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Benthic habitats around Iceland investigated during the IceAGE expeditions

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Abstract: During the IceAGE (*Icelandic marine Animals – Genetics and Ecology*) expeditions in waters around Iceland and the Faroe Islands in 2011 and 2013, visual assessments of habitats and the study of surface sediment characteristics were undertaken in 119–2750 m water depth. Visual inspection was realized by means of an epibenthic sled equipped with a digital underwater video camcorder and a still camera. For determination of surface sediment characteristics a subsample of sediment from box corer samples or different grabs was collected and analyzed in the lab. Muddy bottoms predominated in the deep basins (Iceland Basin, Irminger Basin, deep Norwegian and Iceland Seas), while sand and gravel dominated on the shelves and the ridges, and in areas with high currents. Organic contents were highest in the deep Norwegian and Iceland Seas and in the Iceland Basin, and at these sites dense aggregations of mobile epibenthic organisms were observed. Large dropstones were abundant in the Iceland Sea near the shelf and in the Denmark Strait. The dropstones carried diverse, sessile epibenthic fauna, which may be underestimated using traditional sampling gear. The paper supplies new background information for studies based on IceAGE material, especially studies related to ecology and taxonomy.

Key words: Icelandic waters, North Atlantic, benthic habitat, sediment characteristics, visual assessment.

Introduction

The focus of the IceAGE (*Icelandic marine Animals – Genetics and Ecology*) project (2001 – onwards) is on the benthic fauna of the waters around Iceland, a very important region where the North Atlantic Ocean meets the colder Nordic Seas (Greenland, Iceland and Norwegian Seas). This region holds unique conditions, with temperatures ranging from around -0.9°C to around 12–14°C (Stefánsson 1962; Hansen and Østerhus 2000). Additionally, the region is shaped by the extensive Greenland-Iceland-Faroe Ridge (GIF Ridge), which with its shallow saddle depths (maximum depth of 840 m) isolates the Nordic Seas from the North Atlantic proper.

Studies in this region have extensively dealt with species diversity (*e.g.* Svavarsson 1997), distributions, and composition of benthic assemblages. The focus of these studies has mainly been on the influence of the GIF Ridge (barriers effects) and the temperatures on the distributions (*e.g.* Svavarsson *et al.* 1990; Brix and Svavarsson 2010). For a thorough understanding of species distributions and composition of benthic assemblages, it is necessary to have information not only on temperatures and water masses (see Hansen and Østerhus 2000) but also on the habitats the species live in (Meißner *et al.* 2014). For benthic species the type and the characteristics of substrate are crucial (Degraer *et al.* 2008; Willems *et al.* 2008; Meißner and Darr 2009). However, little information exists on surface sediment characteristics in Icelandic waters. Most studies dealing with surface sediments were conducted long time ago (Boeggild 1900), limited to fjords and often shallow waters (*e.g.* Svavarsson 1980), or are restricted to smaller, offshore regions (*e.g.* Ólafsdóttir 1975; Guđmundsdóttir *et al.* 2012).

Because of this lack of information on benthic habitats in Nordic waters, various data on benthic habitats were collected during the IceAGE1 and IceAGE2 expeditions parallel to the sampling of fauna. Apart from standard parameters such as water depth, water temperature and salinity, this included the collection of surface sediment samples and the use of video and photo cameras. The present paper provides a summary of the results from our collection of data describing the benthic habitats. For an overview, most important information on examined areas is summarized in spreadsheets for different geographic regions. Additional data are compiled in Tables and Figures.

Material and methods

Cruises. — Expedition IceAGE1 was undertaken from 27th August to 28th September 2011 with the German R/V *Meteor* and led from the Iceland Basin in the south of Iceland across the Reykjanes Ridge to the Irminger Basin, along the Denmark Strait to the Iceland Sea in the north and western parts of the Norwegian Sea. Expedition IceAGE2 was from 21st July to 3rd August 2013 on board the German R/V *Poseidon*. During this expedition samples were taken along the Faroe-Shetland Channel and the Iceland-Faroe Ridge.

Topography and hydrography of the study area. — The study area (Fig. 1) is characterized by the extensive GIF Ridge crossing the Atlantic Ocean in

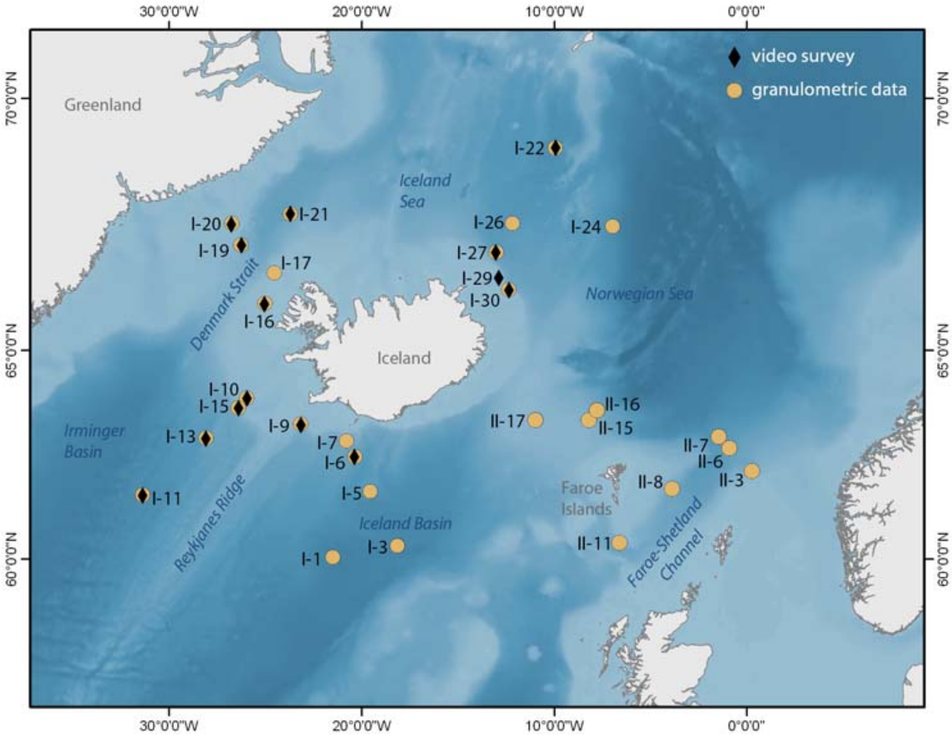


Fig. 1. Map of the study area together with information on locations where sediment sampling (for analyses of sediment parameter) and video surveys (including image analyses) took place.

east-west direction and separating the Nordic Seas (Greenland, Iceland and Norwegian Seas; GIN Seas) from the North Atlantic proper. To the southwest and the south of the GIF Ridge two large oceanic basins occur, *i.e.* the Iceland Basin and the Irminger Basin. The Iceland Basin is surrounded by the Reykjanes Ridge to the west, Iceland to the north and the Iceland-Faroe Ridge to the northeast and east. The shelf slope of Iceland here is steep with numerous deep canyons. The area is characterized by Modified North Atlantic Waters (MNAW) (Hansen and Østerhus 2000). The Iceland-Scotland Overflow Water (ISOW) crosses the Iceland-Faroe Ridge, passes the Iceland Basin and continues into the Irminger Basin. There is an anti-clockwise current in deeper waters. The shallow waters south of Iceland hold a fairly complex system of currents (see Logemann *et al*. 2013). Near shore, the true Icelandic Coastal Current (ICC) flows along the south coast in westerly direction. Further offshore the Icelandic Coastal Undercurrent (ICUC) exists, which mixes with the South Icelandic Current (SIC), flowing on the shelf in easterly direction and subsequently becomes the Faroe Current. Further off the Icelandic Slope Current (ISC) flows along the South Icelandic slope in westerly direction. The region is flushed with generally warm waters (>6°C).

The Irminger Basin is the large oceanic basin to the west of the Reykjanes Ridge. The water mass of the deep part is the Labrador Sea Water (LSW), while MNAW bathes the shallower part. Various Arctic components of the North Atlantic Deep Water (NADW) pass the Denmark Strait from the north at depths of less than 900 m. These form boundary currents as they descend the continental slope to their equilibrium depths (Yashayaev and Clarke 2008). Furthermore, the ISOW flows from the Iceland Basin and subsequently forms the Northeast Atlantic Deep Water (NEADW). Accordingly, there is considerable mixing with the LSW. There is generally an anti-clockwise circulation in the basin. The shallow region off West Iceland is characterized by the Irminger Current (IC), which is the strongest current in Icelandic waters. In shallower waters the IC flows north along the western side of the Reykjanes Ridge. Over the shelf a rather sluggish and broad current flows, *i.e.* the West Icelandic Irminger Current (WIIC) (Logemann *et al*. 2013). Both are warm (>5°C) and saline, with MNAW.

The Denmark Strait is a fairly narrow body of water (minimum of around 290 km) separating Greenland from Iceland, but connecting the Greenland Sea to the North Atlantic Ocean. Currently the minimum sill depth of the strait is about 620 m (Hansen and Østerhus 2000). The shelf on each side of the strait is fairly wide, while the deep channel is somewhat narrow. The Greenland-Iceland Ridge was probably once a land bridge or a chain of islands. The Greenland-Scotland Transverse Ridge (GSTR) may have persisted from the early Cenozoic to the late Oligocene and partly into the Middle Miocene (*e.g.* Grímsson *et al*. 2007). Thus, the current system may have been quite different in the past. The Icelandic shelf of the Denmark Strait is currently bathed with MNAW carried by the North Icelandic Irminger Current (NIIC), which dominates most of the North Icelandic shelf. In the southern part of the Denmark Strait NIIC absorbs the West Icelandic Irminger Current (WIIC) (Logemann *et al*. 2013). Recently, a new current, the North Icelandic Jet (NIJ) (Jónsson and Valdimarsson 2004; Våge *et al*. 2013), has been discovered. This current holds dense, cold water, flowing westwards along the North Icelandic slope. The NIJ is narrow, often less than 20 km wide, and is centred near the 650 m isobath (Våge *et al*. 2011).

The East Greenland shelf is wide adjacent to Iceland, but to the north the shelf is fairly narrow, with a steep slope facing the Blosseville basin. To the south of the strait, the shelf gradually becomes narrower towards about 63°14'N. The East Greenland shelf and slope is mainly bathed by cold water (*i.e.* Polar Water, Denmark Strait Overflow Water, DSOW; sub-zero temperatures to a few degrees above zero) originating from the north, carried with the East Greenland Current (EGC). Approximately 450 km north of the Denmark Strait, the EGC separates into two branches, one being the shelf break EGC, while the deeper one flows along the NIJ and jointly forms the plume of the DSOW (Våge *et al*. 2013). Accordingly, approximately 70% of the DSOW flows along the Icelandic continental slope towards the sill. The northern and deeper part of the Denmark Strait holds a fairly complex system of currents, with the separated EGC being formed by anti-cyclonic eddies that coalesce. The EGC unites with the NIJ, and furthermore a wind-driven anti-cyclonic recirculation occur north of the sill (Våge *et al*. 2013). Accordingly, the sampling sites in the Denmark Strait have north-easterly flowing currents, but cold waters.

The hydrography of the region off North and Northeast Iceland is rather complicated, as several water masses occur in the region, and some mix and others change characteristics with loss of heat, such as the advecting warm Atlantic Water (Stefánsson 1962; Hansen and Østerhus 2000; Våge *et al*. 2013). Generally, in intermediate waters off the Icelandic slope, the near-bottom waters are characterized by a low temperature and a low salinity (Hansen and Østerhus 2000). The water masses MEIW and Norwegian Sea Arctic Intermediate Water (NSAIW) characterize shallow and intermediate waters and in still deeper waters the Norwegian Sea Deep Water (NSDW) occurs (Stefánsson 1962; Hansen and Østerhus 2000). The North Icelandic Irminger Current (NIIC) flows clockwise in shallower waters, while in deeper waters the NIJ flows towards the west (Jónsson and Valdimarsson 2004; Våge *et al*. 2011; Våge *et al*. 2013). The deep waters of the Norwegian and Iceland Seas are characterized by temperatures below 0°C and low-saline (S <34.9) waters (Hansen and Østerhus 2000), with the NSDW as the coldest and deepest occurring water mass.

The Iceland-Faroe Ridge is fairly shallow, with maximum sill depth of 480 m (Hansen and Østerhus 2000) and most of the ridge has sill depths between 300 and 480 m. The southern side of the ridge is bathed with MNAW, while Atlantic water also occurs to the west and north of the Faroes (Hansen and Østerhus 2000). Deep off the northern side of the ridge colder water masses occur. The deeper channels of the Iceland-Faroe Ridge have intermittent overflow of NSAIW and NSDW. One branch of the North Atlantic Current (NAC) crosses the ridge and becomes the Faroe Current (FC), while a branch of the FC separates and becomes the Shetland Current (SC).

The Faroe-Shetland Channel and its continuation towards the west, *i.e.* the Faroe Bank Channel, are the deepest connection between the Greenland, Iceland and Norwegian Seas and the northernmost North Atlantic, with a saddle depth of 840 m. Below 600 m in the Faroe-Shetland Channel the temperatures are cold (<3°C) and the waters are characterized by salinity tending towards the characteristic 34.91–34.92 salinity of the NSDW (Hansen and Østerhus 2000). The Faroe-Shetland Channel has strong currents with average velocities exceeding 1 m/s in an about 100 m thick layer some 100 m above the bottom (Hansen and Østerhus 2000).

Granulometry and determination of organic matter contents. — Granulometry was examined for samples collected with a box corer (or alternatively with a Shipek grab or a van Veen grab). From box corer (or grab) samples a subsample of the uppermost 20 cm of sediment was manually taken with a 4.5 cm diameter corer once the sample was on board and the supernatant water removed. An approximate wet weight of 100 g of sediment was measured and then dried at 110°C until constant weight was achieved to determine the water content of the sediment. Then the sediment was wet sieved through a stack of sieves (4000 µm, 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, 63 µm and 40 µm) by means of a sieving machine (Haver and Boecker EML). Sieving aids (rubber balls 25 mm in diameter) were applied on all sieves with mesh sizes >250 µm. After sieving the fractions were again dried at 110°C until constant weight was achieved. Granulometric parameters were calculated according to Buller and McManus (1979) and sorting classes determined based on Higgins and Thiel (1988). Sediment types were assigned based on methods introduced by Folk (1954). The organic matter content was obtained by loss of ignition at 550°C for 4 h from a subsample of about 50 g.

A photo of the undisturbed surface of the box corer samples and of material in the Shipek and van Veen grabs was taken for documentation of surface sediment appearance.

Visual assessments of habitats. — For photo and video surveys, an epibenthic sled (EBS) was equipped with a digital underwater video camcorder (Sony HDR SR11E/SR12E) on the left side of the sled, two spotlights, a still camera (KONGSBERG oe14-208/Canon G5) on the right side of the sled, flashlights, a control unit and an accumulator (fig. 3 in Brandt *et al.* 2013). The sled was also equipped with epibenthic samplers with two plankton nets (500 µm) on top of each other and with cod ends (300 µm). The sled is 3.5 m long, 1.2 m high and 1.8 m wide. The whole frame is constructed of stainless steel (DIN 1.4462). For more detailed information and all technical specifications see Brenke (2005). The maximum diving depth is 6000 m (600 bar); the weight is 750 kg in air. The camcorder films to the left side, 0.8–1.0 m above the sediment surface, with an angle of 30° to the towing direction from the centre of the sled. The observed area is trapezoidal and close to the sled approximately 2 m wide. The camcorder saves the HD-quality video on an internal hard drive of 120 GB. Simultaneously, the camcorder takes still pictures (10 megapixels) every 20 seconds and saves them on a memory card. The still camera takes photos to the right side, 0.6–0.8 m above the sediment surface, with an angle of 30° to the towing direction from the centre of the sled. The still camera is able to make 1560 pictures (2592x1944 pixels), saved on an internal memory card, and with a minimum time interval of 20 seconds. The entire system is powered using an oil-embedded deep-sea battery (EA-BC 500, 600 bar) which provides 2x 24V with 14 Ah. This allows an operating time of approx. 7 hours. Additionally to the visual observation of the seafloor, the EBS is equipped with an autonomous multi-sensor (SEAGUARD RCM DW-6000). The SEAGUARD RCM DW is a multi-frequency Doppler Current Sensor (DCS) for measurements of current speed and direction. It is also equipped with a conductivity cell (4319A), a temperature sensor (4060B) and a pressure sensor (4117F) (CTD). Furthermore the SEAGUARD RCM DW includes an optrode (4330) for measurements of dissolved oxygen.

Visual assessments were undertaken at 14 locations during the IceAGE1 expedition. Information on the location of the stations and water depths are provided in Fig. 1 and in Table 1.

Table 1

List of stations* investigated during the IceAGE expeditions for information on granulometry, total organic content and image analysis. Because of failure of either the camera or the photo systems pictures are not available for stations #1069, #1090, #1119 and videos have not been recorded at stations #1148 and #1159. (*the list is not a complete list of stations of the IceAGE expeditions).

expedition	area	gear	station	date	latitude	longitude	depth [m]	region
IceAGE1	I-1	box corer	960	28-Aug-11	60°02.73' N	021°30.14' W	2750	Iceland Basin
IceAGE1	I-3	box corer	976	30-Aug-11	60°20.54' N	018°08.67' W	2569	Iceland Basin
IceAGE1	I-3	box corer	977	30-Aug-11	60°20.54' N	018°08.69' W	2572	Iceland Basin
IceAGE1	I-5	box corer	996	01-Sep-11	61°42.49' N	019°32.78' W	1913	Iceland Basin
IceAGE1	I-6	box corer	1002	02-Sep-11	62°33.50' N	020°21.18' W	1392	Iceland Basin
IceAGE1	I-6	video	1006	02-Sep-11	62°33.23' N	020°22.52' W	1389	Iceland Basin
IceAGE1	I-7	box corer	1022	03-Sep-11	62°55.58' N	020°47.36' W	907	Iceland Basin
IceAGE1	I-9	box corer	1031	04-Sep-11	63°20.00' N	023°10.00' W	305	Reykjanes Ridge
IceAGE1	I-9	video	1032	04-Sep-11	63°18.59' N	023°09.50' W	282	Reykjanes Ridge
IceAGE1	I-10	box corer	1042	05-Sep-11	63°55.37' N	025°57.84' W	215	Irminger Basin
IceAGE1	I-10	video	1043	05-Sep-11	63°55.53' N	025°57.34' W	214	Irminger Basin
IceAGE1	I-11	box corer	1051	07-Sep-11	61°37.41' N	031°22.11' W	2539	Irminger Basin
IceAGE1	I-11	video	1054	07-Sep-11	61°36.82' N	031°22.26' W	2546	Irminger Basin
IceAGE1	I-13	box corer	1067	08-Sep-11	62°59.97' N	028°04.78' W	1625	Irminger Basin
IceAGE1	I-13	video	1069	08-Sep-11	62°59.67' N	028°05.19' W	1630	Irminger Basin
IceAGE1	I-15	box corer	1080	09-Sep-11	63°41.90' N	026°24.44' W	741	Irminger Basin
IceAGE1	I-15	video	1082	09-Sep-11	63°42.27' N	026°23.64' W	710	Irminger Basin
IceAGE1	I-16	box corer	1095	10-Sep-11	66°00.62' N	025°01.25' W	135	Denmark Strait
IceAGE1	I-16	video	1090	10-Sep-11	66°00.07' N	025°03.02' W	120	Denmark Strait
IceAGE1	I-17	Shipek grab	1103	13-Sep-11	66°38.56' N	024°32.13' W	119	Denmark Strait
IceAGE1	I-19	box corer	1116	14-Sep-11	67°12.82' N	026°16.31' W	683	Denmark Strait
IceAGE1	I-19	video	1119	14-Sep-11	67°12.83' N	026°13.90' W	705	Denmark Strait
IceAGE1	I-20	box corer	1129	14-Sep-11	67°38.76' N	026°44.80' W	319	Denmark Strait
IceAGE1	I-20	video	1136	14-Sep-11	67°38.06' N	026°46.19' W	316	Denmark Strait
IceAGE1	I-21	box corer	1142	15-Sep-11	67°50.22' N	023°42.12' W	1241	Denmark Strait
IceAGE1	I-21	video	1148	15-Sep-11	67°50.37' N	023°41.77' W	1243	Denmark Strait
IceAGE1	I-22	box corer	1153	17-Sep-11	69°05.60' N	009°56.01' W	2173	Norwegian Sea
IceAGE1	I-22	video	1159	17-Sep-11	69°06.07' N	009°55.61' W	2160	Norwegian Sea
IceAGE1	I-24	box corer	1165	19-Sep-11	67°35.29' N	006°57.48' W	2402	Norwegian Sea
IceAGE1	I-26	box corer	1179	20-Sep-11	67°38.71' N	012°10.11' W	1820	Norwegian Sea
IceAGE1	I-27	box corer	1189	21-Sep-11	67°04.32' N	013°00.89' W	1579	Norwegian Sea
IceAGE1	I-27	video	1194	21-Sep-11	67°04.50' N	013°02.06' W	1579	Norwegian Sea
IceAGE1	I-29	video	1212	22-Sep-11	66°32.76' N	012°52.72' W	312	Norwegian Sea
IceAGE1	I-30	box corer	1217	22-Sep-11	66°18.06' N	012°22.40' W	732	Norwegian Sea
IceAGE1	I-30	video	1222	22-Sep-11	66°17.61' N	012°21.36' W	631	Norwegian Sea
IceAGE2	II-3	box corer	868	25-Jul-13	62°12.49' N	000°15.67' E	669	Faroe-Shetland Channel
IceAGE2	II-6	van Veen	871	26-Jul-13	62°45.31' N	000°54.09' W	1563	Faroe-Shetland Channel
IceAGE2	II-7	box corer	872	27-Jul-13	63°01.80' N	001°27.05' W	1842	Faroe-Shetland Channel
IceAGE2	II-8	van Veen	873	28-Jul-13	61°46.56' N	003°52.40' W	834	Faroe-Shetland Channel
IceAGE2	II-11	box corer	876	29-Jul-13	60°24.78' N	006°37.02' W	534	Faroe-Shetland Channel
IceAGE2	II-15	box corer	880	31-Jul-13	63°24.79' N	008°11.63' W	688	Iceland-Faroe Ridge
IceAGE2	II-16	van Veen	881	01-Aug-13	63°38.50' N	007°47.03' W	1073	Iceland-Faroe Ridge
IceAGE2	II-16	van Veen	881	01-Aug-13	63°38.72' N	007°47.15' W	1080	Iceland-Faroe Ridge
IceAGE2	II-17	van Veen	882	02-Aug-13	63°25.01' N	010°58.80' W	441	Iceland-Faroe Ridge
IceAGE2	II-17	van Veen	882	02-Aug-13	63°25.03' N	010°58.73' W	440	Iceland-Faroe Ridge

Results

Characteristics of surface sediments are provided for 21 locations examined during the IceAGE1 expedition and for 8 locations sampled during IceAGE2. Sediment types found included sandy mud, partially with small fractions of gravel, muddy sand with smaller and larger proportions of gravel, gravelly sand and muddy sandy gravel (Fig. 2, Table 2). Mud predominated in the deep-sea basins whereas sand and gravel were found closer to the shelves and ridges and in areas with strong currents (Fig. 2). Noteworthy is the fact, that proportions of gravel were present in almost two thirds of all samples, among them very fine sediments as sandy mud (Table 2). The sediments were mainly very poorly sorted, occasion-

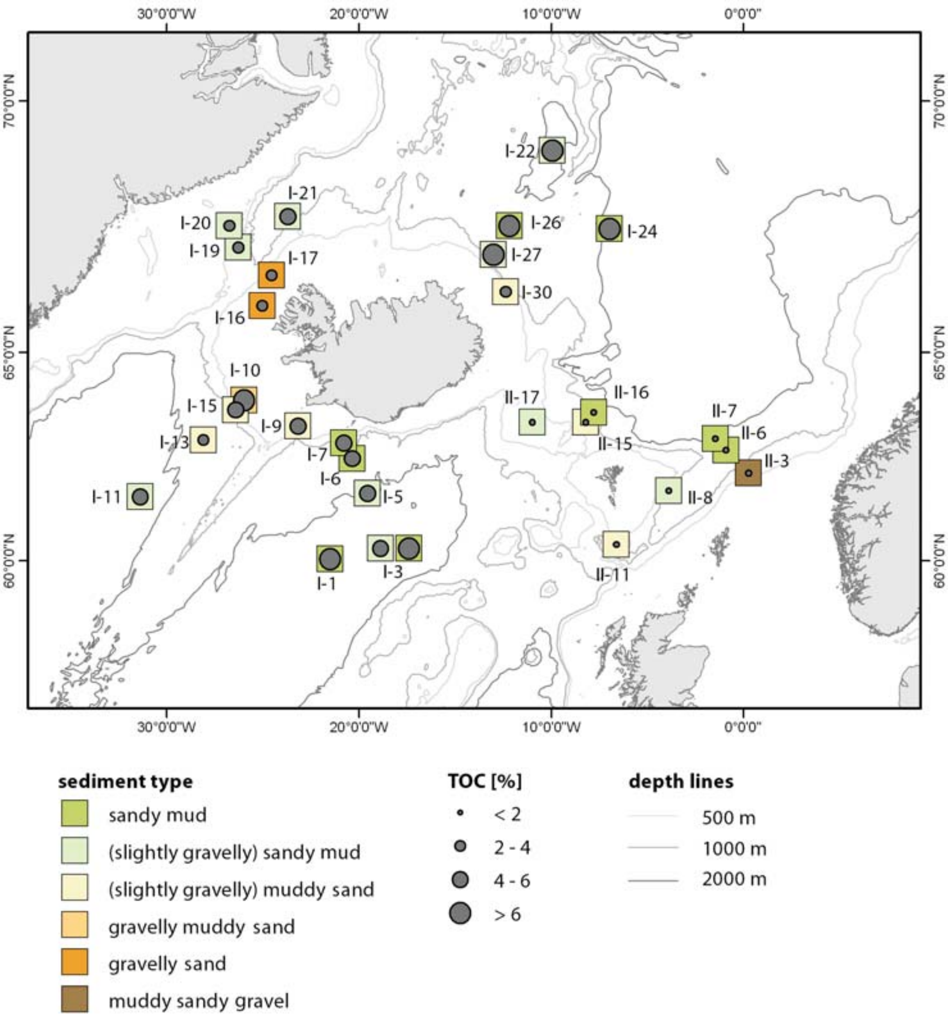


Fig. 2. Important results of sediment analyses.

Table 2

Results of sediment analyses in detail. Organic content determined by loss of ignition

area	station	water content	TOC	mean	d 50 [mm]	SkI	QDI	sort class QDI	mud (silt+clay) <63 µm	sand 63<x<1000 µm	gravel >2000 µm	sediment type after Folk (1954)	abbreviation
I-1	960	70.56	9.25	7.333	0.033	0.857	2.311	very poorly sorted	74.47	25.53	0.00	sandy mud	sM
I-3	976	60.36	5.68	7.000	0.064	0.929	2.561	very poorly sorted	56.57	43.41	0.02	(slightly gravelly) sandy mud	(g)sM
I-3	977	60.99	6.73	7.000	0.064	0.929	2.561	very poorly sorted	54.24	45.76	0.00	sandy mud	sM
I-5	996	44.21	4.86	7.000	0.033	0.929	2.561	very poorly sorted	60.32	39.48	0.20	(slightly gravelly) sandy mud	(g)sM
I-6	1002	53.69	5.80	7.333	0.002	0.857	2.311	very poorly sorted	78.31	21.69	0.00	sandy mud	sM
I-7	1022	57.64	5.97	7.000	0.033	1.000	2.409	very poorly sorted	71.93	28.07	0.00	sandy mud	sM
I-9	1031	42.36	4.51	4.667	0.157	-0.563	2.962	very poorly sorted	24.48	73.24	2.28	(slightly gravelly) muddy sand	(g)mS
I-10	1042	44.20	7.23	4.333	0.126	-0.227	3.667	very poorly sorted	26.21	66.58	7.21	gravelly muddy sand	gmS
I-11	1051	53.16	4.74	6.667	0.126	0.938	2.962	very poorly sorted	59.64	38.32	2.04	(slightly gravelly) sandy mud	(g)sM
I-13	1067	35.66	3.34	3.000	0.188	-0.167	1.864	poorly sorted	12.54	83.48	3.99	(slightly gravelly) muddy sand	(g)mS
I- 5	1080	50.88	4.85	4.333	0.157	-0.389	3.364	very poorly sorted	19.73	78.35	1.93	(slightly gravelly) muddy sand	(g)mS
I-16	1095	17.68	3.05	0.333	0.750	-0.375	0.856	moderately sorted	2.06	82.05	15.89	gravelly sand	gS
I-17	1103	30.40	3.22	1.000	0.625	0.000	1.909	poorly sorted	4.28	74.56	21.16	gravelly sand	gS
I-19	1116	33.11	2.36	7.000	0.033	0.833	2.864	very poorly sorted	56.48	39.21	4.31	(slightly gravelly) sandy mud	(g)sM
I-20	1129	51.07	3.60	7.000	0.064	0.833	2.864	very poorly sorted	52.91	43.63	3.46	(slightly gravelly) sandy mud	(g)sM
I-21	1142	51.23	4.16	6.667	0.064	0.938	2.962	very poorly sorted	61.28	35.91	2.81	(slightly gravelly) sandy mud	(g)sM
I-22	1153	55.06	6.69	7.000	0.064	0.929	2.561	very poorly sorted	57.39	42.05	0.56	(slightly gravelly) sandy mud	(g)sM
I-24	1165	55.01	7.71	7.000	0.064	0.929	2.561	very poorly sorted	58.95	41.05	0.00	sandy mud	sM
I-26	1179	58.73	8.37	7.000	0.048	0.929	2.561	very poorly sorted	70.31	29.69	0.00	sandy mud	sM
I-27	1189	62.51	9.26	7.000	0.033	0.875	2.712	very poorly sorted	71.04	28.77	0.19	(slightly gravelly) sandy mud	(g)sM
I-30	1217	53.05	3.77	5.000	0.126	-0.222	3.114	very poorly sorted	35.06	60.68	4.26	(slightly gravelly) muddy sand	(g)mS
II-3	868	21.93	1.28	3.333	2.032	-0.091	4.417	extremely poorly sorted	27.41	31.72	40.86	muddy sandy gravel	msG
II-6	871	62.52	1.66	7.533	0.002	0.867	2.009	very poorly sorted	86.27	13.73	0.00	sandy mud	sM
II-7	872	64.84	1.84	7.533	0.002	0.867	2.009	very poorly sorted	86.20	13.80	0.00	sandy mud	sM
II-8	873	46.72	1.41	5.533	0.126	-0.329	2.561	very poorly sorted	60.73	37.71	1.51	slightly gravelly sandy mud	(g)sM
II-11	876	21.14	0.97	4.667	0.251	-0.167	3.364	very poorly sorted	47.16	49.60	3.19	slightly gravelly muddy sand	(g)mS
II-15	880	42.05	1.07	5.333	0.064	-0.500	2.561	very poorly sorted	37.25	62.51	0.23	slightly gravelly muddy sand	(g)mS
II-16	881	61.50	1.10	7.533	0.021	0.867	2.009	very poorly sorted	84.32	15.68	0.00	sandy mud	sM
II-16	881	64.13	1.32	7.333	0.021	1.000	2.008	very poorly sorted	83.96	16.04	0.00	sandy mud	sM
II-17	882	47.03	1.76	5.533	0.033	-0.467	2.409	very poorly sorted	52.50	47.50	0.00	sandy mud	sM
II-17	882	49.76	1.19	5.533	0.033	-0.467	2.409	very poorly sorted	50.57	49.39	0.04	slightly gravelly sandy mud	(g)sM

ally also moderately, poorly and extremely poorly sorted (Table 2). The total organic content varied between 0.97 and 9.26%, with highest values in deep waters of the Iceland and Norwegian Seas and in the Iceland Basin (Fig. 2, Table 2). The total organic content was low at all stations along the Iceland-Faroe Ridge and the Faroe-Shetland Channel.

Visual assessments by means of video camera and photography were undertaken during the IceAGE1 expedition. For logistic reasons it was impossible to deploy the respective devices for this kind of data collection during the IceAGE2 cruise. Visual assessments revealed the presence of stones which otherwise would not have been documented. It also documented the presence of different habitats on a small spatial scale (*e.g.* hard and soft bottom, presence of gravel on the sediment surface as well as polychaete tubes or pieces of shells, burrows of crustaceans, *e.g. Nephrops norvegicus* (Linnaeus, 1758)) and the presence or absence of megafauna. Stones were particularly abundant in the Iceland Sea, close to the Icelandic shelf (areas I-29 and I-30), and in the Denmark Strait, close to the Greenland Shelf (areas I-19 and I-20). These sites were populated by a rich megafauna (*e.g.* crinoids, anthozoans, sponges), mainly attached to the hard substrate. Occasional stones on soft sediment were recorded off SW Iceland close to the shelf and the spurs of the Reykjanes Ridge (areas I-9, I-10, I-15). Again, sessile epifauna, in particular sponges, was attached to the stones. In all other areas soft sediments without stones predominated and the observed faunal elements were holothurians, brittle stars and crinoids as well as tubes (most likely belonging to polychaetes). Only in the Denmark Strait, close to the Icelandic shelf (areas I-16 and I-17), small pebbles and fractured shells were sparsely covering the soft sediment.

In the following spreadsheets (Figs 3–13) the most important information for different regions around Iceland gathered during the IceAGE expeditions is compiled.

Discussion

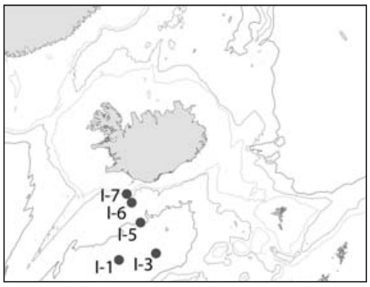
The benthic habitats in waters around Iceland described in the present paper reflect very well the general topography and geology of the area. The Icelandic shelf during the ice ages has been extensively influenced by the Icelandic Ice Sheet. During the Last Glacial Maximum the Icelandic Ice Sheet most likely reached the shelf break (Ólafsdóttir 1974; Geirsdóttir *et al*. 2009). Off Breiđafjörđur, West Iceland, the glacier formed a moraine ridge (20–30 m high, 800–1000 m wide, 100 km long). As the relative sea level rose and the Polar Front began to migrate northward, the Icelandic Ice Sheet catastrophically broke up at around 15 ka (Geirsdóttir *et al.* 2009). Material was transported with the ice and after the retreat of the ice left it behind. Ice as a rafting agent mostly explains the presence of dropstones in high-latitude marine soft-bottom environments (Hasemann *et al*. 2013). Dropstones are large

Iceland Basin

granulometry
I-1 (#960), I-3 (#976, 977), I-5 (#996), I-6 (#1002), I-7 (#1022)

video / photo:
I-6 (#1006)

water depth: 900–2800 m



hydrography

The area is characterized by Modified North Atlantic Waters (MNAW). The Iceland-Scotland Overflow Water (ISOW) crosses the Iceland-Faroe Ridge, passes the Iceland Basin and continues into the Irminger Basin. There is anti-clockwise current in deeper waters. This region is characterized by highly productive surface waters.

visual description

- very homogenous
- soft sands, no stones
- epifauna scarce and mostly absent, few traces of macrofauna

sediments

- very poorly and moderately sorted **sandy mud**, occasionally with small proportion of gravel
- area I-5 (#996) with firm clay underneath upper 20 cm thick layer of sandy mud
- **high total organic carbon content** (4.9–6.7%), in particular in area I-1 with 9.3% TOC
- many Foraminifera and tubes

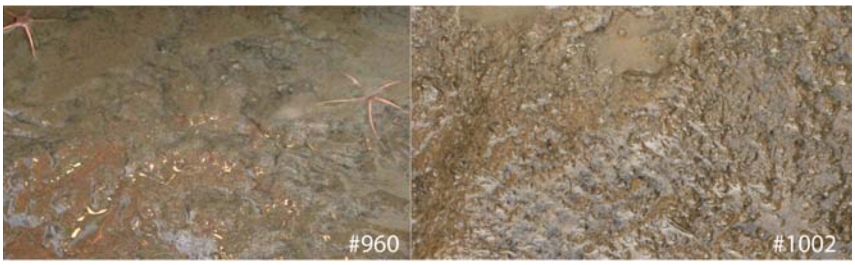


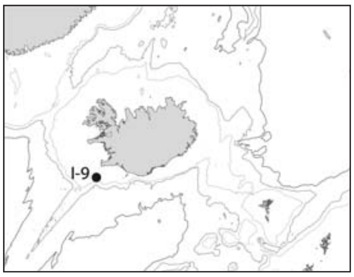
Fig. 3. Habitat descriptions for the Iceland Basin.

spurs of the Reykjanes Ridge, near shelf

granulometry
I-9 (#1031)

video / photo:
I-9 (#1032)

water depth: 282–305 m

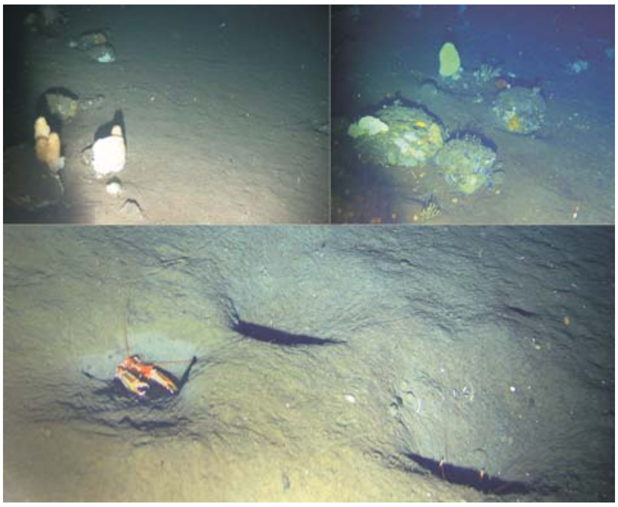


hydrography

Near shore, the true Icelandic Coastal Current (ICC) occurs, while further offshore the Icelandic Coastal Undercurrent (ICUC) exists and further off the Icelandic Slope Current (ISC) flows along the slope. This region is flushed with generally warm water (>6°C).

visual description

- soft sediment with few larger stones which are covered with epifauna; macrofauna not abundant but diverse: sponges, anthozoa, shrimp, Decapoda (*Nephrops*)
- considerable sediment plume due to sledge movement



sediments

- very poorly sorted **muddy sand** with a small proportion of gravel, of dark-brown colour
- total organic carbon content 4.5%
- with Foraminifera and fractured shells

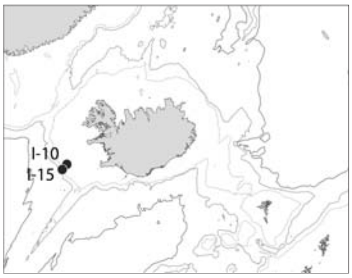
Fig. 4. Habitat descriptions for area I-9 located at the spurs of the Reykjanes Ridge, near the shelf.

off SW Iceland, shelf and slope

granulometry
I-10 (#1042), I-15 (#1080)

video / photo:
I-10 (#1043), I-15 (#1082)

water depth: 215 m (I-10, shelf) and 710–741 m (I-15, slope)

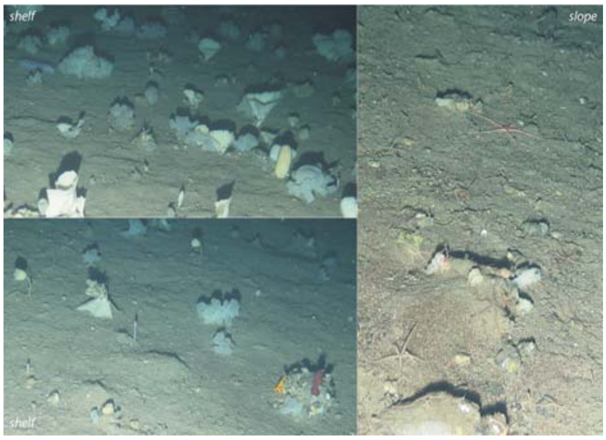


hydrography

The region off SW Iceland is generally characterized by the Irminger Current (IC). This is the strongest current in Icelandic waters. Over the shelf rather sluggish and broad current flows, i.e. the West Icelandic Irminger Current (WIIC). Both are warm (>5°C) and saline, with Modified North Atlantic Water.

visual description

- **shelf** region with occasional stones; abundant and diverse fauna: many different sponges, sea stars, holothurians, cnidarians, bivalves, shrimp, fish etc.
- larger stones rare at **slope**, significant sediment plume due to sledge movement; diverse fauna: small crustaceans swimming after disturbance (by gear), sponges, cnidarians, some fish, sea urchins, ophiurids etc.



sediments

- on the shelf very poorly sorted **gravelly muddy sand** and on the slope very poorly sorted **muddy sand** with a small proportion of gravel
- total organic carbon content 7.2% (shelf) and 4.9% (slope)

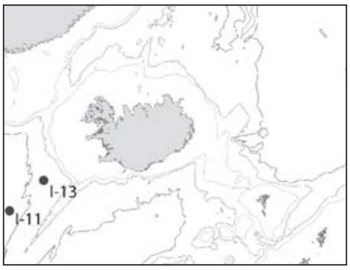
Fig. 5. Habitat descriptions for areas off SW Iceland.

Irminger Basin

granulometry
I-11 (#1051), I-13 (#1067)

video / photo:
I-11 (#1054), I-13 (#1069)

water depth: 1625–2546 m



hydrography

The deep basin holds Labrador Sea Water (LSW), while Modified North Atlantic Waters (MNAW) bathes the shallower part. Various Arctic components of the North Atlantic Deep Water (NADW) pass the Denmark Strait from the north at depths of less than 900 m and these form boundary currents as they descend the continental slope to their equilibrium depths. Icelandic-Scotland Overflow Water (ISOW) arrives from the Iceland Basin and subsequently forms the Northeast Atlantic Deep Water (NEADW). Accordingly, there is considerable mixing with the LSW. There is generally an anti-clockwise circulation in the basin.

visual description

- I-11 with soft sediment, no stones; fauna sparse: crinoids, ophiurids, fish (e.g. *Coryphaenoides* sp.), holothurians
- area I-13 sandy with little black stones on sediment surface; fauna not observed

sediments

- in area I-11 very poorly sorted **grey sandy mud** and in area I-13 poorly sorted dark-brown **muddy sand**, both with small proportion of gravel
- in area I-13 intermixed with shells of pelagic gastropods and coral rubble
- total organic carbon content between 3.3–4.7%

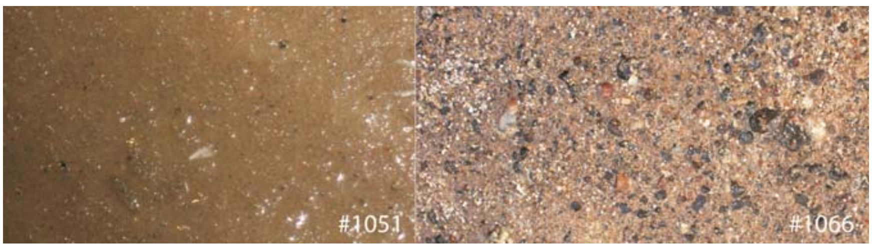


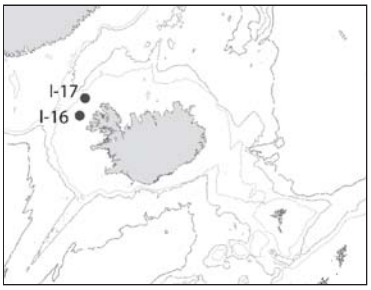
Fig. 6. Habitat descriptions for the Irminger Basin.

Denmark Strait, Icelandic shelf

granulometry
I-16 (#1095), I-17 (#1103)

video / photo:
I-16 (#1090)

water depth: 120–135 m

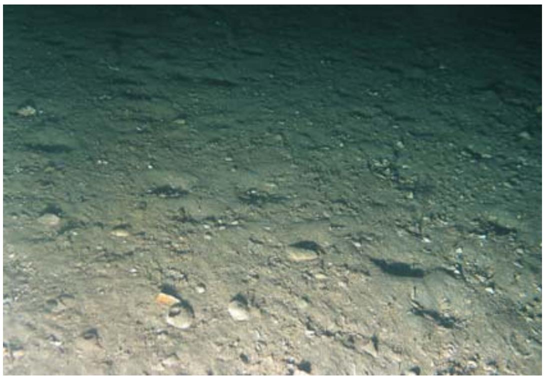


hydrography

The Denmark Strait is a fairly narrow (minimum of around 290 km) , with the minimum sill depth at about 620 m. The shelf on each side is fairly wide and the deep channel is somewhat narrow. The Icelandic shelf is bathed with Modified North Atlantic Water (MNAW) carried by the North Icelandic Irminger Current (NIIC), which dominates most of the North Icelandic shelf. In the southern part of the Denmark Strait NIIC absorbs the West Icelandic Irminger Current (WIIC). The North Icelandic Jet (NIJ) occurs in the deeper part of the strait, holding dense, cold water.

visual description

- sand with shell fragments and occasional megafauna (soft corals, sponges)
- traces of macrofauna on the sediment surface
- abundant macrofauna (i.e. shrimp) swimming above ground (disturbance by sledge placement, light attraction)



sediments

- moderately (I-16) and poorly (I-17) sorted **gravelly sand**
- total organic carbon content 3.1–3.2%)

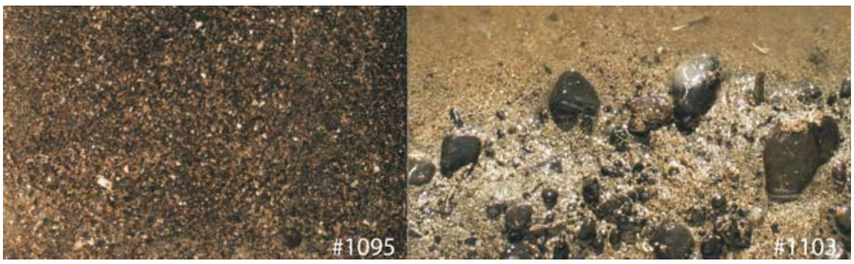


Fig. 7. Habitat descriptions for areas located on the Icelandic shelf, eastern side of the Denmark Strait.

blocks that have an extra-basinal lithology with uncertain origin and are a common feature in polar deep-sea regions (Hasemann *et al*. 2013). There is still little known about the transport of dropstones by the Ice Sheet and their densities in different regions. They are known to occur in marine environments around Iceland (*e.g.* Helland and Holmes 1997). In the study area dropstones are present in the region off SW Iceland and the spurs of the Reykjanes Ridge, at the Greenlandic side of the Denmark Strait, in deep Denmark Strait, and in the Iceland Sea close to the shelf (Figs 4–5, 8, 9–10). When present, these dropstones often hold a diverse fauna of epizootic organisms (*e.g.* Schulz *et al*. 2010; Hasemann *et al*. 2013). The slopes of this region are known to harbour diverse assemblages of sponges (Klitgaard and Tendal 2004). A rich and diverse epifauna on dropstones has been observed also in our study (in particular Figs 4–5, 8, 10).

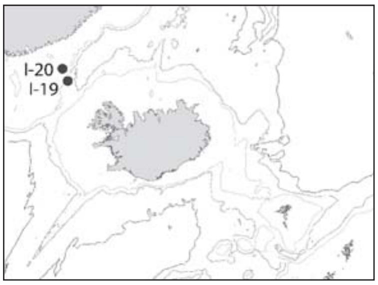
Virtually all oceanic sediments are polygenetic and agents of sediment transportation and deposition exert a significant influence over the nature of the resultant sedimentary deposit (Davies and Laughton 2007). An important sediment transport mechanism is certainly transport of suspended sediments by currents, *e.g.* turbidity currents, deep-ocean and bottom currents, or surface currents, the latter also controlling ice-rafted sediments and the input of fine terrigenous sediments distributed by the wind (Davies and Laughton 2007). High current velocities preclude sedimentation of fine particles but are able to carry coarse sediments. The deposition and accumulation of organic matter also depends on the currents. In regions with strong currents little organic matter is deposited; if currents are weak much is laid down (Trask 1939). Accordingly the organic content of the sediment is closely related to the submarine topography: it is relatively small on ridges, which are exposed to currents, and considerable in protected basins (Trask 1939). The sediment distribution pattern found in the study area is in good agreement with these generalized observations (Fig. 2). Some areas, *i.e.* the Iceland Basin (Fig. 3), the Irminger Basin (Fig. 6), the deep, northern Denmark Strait (Fig. 9), and the deep Norwegian and Iceland Seas (Fig. 11), are apparently sites with considerable sedimentation of fine sediments. These deep-water sites have generally sandy mud and intermediate to high organic matter contents (Fig. 2, Table 2). They typically have a sparse or patchy megabenthos, but in places holothurians can be very abundant (*i.e.* the elasipodid *Kolga hyalina* Danielssen *et* Koren, 1879, north of the GIF Ridge) (Fig. 11). Holothurians have elsewhere been reported as a dominant element of the megabenthos (Billett and Hansen 1982; Gutt and Piepenburg 1991 and references therein). The observation of dense aggregations of holothurians has been related to *e.g.* temporal accumulations of organic matter (Billett and Hansen 1982) and deep-sea holothurians have been generally observed in areas with favourable food conditions (*e.g.* Hansen 1975; Cross 2009; Clary 2013). The latter can be supported by our observations, that high densities of holothurians were observed in deep waters of the Iceland and Norwegian Seas where highest values of total organic content were recorded (see Table 2, Fig. 11).

Denmark Strait, Greenland shelf

granulometry
I-19 (#1116), I-20 (#1129)

video / photo:
I-19 (#1119), I-20 (#1136)

water depth: 316–705 m

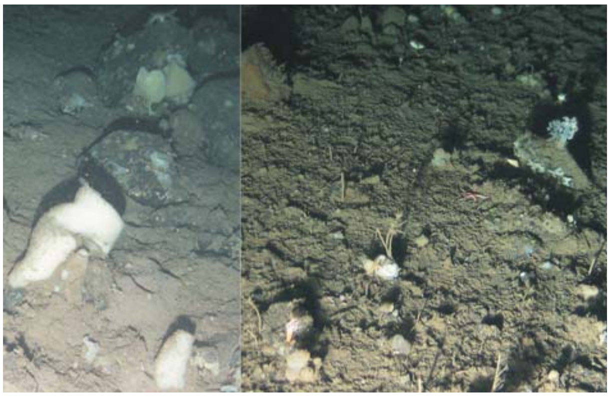


hydrography

The East Greenland shelf and slope is mainly bathed by cold water (i.e. Polar Water, DSOW; sub-zero to a few degrees above zero) originating from the north, carried with the East Greenland Current (EGC). Approximately 450 km north of the Denmark Strait the EGC separates into two branches, one being the shelf break EGC, while the deeper one flows along the NIJ and jointly forms the plume of the Denmark Strait Overflow Water (DSOW). Accordingly, approximately 70% of the DSOW flows along the Icelandic continental slope towards the sill.

visual description

- uppermost cover of fine sediment
- many stones with sessile epifauna
- sponges, crinoids, and swimming amphipods and shrimp (euphausiids)



sediments

- very poorly sorted **sandy mud with** 3.5–4.3% proportion of **gravel**
- total organic carbon content 2.4–3.6%

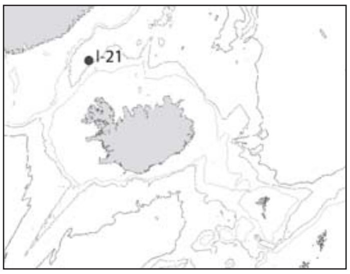
Fig. 8. Habitat descriptions for areas located on the Greenlandic shelf, western side of the Denmark Strait.

Denmark Strait, North, deep waters

granulometry
I-21 (#1142)

video / photo:
I-21 (#1148)

water depth: approx. 1240 m



hydrography

This region holds a fairly complex system of currents, with the separated East Greenland Current (EGC) being formed by anti-cyclonic eddies that coalesce. The EGC unites with the North Iceland Jet (NIJ), and furthermore a possible wind-driven anti-cyclonic recirculation may occur north of the sill. Accordingly, the sampling sites may have northeasterly flowing currents, but cold waters.

visual description

- some stones on soft muddy sediment
- diverse macrofauna detectable: sponges, *Umbellula encrinus* Linnaeus, 1758, brittle stars (*Ophiopleura borealis* Danielssen *et* Koren, 1877), polychaetes (Sabellidae), Pantopoda and other invertebrates

sediments

- very poorly sorted **sandy mud with** small proportion of **gravel** in the uppermost 3cm, lower layer of very sticky grey mud present
- total organic carbon content 4.2%

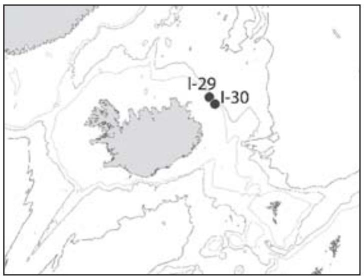
Fig. 9. Habitat descriptions for deep Denmark Strait.

Iceland Sea, close to the Icelandic shelf

granulometry
I-30 (#1217)

video / photo:
I-29 (#1212), I-30 (#1222)

water depth: approx. 1220 m



hydrography

Generally, at intermediate waters off the Icelandic slope, the near -bottom waters are characterized by a low temperature and a low salinity. The water masses Modified East Icelandic Water (MEIW) and Norwegian Sea Arctic Intermediate Water (NSAIW) characterize shallow and intermediate waters and in still deeper waters the Norwegian Sea Deep Water (NSDW) occurs. The North Icelandic Irminger Current (NIIC) flows clockwise in shallower waters, while in deeper waters the North Icelandic Jet (NIJ) flows towards the west.

visual description

- diverse and abundant macrofauna
- area I-29 with many stones on top of soft sediment
- area I-30 with soft sediment and high abundance of soft corals
- abundant macrofauna swimming above seafloor (e.g. euphausiids, chaetognaths)

sediments

- very poorly sorted **muddy sand** with small proportion of **gravel**
- total organic carbon content 3.8%

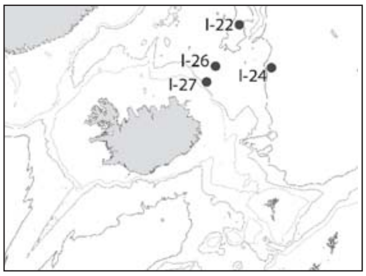
Fig. 10. Habitat descriptions for areas in the Iceland Sea.

Iceland and Norwegian Seas, deep waters

granulometry
I-22 (#1153), I-24 (#1165), I-26 (#1179), I-27 (#1189)

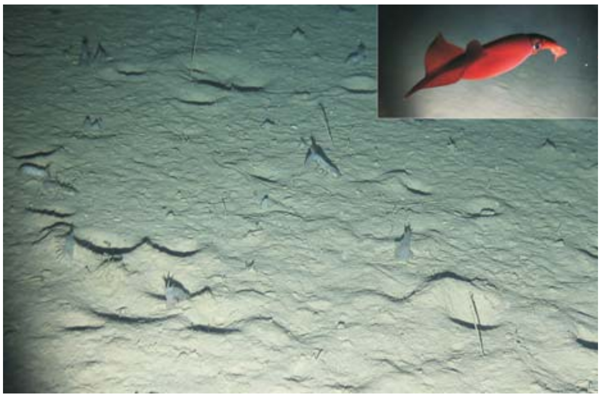
video / photo:
I-22 (#1159), I-27 (#1194)

water depth: approx. 1579–2402 m



hydrography
These deep waters are characterized by temperatures below 0°C and low-saline (S<34.9) waters, with the Norwegian Sea Deep Water (NSDW) as the coldest and deepest occurring water mass.

visual description
- soft sediment, no stones
- area I-22 with many holothurians (*Kolga hyalina*), also polychaete tubes (Sabellidae), Cnidaria (actinia), shrimp (euphausiids), burrows
- area I-27 with squid, shrimp (euphausiids), some polychaete tubes



sediments
- very poorly sorted **sandy mud**, slightly gravelly in area I-27 and area I-22
- area I-24 and I-26 with many Foraminifera
- total organic carbon content 6.7–9.3%

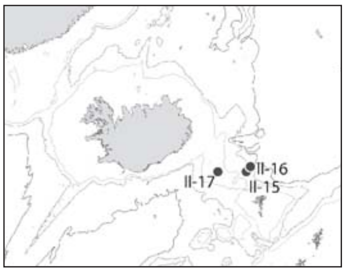
Fig. 11. Habitat descriptions for deep areas of the Iceland and Norwegian Seas.

Iceland-Faroe Ridge

granulometry
II-15 (#880), II-16 (#881), II-17 (#882)

video / photo:
–

water depth: 440–1080 m



hydrography

The Iceland-Faroe Ridge is fairly shallow, with maximum sill depth of 480 m and most of the ridge has sill depths between 300 and 480 m. The southern side of the ridge is bathed with MNAW, while Atlantic water also occurs to the west and north of the Faroes. Deep off the northern side of the ridge colder water masses occur. The deeper channels of the Iceland-Faroe ridge have intermittent overflow of NSAIW and NSDW. One branch of the North Atlantic Current (NAC) crosses the ridge and becomes the Faroe Current (FC), while branch of the FC separates and becomes the Shetland Current (SC).

sediments

- very poorly sorted **muddy sand** with a very small proportion of gravel (II-15), and **sandy mud** (II-16, 17) partially with minor portion of gravel (II-17)
- all with clay in deeper layers
- sediment of area II-17 of black colour
- total organic carbon content low with 1.07–1.76%

Fig. 12. Habitat descriptions for areas located on the Iceland-Faroe Ridge.

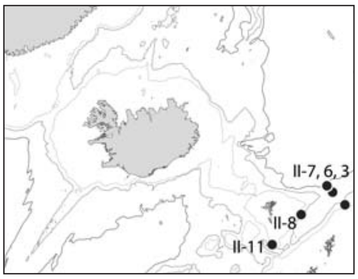
Other sites are strongly influenced by currents, as known from the literature and also reflected by the sediment characteristics documented in this study (predomination of sand and presence of considerable proportions of gravel in the sediments, low total organic matter contents, Fig. 2). For example, the Faroe-Shetland Channel (Fig. 13) is shaped by very strong persistent bottom currents, which have been reported to reach and also exceed current velocities of 1 ms^{-1} (Hansen and Østerhus 2000; Masson *et al.* 2004). Deep cold water flowing from the Norwegian

Faroe-Shetland Channel

granulometry
II-3 (#866), II-6 (#871), II-7 (#872), II-8 (#873), II-11 (#876)

video / photo:
–

water depth: 534–1842 m



hydrography

The Faroe-Shetland Channel and its continuation towards west, i.e. the Faroe Bank channel, are the deepest connection between the GIN Seas and the northernmost North Atlantic, with a saddle depths of 840 m. Below 600 m in the Faroe-Shetland Channel the temperatures are cold (<3°C) and the waters are characterized by salinity tending towards the characteristic 34.91– 34.92 salinity of the NSDW. The Faroe-Shetland Channel holds strong currents with average velocities exceeding 1 m/s in about 100 m thick layer some 100 m above the bottom.

sediments

- extremely poorly sorted **muddy sandy gravel** (II-3), very poorly sorted **sandy mud** (II-6, 7), sandy mud (II-6, 7) with a small proportion of gravel (II-8), and very poorly sorted **muddy sand** with small portion of gravel (II-11)
- area II-3, 6, and 8 with clay in deeper layers
- area II-7 with many Foraminifera
- total organic carbon content low 0.97–1.84%

Fig. 13. Habitat descriptions for areas located in the Faroe-Shetland Channel.

Sea into the main North Atlantic basin passes through the Faroe-Shetland Channel capable of eroding and transporting sediment up, including gravel (Masson *et al.* 2004). Strongest currents have been associated with south-west transport of Norwegian Sea Deep Water at water depths of 800–1200 m (Masson *et al.* 2004). Based on sidescan sonar images, seismic profiles, seabed photographs and sediment cores a large variety of sedimentary bed forms has been identified by Masson *et al.* (2004) in the southern part of the Faroe-Shetland Channel and is also well reflected by the different types of sediments identified in the larger region by our analyses (Fig. 2).

However, other information reported in the literature is not in accordance with our results. Doyle and Garrels (1985) stated that low total organic carbon and low organic carbon accumulation is grouped with deep-sea sediments. Near shore sediments usually have an on average higher organic content than open ocean sediments (1 to 8% opposed to 0.3 to 1.5%) (Trask 1939; Levin and Gage 1998; Levin and Gooday 2003). In contrast the organic matter content in sediments from the study area was highest in the deep-sea basins (Iceland Basin, area I-11 in the Irminger Basin, deep areas of the Norwegian Sea) with values between 4.7 to 9.3% (Fig. 2, Table 2). Organic matter contents at shelf stations along the Denmark Strait and off NE Iceland were considerably lower with 2.4 to 3.8% (areas I-30, I-16, I-17, I-19, I-20). In near-shelf and slope regions off SW Iceland, in vicinity of the Reykjanes Ridge (areas I-9, I-10, I-13, I-15) values were comparatively high and ranged between 3.3 and 7.2%. Lowest organic matter contents altogether of 1.0 to 1.8% were found at stations along the Iceland-Faroe Ridge and the Faroe-Shetland Channel. Hence it can be concluded that the distribution pattern of organic matter in the study area does not follow the general pattern of low organic matter contents in deep-sea and open ocean sediments and higher near shore or shelf sediments, but rather mirrors the complex topography and in particular the current regime around Iceland, the lowest levels being reported in the high current regions. The character of the organic substances in surface sediments is affected by different factors, most importantly by the oxygen content of bottom waters, the biological productivity of overlying water, and the extent of diagenesis in sediments (Meyers *et al.* 2007). Levin and Gage (1998) observed significant negative correlations between sediment organic-carbon content and bottom-water oxygen in three different data sets from the North Atlantic, eastern Pacific and Indian Oceans. Most surface sediments in the northern North Atlantic are well oxygenated and oxidative carbon remineralisation is the dominant process (Ritzrau *et al.* 2001). Noji *et al.* (2001) found that sequestration of biogenic carbon in the Greenland Sea is constrained by the depth of the winter mixed layer and the bulk of carbon fixed by photosynthesis into organic compounds in the surface waters is retained in the upper few hundred meters of the water column. Most of the organic material produced in the euphotic zone is consumed, respired and remineralized within the upper 200 m. Only approximately 1.2% of the primary production in the northern North Atlantic reaches the seafloor (Schlüter *et al.* 2001). Our measurements of the total organic content by loss of ignition are a rather rough measure and do not allow any statement about the nature and sources of organic matter in the surface sediments studied. A plausible explanation is that this is a mixture of an influx of organic matter from the surrounding shelves and an influx carried with the warm waters from the south (North Atlantic Current, Irminger Current).

Summary

The present paper provides descriptions of habitats sampled during the IceAGE1 and IceAGE2 expeditions, with focus on surface sediment characteristics and visual assessments. Since recent information on surface sediment characteristics in Icelandic waters is very sparse and limited to small-scale assessments, it supplies new background information for studies based on IceAGE material, especially studies related to ecology and taxonomy. Results from visual inspections (including photos) are presented for the first time for some large regions of Icelandic waters. Visual inspections proved to be a valuable addition to the study of habitat characteristics since only they allowed the observation of dropstones and attached fauna, which may not have been revealed with classical sampling equipment. The benthic habitats around Iceland are characterized by sandy and gravel bottoms in shallow waters and on the ridges, but muddy, high organic bottoms in deeper waters. The deeper bottoms may have dense aggregations of mobile megabenthos, particularly in organic matter-rich regions. Dropstones in a muddy or sandy environment were observed to provide a substrate for various diverse sessile epifauna. The complex topography and current regime in this region accounts for the great variety of habitats and will certainly be reflected in both the faunal composition and distribution in future studies based on IceAGE material.

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