubinsky 1980). In West Greenland it lives along the coast to Iita in the north (Thorson 1951). In North Greenland it is common in Jørgen Brønlund Fjord at depths between 2 and 16 m (Schiøtte 1989). It is common along the East Greenland coast, however, not found in the Kangerlussuaq area (Ockelmann 1958). Vertical range: From 0 m in Iceland (F.J. Madsen 1949) to 677 m in West Greenland (Ockelmann 1958).

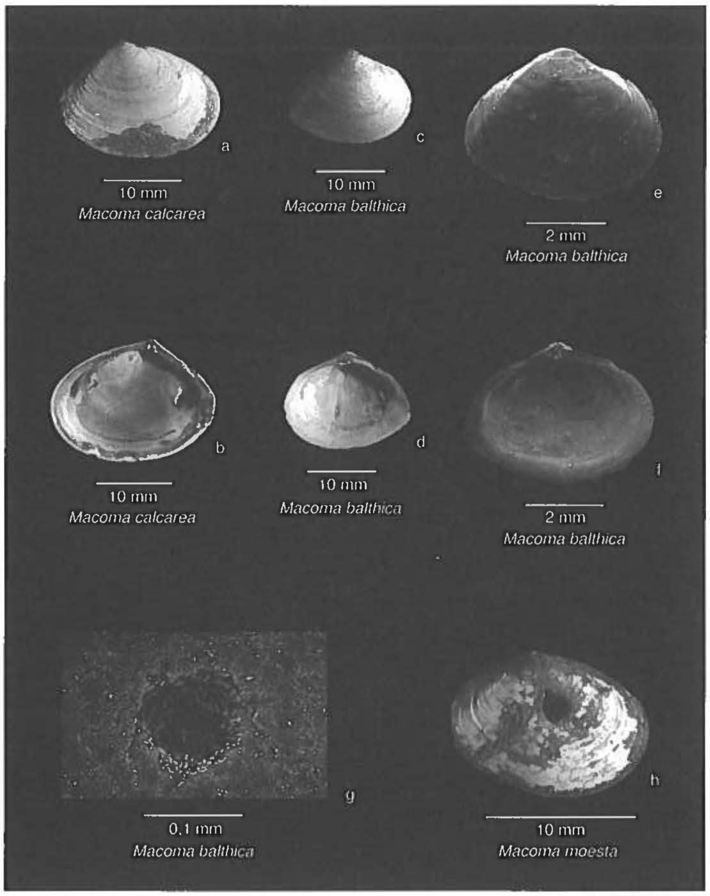

Fig. 28. a-b: *Macoma calcarea* (Gmelin), right valve from locality 74.1, MGUH 22325, GGU/GCI 56874. c-g: *Macoma balthica* (Linné). c-d: right valve from locality 68.1, MGUH 22326, GGU/GCI 56541. e-f: juvenile right valve from locality 68.1, MGUH 22327, GGU/GCI 57504. g: boring in valve from locality 68.1, MGUH 22328, GGU/GCI 57504. h: *Macoma moesta* (Deshayes), right valve with boring from locality 27.1, MGUH 22329, GGU/GCI 56866.

Ecology and biology: In East Greenland this species lives mainly in the fjords in shallow water as a deposit feeder on a bottom of clay or mud which may be mixed with sand, gravel, and stones (Ockelmann 1958). It is one of the most characteristic animals of the Arctic *Macoma* community (Thorson 1957). The larval development is planktotrophic with a pelagic stage (Thorson 1936, Ockelmann 1958).

Fossil occurrence: Miocene: Empire Formation (Grant & Gale 1931). Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Sagavannirktok Formation, Middle Nuwok beds and Gubik Formation (MacNeil 1957). Lower Pleistocene: Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Ludhamnian (Norton 1967), Baventian (West *et al.* 1980), Scaldisian (Heering 1950), *Serripes groenlandicus-Yoldia lanceolata* Zone of the Netherlands (Spaink 1975), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981). Middle Pleistocene: Pinakul, Karagin, Kolvin, Kresta, and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Pre-Cape Christian beds (Andrews *et al.* 1981), Kotzebuan (Hopkins *et al.* 1972). It is considered a Pacific species that migrated into the North Atlantic about 3.5 Ma ago (Durham & MacNeil 1967).

Macoma balthica (Linné, 1758)
Figs 28c-g, 29-30.
1758 *Tellina balthica* Linné p. 677.

Material: Member B, unit B1, 69.1: four umbonal fragments. Unit B2, 68.1: 112 left and 99 right valves, 72.1: eight left valves, nine right valves, and seven umbonal fragments. Member B, locality 128: 52 left and 41 right valves.

Remarks: Length (l), height (h), and breadth (b) were measured for the largest five valves and the h/l and d/l ratios were calculated:

l in mm	h in mm	b in mm	h/l	b/l
19.0	14.4	3.7	0.76	0.19
18.0	14.3	4.1	0.79	0.23
17.5	14.0	4.5	0.80	0.26
16.9	14.0	6.8	0.83	0.40
16.7	13.9	5.4	0.83	0.32

Discussion: The shells from the Kap København Formation are within the range of present *M. balthica*, however, as a whole the population differs slightly. Thus, the shells and hinges are more robust with more prominent growth ridges. The pallial sinus is slightly shorter, but it shows the curvature in the right valve that is characteristic of recent *M. balthica.*

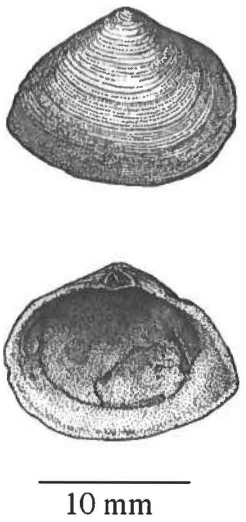

Fig. 29. *Macoma balthica* (Linné), right valve from locality 68.1, MGUH 22326, GGU/GCI 56541. The same valve is photographed Fig. 28c-d, but here the pallial sinus is more distinctly seen.

Recent distribution: Subarctic, boreal, with lusitanian outposts (Fig. 30). *Macoma balthica* occurs from the Barents Sea, the White Sea, the western Kara Sea, and the Laptev Sea in the north to the Bay of Biscay in the south (Jensen 1905, Lubinsky 1980, G.H. Petersen, personal communication 1997). It is absent from Svalbard, Iceland, and the Faeroe Islands (F.J. Madsen 1949, G.H. Petersen 1968). In North America it lives in the Beaufort Sea, southern Baffin Bay, Hudson Bay, and Labrador south to South Carolina and Monterey, California (Bernard 1979, Lubinsky 1980). It also lives in the Bering and Okhotsk Seas south to Japan (Bernard 1979). The species is not known living in North or East Greenland, but occurs scattered in West Greenland northward to 72°37' N at depths between 0 and 120 m (Posselt & Jensen 1898). Vertical range: From 0 m in Denmark (Muus 1967) to 270 m in the Beaufort Sea (Bernard 1979).

The distribution area of *M. balthica* is obviously disrupted in the North Atlantic and apparently the North American and Greenlandic populations differ somewhat from those in the European area (Lubinsky 1980). The European specimens are large, with heavy shells and light purple stribed periostracum on white background. They are elongated with attenuated posterior end and arcuate lower margins. Specimens from the American North Atlantic shores are whitish gray, chalky, thin, and brittle. Anterior and posterior ends of the shell are almost symmetrical, the posterior part slightly shortened and broadened (Coan 1971, Lubinsky 1980).

Ecology and biology: In northwest Europe this deposit feeder is mainly distributed in shallow water in protected areas at depths less than 3 m on a soft or mixed bottom (Muus 1967). It penetrates far into the Baltic where it lives in brackish water at salinities of 2-4‰ (Hessle 1924) and at greater depths (Jensen & Spärck 1934). It penetrates into the St. Lawrence River up to Quebec (Lubinsky 1980). The larval development is planktothropic (Jørgensen 1946).

Fossil occurrence: Lower Pleistocene: Late Baventian (Norton & Spaink 1973, Gibbard *et al.* 1991), Pre-Pastonian (Funnell *et al.* 1979, Gibbard *et al.* 1991), Late Tiglian C4 substage (Gibbard *et al.* 1991), Olkhov Suite (Petrov 1982), Gubik Formation, Fishcreekian (Repenning *et al.* 1987). Middle Pleistocene: Holsteinian of the Netherlands (Spaink & Norton 1967), Kresta,

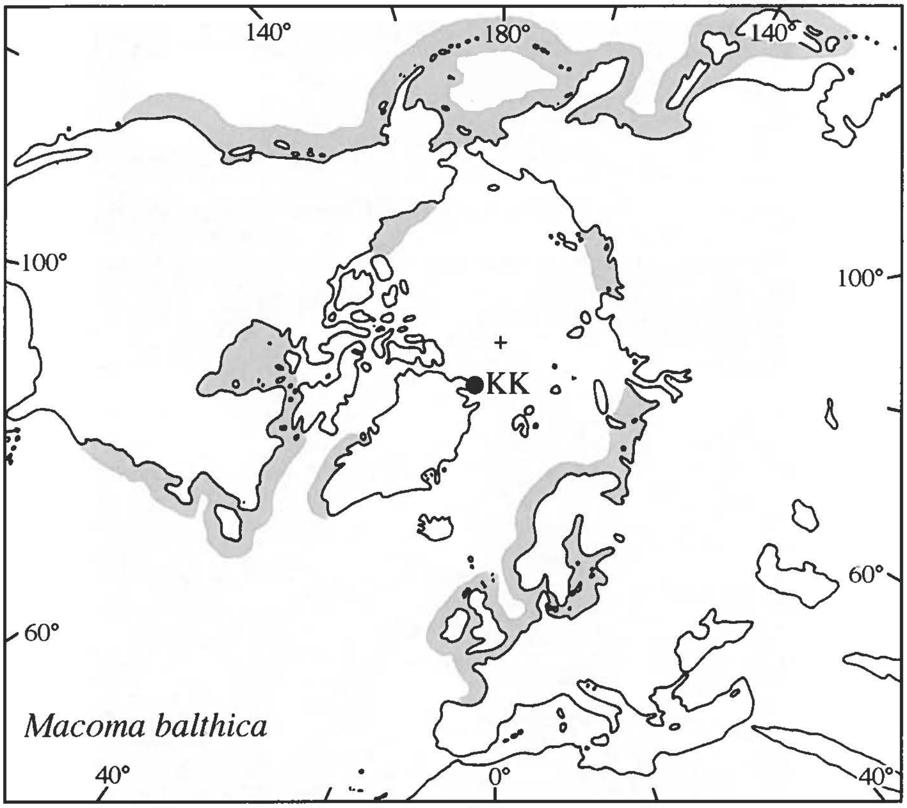

Fig. 30. The recent known geographical distribution of *Macoma balthica* (Linné). KK: Kap København.

Karagin, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1962, 1979, Petrov 1982), Cape Christian beds (Andrews *et al.* 1981), Einahnutan and Kotzebuan (Hopkins 1967, Hopkins *et al.* 1972).

The record from the Kap København Formation is the earliest in the Atlantic. However, if the Fish Creek Fauna is about 2.4 Ma (Repenning & Brouwers 1992) it is almost contemporaneous with the Kap København Formation and these occurrences seem to be the earliest known appearances of the species. Several authors have stressed that *Macoma balthica* originated in the Pacific (Durham & MacNeil 1967, Bernard 1979, Meijer 1993) and invaded the Atlantic in Lower Pleistocene times (Norton & Spaink 1973, Hopkins *et al.* 1972, Gibbard *et al.* 1991). Meijer (1993) proposed a migration route along the Siberian coasts because of the late arrival in the North Sea area and also the absence of the species in Icelandic Pliocene-Pleistocene deposits. The occurrence in the Kap København Formation does not support this idea and actually the Pacific origin of the species must be questioned.

Macoma moesta (Deshayes, 1855)
Fig. 28h.
1855 *Tellina moesta* Deshayes p. 361.

Material: Member B, unit B2, 27.1: one right valve with boring.

Recent distribution: Panarctic, circumpolar, mainly arctic. *Macoma moesta* is known from Svalbard, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea south to Kamchatka (Ockelmann 1958, Coan 1971). In North America it lives in the Beaufort Sea, the Canadian Arctic Archipelago south to Ungava Bay, and Chignik Bay, Alaska (Coan 1971, Lubinsky 1980). Scarlato (1981) reported the species from the Pacific as far south as Japan and California, but Coan (1971) pointed out that the southern occurrence should be referred to as *M. moesta alaskensis* Dall, 1900. In West Greenland it has been found in the Uummannaq area at 71° N (Jensen 1905) and

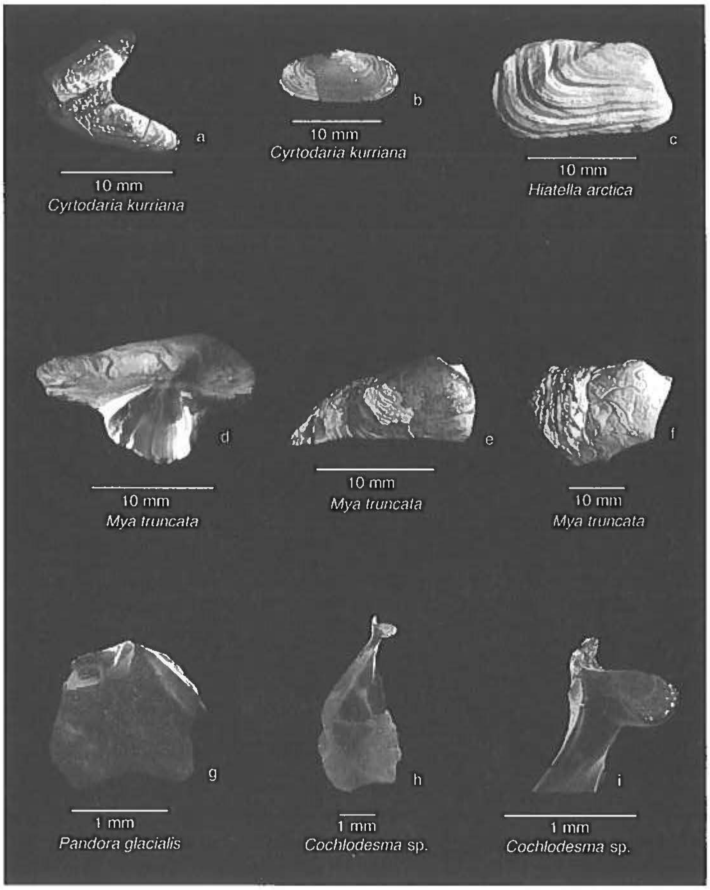

Fig. 31. a-b: *Cyrtodaria kurriana* Dunker. a: two right valves in concretion from locality 50.2, MGUH 22330, GGU/GCI 223296. b: left valve from locality 59.2, MGUH 22331, GGU/GCI 56661. c: *Hiatella arctica* (Linné), right valve from locality 59.2, MGUH 22332, GGU/GCI 56661. d-f: *Mya truncata* Linné. d: umbonal fragment of left valve with chondrophore from locality 112.1, MGUH 22333, GGU/GCI 56533. e: umbonal fragment of left valve from locality 75.1, MGUH 22334, GGU/GCI 223263. f: umbonal fragment of right valve from locality 112.1, MGUH 22335, GGU/GCI 56533. g: *Pandora glacialis* Leach, umbonal fragment from locality 72.1, MGUH 22336, GGU/GCI 56861. h-i: *Cochlodesma* sp. umbonal fragment from locality 72.1, MGUH 22337, GGU/GCI 56860. i: enlarged part of the resilifer of the same specimen.

an isolated occurrence at Nuuk/Godthåb (between 64° and 65° N) was reported by Lubinsky (1980). It has been found living in East Greenland from Danmarkshavn in the north to Lindenow Fjord in the south, mainly at depths less than 50 m (Ockelmann 1958). Vertical range: From 2 m in East Greenland (Ockelmann 1958) to 375 m in the Baffin Bay (Ellis 1960).

Ecology and biology: In East Greenland this deposit feeder is very often found together with *Macoma calcarea* and in places near the outer coast it is even more frequent (Ockelmann 1958). The larval development is lecithotrophic with a very short or no pelagic stage (Ockelmann 1958).

Fossil occurrence: ?Miocene/Pliocene: Etchegoin Formation (Grant & Gale 1931). Lower Pleistocene: Olkhov Suite (Petrov 1982). Middle Pleistocene: Karagin (Petrov 1982), Kotzebuan (?*M.* cf. *calcarea*; Hopkins *et al.* 1972).

Little is known about the history of *M. moesta*, which is considered to have originated in the Pacific (Durham & MacNeil 1967). The record from the Kap København Formation is the earliest in the Atlantic.

Subclass Desmodonta Neumayr, 1883. Order Myoida Stoliczka, 1879. Family Hiatellidae Gray, 1824. Genus *Cyrtodaria* Reuss, 1801.

Cyrtodaria kurriana Dunker, 1862
Figs 31a-b, 32-33.
1862 *Cyrtodaria kurriana* Dunker, p. 38.

Material: Member B, unit B1, 50.2: one specimen with paired valves, five left valves, five right valves, and 33 umbonal

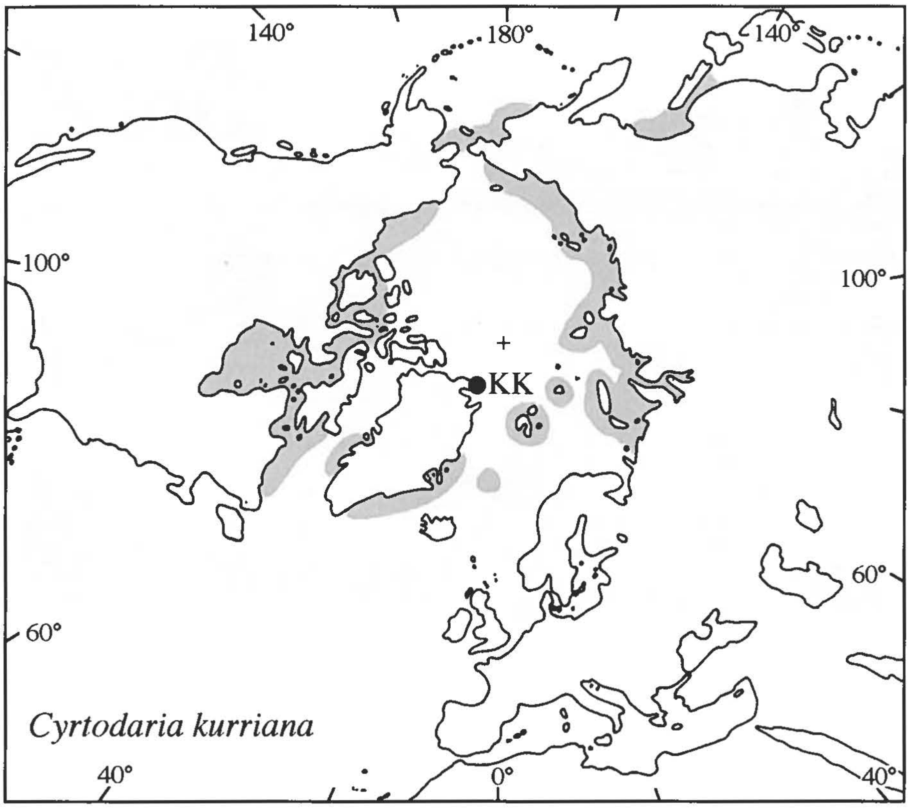

Fig. 32. The recent known geographical distribution of *Cyrtodaria kurriana* Dunker. KK: Kap København.

fragments, 59.2: four specimens with paired valves, 24 left valves, 26 right valves, and 66 umbonal fragments, 69.1: six umbonal fragments. Unit B2, 3.1: one specimen with paired valves and three umbonal fragments, 22.1: two umbonal fragments, 26.1: one umbonal fragment, 27.1: three umbonal fragments, 50.1: one specimen with paired valves and three umbonal fragments, 50.3: one specimen with paired valves, 16 left valves, 11 right valves, and 10 umbonal fragments, 68.1: one left valve and one umbonal fragment, 72.1: two umbonal fragments, 75.1: one left valve. Unit B3, 50.4: three specimens with paired valves, one left valve, and two umbonal fragments. Member B, locality 57.2: two umbonal fragments, locality 128: two left valves, two right valves, and 17 umbonal fragments.

The allochthonous fauna assemblage, 10.1: two umbonal fragments.

Kap Rigsdagen, 200.2: two umbonal fragments.

Remarks: Length of the shell (l) and height (h) were measured for the 10 largest shells and the h/l ratios calculated:

l in mm	h in mm	h/l
23.9	8.7	0.36
22.5	11.2	0.50
22.4	8.9	0.40
22.2	10.9	0.49
21.6	9.1	0.42
21.5	10.4	0.48
20.8	9.7	0.47
20.5	10.8	0.53
19.5	8.2	0.42
19.2	8.6	0.45

Discussion: The two extant cyrtodarias, *Cyrtodaria siliqua* (Spengler, 1793) and *C. kurriana* may be distinguished on the basis of adult as well as juvenile characteristics, amongst which is the considerably smaller size of the latter. Further, *C. kurriana* differs from *C. siliqua* in being comparatively more elongated, in having a thinner shell with a more prominent beak in a more equilateral position, in having somewhat

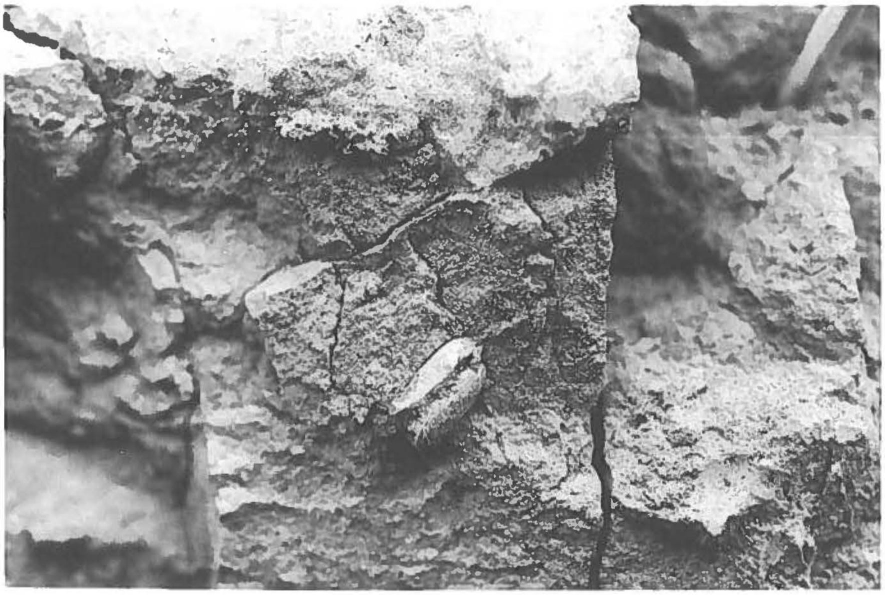

Fig. 33. Paired valves of *Cyrtodaria kurriana* Dunker in the sediment on locality 50.

more distinct growth lines on the surface of the shell, and a less twisted shell (Nesis 1965, Strauch 1972, Símonarson 1974).

Recent distribution: Panarctic, disrupted circumpolar, mainly arctic (Fig. 32). *Cyrtodaria kurriana* is known from Svalbard, Jan Mayen, Franz Josef Land, Novaya Zemlya, Pechora estuary, the Kara Sea, the Laptev Sea, the East Siberian Arctic Sea, the northern coast of Chukchi peninsula, the Anadyr estuary, the Amur estuary, Norton Sound, Alaska east of Point Barrow, Hudson Bay, Hudson Strait, and Ungava Bay (Nesis 1965, Strauch 1972). Furthermore, *C. kurriana* has been found in West Greenland off Qeqertarsuaq/Godhavn, Aasiaat/Egedesminde, and Nuuk/Godthåb (Thorson 1951). In East Greenland it is distributed from Sabine Ø in the north to Kap Tordenskjold in the south (Ockelmann 1958). Vertical range: From 1 m in East Greenland to 56 m in Jan Mayen (Ockelmann 1958).

Ecology and biology: The species is a suspension feeder modified for active burrowing in sandy bottom and adapted to somewhat oligohaline conditions of rather unstable shallow water along the outer coast (Ockelmann 1958, Nesis 1965). It has been recorded from waters with temperatures between -3°C and 6°C (Bernard 1983), but it is questionable if the species adapted to oligohaline conditions can really live at temperature as low as -3°C (G.H. Petersen, personal communication 1997).

Fossil occurrence: Lower PLeistocene: Olkhov and Tusatuva-Yamsk Suites (Petrov 1982). Middle Pleistocene: Kresta Suite (Petrov 1966), Kotzebuan (Hopkins *et al.* 1972). The species is probably of Atlantic origin (Nesis 1965), and the occurrence in the Kap København Formation seems to be the earliest known appearance of the species.

Genus *Hiatella* Bosc, 1801.
Hiatella arctica (Linné, 1767)
Fig. 31c.
1767 *Mya arctica* Linné p. 113.

Material: Member B, unit B1, 59.2: 73 left valves, 101 right valves, and 71 umbonal fragments. Unit B2, 75.1: one umbonal fragment. Member B, 57.2: 27 left valves, 32 right valves, and 62 umbonal fragments, locality 128: one umbonal fragment and some plate fragments.

The allochthonous fauna assemblage, 10.1: one left valve and four umbonal fragments, 15.1: one umbonal fragment and several plate fragments, 33.1: one umbonal fragment, 43.1: one umbonal fragment and a few plate fragments, 46.1: three umbonal fragments, 57.1: one umbonal fragment and several plate fragments, 64.1: two umbonal fragments, 70.1: one umbonal fragment, 107.1: one umbonal fragment, 108.1: one umbonal fragment, 112.1: one left valve, 11 umbonal fragments, 116.1: two left valves, one right valve, and three umbonal fragments.

Kap Rigsdagen, 200.1: one left valve, two right valves, and 14 umbonal fragments.

Discussion: The systematic details of the genus *Hiatella* have often been discussed and opinions have been different, e.g. on the decisive question wether the North Atlantic *Hiatella* comprises one or more species (see Ockelmann 1958, G.H. Petersen 1978, Símonarson 1981). *H. arctica* is usually considered a cosmopolitan, however, at least two different *Hiatella* larvae have been found in the North Atlantic and Canada (Thorson 1951, Ockelmann 1958, Sullivan 1948). It is therefore likely that more than one species of *Hiatella* occurs within this large area. G.H. Petersen (1978) referred the West Greenland specimens, occurring on a hard bottom in shallow water, to the *Hiatella* species first described from Greenland, i.e. *H. byssifera* (Fabricius, 1780). Since this is a northern species it is quite likely that our material should also be referred to it. However, it is distinguished from more southerly species not by shell morphology, but such characters as its parasites and life strategy (G.H. Petersen 1978). Thus, the application of the little used name *H. byssifera* would imply positive identification, which cannot be made on our material. With this uncertainty in mind we therefore retain the more widely used, and less specific name *H. arctica*.

Recent distribution: Panarctic, boreal, lusitanian, circumpolar. *Hiatella arctica* (including *H. byssifera* (Fabricius) and *H. gallicana* Lamarck) is widely distributed and extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward, especially at greater depths, to West Africa (Gabon) and Japan (Ockelmann 1958, Bernard 1979). In North America it is known from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay south to the Gulf of Mexico and ?Patagonia (Bernard 1979). In West Greenland it is distributed along the entire coast (Thorson 1951) and in North Greenland it is common in Jørgen Brønlund Fjord at depths between 2 and 45 m (Schiøtte 1989). The species is common along the coast of East Greenland to Lindenow Fjord in the south, mainly at depths between 5 and 60 m (Ockelmann 1958). Vertical range: From 0 m at several localities to 2190 m west of Ireland, ?alive (Ockelmann 1958).

Ecology and biology: In East Greenland the young animals of this suspension feeder are found attached in large numbers to algae in shallow water, whereas the adults are mainly attached to stones or some small irregularities on the bottom (Ockelmann 1958). Some authors have stated that *H. arctica* has not developed the boring habit of other members of the genus (G.O. Sars 1878, Bernard 1979). However, Hunter (1949) has pointed out that larvae attributed to *H. arctica* may settle and begin to bore, that is determined by the nature of the substratum upon which settlement takes place. The larval development is pelagic and the rounded *Hiatella* larva was found to be the most numerous bivalve larva in the East Greenland plankton (Thorson 1936).

Fossil occurrence: Oligocene: North Sea Basin in Holland, Germany, and Denmark (Sorgenfrei 1958). Oligocene/Miocene: Narrow Cape and Yakataga Formations (Allison 1978, MacNeil 1965). Miocene: Aquitanian and North Sea Basin, Elveziano, Tortoniano (Sorgenfrei 1958). Pliocene: Tjörnes *Serripes* Zone (Gladenkov *et al.* 1980), Coralline Crag, Scaldisian, Astian, Piacenzian (Sorgenfrei 1958), Red Crag (Wood 1857). Plio/Pleistocene: Lodin Elv Formation (Feyling-Hanssen *et al.* 1983). Lower Pleistocene: Hörgi and Threngingar Formations (J. Eiríksson 1981), Baventian (West *et al.* 1980), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981), Gubik Formation, Fishcreekian (Repenning *et al.* 1987). Middle Pleistocene: Numerous occurrences in Pacific and Atlantic localities. Durham & MacNeil (1967) considered the species to have originated in the Atlantic, whereas Bernard (1979) regarded it as a Pacific species evolved from the Miocene *H. sakhaliensis* Oyma, Mizuno and Sakamoto, 1960. Then Repenning *et al.* (1987) claimed it to be of an uncertain origin. Irrespective of its place of origin it is geologically speaking one of the most long-lived and widespread shallow water bivalves at high latitudes.

Family Myidae Lamarck, 1809. Genus *Mya* Linné, 1758.
Mya truncata Linné, 1758
Fig. 31d-f.
1758 *Mya truncata* Linné p. 670.
Material: Member B, unit B2, 75.1: one umbonal fragment. Member B, locality 128: 15 umbonal fragments.
The allochthonous fauna assemblage, 15.1: one umbonal fragment, 33.1: one umbonal fragment and several plate fragments, 107.1: two umbonal fragments and several plate fragments, 108.1: two umbonal fragments and several plate fragments, 112.1: six umbonal fragments, 116.1: one fragment without umbo.
Recent distribution: Panarctic, boreal, circumpolar. *Mya truncata* extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to the western Baltic, the English Channel, and southern Hokkaido (Ockelmann 1958). In North America it is distributed from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay south to Massachusetts and Puget Sound (Bernard 1979, Lubinsky 1980). In West Greenland it lives along the entire coast (Thorson 1951). In North Greenland the species is common in Jørgen Brønlund Fjord at depths between 2 and 40 m (Schiøtte 1989). It is distributed in East Greenland south to Lindenow Fjord, both in the inner fjords and in places near the open sea, mainly at depths less than 50 m (Ockelmann 1958). Vertical range: From 0 m at several localities to 625 m in West Greenland (Ockelmann 1958).
Ecology and biology: In East Greenland the young animals are found attached to algae in large numbers, whereas the adults belong to the Arctic *Macoma* community of the infauna burrowing in the sediment (Ockelmann 1958). According to Ockelmann (1958) it is remarkable that adult animals are comparatively sparsely represented in the East Greenland material and it was suggested that the grab and the dredge were often insufficient for catching the larger, deeply burrowing animals. However, in Godhavn Havn in the Disko Bugt area, West Greenland, most of the animals seem actually to occur in the sediment close to the surface, i.e. the uppermost 5-10 cm (G.H. Petersen 1978). They included specimens of very large sizes, up to 70 mm in length. The species is a suspension feeder (Ockelmann 1958). The larval development is planktotrophic with a long pelagic stage (Jørgensen 1946).
Fossil occurrence: Miocene: Takinoue Formation, Yakataga Formation (MacNeil 1965). Pliocene: Coralline Crag and Red Crag (Harmer 1900, 1915), Scaldisian (Heering 1950, Glibert 1959), Coos Conglomerate, Towsley Formation, Quillayute Formation (MacNeil 1965). Plio/Pleistocene: Lodin Elv Formation (Feyling-Hanssen *et al.* 1983). Lower Pleistocene: Furuvík, Hörgi, Threngingar, and Máná Formations (J. Eiríksson 1981), Baventian (West *et al.* 1980), Emilian and Sicilian (Malatesta & Zarlenga 1986), Olkhov and Tusatuva-Yamsk Suites (Petrov 1982), Pattorfik beds (Símonarson 1981), Gubik Formation, Fishcreekian (Repenning *et al.* 1987), Pico Formation (MacNeil 1965). Middle Pleistocene: Karagin, Pinakul, Kresta, Kolvin, and Padymeiskii Suites (Merklin *et al.* 1979, Petrov 1982), Anvilian (Hopkins *et al.* 1974), Kotzebuan (Hopkins *et al.* 1972).

The geologically long-lived *M. truncata* is a typical exponent for the group of shallow water benthic molluscs that originated in the North Pacific in Late Tertiary times, migrated to Northwest European coasts in Late Pliocene times, and finally reached the North American east coast in Lower or Middle Pleistocene (MacNeil 1965). *M. truncata* shells play a dominant role in almost all Late Quaternary faunas from Greenland and its rarity in the Kap København Formation is peculiar.

Order Pholadomyoida Newell, 1965. Family Pandoridae Rafinesque, 1815. Genus *Pandora* Bruguière, 1797.
Pandora glacialis Leach, 1819
Fig. 31g.
1819 *Pandora glacialis* Leach p. 174.
Material: Member B, unit B1, 74.1: one fragment without umbo. Unit B2, 72.1: one umbonal fragment.
Recent distribution: Panarctic, mainly arctic, probably circumpolar. *Pandora glacialis* extends from Svalbard, Franz Josef Land, the Barents Sea, Novaya Zemlya, the Kara Sea, and the Siberian Arctic Sea southward to the White Sea and northern Japan (Ockelmann 1958, Bernard 1979). In North America it is known from the Beaufort Sea, the Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay south to Massachusetts and Washington (Bernard 1979, Lubinsky 1980). The species is absent from Iceland, the Faeroe Islands, and West Greenland (F.J. Madsen 1949, Thorson 1951, Lubinsky 1980). In North Greenland it has been taken at 6.5 m depth off Kap København (Table 9). It is distributed along the East Greenland coast, where it prefers places not too far from the open sea from Sabine Ø in the north to Kap Dalton in the south, mainly at depths less than 30 m (Ockelmann 1958). Vertical range: From 2 m in Franz Josef Land (Ockelmann 1958) to 270 m in the Beaufort Sea (Bernard 1979).
Ecology and biology: In East Greenland this suspension feeder was found in the epifauna on algae, sand, and clayey sand, but it also lives on mud, clay or stony bottom (Ockelmann 1958). The larval development is probably lecithotrophic with a very short or no pelagic stage (Thorson 1936).
Fossil occurrence: ?Pliocene: Coralline Crag (Heering 1950). Pico Formation (Grant & Gale 1931). Lower Pleistocene: Olkhov Suite (Petrov 1982). *P. glacialis* is considered to have originated in the Pacific (Durham & MacNeil 1967). Its history is rather poorly known, however, it is also reported in deposits from the last interglacial at Langelandselv on Jameson Land, East Greenland (K.S. Petersen 1982).

Family Periplomatidae Dall, 1895. Genus *Cochlodesma* Couthouy, 1839.
Cochlodesma sp.
Fig. 31h-i.
Material: Member B, unit B2, 72.1: one fragment of a left valve with the resilifer preserved.
Remarks: The white desmodont shell is thin with smooth concentric lines, but it is slightly granulated near the posterior margin. Growth stages are not clear. The hinge is without teeth, but there is a prominent supporting rib running from the anterior margin of the posterior adductor scar to the resilifer on the interior of the shell. The height of the shell was apparently close to 5 mm. The fragment is referred to the genus *Cochlodesma*, but the imperfect state of preservation prevents further identification.
Fossil occurrence: The genus is new to the fossil fauna of Greenland.

Brachiopoda

Brachiopoda sp.
Fig. 34.
Material: Member B, unit B1: several hinge fragments and some plate fragments from localities 50.2 and 59.2. Unit B2, 50.3: several hinge fragments and some plate fragments.
The allochthonous fauna assemblage: many hinge fragments and some plate

fragments from localities 10.2, 59.3, 70.1 and 125.1.

Remarks: The thick shells are rather smooth, with only faint growth lines, but usually they are somewhat abraded. They are distinctly punctate and yellow brown in colour except the one from locality 50.3. This particular fragment is the only one which has been found in the sediment while all the others were found on the terrain surface of Member A exposures together with shell fragments of the allochthonous fauna assemblage. The yellow brown colour is therefore most probably somehow connected with the reworking of the shell material. The hinge fragments from locality 50.3 are from a shell that was at least 3.8 cm in breadth and longer than 2.0 cm. They are therefore from a rather large specimen (or specimens) and as they have lateral teeth (Fig. 34) they apparently belong to an articulate brachiopod, most probably to the order Terebratulida. An attempt at closer identification is currently carried out by E. Thomsen, Tromsø Museum (Norway).

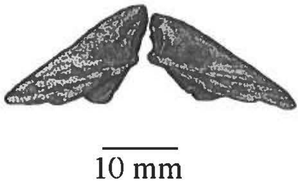

Fig. 34. Brachiopoda sp., hinge fragments from locality 50.2, MGUH 22338, GGU/GCI 223296.

The mollusc fauna in the Kap København Formation and correlatives

Review of the fauna

In the present survey 43 species of marine invertebrates from the Kap København Formation and its correlative at Kap Rigsdagen have been treated, i.e. 12 prosobranchs, three opisthobranchs, 27 bivalves, and one brachiopod.

The fauna in the Kap København Formation does not deviate significantly from other marine Quaternary faunas in Greenland known so far. However, *Pseudosetia turgida, Rissoa parva, Nucula nucleus* (see also p. 41), *Tridonta soror*, and the *Coclodesma* species have not been found elsewhere in Quaternary deposits in Greenland, and are new to the fossil fauna of Greenland (Table 5).

All the species are living today and the

Table 5. The mollusc species found in the Kap København Formation and Kap Rigsdagen and their present distribution in Greenland. The last column shows the species with their first appearance datums (FAD) in the Kap København Formation

The mollusc species found in the Kap København Formation and Kap Rigsdagen.	Living today in West Greenland	Living today in East Greenland	Living today near Kap København*	Not living now in Greenland	First appearance datum (FAD) in the Kap København Formation
Margarites sp.					
Pseudosetia turgida				+	+
Boreocingula globula	+				+
Alvania sp.					
Rissoa parva				+	
Trichotropis bicarinata	+	+			
Lunatia pallida	+	+			
Natica affinis	+	+	+		
Trophonopsis truncatus	+	+			
Buccinum undatum	+				
Admete couthouyi	+	+	+		
Oenopota decussata	+	+			
Propebela reticulata	+	+	+		
Propebela nobilis	+	+			
Retusa obtusa	+	+	+		
Cylichna alba	+	+	+		
Cylichna occulta	+	+	+		+
Nucula nucleus	+				
Nucula tenuis	+	+			
Nuculana pernula	+	+	+		
Portlandia arctica	+	+	+		+
Yoldiella fraterna	+	+			+
Yoldiella intermedia	+	+	+		+
Bathyarca glacialis	+	+	+		+
Mytilus edulis	+	+			
Musculus niger	+	+	+		
Arctinula greenlandica	+	+	+		
Tridonta borealis	+	+	+		
Tridonta elliptica	+	+	+		
Tridonta soror	+				+
Tridonta montagui	+	+	+		
Arctica islandica				+	
Axinopsida orbiculata	+	+	+		
Thyasira gouldi	+	+	+		
Montacuta dawsoni	+				+
Serripes groenlandicus	+	+			
Clinocardium ciliatum	+	+			
Macoma calcarea	+	+	+		
Macoma balthica	+				?
Macoma moesta	+	+			
Cyrtodaria kurriana	+	+			+
Hiatella arctica	+	+	+		
Mya truncata	+	+	+		
Pandora glacialis		+	+		
Cochlodesma sp.				+	

* The occurrences in the Kap København area are recorded elsewhere in this paper and those from Jørgen Brønlund Fjord are from Schiøtte (1989)

majority is still found in Greenland waters, only *Pseudosetia turgida, Rissoa parva, Arctica islandica*, and the *Cochlodesma* species are missing. Furthermore, *Boreocingula globula, Buccinum undatum, Nucula nucleus, Tridonta soror, Montacuta dawsoni*, and *Macoma balthica* are not known to live in East Greenland, while *Pandora glacialis* is missing in West Greenland (Table 5).

The fauna of the Kap København Formation is amphiatlantic in character and has many species in common with the recent Icelandic fauna. About 79% of the gastropod species and 70% of the bivalve species are known to live around Iceland today. *Pseudosetia turgida, Rissoa parva*, and *Nucula nucleus* have not been recorded living in North America, whereas *Tridonta soror* is endemic in the arctic region west of Greenland. This may indicate somewhat stronger relations to recent faunas in the North Atlantic east of Greenland than to distinctly West Atlantic faunas.

The allochthonous fauna assemblage includes seven bivalves and one brachiopod. The species are all well known in the North Atlantic and live in Greenland, with the exception of the thermophilic *Arctica islandica*.

The species belonging to the Kap Rigsdagen fauna, one gastropod and six bivalves, are all living in Greenland today and well known from the North Atlantic area. The fauna does not deviate significantly from other marine Quaternary faunas in Greenland.

Zoogeography and temperatures

Only a sparse bivalve fauna characterised by *Portlandia arctica, Musculus niger*, and *Tridonta montagui* was found in the lowermost Member A. The presence of *P. arctica* in Member A and the low faunal diversity indicate arctic conditions with low sea temperatures at about or below 0°C (Table 6). According to Penney (1993) the presence of cryophilic ostracode species such as *Rabilimis mirabilis* and representatives of the genus *Cytheropteron* indicate frigid to subfrigid marine conditions, and limit the maximum summer bottom temperature to about 4.0°C.

The fauna in Member B, unit B1, has considerably higher diversity than that in Member A (Table 8). It consists of eight gastropod and 15 bivalve species, characterised by *Boreocingula globula, Oenopota decussata, Portlandia arctica, Tridonta borealis, Macoma calcarea, Cyrtodaria kurriana*, and *Hiatella arctica*. From Table 6 it appears that five species are distributed in the arctic and subarctic regions and three of them are pronouncedly arctic, *P. arctica, C. kurriana*, and *Pandora glacialis*. Of special interest is the occurrence of *Nucula nucleus* and *Macoma balthica* in the upper part of this unit because they do not extend into the arctic region. According to Thorson (1951) *N. nucleus, M. balthica*, and *C. kurriana* now live together in the Qeqertarsuaq/Godhavn-Aasiaat/Egedesminde area in West Greenland. The sea surface temperatures at Qeqertarsuaq/Godhavn in 1959-1960 varied from -1.6—1.7°C during the winter to 7.5°C in July and August, whereas the temperatures at a depth of 50 m varied from -1.6—1.7°C in the winter to 3.5°C in September (G.H. Petersen 1964). There are similar conditions in the Fjord water layer in East Greenland, but it has a marked temperature gradient and at a depth of 5 m the maximum temperatures are only 4-5°C (Ockelmann 1958). This indicates subarctic conditions during the deposition of unit B1. Apparently the sea temperature was slightly above 0°C and somewhat higher than of Member A.

In Member B, unit B2, the mollusc fauna has still higher diversity than unit B1. It consists of 13 gastropod and 24 bivalve species, characterised by *Boreocingula globula, Oenopota decussata, Cylichna occulta, Portlandia arctica, Tridonta borealis, Tridonta elliptica, Macoma calcarea, Macoma balthica*, and *Cyrtodaria kurriana*. Six of these species are now living in the arctic and subarctic regions and only two of

Table 6. Recent known geographical distribution of the molluscs from the Kap København Formation and Kap Rigsdagen

Species	Lusitanian	Boreal			Subarctic	Arctic
		Low	Mid	High		
Portlandia arctica					- - -	—
Macoma moesta					- - -	—
Cyrtodaria kurriana					- - —	—
Pandora glacialis					- - —	—
Cylichna occulta					—	—
Bathyarca glacialis					—	—
Arctinula greenlandica					—	—
Tridonta soror					—	—
Boreocingula globula					—	- - -
Trichotropis bicarinata				—	—	—
Serripes groenlandicus				—	—	—
Clinocardium ciliatum				—	—	—
Oenopota decussata			—	—	—	—
Lunatia pallida		—	—	—	—	—
Trophonopsis truncatus		—	—	—	—	—
Admete couthouyi		—	—	—	—	—
Propebela nobilis		—	—	—	—	—
Cylichna alba		—	—	—	—	—
Nucula tenuis		—	—	—	—	—
Nuculana pernula		—	—	—	—	—
Yoldiella fraterna		—	—	—	—	—
Yoldiella intermedia		—	—	—	—	—
Musculus niger		—	—	—	—	—
Tridonta borealis		—	—	—	—	—
Tridonta elliptica		—	—	—	—	—
Tridonta montagui		—	—	—	—	—
Axinopsida orbiculata		—	—	—	—	—
Thyasira gouldi		—	—	—	—	—
Montacuta dawsoni		—	—	—	—	—
Macoma calcarea		—	—	—	—	—
Mya truncata		—	—	—	—	—
Natica affinis	—	—	—	—	—	—
Buccinum undatum	—	—	—	—	—	—
Propebela reticulata	—	—	—	—	—	—
Retusa obtusa	—	—	—	—	—	—
Hiatella arctica	—	—	—	—	—	—
Pseudosetia turgida	—	—	—	—	—	
Rissoa parva	—	—	—	—	—	
Nucula nucleus	—	—	—	—	—	
Mytilus edulis	—	—	—	—	—	
Macoma balthica	- - -	—	—	—	— -	
Arctica islandica	—	—	—	—	—	
Margarites sp.						
Alvania sp.						
Cochlodesma sp.						

them are pronouncedly arctic, *P. arctica* and *C. kurriana* (Table 6). On the other hand, four species do not extend into the arctic region, *Rissoa parva, Nucula nucleus, Mytilus edulis,* and *Macoma balthica,* which is the most common species in this unit. The increase in epifaunal species and appearance of littoral species such as *M. edulis* and decreasing dominance of arctic species, when compared with unit B1, indicate somewhat milder subarctic conditions with higher sea temperatures than unit B1.

Winter and summer bottom palaeotemperatures were estimated on the basis of ostracode assemblages in units B1 and B2 by Brouwers *et al.* (1991) as -2°C for the minimum sea bottom temperatures and 6-8°C for the maximum bottom temperatures, indicating subfrigid to frigid marine conditions. In unit B2 at locality 72 the maximum sea bottom temperatures were estimated at 9-10°C. Penney (1993) suggested comparable temperature range for unit B2 also based on ostracode data. His estimation indicates summer bottom temperatures were on average 7-8°C warmer than today. Thus, sea temperature apparently rose from Member A to unit B2. Feyling-Hanssen's (1990) earlier estimate, where Member A marked the warmest conditions, was based on species which are now considered to be reworked from older sediments.

On the basis of molluscs, very little can be concluded about sea temperatures during the deposition of Member B, unit B3 because only two bivalve species are recorded. Marine palaeotemperatures were estimated on the basis of ostracodes in unit B3 (locality 68) by Brouwers *et al.* (1991) as -2°C for the minimum sea bottom temperature and ranging as high as 12-14°C for the maximum bottom temperatures with summer bottom temperatures 10-12°C higher than at present. Penney (1993) suggested the unit B3 ostracodes indicate summer bottom temperatures up to 12-14°C warmer than today in the marginal marine environment of the unit. This would mark the peak of warming in the record as also indicated by the rich and diverse plant and insect assemblages (Bennike 1990, Böcher 1995).

The sparse fauna in Member B, locality 57.2 consists of eight bivalve species and is dominated by *Portlandia arctica, Tridonta borealis,* and *Hiatella arctica.* The presence of *P. arctica* and the rather low faunal diversity indicate arctic conditions with sea temperatures at or below 0°C. The fauna in locality 128 has a slightly higher faunal diversity than the fauna in locality 57.2. It consists of three gastropod and eight bivalve species, characterised by *Buccinum undatum, Serripes groenlandicus, Macoma calcarea, Macoma balthica, Cyrtodaria kurriana,* and *Mya truncata.* Furthermore, Bennike (1989) found *Trichotropis bicarinata, Natica affinis, Trophonopsis truncatus, Colus* sp., *Nuculana pernula, Yoldiella intermedia, Arctinula greenlandica,* and *Tridonta montagui* at this locality, but *T. bicarinata, T. truncatus, Colus* sp., and *N. pernula* have not been found elsewhere in the sediments in the Kap København area. Apparently two species are restricted in their distribution to the arctic and subarctic regions and only *C. kurriana* is pronouncedly arctic. *M. balthica* does not extends into the arctic region and this indicates subarctic conditions during deposition of the sediments met with at locality 128, and similar sea temperature conditions as prevailed when unit B1 was deposited.

It has been suggested that the percentage distribution of prosobranch and bivalve species with a pelagic larval development distinctly decreases from boreal towards arctic regions with a corresponding increase of the percentage for a non-pelagic larval development (Thorson 1941, Ockelmann 1958). In unit B2 where the highest faunal diversity was found, there are 23 bivalve species and six of them, 26%, have planktotrophic larvae. This is considerably higher than Ockelmann

(1958) described for the East Greenland bivalve fauna, where only seven species of 47, 15%, have a pelagic larval development. The figures for the fauna in unit B2, stress the less arctic character of the fauna in this unit.

Thus, it seems evident from the mollusc assemblages found in the Kap København Formation that from Member A to Member B, unit B2 there was an increase in water temperatures from arctic to subarctic conditions, while the sparse fauna in unit B3 does not allow temperature estimates. From the plant remains found in the Kap København Formation Bennike (1990) concluded that the climate during the deposition was subarctic and oceanic and considerably warmer than today with July mean temperatures at 10-11°C and mean January temperature between -10°C and -15°C. The precipitation probably amounted to 500 mm per year and the winters were rather rich in snow. Palaeotemperature estimates based on insect remains indicate a development from subarctic climate with July mean temperatures between 11°C and 13°C in unit B1 changing to boreal conditions with July temperatures at 12-19°C in unit B3 (Böcher 1995).

In the allochthonous fauna assemblage *Cyrtodaria kurriana* indicates arctic conditions, whereas *Arctica islandica* indicates subarctic-boreal conditions (Funder & Weidick 1991). The thermal limits of *A. islandica* seem to be 0.7°C to 19°C and it cannot withstand more than two hours below 0°C (Malatesta & Zarlenga 1986). In the southeastern Barents Sea it occurs in areas with summer surface temperatures above 6°C (Zenkevitch 1963). Thus, subarctic-arctic conditions which were warmer than at any later time apparently prevailed in the area when these animals lived there.

At Kap Rigsdagen the sparse mollusc fauna is dominated by *Tridonta borealis* and *Hiatella arctica*. The presence of *Portlandia arctica, Bathyarca glacialis*, and *Cyrtodaria kurriana*, and the low faunal diversity, indicate arctic conditions with low sea temperatures at or below 0°C similar to unit B1.

Water depth

The minimal water depths indicated by the vertical range of the molluscs found in the horizontally laminated silt layers of Member A vary from 0 m (*Tridonta montagui*) to 3 m (*Musculus niger*), and the maximum depths vary from 339 m or ?2560 m (*Portlandia arctica*) to 445 m (*Tridonta montagui*). However, the presence of *P. arctica* and *M. niger* indicates sublittoral environments and depths between 5 and 50 m (Ockelmann 1958, Schiøtte 1989). From the sedimentary structures the depositional environment was interpreted as a suspension sedimentation in a low energy environment below storm wave base and with a high sedimentation rate (Bennike 1990). The lowermost marine sediments are interpreted as glacigenic and glaciomarine (Fig. 3) and were probably sedimented during the isostatically conditioned regression that followed the first major glaciation of the Northern Hemisphere.

In Member B, unit B1 the minimal depths vary from 0 m (several species) to 9 m (*Propebela reticulata*). The maximum depths vary from 56 m (*Cyrtodaria kurriana*) to 2900 m (*Yoldiella fraterna*). The presence of *Portlandia arctica* in a considerable number seems to indicate similar depths as for Member A, between 5 and 50 m. The dominance of *C. kurriana*, which is mainly found in East Greenland on sand at depths between 6 and 20 m, indicates shallower water than Member A, but it must be pointed out that this species seems to be dependent on the type of bottom and food conditions along the outer coast (Ockelmann 1958). Sedimentological structures, however, show that the sediments were deposited in the foreshore, shoreface and backshore (Bennike 1990), and possibly the crushed and fragmented shells have been washed up from slightly greater depths. The upper gradational contact to unit B2, with a considerably richer fauna, indicates that at least this part of the sediments was deposited during a slow transgression when sedimentation and sea level kept pace at the end of the isostatic regression.

In unit B2 the minimal water depths vary from 0 m (several species) to 9 m (*Propebela reticulata*) or ?67 m (*Pseudosetia turgida*), and the maximum depths vary from 56 m (*Cyrtodaria kurriana*) to 3150 m (*Montacuta dawsoni*). The minimal water depth for *Pseudosetia turgida* is uncertain and therefore it can hardly be included in this discussion. However, this species might have been temporarily attracted to shallower water than nowadays, when the Arctic Ocean became ice covered for the first time, and before it migrated southward to previous depth conditions (see also p. 86). In East Greenland *Yoldiella intermedia* and *Bathyarca glacialis* are mainly found in deeper waters than 30 m (Ockelmann 1958, Schiøtte 1989). Furthermore, *C. kurriana* is not so common here as in unit B1. Thus, the vertical range of the species as a whole indicates depths between 30 and 60 m while the bioturbated silt layers in unit B2 were deposited in somewhat deeper water than prevailed while unit B1 was formed. This is also reflected in the water depths of the foraminifera within the *Elphidiella rolfi* and *Elphidium* cf. *excavatum* Zones (Feyling-Hanssen 1990). Suspension feeders decrease in number from shallow water towards deeper water zones. The bivalve fauna in unit B2 has 65% suspension feeders which should reflect water depth between 20 and 50 m, when compared with the figures for East Greenland (Ockelmann 1958). The single specimen of the mainly littoral *Mytilus edulis* is apparently transported down from shallower depths. The homogeneous, bioturbated silt in unit B2 was deposited in a low energy environment, below storm wave base (Bennike 1990). This unit, especially the graditional lower and upper parts, contain the richest fauna in the Kap København Formation, which indicates an increase in the transgression rate or decrease in sediment supply.

Very little can be concluded about the depth relations while the sand layers of unit B3 were deposited. However, the dominance of *Cyrtodaria kurriana*, and the coarser sediment with ripple lamination and wavy bedding, indicate decreasing depth compared with unit B2. The sedimentary structures reflect shoreface and beach environments with rapid sedimentation. The beach environment is also documented by driftwood logs found in these sediments (Bennike 1990). The shallow water sediments with only a few marine shells indicate decreasing rate of transgression compared with unit B2.

In Member B, locality 57.2 the minimal depths vary from 0 m (several species) to 3 m (*Musculus niger*), and the maximal depths from 56 m (*Cyrtodaria kurriana*) to 2190 m (*Hiatella arctica*). The presence of these species and *Portlandia arctica* in a considerable number indicates sublittoral environment and depths between 10 and 20 m (Ockelmann 1958). In locality 128 the minimal depths vary from 0 m (several species) to 3.5-4 m (*Oenopota decussata*), and the maximum depths from 56 m (*Cyrtodaria kurriana*) to 2560 m (*Arctinula greenlandica*). The occurrence of *C. kurriana* in a considerable number stress similar depth relations that prevailed while the sand layers of unit B1 were deposited. This is in good agreement with the vertical distribution of the foraminifera indicating palaeodepths hardly more than 20 m (Feyling-Hanssen 1990).

Thus, the depths seem to have decreased from Member A to Member B, unit B1 and there was a recurrence of somewhat deeper water during the deposition of unit B2 and again to shallower waters in unit B3 (see also Funder *et al.* 1984). This may further stress the transgressional character of unit B2 (Table 7).

The presence of *Cyrtodaria kurriana*, *Tridonta borelis*, *Hiatella arctica*, and *Mya truncata* in the allochthonous fauna

Table 7. The depth relations of Member A and Member B of the Kap København Formation

Member	Unit	Minimal depth in m	Maximal depth in m	Depth range in m	Preferred depths in m	Character	Transgression rate
Member B	B3	0-1	56-463	1-56	6-20	transgressive	slower
	B2	0-9 (?67)	56-3150	9 (?67)-56	20-50/30-60	transgressive	faster
	B1	0-9	56-2900	9-56	6-20/5-50	transgressive	slow
Member A		0-3	339-?2560	3-339	5-50	regressive	

assemblage indicates depths between 10 and 20 m (Ockelmann 1958), whereas *Arctica islandica* usually lives closer to the coast in somewhat shallower water, e.g in Iceland, where it occurs on a sandy bottom just below the low water mark (F.J. Madsen 1949, H. Eiríksson 1988).

The minimal water depths indicated by the bivalves found in the Kap Rigsdagen sediments vary from 0 m (several species) to 5 m (*Bathyarca glacialis*), and the maximal depths vary from 56 m (*Cyrtodaria kurriana*) to 2560 m (*Arctinula greenlandica*). The presence of *Portlandia arctica*, *Bathyarca glacialis*, and *Cyrtodaria kurriana* indicates sublittoral environments and depths between 10 and 20 m (Ockelmann 1958).

Salinity

The bivalves *Musculus niger* and *Tridonta montagui* found in Member A are now associated with the Fjord water layer in East Greenland with reduced salinity at about 25-30‰, but the latter also lives in the Polar Current water (Ockelmann 1958). The presence of *Portlandia arctica* in this member also indicates reduced salinity, as this species is mainly found off the mouth of rivers and glaciers fronts (Lubinsky 1980).

In Member B *Cyrtodaria kurriana* was found in all units. According to Nesis (1965) it only inhabits diluted coastal water and is an indicator of lowered salinity. This is in good agreement with the great number of *Portlandia arctica* in unit B1 as well as the presence of the euryhaline *Macoma balthica* in units B1 and B2 and at locality 128 (Muus 1967). Reduced salinity during the deposition of Member B is further stressed by the unusually thin shells and by the abundance of terrestrial organic matter in units B1 and B3 (Bennike 1990). Furthermore, the dominance of ostracode species characteristic of estuarine habitats in unit B3 and the absence of inner shelf species indicate a nearshore environment with reduced salinity near a source of fresh water (Brouwers *et al.* 1991). Thus, it is clear that fresh water did influence the area during deposition in near shore environments.

The presence of *Cyrtodaria kurriana* in the allochthonous fauna assemblage indicates reduced salinity during deposition of some of the sediments that originally contained the fauna, but later became removed by erosion. However, in Iceland *Arctica islandica* mainly lives in the uppermost part of the sublittoral zone with normal salinity (F.J. Madsen 1949, H. Eiríksson 1988).

The presence of *Portlandia arctica* and *Cyrtodaria kurriana* in the Kap Rigsdagen fauna indicates reduced salinity in near shore environments.

Ecological assemblages and bottom conditions

The mollusc fauna in the Kap København Formation comprises infaunal and epifaunal species. Species belonging to the infauna are common in all units, whereas epifaunal species were not found in samples from Member A and Member B, unit B3. Species belonging to the epifauna are mainly found in samples from units B1 and B2, and locality 128.

The molluscs collected in the Kap København Formation can be referred to five ecological assemblages (Table 8):

Table 8. Stratigraphical units and molluscan assemblages in the Kap København Formation and Kap Rigsdagen

Assemblage	Stratigraphical units	Number of species	Simpson's index of diversity	Habitat
V. *Cyrtodaria kurriana - Tridonta borealis*	Member B unit B3	2	0.31	Infaunal bivalves and no epifaunal species
IV. *Macoma balthica - Tridonta borealis - Cyrtodaria kurriana*	Member B unit B2	37	0.90	Infaunal benthos, bivalves and gastropods, and epifaunal species more than 30%
III. *Hiatella arctica - Cyrtodaria kurriana - Portlandia arctica*	Member B unit B1	23	0.80	Infaunal benthos, bivalves and gastropods, and epifaunal species less than 20%
	Locality 57.2	8	0.68	
	Locality 128	11	0.73	
	Kap Rigsdagen	7	0.65	
II. *Portlandia arctica - Tridonta montagui*	Member A	3	0.64	Infaunal bivalves with few epifaunal species
I. *Hiatella arctica - Arctica islandica - Tridonta borealis*	The allochthonous fauna assemblage	7	0.75	Infaunal bivalves with few epifaunal species

I. The *Hiatella arctica-Arctica islandica-Tridonta borealis* assemblage dominated by infaunal bivalves, with few epifaunal species. The faunal diversity is much higher than in assemblage V, but considerably lower than in assemblage IV, and comparable to those in assemblages II and III. The allochthonous fauna assemblage belongs to this category.

II. The *Portlandia arctica-Tridonta montagui* assemblage dominated by infaunal bivalves, with few epifaunal species. The faunal diversity is rather low. This includes Member A.

III. The *Hiatella arctica-Cyrtodaria kurriana-Portlandia arctica* assemblage dominated by infaunal benthos, bivalves and gastropods, with epifaunal species less than 20%. The faunal diversity is much higher than in assemblage V, but considerably lower than in assemblage IV, and comparable to this in assemblage I. Member B, unit B1 and locality 57.2 are in this category and most probably also locality 128, as well as Kap Rigsdagen.

IV. The *Macoma balthica-Tridonta borealis-Cyrtodaria kurriana* assemblage dominated by infaunal benthos, bivalves and gastropods, with epifaunal species more than 30%. Here is the highest faunal diversity in the Kap København Formation. This includes Member B, unit B2.

V. The *Cyrtodaria kurriana-Tridonta borealis* assemblage consisting of infaunal bivalves and no epifaunal species. The faunal diversity is very low. Member B, unit B3 belongs to this category.

Assemblage I consists of shallow burrowing infaunal bivalves dominated by *Hiatella arctica, Arctica islandica, Tridonta borealis, Mya truncata*, and *Cyrtodaria kurriana*, whereas juvenile specimens of *H. arctica* and *M. truncata* are characteristic epifauna of the vegetation, especially on *Desmarestia* at depths between 3 and 35 m in East Greenland (Thorson 1933, 1934). Furthermore, the brachiopod most probably belongs to the epifauna. *Arctica islandica* is characteristic for this assemblage, and has not been found in any other. In Iceland it belongs to the *Spisula elliptica* community on a stable bottom of sand and muddy sand just below low water mark (Spärck 1937, F.J. Madsen 1949, Thorson 1957).

Assemblage II consits of shallow burrowing infaunal bivalves with *Portlandia* *arctica* as the characteristic species. In East Greenland the species is associated with the Polar Current water, but may also live in the Fjord water with somewhat reduced salinity (Ockelmann 1958). The species is almost always found in a muddy or clayey bottom where the sedimentation is heavy and food supply scarce. The only epifaunal species *Musculus niger* was found to live in East Greenland on a bottom of clay or mud (Ockelmann 1958). This assemblage apparently lived in the transitional zone between the Arctic *Macoma* community and the *Portlandia arctica* community in rather low energy environment.

Assemblage III has generally higher faunal diversity than assemblage II, including infaunal and epifaunal species. It is dominated by infaunal benthos consisting of shallow burrowing gastropods and shallow and deep burrowing bivalves. The great number of *Cyrtodaria kurriana* indicates sandy bottom and rather high energy environments along an outer coast as found with the recent *Gomphina fluctuosa* community in East Greenland. However, the considerable number of *Portlandia arctica* and species belonging to the Arctic *Macoma* community emphasize the transitional character of the assemblage, probably posed by increasing amount of silt (see also Thorson 1957). In the *Gomphina fluctuosa* community of East Greenland the number of animals and the weight per square metre are larger than in the *Portlandia arctica* or the Arctic *Macoma* communities due to more favourable food conditions (Ockelmann 1958). The water movement is stronger and the production of phytoplankton is presumably larger in the *Gomphina fluctuosa* community.

The epifaunal species in assemblage III belong to the subtidal epifauna attached either to the vegetation or coarser constituents of the level sea bottom. Juvenile specimens of *Hiatella arctica* and *Mya truncata* are characteristic members of the epifauna of the *Desmarestia* and *Fucus* vegetation described from East Greenland at depths between 3 and 35 m (Thorson 1933, 1934). The sandy bottom seems to favour the *Fucus* epifauna (Thorson 1933, Bertelsen 1937). Furthermore, the brachiopod most probably belongs to the epifauna. In East Greenland *Arctinula greenlandica* is mainly found in the epifauna on stones and pebbles of the level sea bottom (Ockelmann 1958).

Assemblage III includes species characterizing the *Gomphina fluctuosa* community, but the presence of species from the Arctic *Macoma* community as well as the *Portlandia arctica* community stress the transitional character of the assemblage. It probably lived along an outer coast in an environment with considerable higher energy than prevailed during assemblage II as emphasized by the sand sediment with ripple lamination and cross-bedding.

The molluscan assemblage in the Kap Rigsdagen sediments seems to correspond to a reduced form of assemblage III in the Kap København Formation. The assemblage is dominated by infaunal benthos, bivalves and gastropods, with epifaunal species about or less than 20%.

Assemblage IV shows the widest species diversity including infaunal and epifaunal species. The infaunal benthos consists of shallow burrowing gastropods and shallow and deep burrowing bivalves in silt bottom, i.e. sediment indicating somewhat lower energy environment than the sediment inhabited by assemblage III. *Macoma balthica* is a dominating species together with species belonging to the recent Arctic *Macoma* community, but a considerable number of *Cyrtodaria kurriana* indicates that the assemblage lived in the transitional zone between the Arctic *Macoma* community and the *Gomphina fluctuosa* community. The Arctic *Macoma* community, described by Thorson (1933, 1934) from East Greenland, occurs at depths between 0-4 m and 40-50 m on a silty bottom, but increasing amount of sand leads to a transition to the *Gomphina fluctuosa* community (Thorson 1957). This is in a good agreement with the described bioturbated silt sediment in unit B2.

The epifaunal species in assemblage IV belong to the subtidal epifauna. Juvenile specimens of *Hiatella arctica* and *Mya truncata* together with the *Margarites* species are characteristic epifauna of the vegetation, especially on *Desmarestia* at depths between 3 and 35 m in East Greenland (Thorson 1933, 1934). Adult *Mytilus edulis* belong to the epifauna on rocks, stones, and gravel, the juvenile to the epifauna of the vegetation. However, as noted above the single specimen of this species is probably transported from shallower water. In East Greenland *Musculus niger* is mainly found where the vegetation is scarce on sand with clay and *Bathyarca glacialis* on a bottom of clay with gravel and stones (Ockelmann 1958). Thus, the epifauna lived attached to the vegetation and also coarser bottom constituents as stones, pebbles or other benthos on the level sea bottom. Furthermore, the brachiopod most probably belongs to the epifauna.

Compared to the East Greenland bivalve fauna assemblage IV has a similar portion of infauna and epifauna elements as the recent fauna, about 74% and 26%, respectively (see Ockelmann 1958).

Assemblage V has no epifaunal species and consists exclusively of burrowing bivalves with *Cyrtodaria kurriana* as a characteristic species. In East Greenland it is restricted to the outer coast, where it burrows in sandy bottom (Ockelmann 1958). *C. kurriana* therefore indicates somewhat higher energy environment than prevailed while assemblage IV lived as emphasized by the coarser sediment with ripple lamination.

The fossil assemblages

In this study bivalves with various hinge types are considered, because the strengths of the ligament and the hinge are not the same in taxodont, heterodont, and desmodont species and therefore their disarticulation is different in the same physical environment. Furthermore, the hydrodynamic properties of the valves are different which affects their rate of transportation.

In Member A the umbonal fragment of *Portlandia arctica* is in a concretions and there is one fragmentary specimen with paired valves of the robust species *Tridonta montagui.* This indicates some degree of reworking and a death assemblage. Fragments of thick shelled *Hiatella arctica* and *Mya truncata* associated with glacial erratics are commonly met with at the surface in the Kap København area and are most probably derived from older sediments, but they are here treated as the allochthonous fauna assemblage.

In Member B, unit B1 there are 24 complete and five fragmentary specimens of the rather fragile prosobranch *Boreocingula globula* and only two complete and six fragmentary specimens of the robust opisthobranch *Cylichna occulta.* As a whole the gastropod material is fragmented in this unit. There are only a few paired bivalve shells and generally there are many crushed shells and single valves (left or right). No specimens had paired valves, but there were 40 disarticulated single valves and 11 umbonal fragments of the taxodont *Portlandia arctica* and only one specimen with paired valves, but 69 single valves and 20 umbonal fragments of the heterodont *Tridonta borealis.* There were found five specimens with paired valves, 60 single valves, and 105 umbonal fragments of the desmodont species *Cyrtodaria kurriana*, however, there were some specimens with paired articulated valves in the sediment, but disarticulated as soon as they were taken out of it. Some of these were apparently in life position. On the other hand, there was not a single specimen with paired valves, but 174 single valves and 71 umbonal fragments of another desmodont species *Hiatella arctica.* There are 31 disarticulated left valves and 38 right valves of *T. borealis* and 73 left and 101 right valves of *H. arctica.* Thus, the left and right valves are not present in the equal proportions that would be expected in a living population. Most likely the left and right valves of the species were not transported in the same manner by waves and currents in a shallow water marine environment of rather high energy. This indicates some *post-mortem* transport and reworking and therefore the molluscan assemblage in unit B1 is considered a death assemblage, however, of the parautochthonous type where burrowing species such as *Cyrtodaria kurriana* are more often found with articulated valves and occasionally in life position.

In unit B2 there were found 27 complete and 24 fragmentary specimens of the prosobranch *Boreocingula globula* and four complete and 19 fragmentary specimens of the opisthobranch *Cylichna occulta.* In this unit gastropods belonging to the genera *Oenopota* and *Propebela* are generally the best preserved. However, there are 31 complete and 20 fragmentary specimens of the robust *Oenopota decussata*, which stress the fragmentary state of the material. The bivalves were generally not found in life position and there are high portions of single valves as well as crushed shells and paired valves are rare. There is only one specimen with paired valves, two single right valves and 16 umbonal fragments belonging to the six taxodont species found in this unit. Furthermore, there are three specimens with paired valves, but 15 single valves, and 64 umbonal fragments of *Tridonta borealis* and 61 umbonal fragments and no undamaged valve of the heterodont *Macoma calcarea.* There are three specimens with paired valves, but 29 single valves and 25 umbonal fragments of *Cyrtodaria kurriana*, however, as in unit B1 there were some specimens with articulated valves in the sediment and apparently in life position, but became disarticulated as soon as they were taken out of it (Fig. 33). There are nine single disarticulated left valves and six right valves of *T. borealis* and 18 single left valves and 11 right valves of *C. kurriana.* This indicates *post-mortem* transport and reworking and therefore the molluscan assemblage in unit B2 is considered a death assemblage of the parautochthonous type, as was the assemblage in unit B1.

In unit B3 only two bivalve species were found. The material belonging to *Tridonta borealis* is fragmented, i.e. two umbonal fragments and several plate fragments, whereas *Cyrtodaria kurrriana* in somewhat better preservation is represented by three specimens with paired valves, one left valve, and two umbonal fragments. The fact that the paired valves of the burrowing *C. kurriana* were not found in life position, and the fragmentary state of the material, indicates *post-mortem* transport and reworking and a death assemblage.

In Member B, locality 57.2 there are no specimens with paired valves, but 40 disarticulated single valves and 14 umbonal fragments of *Portlandia arctica* and 48 disarticulated single valves and six umbonal fragments of *Tridonta borealis.* Furthermore, there were no specimens with paired valves, but 27 single left valves, 32 right valves, and 64 umbonal fragments of *Hiatella arctica.* In locality 128 the gastropod material is also rather fragmented. The bivalve shells were not found in life position and there are only a few paired bivalve shells and many crushed valves. *Macoma calcarea* is represented by three complete right valves and 78 umbonal fragments and there were found two left and two right valves and 17 umbonal fragments of *Cyrtodaria kurriana.* There were collected 52 disarticulated left valves and 41 right valves of the heterodont *Macoma balthica* which seems to stress that the left and right valves were not transported in the same manner by waves and currents. This strongly indicates *post-mortem* transport and crushing and a death assemblage.

In the bivalve material found in the allochthonous fauna assemblage all the strong and heavy shells of the heterodont *Arctica islandica* are crushed and worn and the very fragmentary state of the material strongly indicates *post-mortem* crushing and grinding of a death assemblage by waves, rivers or glacier ice.

The mollusc material collected at Kap Rigsdagen is fragmented and no paired bivalve shells were found. *Tridonta borealis* is represented by four left valves, five right valves, and 15 umbonal fragments and *Hiatella arctica* by one left valve, two right valves, and 14 umbonal fragments. This indicates *post-mortem* reworking and crushing and most probably we are here dealing with still another death assemblage.

Correlation with Pliocene and Pleistocene faunas

All the mollusc species found in the Kap København Formation are extant. The oldest species are recorded from Oligocene formations, but several species have never been reported from deposits older than Lower Pleistocene. There are ten species that have not been found in older deposits and most probably have their first appearance in the Kap København Formation: *Pseudosetia turgida, Boreocingula globula, Cylichna occulta, Portlandia arctica, Yoldiella fraterna, Yoldiella intermedia, Bathyarca glacialis, Tridonta soror, Montacuta dawsoni*, and *Cyrtodaria kurriana* (Table 5). Additionally, *Macoma balthica* apparently has its first appearance almost contemporaneously in the Kap København Formation and the Fishcreekian. Four species are new to the Greenland fossil fauna: *Pseudosetia turgida, Rissoa parva, Nucula nucleus* (see p. 41), and *Tridonta soror.*

The mollusc fauna in the Kap København Formation is a mixture of Atlantic and Pacific species with 20 distinctly Atlantic species and two of probable Atlantic origin. The Pacific species are 11 and there are, additionally, three species probably of Pacific origin. The remaining species are of unknown origin.

Other Greenlandic sites

The mollusc fauna of the Lower Pleistocene **Pattorfik deposits** in the Uummannaq Fjord, West Greenland (Figs 1, 35), has many species in common with the Kap København Formation (Símonarson 1981, Funder & Símonarson 1984). However, the Pattorfik fauna includes one extinct species, the prosobranch *Alvania patorfikensis* Laursen, 1944, and it is also clearly more thermophilic with greater dominance of epifaunal species. This hardly indicates significant age difference between these deposits when taken into consideration that Kap København is situated between 82°20' N and 82°30' N on the northeast coast of Greenland today surrounded by cold water masses, whereas Pattorfik is close to 70°30' N in the Uummannaq Fjord on the west coast of Greenland today influenced by the warm West Greenland Current. Funder & Símonarson (1984) suggested an Early Quaternary age for the Pattorfik sediments, which may therefore be somewhat younger than the Kap København Formation.

In central East Greenland (Figs 1, 35) the fauna in the Lodin Elv Formation can be correlated with the Kap København fauna on the basis of the foraminiferal and ostracode faunas (Feyling-Hanssen *et al.* 1983, Penney 1993). **The Lodin Elv Formation** is a 40 m thick sequence of marine sand, silt, and diamicton with foraminifera, ostracodes, and molluscs. Foraminifer faunas and amino acid analysis of mollusc shells indicate an Upper Pliocene-Lower Pleistocene age (Feyling-Hanssen *et al.* 1983), either shortly after 2.4 Ma or about 2.6 Ma (Penney 1993), and therefore the age of the Lodin Elv Formation is similar to or a little higher than the Kap København Formation. The Lodin Elv mollusc fauna is poor in species, but they are all living today and of arctic provenance reflecting environmental conditions as harsh as the present. This is emphazised by the occurrence of the arctic *Yoldiella frigida* (Torrell) as well as *Astarte crenata* (Gray) in the Lodin Elv Formation, and also the absence of more thermophilic species such as *Pseudosetia turgida, Rissoa parva, Nucula nucleus, Mytilus edulis, Arctica islandica*, and *Macoma balthica* found in the Kap København Formation.

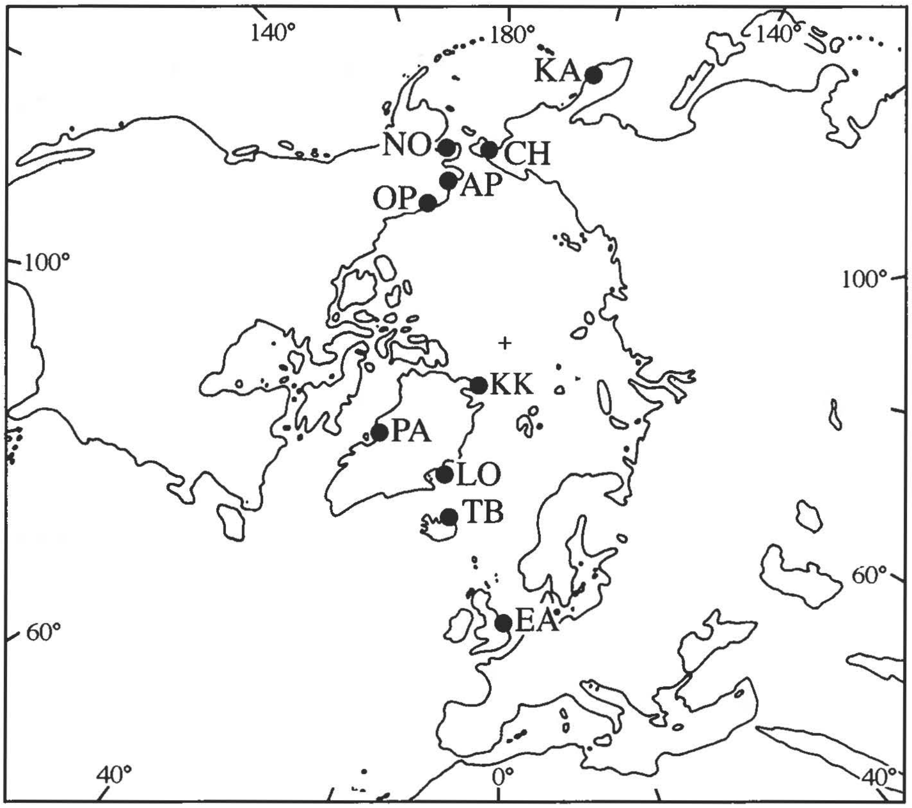

Fig. 35. Map showing some important localities with deposits compared with the Kap København Formation. KK: Kap København, PA: Pattorfik, LO: Lodin Elu, TB: Tjörnes and Breidavík, EA: East Anglia, OP: Ocean Point, AP: Arctic Coastal Plain, No: Nome, CH: Chukotka, and KA: Kamchatka.

Icelandic sites

The faunas in the Tjörnes beds and Breidavík Group in North Iceland (Fig. 35) are of Pliocene and Lower Pleistocene ages. The mollusc fauna in the **Tjörnes beds** differs significantly from the Kap København fauna in having about 22% extinct species (Norton 1975). Not until in the upper part of the Tjörnes beds, the Upper Pliocene ***Serripes* Zone** at 3.5 Ma, did subarctic molluscan species appear to some degree (Einarsson *et al.* 1967, J. Eiríksson *et al.* 1990). *Buccinum undatum, Serrripes groenlandicus, Macoma calcarea,* and several other species of Pacific origin obviously migrated into the North Atlantic during the deposition of the *Serripes* Zone (Durham & MacNeil 1967). These species have since been among the dominants in arctic and subarctic marine assemblages within Quaternary faunas in the North Atlantic area, where they had been present for a long time before the deposition of the Kap København Formation.

The closing of the Central American Seaway, about 3.5 Ma ago, induced a flow of surface water through the Bering Strait and the Arctic Ocean and brought a tide of Pacific molluscs to the North Atlantic and Iceland (Backman 1979). It also increased the transport activity of the Gulf Stream (Brunner 1978). The initiation of the flow might have triggered the onset of the Labrador Current and very strongly affected the ocean current pattern both west and east of Greenland (Backman 1979). Apparently the Bering Strait was already open in the Pliocene when the ***Tapes*** and ***Mactra* Zones** of the Tjörnes sequence were deposited, as indicated by distinct Pacific molluscs in these zones. They are considered to have migrated through the Arctic Ocean (Durham & MacNeil 1967). These events predate the deposition of the Kap

København Formation since several species that have their first appearance in the North Atlantic in the *Serripes* Zone of Tjörnes are also found in the Kap København Formation. These species includes *Natica affinis, Buccinum undatum, Admete couthouyi, Musculus niger, Serripes groenlandicus, Clinocardium ciliatum, Macoma calcarea*, and *Mya truncata*.

The Kap København fauna and the fauna in the Lower Pleistocene **Breidavík Group** on Tjörnes are more similar to one another. In the lower part of the **Hörgi Formation**, dated to about 2.0 Ma, is apparently the oldest occurrence of *Portlandia arctica* in Iceland (J. Eiríksson 1981, J. Eiríksson *et al.* 1990). Although the fauna in the Breidavík Group has two or three extinct species it is certainly Pleistocene in character with recurrent arctic, mesohaline assemblages that lived in proglacial environments (J. Eiríksson 1985). The first sign of glaciation along the north coast of Iceland is the lowermost tillite in the Breidavík Group dated as 2.0 Ma (Albertsson 1978). However, recent palaeomagnetic works indicates that this first major glaciation of Iceland, reaching sea level in the Tjörnes area, may have taken place close to 2.5 Ma or slightly after the Gauss/Matuyama reversal (J. Eiríksson *et al.* 1990). The end of this glaciation may be the same as recorded in the lowermost part of the Kap København Formation (Member A).

North Sea sites

In the Crag basin of the North Sea area (Fig. 35) a Lower Pleistocene **Pre-Pastonian/Baventian** cold marine episode has been recorded from **Covehithe**, Suffolk (West *et al.* 1980, Gibbard *et al.* 1991), with subarctic or even arctic molluscan assemblages reaching the Rhine and Thames estuaries at least as early as the Upper Tiglian or Pre-Pastonian/Baventian about 1.9 Ma ago (Gibbard & Zalasiewicz 1988, Gibbard *et al.* 1991). It is even possible that arctic molluscan assemblages with *Portlandia arctica* reached the North Sea area as early as 2.0 Ma, during the deposition of the Lower Pleistocene ***Serripes groenlandicus-Yoldia lanceolata* Zone** of Netherlands Upper Tiglian (**„Icenian“**) (Heering 1950, Spaink 1975, Zagwijn 1975, 1992). *Macoma balthica* is absent in the Covehithe fauna with *Yoldia* sp., *Serripes groenlandicus, Macoma calcarea*, and *Hiatella arctica* as dominating species. The littoral was obviously unpopulated and only a few boreal elements such as *Cerastoderma edule* (Linné) and *Arctica islandica* occurred. Distinctly arctic species such as *Portlandia arctica* and *Cyrtodaria kurriana* found in the Kap København fauna are not met with in the younger Covehithe fauna which actually is more boreal in character, although there are many species in common. There are some extinct species found in the Covehithe deposits, but they are probably derived from older or distant sources.

Macoma balthica appeared for the first time and became a prominent part of the faunas in Late Baventian deposits on the north coast of Norfolk and in borings in Holland from the cold Tiglian C4 Substage. Its appearance is considered an important time-marker and took place close to the base of the Olduvai Subchron at c. 1.95 Ma (Norton 1967, Norton & Spaink 1973, Gibbard *et al.* 1991, Funnell 1995). The species is abundantly present in the cold Lower Pleistocene of Norfolk of **Post-Bramertonian** age (Funnell *et al.* 1979).

Alaskan sites

Although there is some faunal correlation with marine faunal assemblages in the Pliocene-Pleistocene Gubik Formation in Alaska (MacNeil 1957), it includes more Pacific mollusc species than the Kap København fauna (Fig. 35). Thus, the cool or cold temperate mollusc assemblages of the almost contemporaneous **Fishcreekian (Fish Creek Fauna)** and the slightly older **Bigbendian** marine transgressions of the Arctic Coastal Plain, are distinctly more Pacific (Carter *et al.* 1986, Repenning *et al.* 1987, Repenning & Brouwers, 1992).

The mollusc fauna in the Middle Pleistocene Anvilian deposits, with more extinct species than the Kap København Formation (Hopkins *et al.* 1974) and arctic assemblages with *Portlandia arctica* in Alaska at California River and Nome (MacNeil *et al.* 1943, Hopkins *et al.* 1974), shows similar affinities. The age of the **Anvilian** deposits has been estimated between 1.0 and 1.8 Ma (Hopkins *et al.* 1974, Gladenkov 1981), but recently the age has been reevaluated by Kaufman & Brigham-Grette (1993) to be as young as 410.000 yr. There are certainly more species in common with the more modern fauna of the Middle Pleistocene **Kotzebuan** deposits in Alaska with the first appearance of the arctic bivalve *Cyrtodaria kurriana* in Alaska (Hopkins *et al.* 1972). The marine beds at **Ocean Point** have been assigned to the Beringian transgression by Hopkins (1967), but are now considered as deposited during the Kotzebuan transgression (Carter *et al.* 1977), which render the occurrence in the Kap København Formation the oldest known. In Alaska *Macoma balthica* has been recorded from deposits as old as 2.4 Ma (Repenning *et al.* 1987), but it is most commonly found in Middle Pleistocene and younger beds (Hopkins 1967, Hopkins *et al.* 1974).

Siberian sites

Comparison with Siberian deposits (Fig. 35) shows certain faunal similarities between the Kap København fauna and the fauna in the Upper Pliocene-Lower Pleistocene **Olkhov-Tusatuva Yamsk Suites** in Kamchatka. They are about 2.0 Ma old, with the first appearance of *Cyrtodaria kurriana* in arctic assemblages in Siberia and nearly 20% extinct species, which contrasts with the modern aspect of the faunal assemblages in the older Kap København Formation (Gladenkov 1981, Petrov 1982, 1986). The relationship to the extant arctic marine assemblages with *Portlandia arctica* in the Middle Pleistocene **Karagin beds** in Kamchatka and the **Pinakul Suite** in Chukotka is, however, still stronger (Petrov 1967, 1982, 1986). In Siberia *Macoma balthica* has been found in the Lower Pleistocene **Olkhov Suite** (c. 2.0 Ma) as well as the Middle Pleistocene **Kresta Suite** in Chukotka and younger deposits (Merklin *et al.* 1962, Petrov 1982, 1986). Located closer to the Atlantic area an earlier and stronger development of the Atlantic character of the Kap København fauna is expected. This could explain the fact that the Kap København fauna as well as the allochthonous fauna assemblage and the Kap Rigsdagen fauna seem most related to Lower Pleistocene Atlantic faunas, whereas they seem more related to Middle than Lower Pleistocene faunas in Siberia and Alaska closer to the Pacific area.

Deep Sea records

High-resolution records of benthic oxygen isotopes, ice rafted detritus (IRD) and dust flux from ocean drilling in the Atlantic have shown that major ice sheet began to form in the Northern Hemisphere with the succession of cold isotope stages between 2.8 and 2.45 Ma (Raymo 1992, Wei 1993, Tiedemann *et al.* 1994, Chen *et al.* 1995). Ice rafted detritus data from site 642 in the Norwegian Sea suggest glacial episodes in the area as early as 5.45 Ma ago, but 2.57 Ma ago a dramatic change in the IRD input was noted (Jansen & Sjøholm 1991, Mangerud *et al.* 1996), which is also recorded in the Fram Strait adjacent to Kap København (Thiede *et al.* 1995). Recent work indicates that the first major glaciation of Iceland, with the oldest tillites in coastal section at Tjörnes in North Iceland, may have taken place 2.5 Ma ago or slightly after the Gauss/Matuyama reversal (J. Eiríksson *et al.* 1990, J. Eiríksson & Geirsdóttir 1991, Geirsdóttir & J. Eiríksson 1994). These glacial deposits in the Tjörnes section are the first indication that glaciers reached sea level in Iceland. Thus, the first major glaciations of the Northern Hemisphere apparently occurred between 2.55 and 2.45 Ma (Chen *et al.* 1995, Funnell 1995). As noted above we correlate Member B of the Kap København Formation with succeeding recurrence of warm climate (Fig. 4). As the first appearance of Neogene shallow water arctic-high arctic marine mollusc fauna, with *Portlandia arctica*, the *Yoldiella* species as well as *Cyrtodaria kurriana*, seems to be in the Kap København Formation it is suggested that the fauna developed as a result of adaption to the new and severe conditions during the formation of major ice sheets. Then the arctic-high arctic fauna apparently migrated southwards as it appeared at an earlier date at Kap København than further south. With careful calibration of biostratigraphical events and oxygen isotope stratigraphy it was possible for Raffi *et al.* (1993) to show that within nannofossils some biostratigraphical events are time transgressive. An age difference up to 229.000 yr was found between the disappearance level of the same species in mid latitude North Atlantic (Deep Sea Drilling Site 607) and the eastern equatorial Pacific (Ocean Drilling Site 677).

The origin of the arctic-high arctic shallow water mollusc fauna

In the Upper Tertiary, before the onset of the Cainozoic glaciations, the Polar Basin was inhabited by a benthic fauna of mainly Pacific origin. This fauna was in part a reminiscence of the North Pacific fauna that was brought through the Bering Strait when the Central American Seaway was closed about 3.5 Ma ago and a pronounced flow of surface water took place from the Pacific into the Arctic Ocean (Durham & MacNeil 1967, Bouchet & Warén 1979, Backman 1979). The Arctic Ocean was ice-free during this time and boreal conditions prevailed and also Atlantic boreal species of Mediterranean-lusitanian origin were able to penetrate the Arctic Ocean from the Norwegian Sea (Strauch 1972, Golikov & Scarlato 1989). During the first major glaciation of the Northern Hemisphere between 2.55 and 2.45 Ma the boreal species of the Arctic Ocean which could not adapt to the new and harsher environments declined and eventually became extinct (Gladenkov 1978, Petrov 1982), and the vacant ecological niches were occupied by boreal-arctic species mainly of Pacific origin mingled with some Atlantic species (Golikov & Scarlato 1989). The period from 2.9 to 2.5 Ma was characterized by progressive cooling and increasing ice volume (Tiedemann *et al.* 1994, Chen *et al.* 1995) that led into a major glacial phase between 2.55 and 2.45 Ma and during this time the Arctic Ocean became more or less isolated from the Pacific and Atlantic waters (Strauch 1970, Golikov & Scarlato 1989). An arctic water mass was formed and it filled the deeper parts of the Polar Basin and endemic bathyal and semiabyssal genera and species evolved in the area (Golikov & Scarlato 1989). This major regression was followed by a transgression (Krantz 1991) that shaped the modern continental shelves and probably the first shallow water arctic-high arctic water mass was formed under cold conditions. It had reduced salinity 30-32‰, and annual mean temperatures from -0.1°C to -1.5°C (Golikov & Scarlato 1989). During the isostatic uplift that followed the glacial period between 2.55 and 2.45 Ma Member A of the Kap København was probably deposited and during the following transgression units B1 and B2 of Member B were formed. At this time the first typical arctic-high arctic shallow water mollusc fauna evolved in response to the new and harsher environments and became distributed in the shallower parts of the Polar Basin.

The arctic-high arctic shallow water mollusc fauna in the Kap København Formation includes remarkably many genera and subgenera of bathyal or abyssal origin; *Nucula, Portlandia, Yoldiella, Bathyarca, Arctinula, Thyasira,* and *Montacuta* (Knudsen 1970). Furthermore, *Bathyarca glacialis, Thyasira dunbari,* and *Cuspidaria subtorta,* all found in the recent arctic-high arctic shallow water fauna in North Greenland, are not considered very well adjusted to shallow water conditions as they lack a pelagic larval stage (Schiøtte 1989). This indicates that the shallow water arctic-high arctic mollusc fauna is mainly a result of deep water evolution with subsequent migration into shallow water and simultaneous further evolution, but apparently this evolution and adaption to shallow water environments is not yet completed. This is further indicated by the fact that the most typical arctic-high arctic shallow water bivalves have rather thin and smooth shells with weakly developed sculptures, but these characteristics are more prominent in bathyal and semiabyssal bivalves than shallow water bivalves from more southerly localities (Knudsen 1970). A similar evolution pattern posed by migration from deeper waters into shallower environments has been proposed for arctic isopods by Hessler *et al.* (1979). Apparently these migrations were caused by an extensive perennial sea ice during major Cainozoic glaciation, between 2.55 and 2.45 Ma (Carter *et al.* 1986, Scott *et al.* 1989, Repenning & Brouwers 1992, Kaufman & Brigham-Grette 1993). The ice cover probably caused that bottom living molluscs were attracted towards the ice margin where the food conditions were more favourable and then to shallow water shelves, when the Arctic Ocean gradually became ice covered, and seasonally or episodically ice free areas only existed closer to the coasts. The occurrence of the prosobranch *Pseudosetia turgida* in unit B2 might indicate that while this happened the species was temporarily attracted to even shallower water conditions than it prefers nowadays. However, it did not adapt to these depth environments and soon migrated southward into the North Atlantic to similar depths conditions as previously.

The recent marine mollusc fauna off Kap København

As already mentioned Kap København is situated at the mouth of Independence Fjord, facing the Wandel Sea towards the east. The fjordsystem is covered with persistent ice through many years, therefore the investigation of the recent fauna (Table 9) had to be concentrated to the tidal cracks in the up to 2 m thick ice occurring off the shore in the Kap København area.

The tidal cracks permitted four dredge hauls to be taken, in the northern part of the area (locality 49a; Fig. 2) close to land and out to a distance of 50 m, and therefore in shallow water not deeper than 7 m. Further c. 3 km to the south right off Kap København (locality 49b) one dredge haul was taken 150 m off the shore on a depth of 14.6 m. Informations on depths, salinity, and temperatures of the bottom sediments as well as the surface water were obtained on location, but they do not form a base for detailed quantitative analysis as the measurements are few and performed with simple instruments. Back in the laboratory the granulometric composition of the sediment, loss on ignition, lime content, and salinity were measured.

The information obtained on the recent mollusc fauna is important for the understanding of the fossil Kap København molluscan assemblages. The samples applies to the detailed analysis of the marine mollusc fauna from the nearby Jørgen Brønlund Fjord (Schiøtte 1989).

In the Kap København area a total of 21 mollusc species were found; seven gastropods and 14 bivalve species (Table 9). Furthermore, sea spiders (Pycnogonida), brittle stars (Ophiuroidea), and sea cucumbers (Holothuroidea) were met with. In some of the samples the sea cucumbers were dominating.

Jørgen Brønlund Fjord is situated 130 km westsouthwest of Kap København, further up the Independence Fjord which is usually covered with ice the whole year. However, in Jørgen Brønlund Fjord the ice usually breaks up in the first half of July and new ice starts forming in the beginning of September (Schiøtte 1989). The extensive sampling there during several years compared to the samplings in the Kap København area in 1983, has given a total of 76 mollusc species; four aplacophorans, 42 gastropods, one scaphopod, and 29 bivalves.

Most of the recent mollusc species from the Kap København area are found in the material from Jørgen Brønlund Fjord as presented by Schiøtte (1989). However, two bivalves, *Tridonta elliptica* and *Pandora glacialis*, and one gastropod, *Beringius ossiani*, is only recorded from off Kap København. Both these bivalves are represented in the fossil fauna, as are 15 mollusc species of the 21 found off Kap København. *Beringius ossiani*, which belongs to the Buccinidae, is not recorded in the fossil Kap København fauna, where the material of Buccinidae is remarkably small. Schiøtte (1989) points to the absence of Buccinidae in the Jørgen Brønlund Fjord fauna as most conspicuous compared to the fact that more than one third of the gastropod species recorded by Macpherson (1971) from Canadian Arctic waters belong to this family. Regarding the absence of *Pandora glacialis* in the Jørgen Brønlund Fjord fauna compared to the Kap København fauna, this can be explained by the preference of this species for places not too far from the open sea, avoiding the innermost ramifications of large fjords, as stated by Ockelmann (1958).

The recent fauna at Kap København and in the Independence Fjord area is dominated by panarctic and arctic-high arctic species without pelagic larvae. More than half of the species belong to the Polar Current and Fjord water layer on clayey muddy and sandy mixed bottom. Within the few km in the southern part of Mudderbugt where the dredge hauls were taken remarkable changes occur in the granulometric composition of the bottom sedi-

Table 9. Recent marine molluscs found in dredge hauls in the Kap København area (locality 49a and 49b)

		Locality 49a		Locality 49b	
Sediment type	Clayey silt	Clayey silt	Silty sand	Silty sand	Sandy silt with gravel
Sample No. Kap København No.	56825	56827	56832	56840	57514
GASTROPODA					
Natica cf. *affinis* (Gmelin, 1790)				4	
Beringius ossiani (Friele, 1879)				2	1
Oenopota cinerea (Møller, 1842)	4			3	
Propebela reticulata (Brown, 1827)				9	2
Cylichna alba (Brown, 1827)				5	
Cylichna occulta (Mighels & Adams, 1842)	4	2		12	
Philine finmarchica M. Sars, 1858				1	
BIVALVIA					
Portlandia arctica (Gray, 1824)	77	18	5	851	2
Yoldiella frigida (Torell, 1859)					8
Yoldiella intermedia (M. Sars, 1865)		2			1
Yoldiella lenticula (Møller, 1842)	2				1
Bathyarca glacialis (Gray, 1824)					11
Arctinula greenlandica (Sowerby, 1842)				15	1
Tridonta borealis Schumacher, 1817				4	1
Tridonta elliptica (Brown, 1827)				2	5
Tridonta montagui (Dillwyn, 1817)					21
Macoma loveni (Jensen, 1905)					2
Hiatella arctica (Linné, 1767)				10	1
Mya truncata Linné, 1758					1
Pandora glacialis Leach, 1819				2	
Cuspidaria subtorta (G.O. Sars, 1878)				3	
Depth in m	3.5	3.5	2.8	6.5	14.6
Sediment temperature °C	0.0	0.0	+0.5	-1.0	-1.0
Water temperature °C	-1.0	-1.0		0.0	0.0
Lime content % wt/vol	2.0	3.0	0.5	3.0	8.0
Loss on ignition % of dry wt	2.58	3.08	1.59	2.80	5.61

ment from north to south, as seen on Table 9. This might in part explain the variation observed in the fauna, where shallow water infaunal elements dominate, and why an epifaunal species such as *Bathyarca glacialis* was only found in the one sample from the southern locality (locality 49b; Fig. 2) with a high content of gravel. However, the overwhelming majority of the population consists of *Portlandia arctica* with 851 specimens in one dredge haul (sample 56840). This species is a deposit feeder and belongs to the shallow infauna. The percentage of epifaunal molluscan species is considerably lower for the recent fauna than for the the subarctic assemblages in the Kap København Formation. Additionally, the more thermophilic species found in the subarctic assemblages in the Kap København Formation, species such as *Pseudosetia turgida, Rissoa parva, Nucula nucleus, Mytilus edulis, Arctica islandica*, and *Macoma balthica* are missing in the recent fauna.

The recent mollusc fauna in the Kap København area contains 11 species belonging to the Arctic *Macoma* community: *Natica affinis, Propebela reticulata, Cylichna alba, Cylichna occulta, Tridonta borealis, T. elliptica, T. montagui, Macoma loveni, Hiatella arctica, Mya truncata*, and *Cuspidaria subtorta.* Five species are generally connected with the *Astarte crenata* community: *Yoldiella frigida, Y. intermedia, Y. lenticula, Bathyarca glacialis*, and *Tridonta elliptica* (only in the upper part of this community). Along the coast of East Greenland, where the *Astarte crenata* community has been met with, it is generally on depths more than 25-30 m (Ockelmann 1958), which is outside the actual shallow water area dredged off Kap København. Furthermore, the recent fauna from this area also contains representative species of the *Gomphina fluctuosa* and the *Portlandia arctica* communities: *Pandora glacialis* and *Portlandia arctica.* This indicates that parameters such as dominance of the Polar Current water in the shallow water environment might hamper the immediate correlation with observed assemblages from other places. This has a clear implication for the interpretation of the dates from the Kap København fossil mollusc fauna.

Concluding remarks

Biostratigraphic correlations based on foraminifera, ostracodes, insects, molluscs, and mammals, supplemented by palaeomagnetic studies, indicate that the Kap København Formation was formed during the uppermost Pliocene and lowermost Pleistocene (Feyling-Hanssen 1990, Penney 1993, Böcher 1995, Repenning *et al.* 1987, Abrahamsen & Marcussen 1986). The formation is divided into the lower Member A and the upper Member B, the latter subdivided into three lithological units (Funder *et al.* 1984). The boundary between the two members is dated to the transition between the Praetiglian and Tiglian of northern Europe. The age of this is considered close to 2.45 Ma (Chen *et al.* 1995, Funnell 1995, 1996; Fig. 4). The allochthonous fauna assemblage, with more thermophilic species such as *Arctica islandica*, is regarded as reworked into the glacigene deposits of Member A. On faunal bases and evaluating the rate of amino acid diagenesis the allochthonous fauna assemblage is correlated with the warm phase that preceded the Praetiglian glaciation, i.e. the Reuverian Stage of the uppermost Pliocene in northern Europe. Member A is interpreted as a succession of glacigene and glaciomarine sediments deposited during an isostatic regression at the end of a major glaciation in the area and correlated with the Praetiglian. Member B is divided into three units representing different stages in a transgression that succeeded the isostatic regression during the following warmer period correlated with the Tiglian. The transgression rates were first slow and the sedimentation and sea level kept pace while unit B1 was formed, then the rates were faster when unit B2 was deposited, and then again slower during the sedimentation of unit B3. The deposits at Kap Rigsdagen are correlated with Member B, unit B1 (Table 8).

The sediments in Member A were deposited sublittorally in moderately deep water and contain evidence for glaciation in the area, whereas the sediments in Member B were mainly deposited in foreshore, backshore and shoreface environments. The abundance of organic detritus of terrestrial origin in parts of the sequence probably results from nearby influx of fresh water (Bennike 1990).

The molluscan fauna collected in the Kap København Formation and in the sediments at Kap Rigsdagen comprises 15 gastropd and 27 bivalve species. Furthermore, one brachiopod species was found. The sparse fauna in Member A is fragmented and indicates some degree of reworking and a death assemblage. The fauna in Member B, unit B1 is probably washed up from slightly greater depth and also a death assemblage, whereas the fauna in unit B2 is regarded as a death assemblage of the parautochthonous type. The faunas in unit B3 and the sediments at Kap Rigsdagen are also fragmented and certainly indicate *post-mortem* transport and reworking death assemblages. The allochthonous fauna assembleges is very fragmented and strongly indicates *post-mortem* crushing and transport of a death assemblage by waves and currents or with a fluvial transport agent.

The distribution of molluscan species with different thermal requirements within the sediments indicates arctic sea temperatures during the deposition of Member A and subarctic temperatures during the deposition of Member B that rose to even milder subarctic conditions when unit B2 was formed. All the faunas lived in waters with reduced salinity.

The mollusc fauna from the Kap København Formation is amphiatlantic in character, but five species are new to the Greenland fossil fauna and four species are not known to live in Greenland today. All the species are extant, but ten have not been recorded from older deposits and apparently have their FAD - their first appearance datums - in the formation.

The mollusc fauna in the Kap København Formation is considered to be the oldest arctic-high arctic fauna from marine, shallow water environments known so far. It is suggested that it evolved in response to the new and harsher environments following the Praetiglian glaciation, most probably during migration into shallow water environments. When the Polar Basin became ice covered the molluscs were attracted to the ice margin where food conditions were more favourable and then to the shallow water shelves with seasonally ice free areas close to the coasts.

The recent mollusc fauna at Kap København and in Independence Fjord is dominated by arctic-high arctic species and more than half of them belong to the Polar Current and Fjord water layer on clayey muddy and sandy mixed bottom (Table 9). The recent fauna has about 70% species in common with the fossil fauna of the Kap København Formation. However, the more thermophilic species found in the subartic assemblages in the Kap København Formation, species such as *Nucula nucleus, Arctica islandica*, and *Macoma balthica* are missing in the recent fauna.

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BIOSCIENCE · GEOSCIENCE · MAN & SOCIETY

The sediments of the Kap København Formation, with an age of c. 2.4 ma and located in the world's northernmost land area, have yielded an unusual glimpse of some of the oldest known Arctic ecosystems. The marine mollusc fauna surprisingly indicates nearshore marine conditions which were similar to the present.

Earlier palaeontological monographs from the Kap København Formation comprise works on the terrestrial vegetation (Meddelelser om Grønland Geoscience 23), foraminifera (Meddelelser om Grønland Geoscience 24), and insects (Meddelelser om Grønland Geoscience 33)

Leifur A. Símonarson (born 1941) is professor of palaeontology at the University of Iceland in Reykjavik. He took his PhD at the University of Copenhagen in 1978. His major research interests are Upper Tertiary and Quaternary molluscs and his working area, besides Iceland, also comprises Denmark and Greenland.

Svend Funder (born 1941, PhD University of Copenhagen 1976) is curator of Quaternary collections at the Geological Museum, University of Copenhagen. His research interests are Quaternary climate and environments, and he has many years' working experience in the Arctic.

Kaj Strand Petersen (born 1937, Mag. Scient. University of Copenhagen 1971) is senior researcher at the Geological Survey of Denmark and Greenland. His research interest is Quaternary geology with emphasis on molluscs and sea level change. He has many years' experience of mapping Quaternary sediments in Denmark, and has participated in several expeditions to Greenland.