Chapter 12
Foraminifera in the Early Pleistocene Part of the Breiðavík Group, North Iceland

Karen Luise Knudsen, Jón Eiríksson, and Leifur A. Símonarson

Abstract Foraminiferal assemblages have been studied in the Early Pleistocene sediments of the Tjörnes section, North Iceland. A systematic description of the foraminiferal contents in three different formations of the Breiðavík Group, i.e., the Hörgi Formation, the Þrengingar Formation (Svarthamar Member), and the Máná Formation, is presented. Only the 1.5 Ma old Svarthamar Member (upper part of the Þrengingar Formation) contained enough foraminifera for stratigraphical and environmental interpretations of the Breiðavík Group sediments. The foraminiferal assemblage compositions in the Svarthamar Member indicate a change from arctic to boreal-arctic (subarctic) or even boreal conditions in the sea around Iceland just after the Olduvai event of the Matuyama time interval. This climatic cycle is comparable to the Late Pleistocene glacial-interglacial cycles in the North Atlantic and indicates a northward shift of the Polar Front to a position off North Iceland during at least a part of the Early Pleistocene.

Keywords Tjörnes · North Iceland · Early Quaternary foraminifera · Glacial-interglacial paleoecology · Quaternary foraminiferal stratigraphy

12.1 Introduction

The Breiðavík Group is the youngest lithostratigraphical unit on Tjörnes, and it contains a remarkable record of Early and Middle Pleistocene glaciations in Iceland, including 14 lithological cycles showing alternations of ice cover and ice-free conditions on the peninsula. Northern Iceland is located in an area, which is particularly sensitive to shifts of the Polar Front between the water masses of the relatively

K. L. Knudsen (✉)
Department of Geoscience, Aarhus University, Aarhus, Denmark
e-mail: karenluise.knudsen@geo.au.dk

J. Eiríksson · L. A. Símonarson
Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland
e-mail: jeir@hi.is; leifuras@hi.is

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warm Irminger Current, a branch of the North Atlantic Current, and the cold East Greenland and North Icelandic currents (Fig. 12.1). This geographical location is the background for a diverse series of lithological elements of the Breiðavík Group sediments (Figs. 12.2 and 12.3), which is particularly characterized by its recurring sheets of diamictite. The lithologies range from basaltic lava flows, volcanic tufts, and subglacial/aquatic eruptives to mudrocks, sandstones, conglomerates, and diamictites. Exposures of the Breiðavík Group sediments occur almost continuous in sea cliffs along the coast and along brook gullies around the Tjörnes Peninsula, North Iceland (Fig. 12.2). These are the basis for reconstructing the composite log of Fig. 12.4 (see Eiríksson et al., 2020a, 2020b). Most of the sediments are lithified and form very hard rocks.

The Breiðavík Group was subdivided into units by Bárðarson (1925), and these units are currently used (cf. Fig. 12.4). A detailed survey of the stratigraphy and the

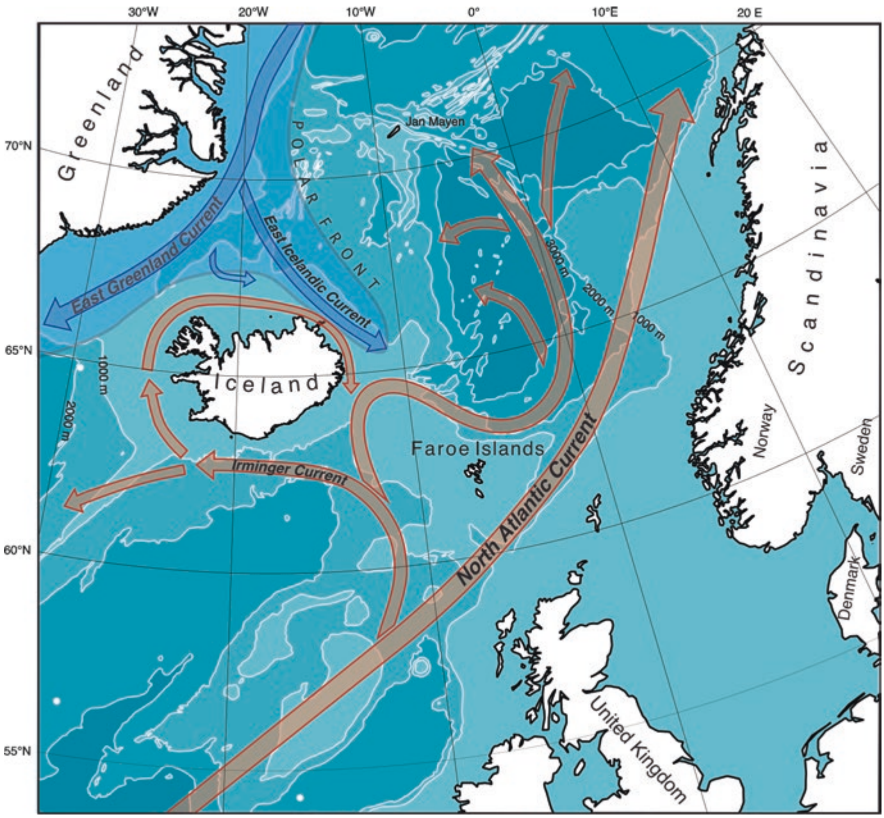

Fig. 12.1 Map of the North Atlantic Ocean with the main present-day oceanic surface currents around Iceland. The warm Atlantic Current is marked with red color and the cold East Greenland Current in blue. Black line marks the present Polar Front (modified after Hurdle, 1986). The map illustrates how the Tjörnes Peninsula on Iceland is located in an area ideal for tracking even minor change in ocean circulation

Fig. 12.2 Map of the Tjörnes Peninsula with locality names. The insert map shows the location of Tjörnes in northern Iceland. Most of the foraminiferal samples are collected from sites along the coastal section in Breiðavík (marked with at dotted line from A to B) but a few (1191–1193) are from Þrengingar, a few kilometers further inland

sedimentology of the Breiðavík Group has been presented by Eiríksson (1981, 1985) and Eiríksson et al. (2020a), and a compiled description of the sedimentary facies, molluscs, and foraminifera was published by Eiríksson et al. (1992, 1993, later updated by Eiríksson et al. 2020b). This work has been supplemented by Cronin (1991), including a discussion of the environmental indication of ostracod assemblages from the Breiðavík Group, and a stratigraphical study of Verhoeven et al. (2011) based on dinoflagellates.

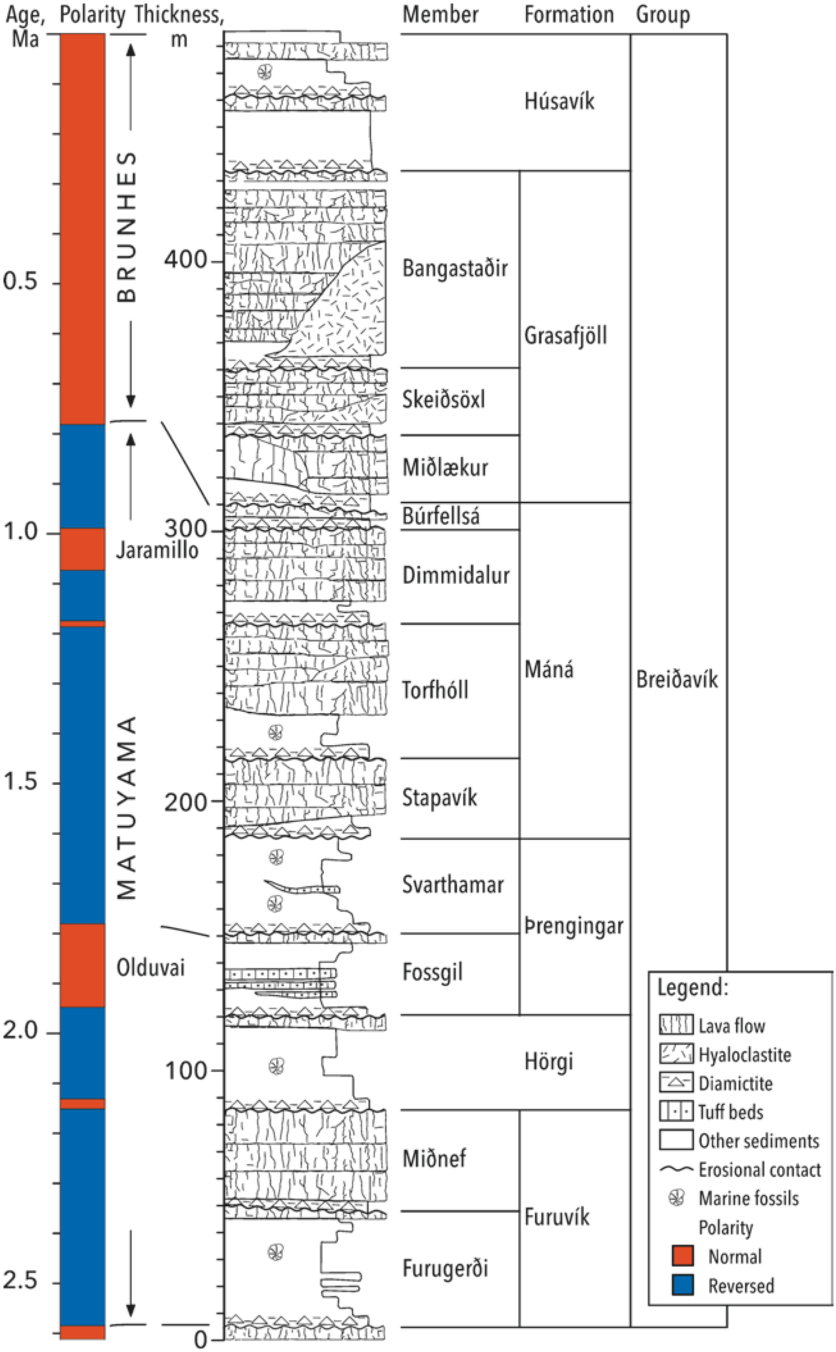

Fig. 12.3 Stratigraphic column with indication of fossiliferous intervals and paleomagnetic time scale (Ogg & Smith, 2004; modified after Eiríksson et al., 1990). The fossiliferous intervals of the Hörgi, Þrengingar, and Máná Formations are shown in detail on Fig. 12.4. For the stratigraphy, see also Eiríksson (2020a)

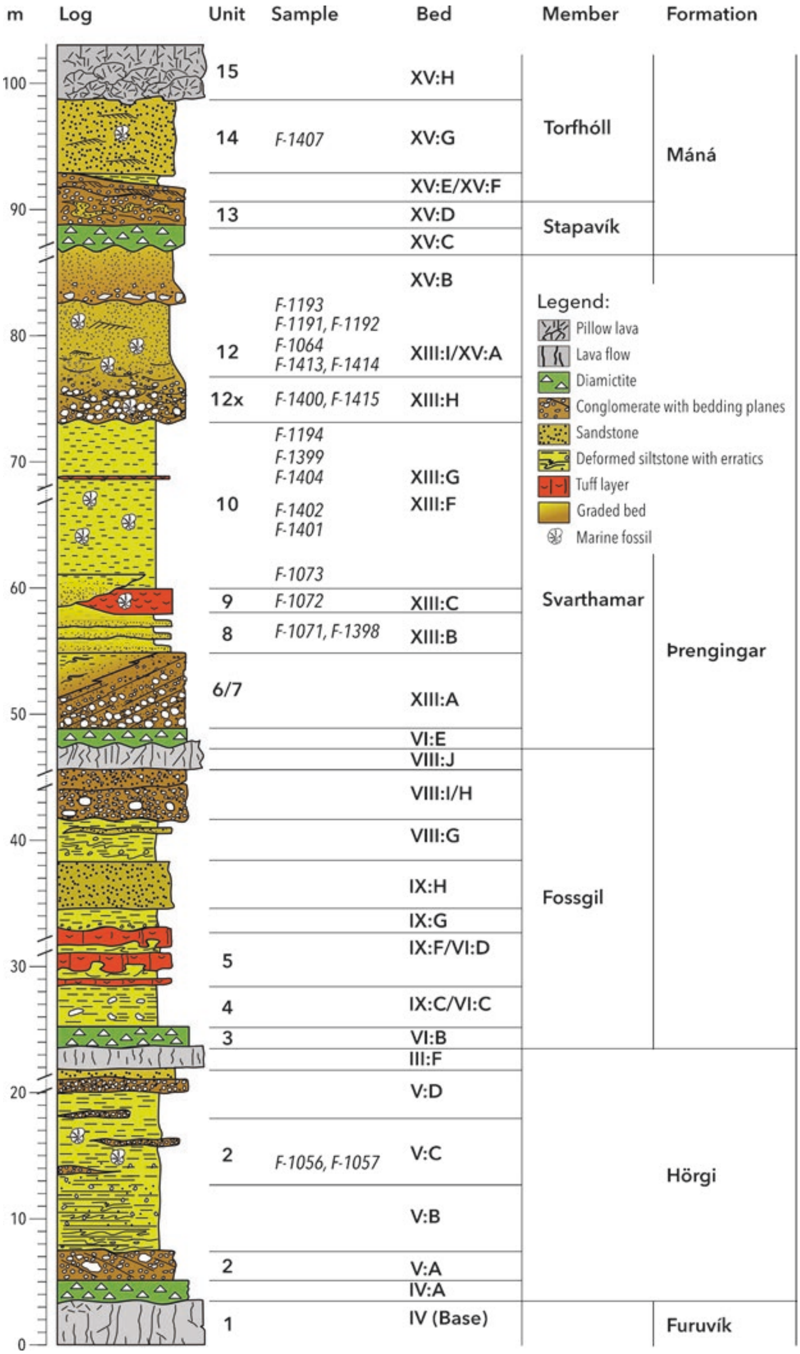

Fig. 12.4 Detailed composite lithological log of the studied fossiliferous intervals from the Hörgi, Þrengingar, and Máná Formations with indication of the lithological units of Bárðarson (1925) and lithostratigraphical beds of Eiríksson et al. (1992, 2020a). Note that the scale indicates minimum thickness of the sequence, partly due to varying thicknesses of the units in different profiles and partly due to missing intervals (marked on the scale). The stratigraphical location of the studied foraminiferal samples (marked F-) are indicated

The aim of the present chapter is to demonstrate a detailed study of foraminifera in the fossiliferous units of the Breiðavík Group, i.e., the Hörgi Formation, the Þrengingar Formation, and the Máná Formation (cf. Figs. 12.3 and 12.4), including a systematic description of all the taxa and a paleoecological and stratigraphical interpretation when possible. The Þrengingar Formation is subdivided into two members, the Fossgil Member and Svarthamar Member. Both members consist mainly of marine sediments, but foraminiferal tests were not found preserved in the Fossgil Member. Only a few foraminifera were found in the Hörgi and Máná Formations, but the assemblages from the Svarthamar Member represent an interesting example of a glacial-interglacial sequence from the Matuyama time interval (cf. Eiríksson et al., 1992). A detailed discussion of the age of the Breiðavík Group is presented by Eiríksson et al. (2020c).

12.2 Sampling and Methods

The stratigraphical location of each sample for the present foraminiferal study is indicated on the composite lithological log of Fig. 12.4, where the stratigraphical units and beds refer to Bárðarson (1925) and Eiríksson et al. (1992, 2020a), respectively. Most of the samples were collected by the authors during the period from 1989 to 1991, supplemented by one sample (1415), collected by Thomas M. Cronin in 1989 north of Svarthamar (sample 1–59 of Cronin, 1991; note that Cronin incorrectly referred sample 1–59 to Bárðarson's unit 10; it should instead be referred to unit 12x). In addition, two samples (1413 and 1414) were collected by Rolf W. Feyling-Hanssen and Jón Eiríksson in 1975.

Lithification of the sediments in Tjörnes is a problem for the preservation of foraminiferal tests. Samples were therefore preferably collected from less lithified horizons when possible, sometimes even from protected "environments" inside coupled mollusc shells, where the lithification was less developed. The lithified samples were crushed to pieces with a maximum size of around 0.5 cm by the help of a hydraulic press. Subsequently, they were disintegrated by boiling in a 5% solution of hydrogen peroxide and finally washed through sieves with mesh diameters of 1.0 and 0.1 mm. The foraminifera in the size fraction 0.1–1.0 mm were picked and quantitatively analyzed. The foraminiferal contents in the samples are not fully representative for the original faunas, partly caused by bad preservation state and partly because only some of the foraminifera in the samples could be extracted from the lithified samples. Thus, the registered assemblages presumably do not represent the entire biocoenosis, but rather a residual of the most chemically and mechanically resistant tests.

The taxonomic determinations were often difficult because of the bad preservation state of the tests, and it was sometimes not possible to determine the specimens to species level. The indeterminate species were grouped in genera or even higher taxa. Therefore, the number of foraminifera per sediment unit is not calculated, and the relative distributions of taxa are calculated only for samples with more than 50 counted specimens.

12.3 Foraminiferal Content

The quantitative analyses of the foraminiferal content in each of the samples in the Breiðavík Group formations are presented in Fig. 12.5. The percentage frequencies of the taxa are usually illustrated by symbols in the range chart, but for poor samples (less than 50 specimens), the counts have been entered directly. The total number of counts in each sample is shown on the right-hand side of the diagram, whereas the

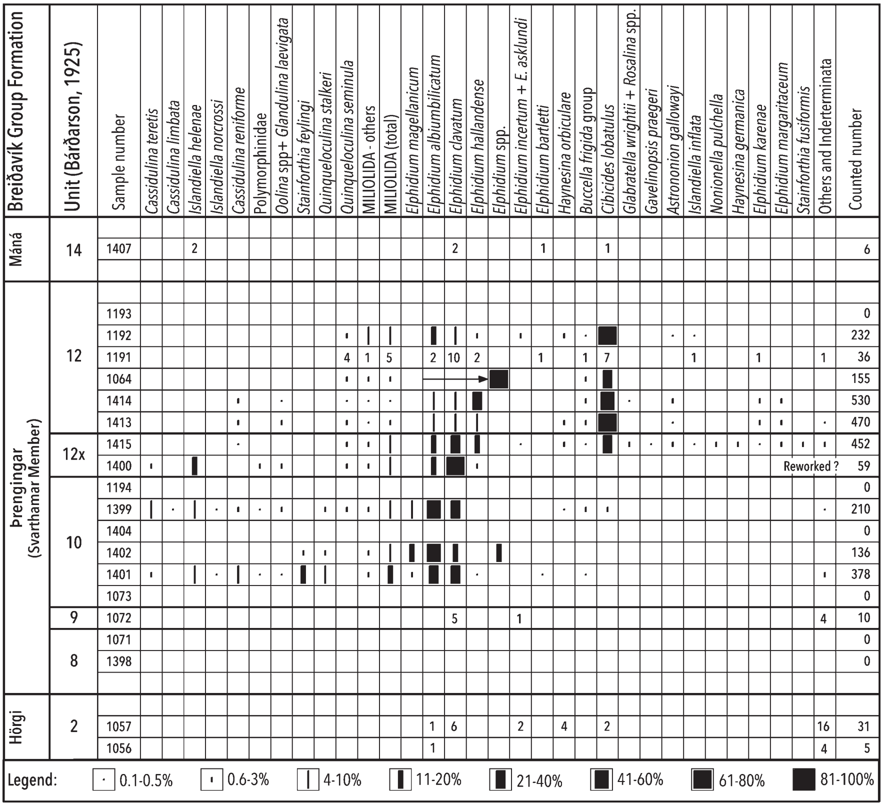

Fig. 12.5 Foraminiferal stratigraphy. Range chart for the most common taxa of foraminifera. Badly preserved specimens of different species of the genus *Elphidium* (mainly *E. magellanicum, E. albiumbilicatum,* and *E. hallandense)* are grouped as *Elphidium* spp. for sample 1064. A similar kind of grouping has been made for part of the *Elphidium* specimens in sample 1402. The *Buccella frigida* group includes the following taxa: *Buccella frigida*, *B. frigida calida,* and *B. tenerrima*. The number of counts is marked in the right-hand column. Percentages are only calculated for samples with more than 50 specimens

sample numbers and the stratigraphy are given on the left side of the diagram together with the units of Bárðarson (1925).

In the following systematic section, the occurrence of each taxon in the different formations of the Breiðavík Group, i.e., the Hörgi Formation, the Þrengingar Formation, and the Máná Formation, is specified, using the units of Bárðarson (1925). For the equivalent stratigraphical beds of Eiríksson et al. (1992, 2020a), see Fig. 12.4. The ecological preference is discussed for the most common taxa when possible, with reference to the present-day biogeographical zones of Fig. 12.6, and examples of stratigraphical occurrences, particularly in the northern North Atlantic and in the Canadian and Siberian Arctic, are entered when possible. For some species, the stratigraphical range is given as well.

12.4 Systematics

The systematic subdivision of foraminifera follows Loeblich and Tappan (1987, 1992, modified by Sen Gupta, 1999), who based their classification on the ordinal importance of the chemistry, mineralogy, and structure of the foraminiferal test wall. Species identification is based on Ellis and Messina (1949 and update supple-

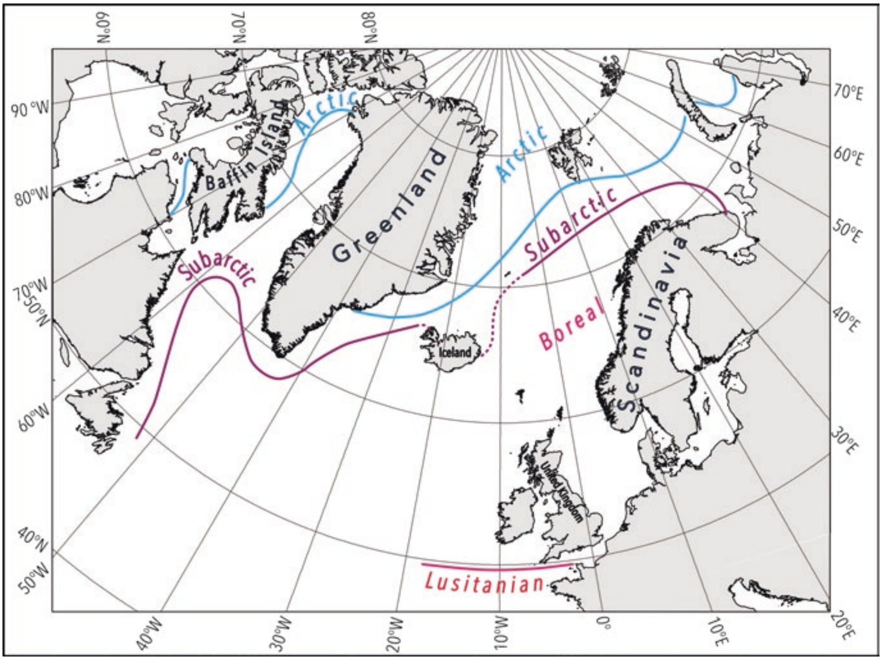

Fig. 12.6 Present-day biogeographical zones for the northern North Atlantic (modified after Feyling-Hanssen, 1955; Dinter, 2001; Funder et al., 2002). When possible, the foraminiferal taxa are referred to these zones in the discussion of their ecology

Table 12.1 List (alphabetically arranged) of foraminiferal taxa found in the Breiðavík Group (Hörgi, Þrengingar, and Mána Formations)

Astrononion gallowayi Loeblich and Tappan,1953	HAUERJNIDAE, gen. et spec, indet.
	Haynesina depressula (Walker and Jacob, 1798)
Buccella frigida (Cushman, 1922)	*Haynesina germanica* (Ehrenberg, 1841)
Buccella frigida calida (Cushman and Cole, 1931)	*Haynesina orbiculare* (Brady, 1881)
Buccella tenerrima (Bandy, 1950)	*Islandiella helenae* Feyling-Hanssen and Buzas, 1976
Bulimina spp.	
Cassidulina limbata Cushman and Hughes, 1925	*Islandiella inflata* (Gudina, 1966)
	Islandiella norcrossi (Cushman, 1933)
Cassidulina reniforme Nørvang, 1945	*Islandiella* spp.
Cassidulina teretis Tappan, 1951	*Lagena* sp.
Cibicides lobatulus (Walker and Jacob, 1798)	*Miliolinella subrotunda* (Montagu, 1803)
	Nonionella pulchella Hada, 1931
Cibicides spp.	*Nonionella* sp.
Cornuspira involvens (Reuss, 1850)	*Nonionellina labradorica* (Dawson, 1860)
Elphidium albiumbilicatum (Weiss, 1954)	*Oolona melo* d'Orbigny, 1839
Elphidium asklundi Brotzen, 1943	*Oolina* sp.
Elphidium bartletti Cushman, 1933	POLYMORPHINIDAE, gen. et spec, indet.
Elphidium clavatum (Cushman, 1930)	*Quinqueloculina agglutinata* Cushman, 1917
Elphidium hallandense Brotzen, 1943	
Elphidium incertum (Williamsen, 1858)	*Quinqueloculina seminula* (Linné, 1758)
Elphidium karenae Ásbjörnsdóttir, 1994	*Quinqueloculina stalkeri* Loeblich and Tappan, 1953
Elphidium magellanicum Heron-Allen and Earland. 1932	*Rosalina* spp.
Elphidium margaritaceum Cushman, 1930	*Stainforthia feylingi* Knudsen and Seidenkrantz, 1994
Gavelinopsis praegeri (Heron-Allen and Earland, 1913)	*Stainforthia fusiformis* (Williamson, 1858)
Glabratella wrightii (Brady, 1881)	
Glandulina laevigata d'Orbigny, 1826	*Stainforthia* sp.

ments), as well as literature referred to below. A list of the foraminiferal taxa with their original descriptions is presented in Table 12.1, and the total counts are listed in Table 12.2. Selected taxa are illustrated as light microscope photographs on Plates 12.1 and 12.2, using the Stackshot Macro Rail Package from Cognisys for focus stacking, and version 1.04 of the Zerene Stacker software from Zerene Systems for controlling Stackshot and post-processing the photographs of foraminifera. In addition, selected taxa are illustrated as scanning electron micrographs (SEM) on Plate 12.3.

Class Foraminifera
Order Miliolida
Superfamily Cornuspiracea Schultze, 1854

Table 12.2 Foraminiferal counts for the Early Pleistocene Hörgi, Þrengingar, and Máná Formations. The units refer to Bárðarson (1925)

Formation	Unit (Bárðarson, 1925)	Sample number	*Astrononion gallowayi*	*Buccella frigida*	*Buccella frigida calida*	*Buccella tenerrima*	*Bulimina* spp.	*Cassidulina limbata*	*Cassidulina reniforme*	*Cassidulina teretis*	*Cibicides lobatulus*	*Cornuspira involvens*	*Elphidium albiumbilicatum*	*Elphidium asklundi*	*Elphidium bartletti*	*Elphidium clavatum*	*Elphidium hallandense*	*Elphidium incertum*	*Elphidium karenae*	*Elphidium magellanicum*	*Elphidium margaritaceum*	*Elphidium* spp.	*Gavelinopsis praegeri*	*Glabratella wrightii*	*Glandulina laevigata*	*Haynesina germanica*
Máná	14	1407									1				1	2										
	12	1193																								
		1192	1			1					165		25	2		21	4									
		1191		1							7		2		1	10	2		1							
		1064		1							57											94				
		1414	4	4					12		290		36			22	150		5		3			1		
		1413	1	4		1	1		8		326		31			25	45		11		6					
Þrengingar	12x	1415	10	2					1		161	1	54	1		111	49	1	1		5		1			3
		1400								1			6			38	1									
	10	1194																								
		1399		3	1			1	3	21	5		94			45				10						
		1404																								
		1402											79			18				15		15				
		1401				1			30	11			94		1	113	1			6					1	
		1073																								
	9	1072												1		5										
	8	1071																								
		1398																								
Hörgi	2	1057									2		1	2		6										
		1056					3						1													

Table 12.2 (Continued)

Formation	Unit (Bàrðarson, 1925)	Sample number	*Haynesina orbiculare*	*Haynesina depressula*	*Islandiella helenae*	*Islandiella inflata*	*Islandiella norcrossi*	*Islandiella* spp.	*Lagena* sp.	HAUERINIDAE (indet.)	*Miliolinella subrotunda*	*Nonionella pulchella*	*Nonionella* sp.	*Nonionellina labradorica*	*Oolina melo*	*Oolina* sp.	POLYMORPHINIDAE (indet.)	*Quinqueloculina seminulum*	*Quinqueloculina* spp.	*Quinqueloculina stalkeri*	*Rosalina* spp.	*Stainforthia feylingi*	*Stainforthia fusiformis*	*Stainforthia* sp.	Indeterminata
Máná	14	1407			2																				
	12	1193																							
		1192	2			1					3							2	5						
		1191				1					1							4							6
		1064																2						1	
		1414								1					1			1							
		1413	3													3		3		2					
Þrengingar	12x	1415	7			2					4	7						11	2		5		3		10
		1400			9					1						1	1	1							
	10	1194																							
		1399	1		9		1			4					3	1	1	3		3					1
		1404																							
		1402								3										2		4			
		1401			18		1			11				1			1			36		47			5
		1073																							
	9	1072																							4
	8	1071																							
		1398																							
Hörgi	2	1057	4	1				4	1				1											1	8
		1056																							1

Family Cornuspiridae Schultze, 1854
Genus *Cornuspira* Schultze, 1854

***Cornuspira involvens* (Reuss, 1850)**
Plate 12.3, Fig. 16

1850 *Operculina involvens* Reuss: p. 370, pl. 46, fig. 30.
1953 *Cornuspira involvens* (Reuss) – Loeblich and Tappan: p. 49, pl. 7, figs. 4, 5.
1964 *Cyclogyra involvens* (Reuss) – Feyling-Hanssen: p. 246, pl. 4, fig. 9.
1971 *Cyclogyra involvens* (Reuss) – Feyling-Hanssen et al.: p. 192, pl. 1, fig. 14.

Material: A single specimen was found in the Svarthamar Member (Þrengingar Formation), unit 12x (sample 1415).

Distribution and ecology: Cornuspira involvens is common in shallow Arctic waters (e.g., Loeblich & Tappan, 1953; Madsen & Knudsen, 1994), but it has also been registered in warmer areas (Cushman, 1929).

Superfamily Miliolacea Ehrenberg, 1839
Family Hauerinidae Schwager, 1876
Genus *Miliolinella* Wiesner, 1931

***Miliolinella subrotunda* (Montagu, 1803)**

1784 "*Serpula subrotunda dordo elevato"* Walker and Boys: p. 2, pl. 1, fig. 4.
1803 *Vermiculum subrotundum* Montagu: pt. 2, p. 521.
1971 *Miliolinella subrotunda* (Montagu) – Feyling-Hanssen et al.: p. 197, pl. 2, figs. 10–12.

Material: A few specimens were found in the Svarthamar Member (Þrengingar Formation), units 12x and 12 (samples 1415, 1191, and 1192).

Distribution and ecology: Miliolinella subrotunda is an epifaunal shelf species, which is generally connected to normal-salinity, open-water conditions (Murray, 1991, 2006; Rytter et al., 2002).

Fossil occurrence: Miliolinella subrotunda was found in the Early Pleistocene in NE Greenland, both in the Kap København Formation (Feyling-Hanssen, 1990a) and on Store Koldewey (Bennike et al., 2010). It also occurred in the Pliocene and Pleistocene of Baffin Island, Canada (e.g., Feyling-Hanssen, 1980a, b).

Genus *Quinqueloculina* d'Orbigny, 1826

***Quinqueloculina seminula* (Linné, 1758)**
Plate 12.1, Fig. 1; Plate 12.3, Fig. 13.

1758 *Serpula seminulum* Linné: p. 786, pl. 2, fig. 1.
1884 *Miliolina seminulum* (Linné) – Brady: p. 157, pl. 5, fig. 6.
1944 *Quinqueloculina seminula* (Linné) – Cushman: p. 13, pl. 2, fig. 14.
1971 *Quinqueloculina seminulum* (Linné) – Feyling-Hanssen et al.: p. 194, pl. 1, figs. 18–20.

Material: This species occurred in low frequencies in units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Quinqueloculina seminula is an epifaunal shelf species, which is usually connected to normal-salinity, open-water conditions in both cold and warm areas (Murray, 1991, 2006).

Fossil occurrence: Quinqueloculina seminula was found scattered throughout the Pliocene and Lower Pleistocene Kap København Formation, NE Greenland (Feyling-Hanssen, 1990a), and in the Pliocene and Pleistocene of Baffin Island, Canada (e.g., Feyling-Hanssen, 1980a).

***Quinqueloculina stalkeri* Loeblich and Tappan, 1953**

Plate 12.1, Fig. 2; Plate 12.3, Fig. 14.

1953 *Quinqueloculina stalkeri* Loeblich and Tappan: p. 40, pl. 5, figs. 5–9.

1967 *Quinqueloculina stalkeri* Loeblich and Tappan – Todd and Low: p. 19, pl. 2, fig. 17.

1971 *Quinqueloculina stalkeri* Loeblich and Tappan – Feyling-Hanssen et al.: p. 194, pl. 2, figs. 1–3.

Material: Quinqueloculina stalkeri occurred in unit 10 of the Svarthamar Member (Þrengingar Formation) with a maximum of 10% of the assemblage in sample 1401.

Distribution and ecology: Quinqueloculina stalkeri is an arctic to subarctic, opportunistic species that tolerates a wide range environments, and it is suggested to be indicator of glacier-proximal shallow-marine (<50 m) environments (Elverhøi et al., 1980; Murray, 1991; Korsun & Hald, 1998). It is rare in open-marine areas (Steinsund et al., 1994; Korsun et al., 1995). The species is, however, also recorded in boreal assemblages (e.g., Risdal, 1964).

Fossil occurrence: Quinqueloculina stalkeri is common in the Quaternary of NW Europe, both in glacials and in interglacial deposits (e.g., Feyling-Hanssen, 1964; Fisher et al., 1969; Knudsen, 1982; Knudsen et al., 2014).

Hauerinidae, gen. et spec. indet.

Material: Unspecified members of the family Hauerinidae occurred in most samples of units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation). This group was most common in the upper part of unit 12.

Distribution and ecology: Species of this group are generally connected to normal-salinity, open-water conditions (Murray, 1991, 2006).

Order Lagenida
Superfamily Nodosariacea Ehrenberg, 1838
Family Lagenidae Reuss, 1862
Genus *Lagena* Walker and Jacob, 1798

***Lagena* sp.**

Material: A single specimen was found in the Hörgi Formation (unit 2).

Superfamily Polymorphinacea d'Orbigny, 1839
Family Polymorphinidae d'Orbigny, 1839

Polymorphinidae, gen. et spec. indet.

Material: Unspecified members of the family Polymorphinidae occurred in a few samples of unit 10 and in the lower part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Family Ellipsolagenidae A. Silvestri, 1923
Genus *Oolina* d'Orbigny, 1839

***Oolona melo* d'Orbigny, 1839**

1839 *Oolona melo* d'Orbigny: p. 20, pl. 5, fig. 9.
1953 *Oolona melo* d'Orbigny – Loeblich and Tappan: p. 71, pl. 12, figs. 8–15.
1971 *Oolona melo* d'Orbigny – Feyling-Hanssen et al.: p. 226, pl. 6, fig. 5; pl. 17, fig. 9.
Material: A single specimen of *Oolona melo* was found in unit 12 of the Svarthamar Member (Þrengingar Formation).

***Oolina* spp.**

Material: A few specimens of *Oolina* spp. occurred in samples of units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation).

Family Glandulinidae Reuss, 1850
Genus *Glandulina* d'Orbigny, 1826

***Glandulina laevigata* d'Orbigny, 1826**

1826 *Nodosaria (Glandulina) laevigata* d'Orbigny: p. 252, pl. 10, figs. 1–3.
1953 *Glandulina laevigata* d'Orbigny – Loeblich and Tappan: p. 81, pl. 16, figs. 2–5.
1971 *Glandulina laevigata* d'Orbigny – Feyling-Hanssen et al.: p. 220, pl. 5, fig. 12.
1990a *Glandulina laevigata* d'Orbigny – Feyling-Hanssen: p. 20, pl. 3, figs. 19–22.
Material: A single specimen *Glandulina laevigata* was found in unit 10 of the Svarthamar Member (Þrengingar Formation).
Distribution and ecology: Glandulina laevigata has been widely recorded in the Arctic (e.g., Loeblich & Tappan, 1953; Leslie, 1965). It was also found by Nørvang (1945) in modern faunas around Iceland, although rare, and he suggested it to be a cosmopolitan species.
Fossil occurrence: Scattered specimens were found throughout the Plio-Pleistocene Kap København Formation, NE Greenland (Feyling-Hanssen, 1990a), and it was also found in the Early Pleistocene deposits on Store Koldewey, NE Greenland (Bennike et al., 2010).

Order Buliminida
Superfamily Cassidulinacea d'Orbigny, 1839
Family Cassidulinidae d'Orbigny, 1839
Genus *Cassidulina* d'Orbigny, 1826

***Cassidulina limbata* Cushman and Hughes, 1925**
Plate 12.1, Figs. 3–4

1925 *Cassidulina limbata* Cushman and Hughes: p. 12, pl. 2, fig. 2.

1947 *Cassidulina limbata* Cushman and Hughes – Cushman and Todd: p. 68, pl. 16, fig. 22.
1973 *Cassidulina limbata* Cushman and Hughes – Lankford and Phleger: p. 116, pl. 6, fig. 4.
2015 *Cassidulina limbata* Cushman and Hughes – Cerreño et al.: p. 212, pl. 3, fig. 27.
Material: A single specimen *Cassidulina limbata* was found in unit 10 of the Svarthamar Member (Þrengingar Formation).
Distribution and ecology: Cassidulina limbata is recorded in recent nearshore assemblages from western North America (Lankford & Phleger, 1973).
Fossil occurrence: Cassidulina limbata was described from Pliocene deposits in California, and it is found both in Pliocene and Pleistocene deposits in that area (e.g., Galloway & Wissler, 1927; Cushman & Todd, 1947; Bandy, 1950). Its occurrence in the Breiðavík sequence supports the idea of a Pacific influence in the Early Pleistocene foraminiferal assemblages of Iceland.

***Cassidulina reniforme* Nørvang, 1945**
Plate 12.1, Fig. 5

1945 *Cassidulina crassa* d'Orbigny var. *reniforme* Nørvang: p. 41, pl. 6e-h.
1953 *Cassidulina islandica* Nørvang – Loeblich and Tappan: p. 118, pl. 24, fig.1.
1958 *Cassidulina crassa* d'Orbigny – Nørvang: p. 36, pl. 9, figs. 24–25 (not pl. 8, figs. 20–23).
1971 *Cassidulina crassa* d'Orbigny – Feyling-Hanssen et al.: p. 245, pl. 7, figs. 18–19.
1980 *Cassidulina reniforme* Nørvang – Sejrup and Guilbault: p. 79–81, figs. 2 F-K.
Material: Cassidulina reniforme was found in units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation). It was particularly common in unit 10.
Distribution and ecology: Cassidulina reniforme is a common and widespread arctic species, which is particularly frequent in glacier-proximal environments, being tolerant to sediment-loaded waters (Hald & Korsun 1997). *Cassidulina reniforme* may also be related to cool, Modified Atlantic Water in glacier-distal settings, and to seasonal ice cover (e.g., Polyak et al., 2002). It is a common species in modern faunas off NW and North Iceland (Rytter et al., 2002; Jennings et al., 2004).
Fossil occurrence: Cassidulina reniforme was frequent in most samples of the Plio-Pleistocene Kap København Formation, NE Greenland (Feyling-Hanssen, 1990a), and it was also common in the Early Pleistocene deposits on Store Koldewey, NE Greenland (Bennike et al., 2010). In the Plio-Pleistocene sequence of the Central North Sea, *Cassidulina reniforme* was a common species in most of the samples (Knudsen & Ásbjörnsdóttir, 1991).

***Cassidulina teretis* Tappan, 1951**
Plate 12.1, Figs. 6–7.

1951 *Cassidulina teretis* Tappan: p. 7–8, pl. 1, fig. 30.
1980b *Cassidulina teretis* Tappan – Feyling-Hanssen: pl. 4, figs. 10, 11, 15.

1983 *Cassidulina teretis* Tappan – Feyling-Hanssen et al.: p. 105, pl. 1, figs. 6–9, 11–13.

1990a *Cassidulina teretis* Tappan – Feyling-Hanssen: p. 22, pl. 4, figs. 10–14.

1995 *Cassidulina teretis* Tappan – Seidenkrantz: p. 151–152, pl. 1, figs. 13–15; pl. 2, figs. 15–18; pl. 4, figs. 1–5; pl. 5, fig. 4.

Material: Some specimens of *Cassidulina teretis* were found in unit 10 and a single specimen also in the lower part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: The fossil record of *Cassidulina teretis* often points to relatively shallow, warm-water conditions in the Arctic region, and possibly also in boreal environments, but fossil records from deep-sea and shelf areas show that it occurs at a paleo-water depths between 50 and 2000 m (cf. Seidenkrantz, 1995).

Fossil occurrence: Cassidulina teretis had its first occurrence in the North Sea area during relatively warm climate of the Middle and Upper Miocene (Jansen et al., 1990). *Cassidulina teretis* occurs frequently in Pliocene and Early Pleistocene deposits of the Arctic and the North Atlantic region (i.e., Feyling-Hanssen, 1980b, 1983, 1990a; Diester-Haass & Schnitker, 1989; Jansen et al., 1990; Knudsen & Asbjörnsdóttir, 1991; Knudsen & Sejrup, 1993; Seidenkrantz, 1995). In the Plio-Pleistocene deposits of the Central North Sea, *Cassidulina teretis* was frequent in most of the Late Pliocene and Early Pleisocene samples (Knudsen & Ásbjörnsdóttir, 1991). In the northern North Sea, *Cassidulina teretis* was apparently most common in the Pliocene, but it also occurred in the Early Pleistocene until slightly above the Matuyama-Brunhes boundary (Sejrup et al., 1987; Jansen et al., 1990; Seidenkrantz, 1992, 1995). In addition, *Cassidulina teretis* has been found in Pliocene or Early Pleistocene deposits in Arctic Russia (Möller et al., 2008). *Cassidulina teretis* apparently characterizes preglacial Pliocene and Early Pleistocene deposits of the North Sea, Greenland, Canada, and Russia. An Early Pleistocene age for the present glacial-interglacial cycle is thus supported by the occurrence of *Cassidulina teretis* in the Svarthamar Member (Þrengingar Formation).

Genus *Islandiella* Nørvang, 1958

***Islandiella helenae* Feyling-Hanssen and Buzas, 1976**
Plate 12.1, Figs. 8–9

1976 *Islandiella helenae* Feyling-Hanssen and Buzas: p.155–157, figs. 1–4 (often mistakenly referred to *Cassidulina teretis* Tappan, 1951).

1953 *Cassidulina teretis* Tappan – Loeblich and Tappan: p. 121, pl. 24, figs. 3–4.

1971 *Islandiella teretis* (Tappan) – Feyling-Hanssen et al.: p. 249, pl. 8, figs. 3–6; pl. 18, fig. 13.

1994 *Islandiella helenae* Feyling-Hanssen and Buzas – Jennings and Helgadottir: pl. 2, fig. 4.

Material: Islandiella helenae was relatively common in two samples of unit 10 and in the lowermost sample of unit 12x of the Svarthamar Member (Þrengingar Formation). A few specimens were found in the Máná Formation (unit 14).

Distribution and ecology: Islandiella helenae is a high-arctic inner-shelf species (Loeblich & Tappan, 1953; Steinsund et al., 1994; Hald & Korsun, 1997), which tolerates reduced salinity. It seems to be linked to sea-ice marginal regions, presumably due to the productivity bloom in these environments (Seidenkrantz, 2013).

Fossil occurrence: Islandiella helenae is found in Early Pleistocene deposits in Siberia, Baffin Island, and Greenland (e.g., Gudina, 1966, 1969: as *Cassidulina teretis*; Feyling-Hanssen, 1980a), and it is a common species in the Late Pleistocene of the entire North Atlantic region (e.g., Feyling-Hanssen 1964; Feyling-Hanssen & Buzas, 1976; Kelly et al., 1999).

***Islandiella inflata* (Gudina, 1966)**

Plate 12.1, Fig. 10

1966 *Cassidulina inflata* Gudina 1966: p. 63, pl. 6, figs. 4–6; pl. 7, fig. 1; pl. 13, fig. 1.

1976 *Islandiella inflata* (Gudina) – Feyling-Hanssen: p. 357, pl. 6, figs. 12–14; pl. 7, figs. 1–3.

1980a *Islandiella inflata* (Gudina) – Feyling-Hanssen: p. 274, pl. 1, figs. 17–18.

Material: A few specimens of *Islandiella inflata* were found in the upper part of unit 12x and in unit 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Islandiella inflata is suggested to be an indicator of relatively warm (subarctic) shallow water conditions (cf. Gudina & Evserov, 1973; Kelly et al., 1999).

Fossil occurrence: Islandiella inflata was originally described from the Quaternary of NW Siberia, and it was found in the Early and in the Late Pleistocene deposits in the Siberian Arctic (Gudina, 1966; Gudina & Evserov, 1973). In Baffin Island, Arctic Canada, Feyling-Hanssen (1976, 1980a, b) found *Islandiella inflata* frequently in Upper Pliocene and lowermost Pleistocene deposits, and he suggested that *Islandiella inflata,* together with *Cassidulina limbata,* may constitute an originally Pacific faunal element, which immigrated into the Arctic Canadian nearshore waters at a relatively late stage of the geologic development (Feyling-Hanssen, 1980b). *Islandiella inflata* was rather common in ameliorated assemblages from the last interglacial at Thule in NW Greenland (Kelly et al., 1999), and Feyling-Hanssen (1990b) found it to be frequent in the supposed Middle Pleistocene Ymer Formation in NE Greenland.

***Islandiella norcrossi* (Cushman, 1933)**

1933 *Cassidulina norcrossi* Cushman: p. 7, pl. 2, fig. 7.

1953 *Cassidulina norcrossi* Cushman – Loeblich and Tappan: p. 120, pl. 24, fig. 2.

1958 *Islandiella norcrossi* (Cushman, 1933) – Nørvang: p. 32, pl. 7, figs. 8–11 (not figs. 12, 13); pl. 8, fig. 14.

1971 *Islandiella norcrossi* (Cushman, 1933) – Feyling-Hanssen et al.: p. 248, pl. 8, figs. 1–2.

Material: A few specimens of *Cassidulina norcrossi* occurred in unit 10 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Islandiella norcrossi is an arctic to subarctic shelf and upper slope species occurring down to ca. 1200 m water depth (Hald & Korsun, 1997; Belanger & Streeter, 1980). It is common at temperatures between −1 and + 1 °C and is associated with relatively high and stable bottom water salinity (Mudie et al., 1984; Steinsund et al., 1994; Korsun & Hald, 1998; Rytter et al., 2002). The species has, however, also been found to depend on the influence of chilled Atlantic water (Lloyd, 2006), and thus it reflects relatively warmer waters than *Islandiella helenae*.

Fossil occurrence: Islandiella norcrossi is a common species in the Pleistocene of the Canadian Arctic, Greenland, and the entire North Atlantic region (e.g., Feyling-Hanssen et al., 1971; Gudina & Evserov, 1973; Feyling-Hanssen, 1976, 1980a, b; Kelly et al., 1999).

***Islandiella* spp.**

Material: Indeterminate specimens of this genus were found in the Hörgi Formation (unit 2).

Superfamily Turritelinacea Cushman, 1927
Family Stainforthiidae Reiss, 1963
Genus *Stainforthia* Hofker, 1956

***Stainforthia feylingi* Knudsen and Seidenkrantz, 1994**
Plate 12.1, Figs. 11–12; Plate 12.3, Fig. 12

1964 *Virgulina schreibersiana* (Czjzek) – Feyling-Hanssen: p. 309, pl. 14, figs. 19–21.

1971 *Stainforthia schreibersiana* (Czjzek) – Feyling-Hanssen et al.: p. 240, pl. 7, figs. 6–8.

1994 *Stainforthia feylingi* Knudsen and Seidenkrantz: p. 5, pl. 1, figs. 1–32; pl. 2, figs. 1–6, 8.

Remarks: This species was nominated *Stainforthia schreibersiana* in previous papers about foraminifera in the Breiðavík sediments (Eiríksson et al., 1992, 1993).

Material: Stainforthia feylingi was a common species in part of unit 10 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: The exact modern and fossil record of *Stainforthia feylingi* is hampered by the taxonomic confusion with i.a. *Virgulina schreibersiana* Czjzek and *Stainforthia fusiformis* (Williamson). *Stainforthia feylingi* is widely distributed in the northern arctic and subarctic waters, both in the Pacific and the Atlantic regions (for references, see Knudsen & Seidenkrantz, 1994). In fossil deposits, *Stainforthia feylingi* often occurs with high frequency in transitional environments between arctic and subarctic conditions, indicating that it is tolerant to unstable temperature environments, and it seems to bloom in high-productivity sea-ice edge environments (Seidenkrantz, 2013).

Fossil occurrence: The species *Stainforthia feylingi* is described from deposits of Early Pleistocene to the Recent age (Knudsen & Seidenkrantz, 1994).

***Stainforthia fusiformis* (Williamson, 1858)**

1858 *Bulimina pupoides,* var. *fusiformis* Williamson: p. 63, pl. 5, figs. 129, 130.
1964 *Virgulina fusiformis* (Williamson) – Feyling-Hanssen: p. 307, pl. 14, figs. 15–18.
1973 "*Stainforthia" fusiformis* (Williamson) – Haynes: p. 124, pl. 5, figs. 7, 8.
1994 *Stainforthia fusiformis* (Williamson) – Knudsen and Seidenkrantz: pl. 3, figs. 1–7.
2001 *Stainforthia fusiformis* (Williamson) – Gooday and Alve: p. 279, pl. 3, figs. A-J.

Material: A few specimens of *Stainforthia fusiformis* were found in the upper part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Stainforthia fusiformis is an opportunistic fiord and shelf species that thrives under stressed conditions where salinity exceeds 30, and it can withstand short periods of anoxia (Alve, 1994, 2003). It was found to be common in the Gulmar Fjord at depths exceeding 20 m (Höglund, 1947) and in the Oslofjord at depths exceeding 15 m (Risdal, 1964). *Stainforthia fusiformis* has a rather patchy distribution in the Kattegat-Skagerrak area (Conradsen et al., 1994).

Fossil occurrence: Stainforthia fusiformis was found to be common in a certain interval of the Early Pleistocene of the Central North Sea (Pedersen, 1995a), and it is found commonly in the Late Pleistocene deposits in NW Europe (e.g., Feyling Hanssen, 1964; Feyling-Hanssen et al., 1971). The stratigraphic range of *Stainforthia fusiformis* is suggested to be Miocene to Recent (Kihle & Løfaldli, 1974).

***Stainforthia* sp.**

Material: A single undetermined specimen of the genus *Stainforthia* was found in the Hörgi Formation (unit 2).

Superfamily Buliminacea Jones, 1875
Family Buliminidae Jones, 1875
Genus *Bulimina* d'Orbigny, 1826

***Bulimina* spp.**

Material: A few specimens occurred in the Hörgi Formation (unit 2), and one specimen was found in the lower part of unit 12 of the Svarthamar Member (Þrengingar Formation).

Order Rotaliida
Superfamily Discorbacea Ehrenberg, 1838
Family Rosalinidae Reiss, 1963
Genus *Gavelinopsis* Hofker, 1951

***Gavelinopsis praegeri* (Heron-Allen and Earland, 1913)**

1913 *Discorbina praegeri* Heron-Allen and Earland: p. 122, pl. 10, figs. 8–10.
1971 *Gavelinopsis praegeri* (Heron-Allen and Earland) – Murray: p. 133, pl. 55, figs. 1–5.

1973 *Gavelinopsis praegeri* (Heron-Allen and Earland) – Gudina and Evserov: p. 88, pl. 7, figs. 3–5.
1973 *Gavelinopsis praegeri* (Heron-Allen and Earland) – Haynes: p. 159, pl. 17, figs. 6–9; pl. 19, fig. 4; pl. 30, fig. 3; text-fig. 30, nos 4–9.
2003 *Gavelinopsis praegeri* (Heron-Allen and Earland) – Murray: p. 24, figs. 8.5–8.6.

Material: A single specimen was found in the upper part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: This species was described from the west coast of Ireland (Heron-Allen & Earland, 1913), and Haynes (1973) also recorded it from the Cardigan Bay, England. Gudina and Evserov (1973) listed *Gavelinopsis praegeri* as a boreal-lusitanean species.

Fossil occurrence: Gavelinopsis praegeri was found in the Plio-Pleistocene deposits from the Baffin Island, Canada (Feyling-Hanssen, 1980a, b) and in samples from the Early Pleistocene deposits on Store Koldewey, NE Greenland (Bennike et al., 1994). In the Thule area, NW Greenland, it was a relatively common species in the interglacial Qarmat unit (Kelly et al., 1999). *Gavelinopsis praegeri* was also recorded from Late Quaternary deposits on the Kola Peninsula, northern Russia (Gudina & Evserov, 1973).

Genus *Rosalina* d'Orbigny, 1826

***Rosalina* spp.**

Material: A few specimens of *Rosalina* spp. were found in the upper part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: This genus is regarded as a temperate to warm, inner shelf taxon, and its species are often found attached to seaweed or in high-energy environments (Murray, 1991).

Superfamily Glabratellacea Loeblich and Tappan, 1964
Family Glabratellidae Loeblich and Tappan, 1964
Genus *Glabratella* Dorreen, 1948

***Glabratella wrightii* (Brady, 1881)**

1881 *Discorbis wrightii* Brady: p. 413, pl. 21, fig. 6.
1965 *Glabratella wrightii* (Brady) – Leslie: p. 161, pl. 10, fig. 7.
1980a *Rosalina wrightii* (Brady) – Feyling-Hanssen: p. 276, pl. 2, figs. 11–12.
1980b *Rosalina wrightii* (Brady) – Feyling-Hanssen: pl. 4, figs. 16–17.

Material: A single specimen occurred in the lower part of unit 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: The main recent distribution of *Glabratella wrightii* is arctic, but it is also found in the boreal waters (Gudina & Evserov, 1973).

Fossil occurrence: Glabratella wrightii was found in the Early Pleistocene of NE Greenland, both in the Kap København Formation (Feyling-Hanssen, 1990a) and on Store Koldewey (Bennike et al., 2010), as well as in the Middle and Late

Pleistocene in NW Greenland (Kelly et al., 1999). It was a common species in the Pliocene and Pleistocene of Baffin Island, Canada (e.g., Feyling-Hanssen, 1980a, b), and it was also recorded from Late Quaternary deposits on the Kola Peninsula, northern Russia (Gudina & Evserov, 1973: as *Eponides wrightii*).

Superfamily Planorbulinacea Schwager, 1876
Family Cibicidae Cushman, 1927
Genus *Cibicides* Montfort, 1808

***Cibicides lobatulus* (Walker and Jacob, 1798)**
Plate 12.1, Figs. 13–16; Plate 12.3, Figs. 7–8.

1798 *Nautilus lobatulus* Walker and Jacob: p. 642, pl. 14, fig. 36.
1961 *Cibicides lobatulus* (Walker and Jacob) – Nyholm: p. 157–196, pl. 1–5, text-figs. 1–21.
1971 *Cibicides lobatulus* (Walker and Jacob) – Feyling-Hanssen et al.: p. 260, pl. 9, figs. 9–14.

Material: This was one of the dominant species in the upper part of unit 12x and throughout unit 12 of the Svarthamar Member (Þrengingar Formation). Single specimens were found in the Hörgi Formation (unit 2) and in the Máná Formation (unit 14).

Distribution and ecology: Cibicides lobatulus is a cosmopolitan species, which is related to high bottom water current velocity and coarse substrate in glacial-distal settings (e.g., Murray, 1991, 2006; Steinsund et al., 1994; Hald & Korsun, 1997). It has an epifaunal microhabitat and is generally attached. *Cibicides lobatulus* requires normal-marine salinity (Steinsund et al., 1994).

Fossil occurrence: Cibicides lobatulus is widely stratigraphically distributed, and it has been registered throughout the Paleogene, Neogene, and Pleistocene. It is common in the Upper Miocene, Pliocene, and Pleistocene of the entire North Atlantic region (e.g., ten Dam & Reinhold, 1942; Funnell et al., 1979; Feyling-Hanssen, 1980a; Knudsen & Ásbjörnsdóttir, 1991).

***Cibicides* spp.**

Material: Indeterminate specimens of this genus are found in the Hörgi Formation (unit 2).

Superfamily Nonionacea Subbotina, 1959
Family Nonionidae Schultze, 1854
Genus *Astrononion* Cushman and Edwards, 1937

***Astrononion gallowayi* Loeblich and Tappan, 1953**
Plate 12.2, Figs. 1–2; Plate 12.3, Fig. 15.

1953 *Astrononion gallowayi* Loeblich and Tappan: p. 90, pl. 17, figs. 4–7.
1971 *Astrononion gallowayi* Loeblich and Tappan – Feyling-Hanssen et al.: p. 266, pl. 10, figs. 10–12.
1976 *Astrononion gallowayi* Loeblich and Tappan – Feyling-Hanssen: p. 92, fig. 8, no. 5–6.

1980b *Astrononion gallowayi* Loeblich and Tappan – Feyling-Hanssen: p. 178, pl. 5, figs. 12–13.

Material: A few specimens occurred in the upper part of unit 12x and in unit 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Astrononion gallowayi is an arctic species, which is often related to high-energy areas with relatively stable normal-marine salinity (e.g., Murray, 1991, 2006; Rytter et al., 2002).

Fossil occurrence: Astrononion gallowayi was a characteristic and common species in the Pliocene to Lower Pleistocene deposits of Clyde Foreland and the Qivituq Peninsula in the Canadian Arctic (Feyling-Hanssen, 1976, 1980b).

Genus *Haynesina* Banner and Culver, 1978

***Haynesina depressula* (Walker and Jacob, 1798)**

1798 *Nautulus depressulus* Walker and Jacob, *in* Adams, G.: p. 641, fig. 33.

1965 *Nonion depressulus* (Walker and Jacob) – Murray: p. 148, pl. 25, figs. 6–7; pl. 26, figs. 7–8.

1978 *Haynesina depressula* (Walker and Jacob) – Banner and Culver: p. 200–201, pl. 10, figs. 1–8.

Material: A single specimen was found in the Hörgi Formation (unit 2).

***Haynesina germanica* (Ehrenberg, 1840), emend. Banner and Culver, 1978**

1840 *Nonionina germanica* Ehrenberg: p. 23; type figure in Ehrenberg, 1841: pl. 2, fig. 1.

1965 *Protelphidium anglicum* Murray: p. 149, pl. 25, figs. 1–5; pl. 26, figs. 1–6.

1971 *Protelphidium anglicum* Murray – Feyling-Hanssen et al.: p. 286–288, pl. 14, figs. 2–5; pl. 24, figs. 2–5.

1978 *Haynesina germanica* (Ehrenberg, 1840) – Banner and Culver: p. 191–195, pl. 4, figs. 1–6; pl. 5, figs. 1–8; pl. 6, figs. 1–7; pl. 7, figs. 1–6; pl. 8, figs. 1–10; pl. 9, figs. 1–11, 15.

Material: A few specimens were found in the upper part of unit 12x of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Haynesina germanica is widespread in the shallow intertidal to subtidal brackish waters in lusitanean and boreal water masses, and it is tolerant to relatively large variability in temperature and salinity (e.g., Haynes, 1973: as *Protelphidium anglicum*; Banner & Culver, 1978; Murray, 1991; Alve & Murray, 1999).

***Haynesina orbiculare* (Brady, 1881)**
Plate 12.2, Fig. 3

1881 *Nonionina orbicularis* Brady: p. 415, pl. 21, fig. 5.

1971 *Protelphidium orbiculare* (Brady) – Feyling-Hanssen et al.: p. 289, pl. 14, figs. 8–11; pl. 24, figs. 6–8.

2002 *Haynesina orbiculare* (Brady) – Polyak et al.: p. 269, pl. 2, figs. 1–3.

Material: A few specimens were found in the Hörgi Formation (unit 2), as well as in some of the samples in units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Haynesina orbiculare is a widespread arctic subtidal species, which may also occur in the intertidal zone (e.g., Korsun et al., 2014), and it has been found to be a major indicator of river-proximal environments (Polyak et al., 2002). *Haynesina orbiculare* is also common in cold waters with relatively stable salinity (e.g., Loeblich & Tappan, 1953: as *Elphidium orbiculare*).

Genus *Nonionella* Cushman, 1926

***Nonionella pulchella* Hada, 1931**
Plate 12.2, Fig. 4; Plate 12.3, Figs. 9–11

1931 *Nonionella pulchella* Hada: p. 121, text-fig. 79a-c.
1939 *Nonionella pulchella* Hada – Cushman: p. 34, pl. 9, fig. 11.
Material: A few specimens of this species were found in the upper part of unit 12x of the Svarthamar Member (Þrengingar Formation).
Distribution and ecology: Nonionella pulchella was originally described from recent shallow waters off Japan (Hada, 1931). Its occurrence in the Breiðavík sequence supports the idea of a Pacific influence in the Early Pleistocene foraminiferal assemblages of Iceland.

Family Trichohyalidae Saidova, 1981
Genus *Buccella* Andersen, 1952

***Buccella frigida* (Cushman, 1922)**
Plate 12.2, Figs. 5–6

1922 *Pulvinulina frigida* Cushman: p. 12 (144).
1948 *Eponides frigidus* (Cushman) – Cushman: p. 71, pl. 8, fig. 7.
1952 *Eponides frigidus* (Cushman) – emend. Andersen: p. 145–147, text-figs. 4–6.
1953 *Buccella frigida* (Cushman) – Loeblich and Tappan: p. 115, pl. 22, figs. 2, 3.
1990a *Buccella frigida* (Cushman) – Feyling-Hanssen: p. 22–23; pl. 4, figs. 15–20.
Material: A few specimens occurred scattered in units 10, 12x, and 12 of the Svarthamar Member (Þrengingar Formation).
Distribution and ecology: Buccella frigida is described from the Canadian Arctic, and it is typical in shallow, cold-water areas (cf. Todd & Low, 1967). Along the European coasts, *Buccella frigida* is recorded by Murray and Alve (2016) as a species with a southern boundary, extending south to the shelf, slopes, and fiords of the Norwegian coast. *Buccella frigida* is found to be related to high-productivity areas (e.g., Steinsund et al., 1994).
Fossil occurrence: Buccella frigida occurred scattered in the Plio-Pleistocene Kap København Formation in NE Greenland (Feyling-Hanssen, 1990a). It was common in the Pliocene and Pleistocene of the North Sea Basin (King & Hughes 1983; Knudsen & Ásbjörnsdóttir, 1991).

***Buccella frigida calida* (Cushman and Cole, 1930)**

1930 *Eponides frigida* (Cushman) var. *calida* Cushman and Cole: p. 98, pl. 13, fig. 13.

1980a *Buccella calida* (Cushman and Cole) – Feyling-Hanssen: pl. 2, figs. 6–10.

Material: A single specimen was found in unit 10 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Cushman and Cole (1930) separated the variety *calida* as a more thermophilous form of *Buccella frigida* than the typical form, and Gudina (1969: as *Buccella troitzkyi* Gudina) considered it to be a boreal form (cf. Feyling-Hanssen, 1980a). Fossil data indicate that this taxon may also be linked to high-productivity zones, for instance at sea-ice margins (Seidenkrantz, 2013: as *Buccella calida*).

Fossil occurrence: Buccella frigida calida has been recorded from the Pliocene of Timms Point, California (Cushman & Gray, 1946), and it was found in Pliocene and Pleistocene deposits from Baffin Island, Canadian Arctic (Feyling-Hanssen, 1976, 1980a, b).

***Buccella tenerrima* (Bandy, 1950)**

1950 *Rotalia tenerrima* Bandy, p. 278, pl. 42, fig. 3.

1952 *Buccella inusitata* Andersen: p. 148, figs. 10–11.

1971 *Buccella tenerrima* (Bandy) – Feyling-Hanssen et al.: p. 254, pl. 8, figs. 15–17.

1990a *Buccella tenerrima* (Bandy) – Feyling-Hanssen: p. 24, pl. 4, figs. 21–23.

Material: A few specimens occurred scattered in units 10 and 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Buccella tenerrima is found today in arctic waters off Canada (Loeblich & Tappan, 1953; Leslie, 1965; Wagner 1968), North Iceland (Rytter et al., 2002), and Spitsbergen (Nagy, 1965).

Fossil occurrence: This species was found in the Upper Pliocene and Lower Pleistocene of the Kap København Formation, NE Greenland (Feyling-Hanssen, 1990a) and in the Early Pleistocene deposit of Store Koldewey, NE Greenland (Bennike et al., 2010).

Superfamily Rotaliacea Ehrenberg, 1939
Family Elphidiidae Galloway, 1933
Genus *Elphidium* Montfort, 1808

***Elphidium albiumbilicatum* (Weiss, 1954)**
Plate 12.2, Figs. 7–8; Plate 12.3, Fig. 5.

1954 *Nonion pauciloculum* Cushman subsp. *albiumbilicatum* Weiss: p. 157, pl. 32, figs. 1, 2.

1957 *Nonion depressulus* (Walker and Jacob) forma *asterotuberculatus* van Voorthuysen: p. 28, pl. 23, fig. 3.

1971 *Elphidium albiumbilicatum* (Weiss) – Feyling-Hanssen et al.: p. 269–270, pl. 10, figs. 15–19; pl. 19, figs. 4–8.

1973 *Protelphidium asterotuberculatum* (van Voorthuysen) – Gudina and Evserov, p. 104, pl. 13, fig. 8.

Material: A few specimens of *Elphidium albiumbilicatum* were found in the Hörgi Formation (unit 2). It was dominant in unit 10 and common in units 12x and 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Elphidium albiumbilicatum has its main distribution in shallow, intertidal to subtidal, low-salinity waters, and it is distributed from lusitanean to arctic water masses (e.g., Alve & Murray, 1999; Murray, 2006; Korsun et al., 2014). The species tolerates extremely low salinity (Lutze, 1965: as *Cribrononion asklundi*; Korsun et al., 2014).

Fossil occurrence: Elphidium albiumbilicatum has been found throughout the Upper Pliocene and Pleistocene deposits of Baffin Island, Canada (Feyling-Hanssen, 1976, 1980a, b), and it was common in Early Pleistocene deposits in NE Greenland (Feyling-Hanssen, 1990a; Bennike et al., 2010). It was reported by Gudina (1976: as *Protelphidium asterotuberculatum*) from the Pleistocene of the Arctic Sovjet Union, and it is widely distributed in NW European glacial and interglacial deposits (e.g., Feyling-Hanssen et al., 1971; Knudsen, 1978; Kristensen & Knudsen, 2006; Knudsen et al., 2014).

Elphidium asklundi Brotzen, 1943

1943 *Elphidium? asklundi* Brotzen, in Hessland: p. 267, fig. 109.1.

1971 *Elphidium asklundi* Brotzen – Feyling-Hanssen et al.: p. 270, pl. 10, figs. 20, 21; pl. 11, figs. 1–5.

Material: Two specimens were found in the Hörgi Formation (unit 2), and a few specimens occurred in units 9, 12x, and 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Elphidium asklundi is an arctic shallow, inner shelf species which has been found off North Iceland (Rytter et al., 2002) and in the modern Siberian Arctic (Polyak et al., 2002: as *Elphidium incertum* Williamson). Knowledge on the modern and fossil distribution is hampered by the fact that this species has often not been distinguished from *Elphidium incertum* (Williamson) (e.g., Feyling-Hanssen, 1990a).

Fossil occurrence: Elphidium asklundi was described by Brotzen (1943, 1951) from the Weichselian and Early Holocene in southwestern Sweden, and it was common in the Weichselian deposits of Norway and Denmark (Feyling-Hanssen et al., 1971) and in the Pleistocene of the Sovjet Union (Gudina, 1966, 1969: as *Cribrononion obscurus* Gudina). It was also recorded in the Early Pleistocene of the Netherlands (van Voorthuysen, 1949). *Elphidium asklundi* was widely distributed in Pliocene and Pleistocene deposits of Baffin Island, Canada (e.g., Feyling-Hanssen, 1976, 1980a), as well as in the Early Pleistocene of NE Greenland (Feyling-Hanssen, 1990a; Bennike et al., 2010).

Elphidium bartletti Cushman, 1933

1933 *Elphidium bartletti* Cushman: p. 4, pl. 1, fig. 9.

1971 *Elphidium bartletti* Cushman – Feyling-Hanssen et al.: p. 271, pl. 11, figs. 6–9; pl. 20, figs. 1–4.

2002 *Elphidium bartletti* Cushman – Polyak et al.: pl. 2, figs. 4, 5.

Material: Only few specimens were found in the Breiðavík Group, i.e., one in each of the units 10 and 12 of the Þrengingar Formation, and one in the Máná Formation (unit 14).

Distribution and ecology: This species is restricted to arctic waters (e.g., Hald & Korsun, 1997; Polyak et al., 2002; Darling et al., 2016). It is a subtidal species, which is common in brackish, river-proximal environments (e.g., Korsun et al., 2014).

Fossil occurrence: Elphidium bartletti is common in northern European Quaternary deposits, such as the Lateglacial deposits of the Hebridean shelf, NW Scotland (e.g., Austin & Kroon, 1996), southern Norway (Feyling-Hanssen, 1964), and Denmark (Feyling-Hanssen et al., 1971). The species also occurs in the Early and Middle Quaternary of the North Sea region (Knudsen & Ásbjörnsdóttir, 1991; Pedersen, 1995b).

***Elphidium clavatum* (Cushman, 1930)**
Plate 12.2, Figs. 9–11; Plate 12.3, Figs. 2–3.

1930 *Elphidium incertum* (Williamson) var. *clavatum* Cushman: p. 20, pl. 7, fig. 10.
1953 *Elphidium clavatum* (Cushman) – Loeblich and Tappan: p. 98, pl. 19, figs. 8–10.
1964 *Elphidium subclavatum* Gudina: p. 69, pl. 1, figs. 4–10, text-fig. 1.
1971 *Elphidium clavatum* (Cushman) – Feyling-Hanssen et al.: p. 273–274 (part), pl. 11, figs. 10–13; pl. 20, figs. 7–8 (not figs. 5–6).
1972 *Elphidium excavatum* (Terquem) forma *clavata* Cushman – Feyling-Hanssen: p. 339–340, pl. 1, figs. 1–9; pl. 2, figs. 1–9.

Remarks: This species is now referred to *Elphidium clavatum* (Cushman) based on the discussion in Darling et al. (2016), who described the genetic and morphological relationship between different species of the genus *Elphidium.* It cannot be excluded that some specimens of *Elphidium selseyensis* (Heron-Allen and Earland, 1911) also occur in the material (see image of the specimen on Plate 3, Fig. 3).

Material: A few specimens of *Elphidium clavatum* were found in the Hörgi Formation (unit 2). It was one of the dominant species in units 10 and 12x, and it was common in unit 12 of the Svarthamar Member (Þrengingar Formation). A few specimens also occurred in the Máná Formation (unit 14).

Distribution and ecology: Elphidium clavatum is an opportunistic, very widespread taxon (e.g., Murray 2006). The species has its main distributions in the Arctic (e.g., Gudina, 1976; Polyak et al., 2002; Korsun et al., 2014), where it is particularly frequent in glacier-proximal environments, being tolerant to sediment-loaded waters (Elverhøi et al., 1980; Hald & Korsun 1997). This species has, however, been found living down to several hundreds of meters depths in the Arctic (Bergsten, 1994). In addition, it is common in restricted environments in boreal areas, for instance, in the Baltic, in the Kattegat-Skagerrak area, and around northern British Isles (e.g., Alve & Murray 1999: as *E. excavatum*; Polodova et al. 2009: as *E. excavatum excavatum* and *E. excavatum clavatum*).

Fossil occurrence: Elphidium clavatum is often a dominant species in the Early, Middle, and Late Pleistocene, particularly in glacial deposits, of the entire Arctic and North Atlantic region. Thus, it was commonly found in the Pleistocene deposits from NW Canada (e.g., Guilbault et al., 1997), Baffin Island (Feyling-

Hanssen, 1976, 1980a), Greenland (e.g., Feyling, Hanssen 1990a; Kelly et al., 1999; Knudsen et al. 2008; Bennike et al., 2010), Iceland (Eiríksson et al., 2004; Knudsen et al., 2004), and the Arctic SSSR (Gudina, 1964, 1966, 1969), as well as Svalbard and the NW European margin (e.g., Feyling-Hanssen et al., 1971; Hansen & Knudsen, 1995; Kubischta et al., 2011). *Elphidium clavatum* is common or dominant in the Pliocene, as well as the Early Pleistocene in the North Sea region, (e.g., van Voorthuysen, 1949, Funnell, 1961; Funnell & West, 1977; King & Hughes, 1983; Knudsen & Ásbjörnsdóttir, 1999).

***Elphidium hallandense* Brotzen, 1943**
Plate 12.2, Fig. 12; Plate 12.3, Fig. 4.

1943 *Elphidium hallandense* Brotzen, in Hessland: p. 268, pl. 109, fig. 21-c.
1944 *Elphidium subarcticum* Cushman (younger synonym): p. 27, pl. 4, figs. 34, 35.
1953 *Elphidium subarcticum* Cushman – Loeblich and Tappan: p. 105, pl. 19, figs. 5–7.
1971 *Elphidium subarcticum* Cushman – Feyling-Hanssen et al.: p. 280, pl. 13, figs. 3–7; pl. 22, fig. 9.
1982 *Elphidium hallandense* Brotzen – Knudsen: p. 170, fig. 14:12, no. 15.
Material: Elphidium hallandense was common in units 12x and 12 of the Svarthamar Member (Þrengingar Formation). Only a single specimen was found in unit 10.
Distribution and ecology: Elphidium hallandense is an arctic, subtidal shelf species, which tends to prefer river-distal rather than river-proximal environments (e.g., Korsun et al., 2014: as *E. subarcticum*).
Fossil occurrence: Elphidium hallandense is widely distributed in arctic and subarctic Pleistocene deposits in the Sovjet Union (Gudina, 1966; Gudina & Evserov, 1973), NW Europe (e.g., Feyling-Hanssen et al., 1971; Knudsen, 1978, 1982), Greenland (e.g., Feyling-Hanssen, 1990a; Kelly et al., 1999; Bennike et al., 2010), and Canada (e.g., Feyling-Hanssen, 1980a).

***Elphidium incertum* (Williamson, 1858)**

1858 *Polystomella umbilicatula*, var. *incerta* Williamson: p. 44, pl. 3, fig. 82a.
1948 *Elphidium incertum* (Williamson) – Cushman: p. 56, pl.6, figs. 7a, b.
1965 *Cribrononion incertum* (Williamson) – Lutze: p. 103, pl. 21, figs. 43–44.
1971 *Elphidium incertum* (Williamson) – Feyling-Hanssen et al.: p. 277, pl. 12, figs. 11–12; pl. 21, figs. 8–9.
Material: A single specimen was found in unit 12x of the Svarthamar Member (Þrengingar Formation).
Distribution and ecology: Elphidium incertum is an intertidal to subtidal species, which commonly occurs in the brackish, inner-shelf waters (salinity >25) of lusitanean and boreal areas (e.g., Murray, 1991), but it also occurs in arctic estuaries (Polyak et al., 2002).

***Elphidium karenae* Ásbjörnsdóttir, 1994**
Plate 12.2, Figs. 13–14; Plate 12.3, Fig. 1

1994 *Elphidium karenae* Ásbjörnsdóttir: p. 25–31, pl 1, figs. 11–25; pl. 2, figs. 1–9.

Remarks: Elphidium karenae was previously recorded as *Elphidium* cf. *advenum* (Cushman, 1922) in the present Early Pleistocene deposits from Breiðavík (Eiríksson et al., 1992, 1993).

Material: A single specimen was found in the upper part of unit 12x and some specimens occurred in unit 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: The modern distribution of this species is unknown. The composition of the fossil foraminiferal assemblages in SW Iceland would indicate a cold boreal environment, shallow to moderate water depth, and close to normal-marine salinity (Ásbjörnsdóttir, 1994).

Fossil occurrence: Elphidium karenae was described from interglacial pre-Weichselian (probably Eemian) deposits in the Reykjavík area in SW Iceland, where it occurred as one of the dominant species, together with *Cibicides lobatulus* and *Elphidium clavatum* (as *Elphidium excavatum*), and it is regarded as a warm-water indicator in the Quaternary assemblages of Iceland.

***Elphidium magellanicum* Heron-Allen and Earland 1932**
Plate 12.2, Fig. 15

1932 *Elphidium magellanicum* Heron-Allen and Earland: p. 440, pl. 16, figs. 26–28.

1939 *Elphidium magellanicum* Heron-Allen and Earland – Cushman p. 62, pl. 17, figs. 11–12.

1971 *Elphidium magellanicum* Heron-Allen and Earland – Feyling-Hanssen et al.: p. 279, pl. 12, figs. 15–16.

Material: Elphidium magellanicum was only found in samples from unit 10 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Elphidium magellanicum is an opportunistic, shallow shelf species, which tolerates reduced salinity and periodically hypoxic conditions (e.g., Gustafsson & Nordberg, 2000).

Fossil occurrence: Elphidium magellanicum is found in NW European Pleistocene, as well as Holocene deposits (e.g., Lafrenz, 1963; Feyling-Hanssen et al., 1971; Knudsen, 1982).

***Elphidium margaritaceum* (Cushman, 1930)**
Plate 12.2, Fig. 16; Plate 12.3, Fig. 6.

1930 *Elphidium advenum* Cushman) var. *margaritaceum* Cushman: p. 25, pl. 10, fig. 3.

1957 *Elphidium margaritaceum* (Cushman) – van Voorthuysen: p. 32, pl. 23, fig. 13.

1971 *Elphidium margaritaceum* (Cushman) – Feyling-Hanssen et al.: p. 279, pl. 13, figs. 1–2; pl. 22, figs. 5–8.

Material: A few specimens were found in the upper part of unit 12x and in unit 12 of the Svarthamar Member (Þrengingar Formation).

Distribution and ecology: Elphidium margaritaceum is a shallow intertidal to subtidal species, which is distributed in boreal to lusitanean waters (e.g., Haake 1962; Haynes 1973). It is an open-marine, relatively stenohaline species, which tolerates only slightly lowered salinity (>25; Alve & Murray 1999).

Fossil occurrence: Elphidium margaritaceum was recorded from the Lower Pleistocene of the Netherlands (van Voorthuysen, 1950a, b), and it is widely distributed, particularly in the interglacial deposits throughout the Quaternary of NW Europe (e.g., van Voorthuysen, 1957; Lafrenz, 1963; Konradi, 1976; Knudsen et al., 2009), as well as in the Holocene (Feyling-Hanssen et al., 1971).

12.5 Environmental and Stratigraphical Summary

Iceland is located at the boundary between the Arctic and Atlantic climate regions in the northern North Atlantic, an ideal area for tracking even minor change in ocean circulation. An example of the results of such climatic changes is represented by the Svarthamar Member of the Breiðavík Group, in which the foraminiferal assemblages reflect a glacial-interglacial transition in a shallow inner-shelf environment. The following section presents a short description of the foraminiferal contents in the Breiðavík Group and an overview of the environmental interpretations, as well as some stratigraphical remarks (see also Eiríksson et al., 1992, 1993). The combined environmental development, including sedimentological results and mollusc indications in the Breiðavík Group, is described by Eiríksson et al. (2020b), who also compared the record with the benthic oxygen isotope stack curve of Lisiecki and Raymo (2005).

12.5.1 The Hörgi Formation (Unit 2)

The sparse content of extremely badly preserved foraminiferal tests in samples from the Hörgi Formation only give a vague indication of the ecology, but the dominant species *Elphidium clavatum* and *Haynesina orbiculare* would point to an arctic shallow-water environment (Fig. 12.5). An arctic environment is also indicated by the mollusc assemblages (Vilhjálmsson, 1985; Símonarson & Eiríksson, 2020).

12.5.2 The Þrengingar Formation (Units 8–12)

Foraminiferal tests are preserved in four of the units in the Þrengingar Formation (i.e., units 9, 10, 12x, and 12; Fig. 12.5). Unit 9 only contained very few specimens and not enough for an environmental interpretation. Some of the samples from units 10, 12x, and 12 are relatively rich in foraminifera, and the species composition reflects an interesting environmental and stratigraphical development.

Unit 10: The dominant foraminiferal species in unit 10 are *Elphidium clavatum, E. albiumbilicatum,* and *E. magellanicum* (Fig. 12.5). Some indeterminate specimens of the genus *Elphidium* in sample 1402 (*Elphidium* spp.) presumably also belong in one or more of these three species, but they cannot be determined with certainty because of their bad preservation state. *Islandiella helenae* and *Cassidulina teretis* are characteristic elements of the fauna. A remarkable feature in unit 10, especially in the lower part, is a relatively high content of Miliolida, mainly *Ouinqueloculina stalkeri,* which indicates close to normal-marine salinity (Murray, 1991). The content of *Stainforthia feylingi, Cassidulina reniforme,* and *Islandiella helenae* points to similar environmental conditions (i.e., Nagy, 1965; Elverhøi et al., 1980; Osterman & Nelson, 1989) with a relatively open oceanic connection and a water depth of presumably more than 25 m. There is a decrease in the amount of *Cassidulina reniforme* and Miliolida through unit 10, and a few percentages of the shallower water species *Buccella frigida* appear towards the top of this unit. The unfossiliferous sample 1404 was taken from a thin ash layer within unit 10 (Fig. 12.4).

The assemblages in unit 10 indicate an arctic to boreal-arctic (subarctic) marine environment (cf. Fig. 12.6) with a relatively fast marine transgression followed by a regression towards the end. Most of the foraminifera are infaunal species indicating low-energy environments (cf. Murray, 1991).

Units 12x and 12: The assemblages in unit 12x and unit 12 are generally rich both in species and in specimens (Fig. 12.5). It should be mentioned, however, that the sparse foraminiferal content in the lowermost sample (1400) is suggested to represent reworked specimens from the underlying unit 10, and this sample will, therefore, not be included in the following description. The dominant species throughout units 12x and 12 is *Cibicides lobatulus,* and *Elphidium clavatum, E. albiumbilicatum,* and *E. hallandense* are common as well. A large amount of badly preserved indeterminate specimens of the genus *Elphidium* (*Elphidium* spp.) in sample 1064 presumably also represents one or more of these three species. The group Miliolida is still present (e.g., *Ouinqueloculina seminulum*), but *Quinqueloculina stalkeri* is no longer present. Only few specimens of *Cassidulina reniforme* still occur in the lower part of units 12x and 12, and new elements in the assemblages, although in low frequencies, are taxa such as *Astrononion gallowayi, Islandiella inflata, Nonionella pulchella, Elphidium karenae, E. margaritaceum, E. incertum, Haynesina germanica, Stainforthia fusiformis, Gavelinopsis praegeri, Glabratella wrightii,* and *Rosalina* sp. Together, these taxa constitute an important and characteristic faunal element indicating ameliorated temperature conditions, i.e., a boreal-arctic (subarctic) or even a boreal environment (cf. Gudina & Evserov, 1973; Feyling-Hanssen, 1980a, 1983, 1990c; Kelly et al., 1999). *Cibicides lobatulus* is an epifaunal, attached species indicating high-energy conditions (Mackensen, 1987; Wagener, 1988), and a similar environment is also reflected by taxa such as *Gavelinopsis praegeri, Glabratelle wrightii, Rosalina* sp., and some of the Miliolida (*Ouinqueloculina seminulum* and *Miliolinella subrotunda*) (cf. Murray, 1991). The assemblages are pointing to shelf environments, shallowing towards the top of unit 12. The uppermost samples (1191–1193) are, however, collected at the location of Þrengingar a few kilometers further inland in a southeastern direction (Fig. 12.2), which is closer to the former coastline (Eiríksson et al., 2020b), and they may represent a relatively shallower facies rather than a younger age than samples 1413–1415.

In general, the assemblages of units 12x and 12 reflect temperature conditions warmer than at present around Iceland, even warmer than found on the south coasts of Iceland today, indicating a northward shift of the Polar Front (cf. Fig. 12.1).

In summary, the foraminiferal assemblages in units 10, 12x, and 12 indicate a climatic change through a glacial-interglacial cycle. The regressive trend through the cold unit 10 may be a result of isostatic uplift of the area after deglaciation, while the assemblages at the base of units 12x and 12 indicate a transgression, presumably caused by the subsequent eustatic rise in sea level at the beginning of a following relatively warmer interglacial period. This corresponds to similar patterns of regression and a subsequent transgression through glacial-interglacial sequences from areas along the eastern margin of the North Atlantic during the Late Pleistocene. The fast transgression after deglaciation is supposed to be local and isostatically controlled, while the regression took place concurrently with the isostatic rebound, perhaps before a global interglacial eustatic rise of sea level began (cf. discussion in Boulton, 1990).

Mollusc studies of the units 10, 12x, and 12 indicate a similar glacial-interglacial environmental change from arctic to boreal-arctic (subarctic) and boreal conditions (Vilhjálmsson, 1985; Eiríksson et al., 1992, 2020b; Símonarson & Eiríksson, 2020). In Cronin's (1991) study of the ostracods from the Þrengingar Formation, only samples from unit 12x and unit 12 were represented, and only one of his samples contained enough ostracod shells for temperature estimates, i.e., his sample 59-I (foraminiferal sample 1415) from unit 12x (see above). This sample would represent the initial transgression of the interglacial as indicated by the foraminiferal assemblages. Cronin (1991) described the climate indication of sample 59-I as cool, with a mean winter and summer temperature estimate of −0.8 and 3.0 °C, respectively, never exceeding 8 °C during the warmest months.

A development from cold to warmer foraminiferal assemblages during the accumulation of the Svarthamar Member thus indicates an Early Pleistocene glacial-interglacial cycle of a range comparable to the Late Pleistocene cycles (see also Eiríksson et al. (2020b).

12.5.3 The Máná Formation (Unit 14)

The few foraminiferal tests found in one fossiliferous sample from the Máná Formation (Fig. 12.5) points to a relatively shallow, arctic environment. A more precise environmental interpretation is possible based on mollusc contents (Vilhjálmsson, 1985; Símonarson & Eiríksson, 2020; Eiríksson et al., 2020b), which show clearly ameliorated temperature conditions during an interglacial period.

12.5.4 Remarks on Stratigraphy and Immigration

Most of the foraminiferal taxa found in the Breiðavík Group sediments are also living today in the North Atlantic region. However, an Early Pleistocene age for the present glacial-interglacial cycle is supported by the occurrence of *Cassidulina teretis* in assemblages of unit 10. This species is common in Pliocene and Early Pleistocene deposits of the Arctic and the North Atlantic region (i.e., Feyling-Hanssen, 1980a, b; Diester-Haass & Schnitker, 1989; Jansen et al., 1990; Knudsen & Ásbjörnsdóttir, 1991; Knudsen & Sejrup, 1993; Seidenkrantz, 1995). The species *Cassidulina teretis* occurs until slightly above the Matuyama-Brunhes boundary both in the North Sea (Sejrup et al., 1987) and in the Norwegian Sea (Jansen et al., 1990; Seidenkrantz, 1995).

A possible immigration of Pacific species into the Atlantic Ocean is suggested by the sparse occurrences of the three species *Cassidulina limbata, Islandiella inflata,* and *Nonionella pulchella* in the Breiðavík material (see also descriptions for each of the species above). These three species are not usually found in assemblages from the Atlantic Ocean. *Cassidulina limbata* was described from Pliocene deposits in California. It occurs both in Pliocene and Pleistocene deposits in that area (i.e., Galloway & Wissler, 1927; Cushman & Todd, 1947; Bandy, 1950), and it is also recorded in recent nearshore assemblages from western North America (Lankford & Phleger, 1973). *Islandiella inflata* was originally described from the Quaternary of NW Siberia, and it occurs both in the Early and Late Pleistocene deposits in the Siberian Arctic (Gudina, 1966; Gudina & Evserov, 1973). Feyling-Hanssen (1976, 1980a, b) found *Islandiella inflata* to be frequent in the Upper Pliocene and lowermost Pleistocene deposits in Baffin Island, Arctic Canada. *Nonionella pulchella* was originally described from recent shallow waters off Japan, and it has not previously been reported from the Atlantic.

An Early Pleistocene migration of Pacific species into the North Atlantic was strongly supported by the study of ostracods in the Breiðavík Group sediments (Cronin 1991). Thus, Cronin found several Pacific ostracod species which had their first North Atlantic stratigraphic appearance in the Þrengingar Formation (sample 59-I/1415).

12.6 Conclusions

A systematic description of the foraminiferal taxa found in the Breiðavík Group sediments is presented for the first time, including notes on their ecological preferences and stratigraphical distributions. The assemblage development through the Early Pleistocene (about 1.5 Ma old) Þrengingar Formation (Svarthamar Member) reflects a change from an arctic glacier-proximal environment (unit 10) to boreal-arctic (subarctic) or even boreal conditions (units 12x and 12). The deposits represent a full glacial-interglacial cycle comparable to those known from Late Pleistocene glacial-interglacial deposits along the margins of the North Atlantic.

Thus, the Polar Front must have shifted northwards across Iceland into the Norwegian-Greenland Seas during warm stages in Middle Matuyama time. As previously described for ostracods from the same section (Cronin, 1991), an Early Pleistocene migration of Pacific species into the North Atlantic is also indicated by some of the foraminiferal species.

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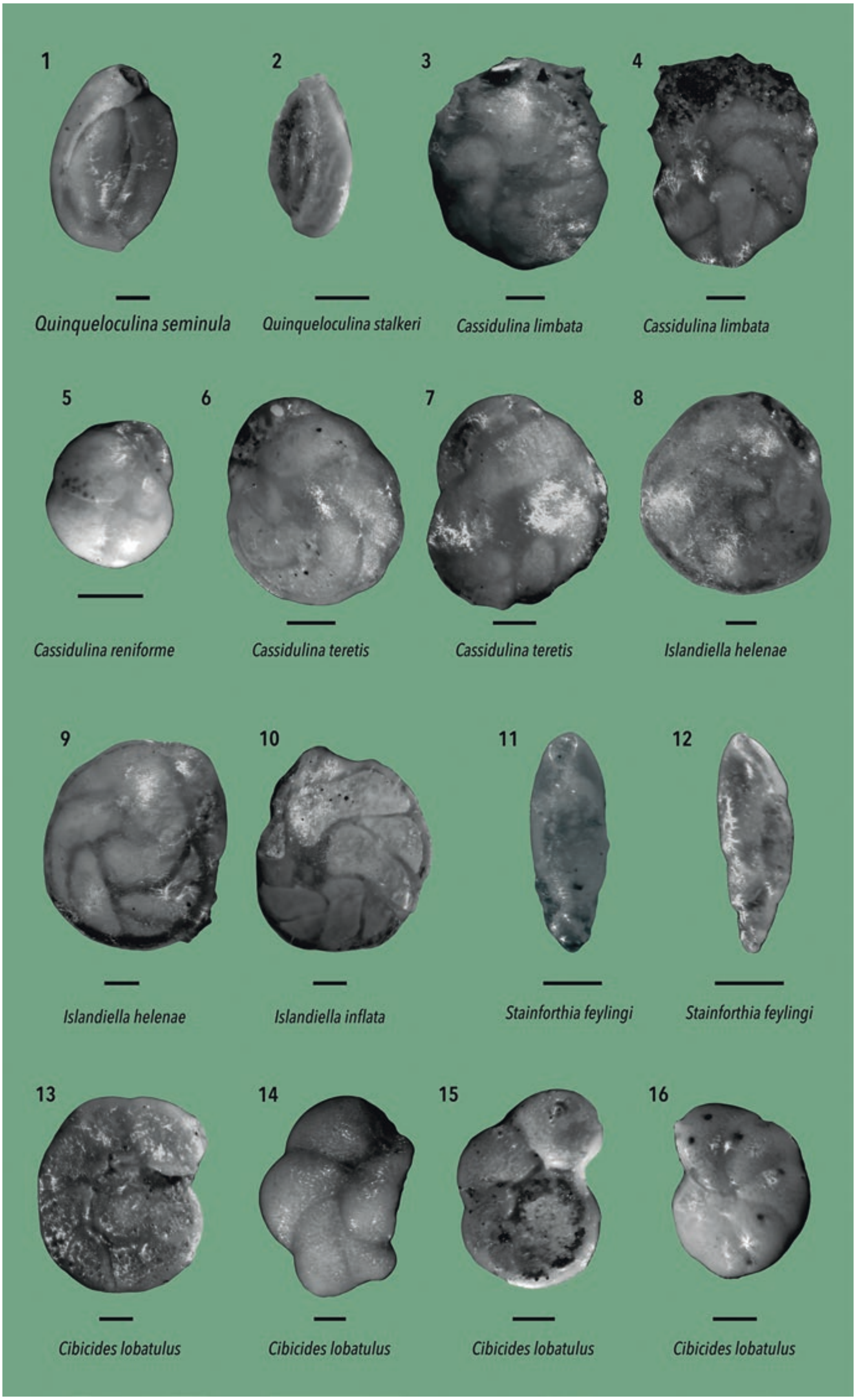
Plate 12.1 Light microscope multifocus images of specimens from the Svarthamar Member of the Þrengingar Formation. **1.** *Quinqueloculina seminula* (Linné), from sample 1415 (unit 12x). **2.** *Quinqueloculina stalkeri* Loeblich and Tappan, from sample 1401 (unit 10). **3–4.** *Cassidulina limbata* Cushman and Hughes, from sample 1399 (unit 10). **5.** *Cassidulina reniforme* Nørvang, from sample 1399 (unit 10). **6–7.** *Cassidulina teretis* Tappan, from sample 1399 (unit 10). **8–9.** *Islandiella helenae* Feyling-Hanssen and Buzas, from samples 1401 (unit 10) and 1400 (unit 12x), respectively. **10.** *Islandiella inflata* (Gudina), from sample 1415 (unit 12x). **11–12.** *Stainforthia feylingi* Knudsen and Seidenkrantz, from sample 1401 (unit 10). **13–16.** *Cibicides lobatulus* (Walker and Jacob), from sample 1415 (unit 12x). Scale bar = 0.1 mm. Lithological units refer to Bárðarson (1925)

Plates


1
Quinqueloculina seminula
2
Quinqueloculina stalkeri
3
Cassidulina limbata
4
Cassidulina limbata
5
Cassidulina reniforme
6
Cassidulina teretis
7
Cassidulina teretis
8
Islandiella helenae
9
Islandiella helenae
10
Islandiella inflata
11
Stainforthia feylingi
12
Stainforthia feylingi
13
Cibicides lobatulus
14
Cibicides lobatulus
15
Cibicides lobatulus
16
Cibicides lobatulus

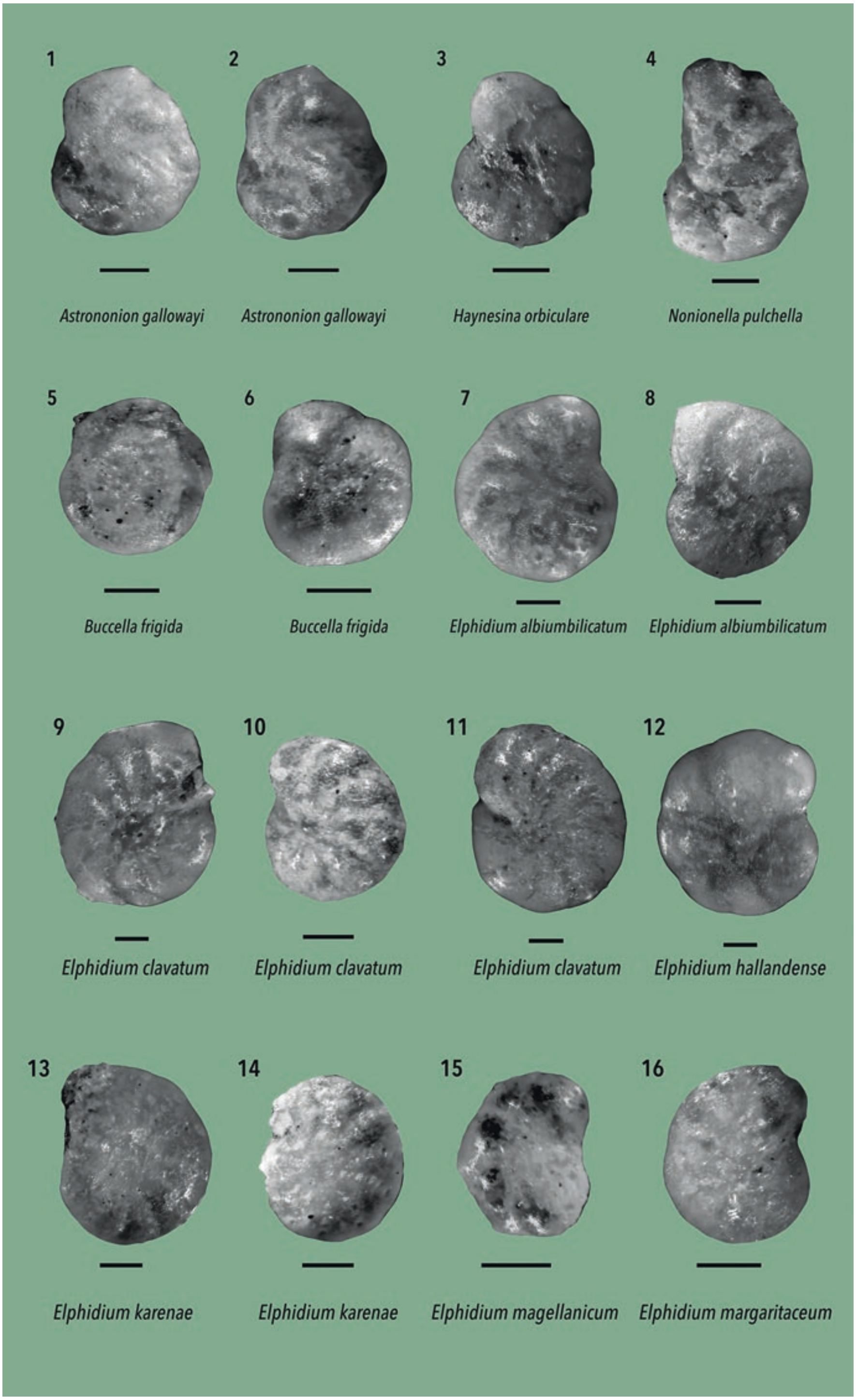


Plate 12.2 Light microscope multifocus images of specimens from the Svarthamar Member of the Þrengingar Formation. **1–2.** *Astrononion gallowayi* Loeblich and Tappan, from sample 1415

Plate 12.2 (continued) (unit 12x). **3.** *Haynesina orbiculare* (Brady), from sample 1415 (unit 12x). **4.** *Nonionella pulchella* Hada, from sample 1415 (unit 12x). **5–6.** *Buccella frigida* (Cushman), from sample 1399 (unit 10). **7–8.** *Elphidium albiumbilicatum* Weiss, from sample 1415 (unit 12x). **9–11.** *Elphidium clavatum* (Cushman), from samples 1415 (unit 12x), 1401 (unit 10), and 1091 (unit 12), respectively. **12.** *Elphidium hallandense* Brotzen, from sample 1415 (unit 12x). **13–14.** *Elphidium karenae* Ásbjörnsdóttir, from sample 1413 (unit 12). **15.** *Elphidium magellanicum* Heron-Allen and Earland, from sample 1401 (unit 10). **16.** *Elphidium margaritaceum* Cushman, from sample 1414 (unit 12). Scale bar = 0.1 mm. Lithological units refer to Bárðarson (1925)

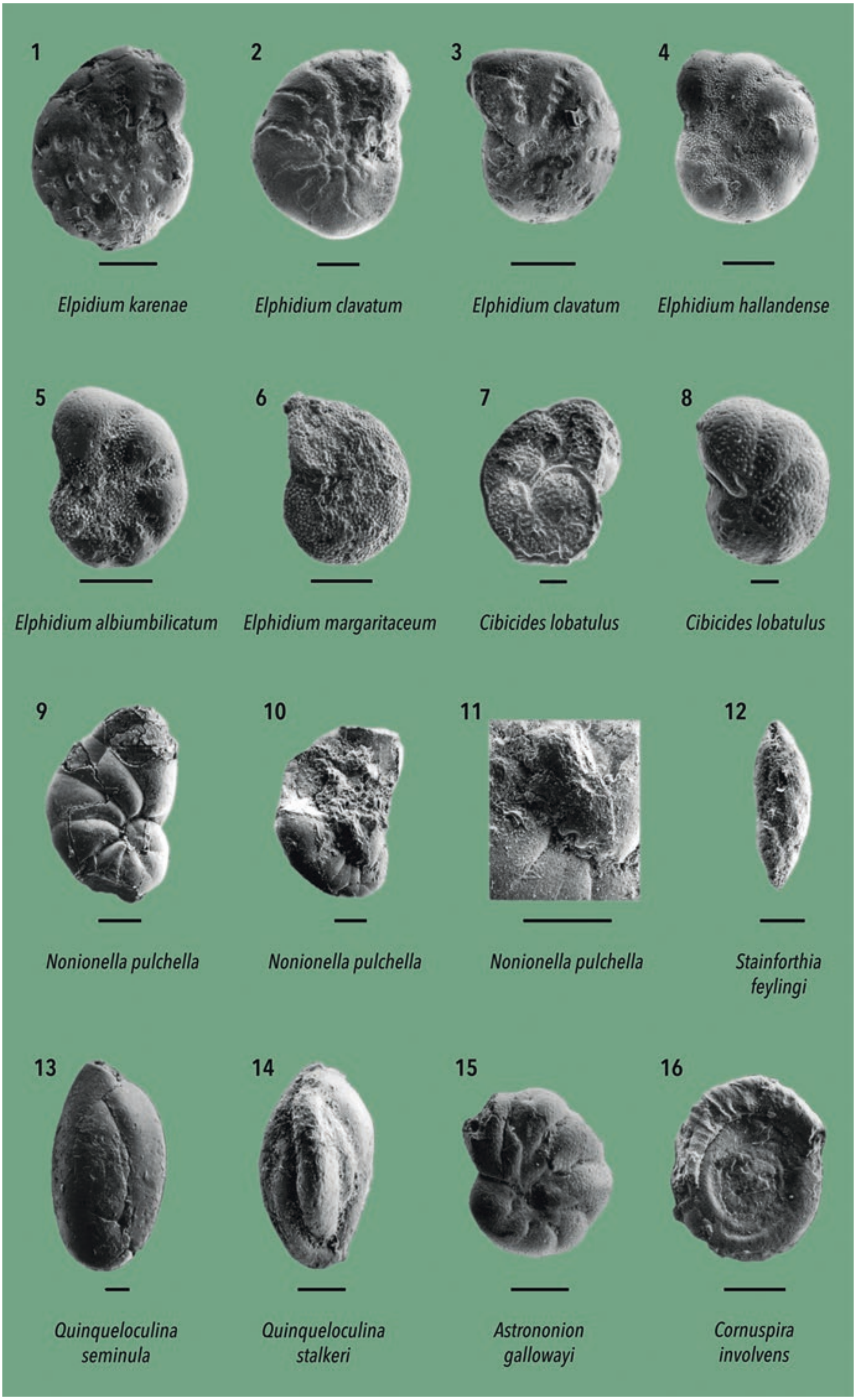


Plate 12.3 Scanning electron micrographs (SEM) of specimens from the Svarthamar Member of the Þrengingar Formation (modified from Eiríksson et al., 1993, with updated taxonomy).

Plate 12.3 (continued) **1.** *Elphidium karenae* Ásbjörnsdóttir, from sample 1413 (unit 12). **2.** *Elphidium clavatum* (Cushman), from sample 1191 (unit 12). **3.** *Elphidium clavatum* (Cushman), from sample 1092 (unit 12). **4.** *Elphidium hallandense* Brotzen, from sample 1092 (unit 12). **5.** *Elphidium albiumbilicatum* Weiss, from sample 1399 (unit 10). **6.** *Elphidium margaritaceum* Cushman, from sample 1415 (unit 12x). **7–8.** *Cibicides lobatulus* (Walker and Jacob), from sample 1413 (unit 12). **9–11.** *Nonionella pulchella* Hada, from sample 1415 (unit 12x). **12.** *Stainforthia feylingi* Knudsen and Seidenkrantz, from sample 1401 (unit 10). **13.** *Quinqueloculina seminula* (Linné), from sample 1415 (unit 12x). **14.** *Quinqueloculina stalkeri* Loeblich and Tappan, from sample 1401 (unit 10). **15.** *Astrononion gallowayi* Loeblich and Tappan, from sample 1415 (unit 12x). **16.** *Cornuspira involvens* (Reuss), from sample 1415 (unit 12x). Scale bar = 0.1 mm. Lithological units refer to Bárðarson (1925)