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Shoreline dynamics of Calypsostranda (NW Wedel Jarlsberg Land, Svalbard) during the last century

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Abstract: A 6 km long stretch of the coast of Calypsostranda between Skilvika and Josephbukta, situated on the western side of Recherchefjorden, was investigated. It is made of an accumulative marine terrace at a height of 2–8 m a.s.l. (terrace 1) and width of 40–180 m, divided by a cliffed section in the frontal moraines of Renardbreen. From the character and intensity of changes, the area was divided into 6 zones. The aim was to analyse the dynamics of changes within coastal zone from 1936 to 2007 and to characterise the influence of various morphogenetic factors (marine, fluvial, cryospheric). The important element of this study has been to determine sources and directions of sediment transport. The dynamics of changes of coastal zone in the Calypsostranda region was established from archival maps and precise GPS measurements for the periods: 1936–1960, 1960–1990, 1990–2000, 2000–2005, 2005–2006, 2006–2007. Comparing the extension of shoreline between 1936 and 2007 showed that there was more erosion than accumulation. Nearly 110 000 m^2 of the area of terrace 1 decreased, whereas about 77 000 m^2 appeared. The net balance for 1936–2007 was about -32 700 m^2, on average over the whole length of the shoreline, it retreated by 5.7 m (0.08 m a^{-1}). The cease of sediment delivery in the extramarginal sandur fans area of Renardbreen caused intensification of marine processes, that made the shoreline retreat by over 100 m. Continuing sediment delivery from the Scottelva catchment, with contribution of material from erosion of the north end of the shoreline studies, caused the aggradation of coastal zone by over 60 m near its mouth.

Key words: Arctic, Spitsbergen, coastal zone, shoreline changes, sediment supply.

Introduction

The coastal zone is characterised by processes that operate at short *i.e.* daily, weekly and annual, and long frequencies of tens and hundreds of years. Monitoring these processes requires characterisation of interactions between various factors, which overlap and may strengthen or weaken their individual influence.

Changes, that take place in the Arctic coastal zone, are the function of environmental factors, often of local origin, such as atmosphere, cryosphere, hydrosphere and lithosphere.

Research on the evolution and dynamic of the Arctic coastal zone has a long tradition with distinct approaches used for particular morphoclimatic zones (Davies 1964, 1980; King 1972; Smith and Zarillo 1990; Furmańczyk and Musielak 2002; Brown *et al.* 2003; Lestak *et al.* 2003; Manson *et al.* 2005; Wangensteen *et al.* 2007; Zarillo *et al.* 2008; Włodzinowski 2009). Recently, the majority of the studies, especially on Arctic coasts, are conducted as part of the "Arctic Coastal Dynamics" ACD/IASC/IPA programme *e.g.* ACD Rapport (2005). In the NW part of Wedel Jarlsberg Land, research on modelling of the coastal zone began during the 1st Polar Expedition of Maria Curie-Skłodowska University to Spitsbergen in 1986. In the following years, the development, dynamics and types of shore observed in southern Bellsund was described in detail (Harasimiuk 1987; Harasimiuk and Jezierski 1991; Harasimiuk and Król 1992; Jezierski 1992). Further studies of contemporary development of the littoral zone were undertaken in 1995 with a particular focus on the importance of shore ice (Zagórski 1996, 2004). The significance of archaeological sites was stressed as means to estimate littoral zone changes in historic times (Jasinski and Zagórski 1996; Jasinski *et al.* 1997). Further studies in the summer seasons of 1998, 1999, 2000, 2005, 2006 and 2007 concentrated on measuring shoreline aggradation (accretion) and erosion (recession) rates, and coastal zone dynamics, using GPS measurements, with consideration of the role of polygenetic shore ice (Zagórski 2004, 2007a; Rodzik and Zagórski 2009).

The aim of this study is to analyse the dynamics of the coastal zone in the 20th and at the beginning of the 21st century, and to characterise the influence of various morphogenetic factors, *e.g.* marine, fluvial, cryospheric, on these changes. Marine processes, *e.g.* waves and longshore drift, must be considered the most important in leading to shore and underwater slope erosion and modification and accumulation of material in storm ridges zone. These processes are increased or weakened by land processes of varied origin: fluvial, glacial, mass movement. An important element of this study is to determine sources and directions of transport of sediment, delivered to the coastal zone.

Study area

The study area is a 6 km stretch of coast at Calypsostranda (Calypso Plain), situated between Skilvika (Skil Bay) and Josephbukta (Joseph Bay) on the western side of Recherchefjorden (Recherche Fiord), Spitsbergen (Figs 1, 2). It comprises an beach ridge terrace with a height of 2–8 m a.s.l. (terrace 1). In the northern and central part it adjoins to relic cliff of Calypsostranda (Fig. 3A), while in the south it

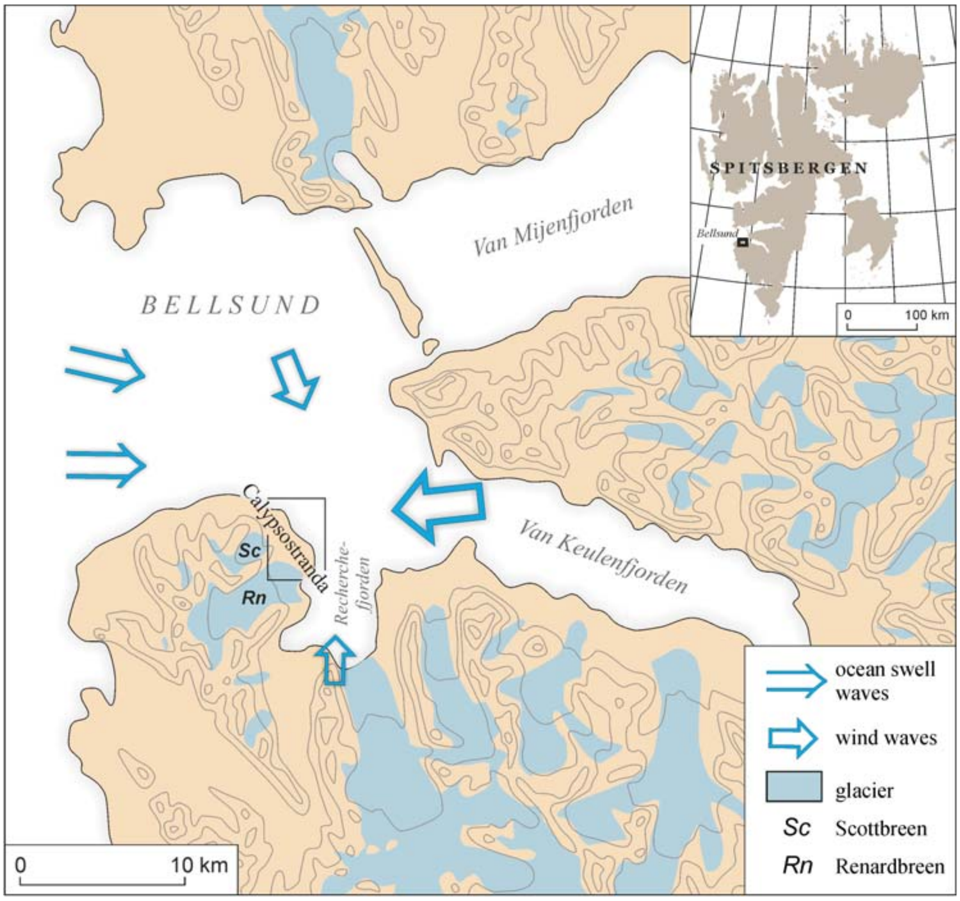

Fig. 1. Location of the study area. Directions of waves reaching the coast of Calypsostranda. See Fig. 2 for enlargement of the inset.

has aggraded with extra-marginal sandur fans from Renardbreen (Renard Glacier). Marine formations and fossil flora are found under the frontal moraines of Renardbreen that mark its maximum extent in Little Ice Age (LIA) (Dzierżek *et al.* 1990a, b; Pękala and Repelewska-Pękalowa 1990) (Fig. 3B). The study area was divided into a series of zones and subzones for description (Fig. 2):

1. Skilvika – alluvial fan of Scottelva (Scott River), 1000 m in length, comprising a few fossil storm ridges (Figs 2, 4A). On their surface, numerous archaeological sites date from the 17th and 19th centuries (Jasinski 1994; Krawczyk and Reder 1989; Jasinski and Starkov 1993; Krawczyk 1993; Jasinski and Zavyalov 1995; Zagórski 2007b):

1a. Skilvika-Renardodden (Renard Cap, western part), facing north, 450 m in length. Storm ridges are largely destroyed and cling to shoreline almost perpendicularly;

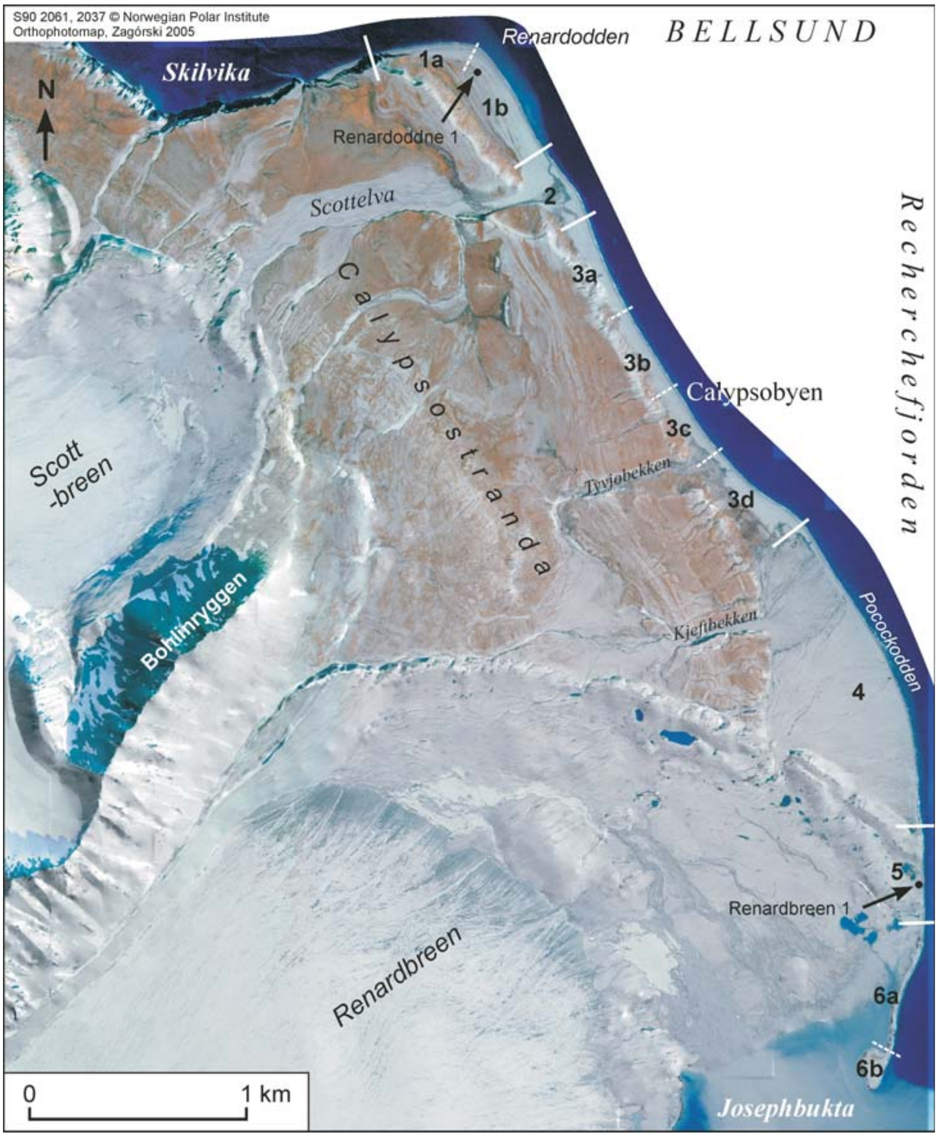

Fig. 2. Location of separated zones and subzones of study coast with location of two archaeological sites Renardodden 1 and Renardbreen 1.

1b. Renardodden (eastern part), an alluvial fan of the Scottelva, facing ENE, 550 m in length.

2. Alluvial fan of the Scottelva, facing ENE, 350 m in length. It was deposited in a gorge outlet through an emerged marine terrace system (Fig. 4B). On the surface of the fan, a braided river discharges to the fiord with one or two mouths, that cut a gravel storm ridge a few metres wide (Harasimiuk and Król 1992; Superson and Zagórski 2007).

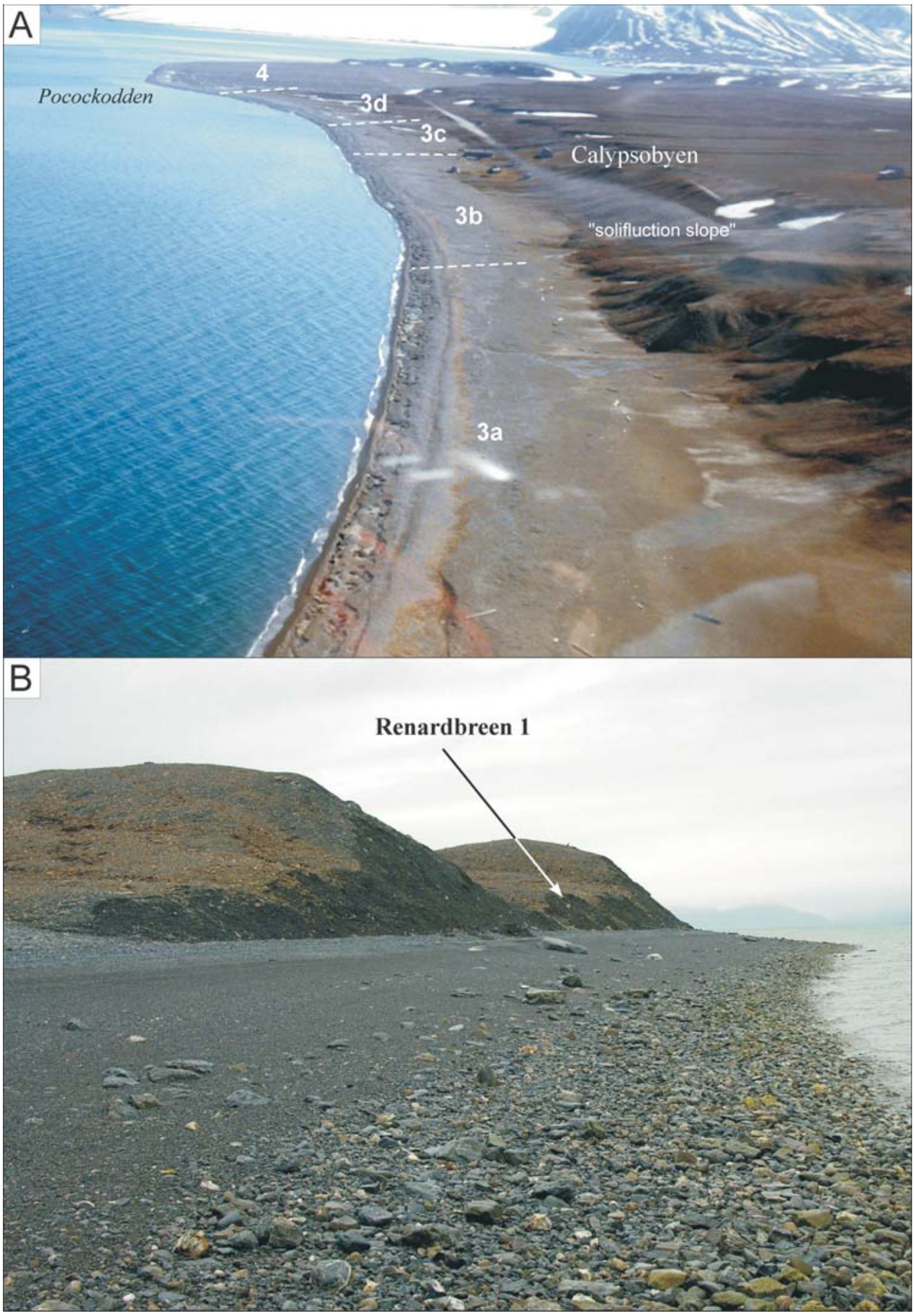

Fig 3. **A**. Terrace 1 near Calypsobyen (zone 3) (Photo by P. Zagórski, 1998). **B**. Active cliff developed on frontal moraine of Renardbreen (zone 5) and location of archaeological side Renardbreen 1 (Photo by P. Zagórski, 2007).

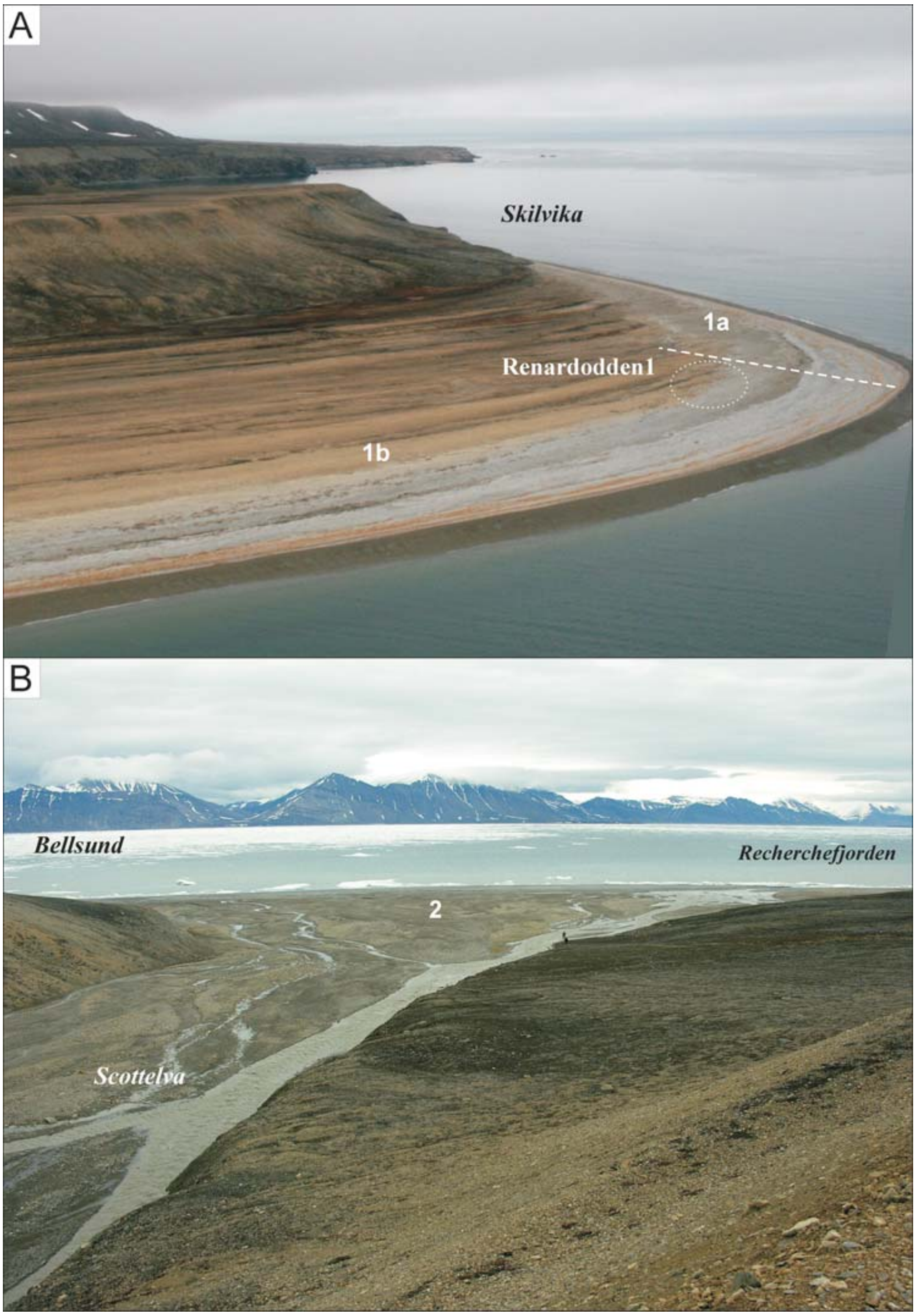

Fig. 4. **A**. Terrace 1 in Renardodden region (zone 1) and location of archaeological side Renardodden 1 (Photo by J. Jania, 2008). **B**. Mouth of Scottelva (zone 2) – alluvial fan (Photo by P. Zagórski, 2006).

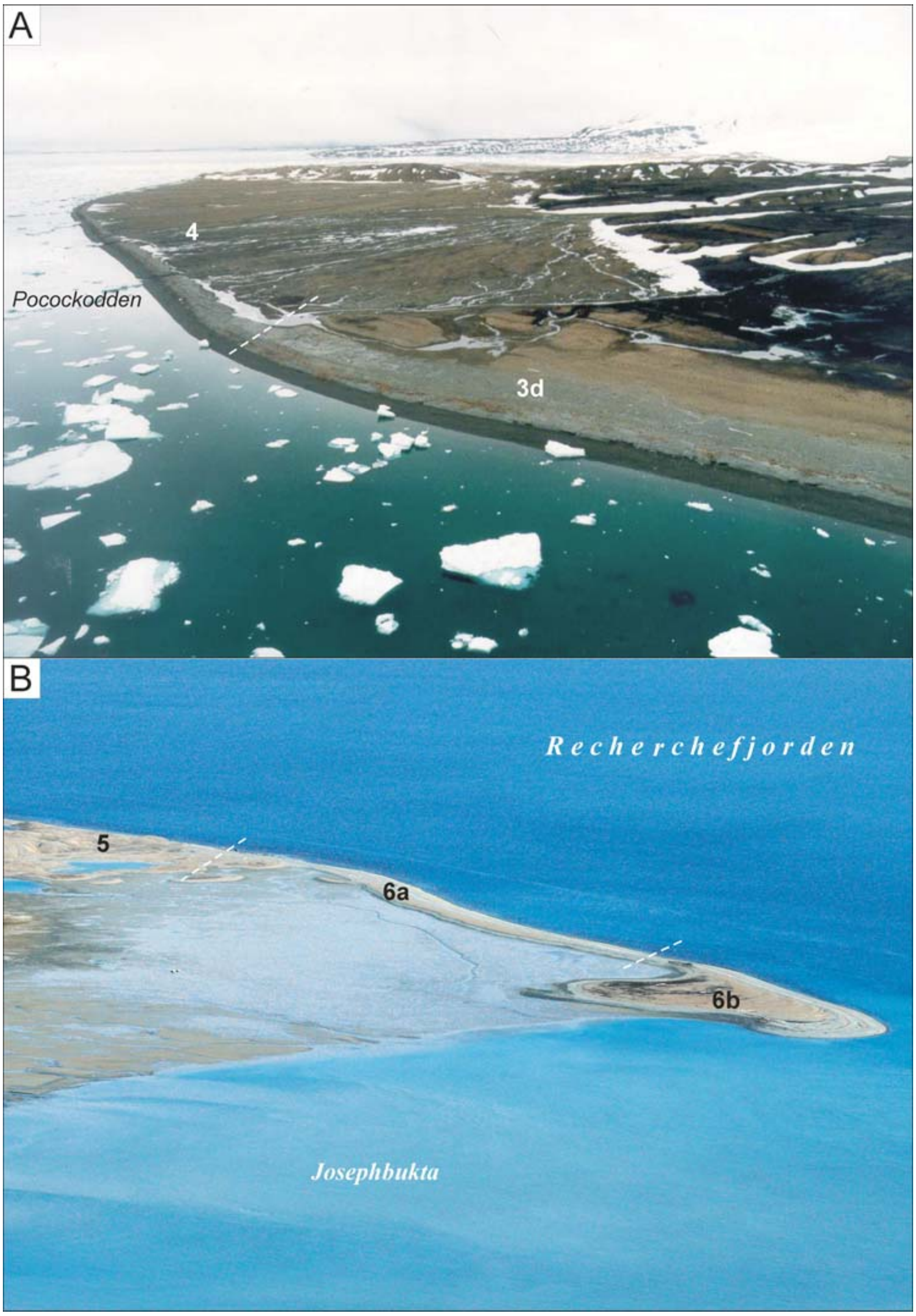

Fig. 5. **A**. Extra-marginal sandur fans of Renardbreen near Pocockodden (zone 4) (Photo by K. Pękala, 1992). **B**. The spit in Josephbukta (zone 6) (Photo by J. Jania, 2008).

3. Alluvial fan of Scottelva-Pocockodden (Pocock Cap, extra-marginal sandur fans of Renardbreen), facing ENE, 1850 m in length (Fig. 3A). Terrace 1 consists of two storm ridges. The outermost is a gravel-sandy active storm ridge, and the inner clings to the edge of fossil cliff, partially covered by alluvial fans and solifluction debris (Harasimiuk and Jezierski 1991; Zagórski 2004).

4. Extra-marginal sandur fans of Renardbreen, facing east, 1450 m in length, related to proglacial waters outflow during the LIA maximum, currently inactive but rapidly eroding (Zagórski 2007a) (Fig. 5A).

5. Cliff zone formed by erosion of the frontal moraine of Renardbreen of various ages (Pękala and Repelewska-Pękalowa 1990; Zagórski *et al.* 2007), 500 m in length (Fig. 3B).

6. Spit (Josephbukta), exposure ESE, 750 m in length (Fig. 5B):

6a. Spit arm, 550 m in length, incorporating preserved fragments of ground moraine;

6b. End of spit, 200 m in length, extending zone with well developed storm ridges, formed after recession of Renardbreen in the first half of the 20th century.

Methods and data

The 20th century development of the coastal zone in the Calypsostranda region was reconstructed on the base of archival maps and precise GPS measurements for the following years:

1936, based on the Norwegian archival topographical map at 1:100 000 scale (B11 Van Keulenfjorden 1952);

1960, Norwegian vertical aerial photos: S60 7399 and 7400, made available by the University of Silesia;

1990, the orthophotomap (Zagórski 2005), based on vertical aerial photographs in original resolution of 1270 dpi rendered by the Norwegian Polar Institute;

2000, 2005, 2006, 2007, precise measurements using GPS receivers Ashtech and Leica.

It is thus possible to discuss recent short-term changes, as well as medium-term changes since 1936. The biggest error in these data occurred with regard to the 1936 topographical map (B11 Van Keulenfjorden 1952). The map calibration to unit UTM33 suggests a precision of ±5–7 m for known tie points. An important source used during that work was vertical air photos (S60 7399 and 7400), taken on 15th August 1960. The flight was done during the third lunar quarter and at a time of minimal tides (moon quarters according to online http://stardate.org). The error of evaluation of high water position was about ±5 m.

More precise data are provided by the 1990 orthophotomap, which has an error range of ±1–2 m (Zagórski 2005). The air photos used in this study were taken on

22nd July 1990: S90 2037 (10:12 am) and 2061 (10:35 am) during new moon, so when spring tides were high and the tide was out.

GPS receivers Ashtech and Leica have been used since 2000 and in 2005, 2006 and 2007 in studies monitoring shoreline changes in the Calypsostranda region. Measurements were performed using mainly differential methods (DGPS, post-processing, accuracy was about 0.005–0.01 m). The observation data were calculated in relation to the reference station point in Calypsobyen (CALY point), which were corrected to the permanent station IGS on Spitsbergen (ITRF 2000). A series of point data were recorded in the UTM projection, zone 33 on the ellipsoid WGS 84, throughout this region.

The main aim of measurements with GPS receivers was to record the shoreline during high water, usually marked by an ephemeral gravel ridge and to determine the tidal range especially in periods of maximal spring tides. Dates of measurements are listed in Table 1. In the region of south Bellsund, there are regularly 12-hour moon tides of M_2 with maximum spring tidal range (H_P) of 1.88 m. Basing on those measurements, the geoid undulation (Δh = 33.45 m) was determined and assumed for all the calculations.

Table 1

Dates of GPS measurements used in this study

Year	Measurement date	Moon phase	Tide
2000	15th August	Full Moon	Spring
2005	5th August	New Moon	Spring
2006	9th August	Full Moon	Spring
2007	12th August	New Moon	Spring

An important element of the study was comparison and data analysis with Geographic Information System (GIS) programs ArcInfo and ArcView. In order to study the speed of shoreline changes in certain time periods, the same method as Brown *et al.* (2003) was used. The study area was divided into 114 sections ($n = 1, \ldots, 114$) 50 m wide, and then for each section the area balance (P_n) was calculated, in relation to shoreline extent in each measurement period (L1, L2) (Fig. 6A):

$$P_n = P_na - P_nb$$

where: P_na – increase of area in certain period, P_nb – decrease of area in certain period; all in m².

The next stage of the study was to divide P_n value by 50 to give shoreline advance or recession (D_n) for each section in the measurement period. Using this method, total surface area increase or decrease was calculated for sections and subsections. Using maximal values of spring tides (H_p = 1.88 m), it was then possible to calculate the approximate volume of sediment accumulated or removed. These values are considerably understated because they do not consider the off-

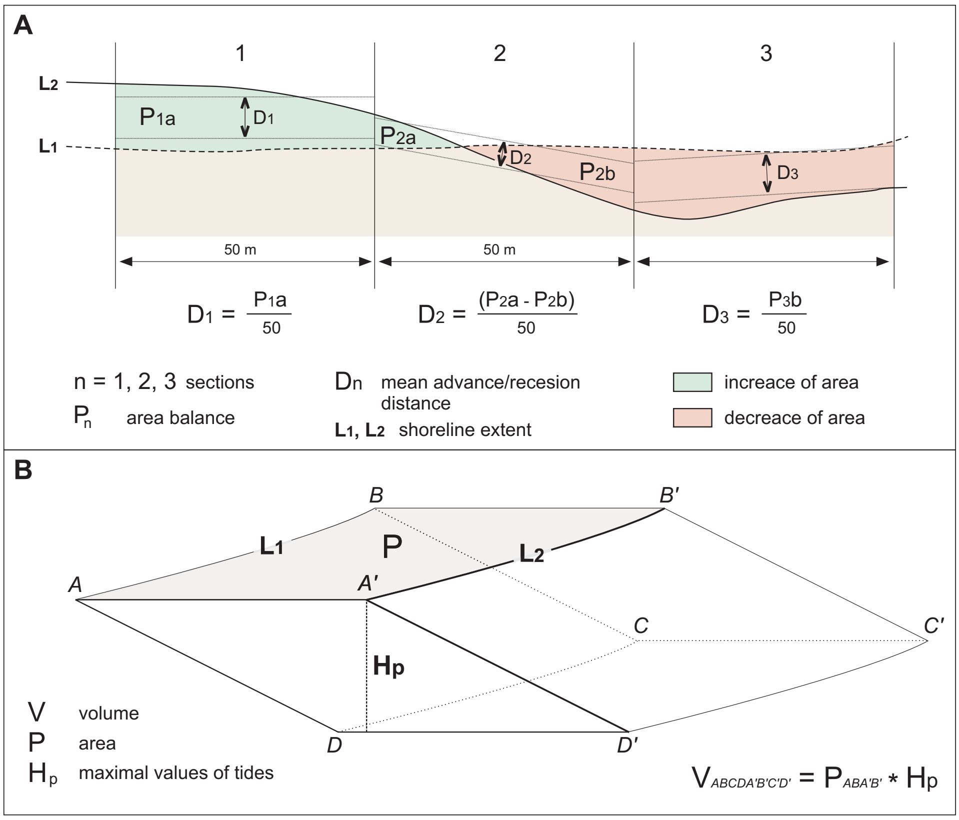

Fig. 6. Calculation schemes. **A**. The value of changes in shoreline range. **B**. The volume of material for tidal zone. See text for more explanation.

shore zone. It was assumed that inclination of the tidal zone has not changed from its initial position (ABCD) to its final one (A'B'C'D'), see Fig. 6B. On that basis, areas of maximum and minimum change were identified and it was possible to make inferences about the importance of sources of sediment supply in certain periods.

Results

Period 1936–1960. — North of Calypsobyen, the width of terrace 1, adjacent to the inactive Calypsostranda cliff (zones 1b, 3) in 1960, was much larger than in 1936 (Fig. 7A, B). There is no doubt that in the southern part, under the direct influence of proglacial waters from Renardbreen, the shoreline was extended much further in 1936 than in 1960 (Fig. 7C). Such conditions could have persisted until the 1940s when a major phase of progradation occurred, as well as increased outflow of glacial waters resulting from climate change at that time

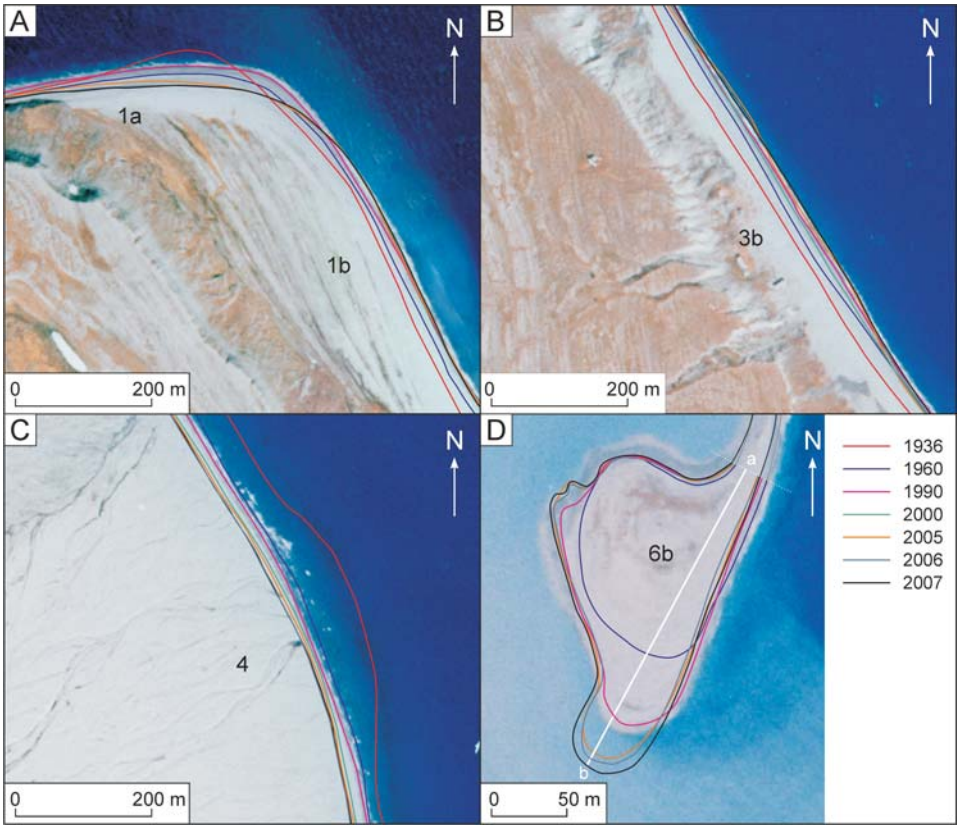

Fig. 7. Shoreline change in selected fragments of coast (background: aerial photo form 1990, orthophotomap Zagórski 2005). **A**. Renardodden region (subzones 1a and 1b). **B**. The Calypsobyen region (subzone 3b). **C**. The extra-marginal sandur fan of Renardbreen (zone 4). **D**. The tip of the spit in Josephbukta (subzone 6b), a–b long axis of the spit tip.

(Førland and Hanssen-Bauer 2003; Przybylak 2007) (Figs 8, 9A, B). This increase is clearly seen in the northern section of the study area (zones 1b, 2, 3) (Fig. 10, Table 2). The area of alluvial fan in the outlet of Scottelva increased by nearly 20% (0.06 km^2) compared to 1936. Therefore, there was a large increase in the area of terrace 1 in that part of the shore (Table 2). A totally different situation was observed south from Pocockodden. In zone 4, the shoreline retreated by up to 82 m (mean 36.5 m), at a rate of about 4–5 m per year since the 1940s (Fig. 10). The loss of area exceeded 52 000 m^2, with about 100 000 m^3 of sediment (Tables 2, 3). This large volume of material was removed or spread along the shore by longshore drift. In the Pocockodden region, the zone of divergence of two longshore drifts was localized. One heads north and the other south, where, as the result of recession of the front of Renardbreen, it was possible to contract a 750 m long spit that partly closes Josephbukta (Fig. 9B). The spit was made from material delivered mainly from extra-marginal fans (zone 4) and frag-

Table 2

Area balance and mean shoreline changes in each study period, by zone and subzone

Zone/ sub-zone	1936–1960					1960–1990				
	Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change		Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change	
				[m]	[m a^{-1}]				[m]	[m a^{-1}]
1	5 960	6 270	310	0.31	0.01	0	9 990	9 990	9.99	0.33
1a	5 960	0	-5 960	-13.24	-0.55	0	4 160	4 160	9.24	0.31
1b	0	6 270	6 270	11.40	0.48	0	5 830	5 830	10.60	0.35
2	0	12 080	12 080	34.51	1.44	0	4 650	4 650	13.29	0.44
3	4 430	26 020	21 590	11.67	0.99	0	15 240	15 240	8.24	0.27
3a	0	6 070	6 070	12.14	0.51	0	6 470	6 470	12.94	0.43
3b	0	10 890	10 890	24.20	1.01	0	5 360	5 360	11.91	0.40
3c	0	6 940	6 940	17.35	0.72	0	2 600	2 600	6.50	0.22
3d	4 430	2 120	-2 310	-4.62	-0.19	0	810	810	1.62	0.05
4	52 860	0	-52 860	-36.46	-1.52	10 600	90	-10 510	-7.25	-0.24
5	1 460	0	-1 460	-2.92	-0.12	330	1 210	880	1.76	0.06
6a	480	370	-110	-0.15	-0.01	1 220	390	-830	-1.11	-0.04
Total	65 190	44 740	-20 450	-3.59	-0.15	12 150	31 570	19 420	3.41	0.11

Zone/ subzone	1960–1990					1990–2000				
	Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change		Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change	
				[m]	[m a^{-1}]				[m]	[m a^{-1}]
1	0	9 990	9 990	9.99	0.33	8 010	2 290	-5 720	-5.72	-0.57
1a	0	4 160	4 160	9.24	0.31	6 730	0	-6 730	-14.96	-1.50
1b	0	5 830	5 830	10.60	0.35	1 280	2 290	1 010	1.84	0.18
2	0	4 650	4 650	13.29	0.44	1 430	840	-590	-1.69	-0.17
3	0	15 240	15 240	8.24	0.27	9 650	250	-9 400	-5.08	-0.51
3a	0	6 470	6 470	12.94	0.43	910	100	-810	-1.62	-0.16
3b	0	5 360	5 360	11.91	0.40	450	150	-300	-0.67	-0.07
3c	0	2 600	2 600	6.50	0.22	1 780	0	-1 780	-4.45	-0.45
3d	0	810	810	1.62	0.05	6 510	0	-6 510	-13.02	-1.30
4	10 600	90	-10 510	-7.25	-0.24	17 510	0	-17 510	-12.08	-1.21
5	330	1 210	880	1.76	0.06	2 230	0	-2 230	-4.46	-0.45
6a	1 220	390	-830	-1.11	-0.04	2 140	270	-1 870	-2.49	-0.25
Total	12 150	31 570	19 420	3.41	0.11	40 970	3 650	-37 320	-6.55	-0.65

ments of ground moraine from Renardbreen. The surface area of subzone 6b was 11 000 m^2 in 1960 (Fig. 7D, Table 4). A retreat of the shoreline in 1960, as compared with 1936, occurred in subzone 1a (Renardodden) and also in zone 5, where a cliff developed within the frontal moraines of Renardbreen (Fig. 10). Despite the accumulation in zones and subzones 1b, 2 and 3, the total area balance for 1936–1960 was negative by 20 450 m^2 (*i.e.* -854 m^{2}a^{-1}) (Table 2).

Table 2 – *continued*

Zone/ subzone	2000–2005				
	Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change [m]	Mean value of shoreline change [m a^{-1}]
1	1 910	0	-1 910	-1.91	-0.38
1a	820	0	-820	-1.82	-0.36
1b	1 090	0	-1 090	-1.98	-0.40
2	340	2 730	2 390	6.83	1.37
3	2 660	9 860	7 200	3.89	0.78
3a	2 020	1 490	-530	-1.06	-0.21
3b	140	3 120	2 980	6.62	1.32
3c	130	1 840	1 710	4.28	0.86
3d	380	3 410	3 030	6.06	1.21
4	4 900	1 530	-3 370	-2.32	-0.46
5	940	0	-940	-1.88	-0.38
6a	1 390	90	-1 300	-1.73	-0.35
Total	12 150	14 210	2 060	0.36	0.07

Zone/ subzone	2005–2006				2006–2007			
	Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change [m]	Decrease [m^2]	Increase [m^2]	Balance [m^2]	Mean value of shoreline change [m]
1	1 610	290	-1 320	-1.32	260	1 200	940	0.94
1a	1 300	30	-1 270	-2.82	250	210	-40	-0.09
1b	310	260	-50	-0.09	10	990	980	1.78
2	720	460	-260	-0.74	990	170	-820	-2.34
3	1 090	3 860	2 770	1.50	1 780	3 970	2 190	1.18
3a	390	600	210	0.42	0	2 710	2 710	5.42
3b	460	870	410	0.91	70	380	310	0.69
3c	0	840	840	2.10	30	610	580	1.45
3d	240	1 550	1 310	2.62	1 680	270	-1 410	-2.82
4	5 240	640	-4 600	-3.17	740	2 060	1 320	0.91
5	960	0	-960	-1.92	0	1 090	1 090	2.18
6a	230	460	230	0.31	0	960	960	1.28
Total	9 850	5 710	-4 140	-0.73	3 770	9 450	5 680	1.00

Period 1960–1990. — Limited archival data means that this is the longest interval analysed of 30 years. Unfortunately, this is the reason of many simplifications especially in analysing shoreline variability. Between 1960 to 1990, an expansion of surface of terrace 1 by about 20 000 m^2 (Table 2) occurred at about 660 m^{2}a^{-1}. As in the previous period, the biggest increase of the shore was seen in outlet zone of Scottelva, up to 30 m, 13.3 m on average, and in the zone 3 up to 30 m in northern but

Table 3

The volume of sediments in each study period, by zone and subzone

Zone/ subzone	1936–1960			1960–1990			1990–2000		
	Decrease [m^3]	Increase [m^3]	Balance [m^3]	Decrease [m^3]	Increase [m^3]	Balance [m^3]	Decrease [m^3]	Increase [m^3]	Balance [m^3]
1	11 200	11 800	600	0	18 800	18 800	15 100	4 300	-10 800
1a	11 200	0	-11 200	0	7 800	7 800	12 700	0	-12 700
1b	0	11 800	11 800	0	11 000	11 000	2 400	4 300	1 900
2	0	22 700	22 700	0	8 700	8 700	2 700	1 600	-1 100
3	8 300	48 900	40 600	0	28 600	28 600	18 000	500	-17 500
3a	0	11 400	11 400	0	12 200	12 200	1 700	200	-1 500
3b	0	20 500	20 500	0	10 000	10 000	800	300	-500
3c	0	13 000	13 000	0	4 900	4 900	3 300	0	-3 300
3d	8 300	4 000	-4 300	0	1 500	1 500	12 200	0	-12 200
4	99 400	0	-99 400	19 900	200	-19 700	32 900	0	-32 900
5	2 700	0	-2 700	600	2 300	1 700	4 200	0	-4 200
6a	900	700	-200	2 300	700	-1 600	4 000	500	-3 500
Total	122 500	84 100	-38 400	22 800	59 400	36 600	77 000	6 900	-70 100

Zone/ subzone	2000–2005			2005–2006			2006–2007		
	Decrease [m^3]	Increase [m^3]	Balance [m^3]	Decrease [m^3]	Increase [m^3]	Balance [m^3]	Decrease [m^3]	Increase [m^3]	Balance [m^3]
1	3 600	0	-3 600	3 000	600	-2 400	500	2 300	1 800
1a	1 500	0	-1 500	2 400	100	-2 300	500	400	-100
1b	2 000	0	-2 000	600	500	-100	0	1 900	1 900
2	600	5 100	4 500	1 400	900	-500	1 900	300	-1 600
3	4 900	18 600	13 700	2 100	7 200	5 100	3 400	7 400	4 000
3a	3 800	2 800	-1 000	700	1 100	400	0	5 100	5 100
3b	200	5 900	5 700	900	1 600	700	100	700	600
3c	200	3 500	3 300	0	1 600	1 600	100	1 100	1 000
3d	700	6 400	5 700	500	2 900	2 400	3 200	500	-2 700
4	9 200	2 900	-6 300	9 900	1 200	-8 700	1 400	3 900	2 500
5	1 800	0	-1 800	1 800	0	-1 800	0	2 000	2 000
6a	2 600	200	-2 400	400	900	500	0	1 800	1 800
Total	22 800	26 800	4 000	18 600	10 800	-7 800	7 200	17 700	10 500

up to 3 m in southern part (mean 8.2 m) (Figs 9C, 10, Table 2). Those changes can be attributed to the retreat of the Scottbreen (Scott Glacier), which in 1960–1987 receded at 6 ma^{-1} and 9.3 ma^{-1} between 1987 and 1990 (Zagórski *et al.* 2008b). A positive area balance was recorded in zones 1, 5 and 6 (Figs 7A, 10, Table 2). The surface of spit end (subzone 6b) increased by nearly 35% (Tables 4, 5). The area of sediment loss was still within the extra-marginal fans (zone 4) that decreased by 1000 m^2, although the retreat of shoreline was not so pronounced as in the period 1936–1960 with the maximum *ca* 18 m, and 7.2 m in average (Figs 7C, 9, Table 2).

Table 4

Changes of area, length of the shoreline and length of axis of spit end (zone 6b) in Josephbukta in selected years

Year	Area			Length of the shoreline			Length of spit axis (a–b)		
	$[m^2]$	Relatively to [%]		[m]	Relatively to [%]		[m]	Relatively to [%]	
		1960	previous observation		1960	previous observation		1960	previous observation
1960	11 340	–	–	399	–	–	138.8	–	–
1990	14 950	31.8	31.8	492	23.3	23.3	187.2	34.9	34.9
2005	15 910	40.3	6.4	551	38.1	12.0	214.5	54.5	14.6
2006	15 620	37.7	-1.8	556	39.3	0.9	218.1	57.1	1.7
2007	17 230	51.9	10.3	577	44.6	3.8	224.3	61.6	2.9

Table 5

Area and sediments volume balance of spit tip (zone 6b) in Josephbukta in selected periods

Period	Decrease		Increase		Balance	
	Area $[m^2]$	Volume $[m^3]$	Area $[m^2]$	Volume $[m^3]$	Area $[m^2]$	Volume $[m^3]$
1960–1990	510	970	3 720	7 000	3 210	6 030
1990–2005	550	1 040	1 520	2 850	960	1 810
2005–2006	550	1 040	260	480	-300	-560
2006–2007	0	0	1 620	3 040	1 630	3 040
1960–2007	500	940	6 400	12 030	5 890	11 080

Period 1990–2000. — Within the studied area, the shore retreated on almost its entire length by 41 000 m^2 (Table 2). As in earlier periods, as much as 47% of the loss took place in the zone of extra-marginal fans of Renardbreen (zone 4). The shoreline retreated by over 20 m at some sites within the mean of 5.5 m (Figs 7C, 10). The beach that had been deposited before, was reducted by a few metres into a storm ridge of 1.5 m width (Harasimiuk 1987). About 25% of the loss in area took place in zone 3, which had previously been expanding. North to Pocockodden, the shoreline retreated by up to 24 m, and in the area of Calypsobyen station by up to 10–15 m with the mean of 5.1 m (Zagórski 1996, 2007a) (Figs 7B, 11A, Table 2). Considerable shoreline changes took place in zone 1 too. The western part 1a, especially Renardodden, retreated by about 37 m (mean for zone 15 m), whereas in zone 1b the shoreline advanced by 5–10 m (mean 1.8 m). This was undoubtedly the result of local redistribution of material from subzone 1a. In the period analysed, the spit was upbuilt too, especially in its southern part 6b (Fig. 7D).

The main reason for such large changes in this decade was the strong storms that occurred in the Autumn of 1994. Additionally, the strong erosional influences of swell and wind waves were due to a lack of fast ice on the fiord and polygenetic

Fig. 8. The coast and extent of Renardbreen in 1936 with coastal zones indicated. Aerial photo (S36 92) taken in August 1936 by Norwegian Polar Institute; from the archives of the 3rd International Geophysical Year (Silesia University).

shore ice on the coastal zone. It is acknowledged by Rodzik's observations conducted in the Polish Polar Station in Hornsund (Rodzik and Wiktorowicz 1996). During earlier autumn periods (1991, 1992, 1993), strong storms were not noted, moreover polygenetic shore ice developed well, partially protecting the coast (Giżejewski and Rudowski 1994; Zagórski 1996; Rodzik and Zagórski 2009). Observations in the following years (1998, 1999, 2000) showed gradual reconstruction of the beach, especially in zones 2 and 3 (Zagórski 2004, 2007a). Since 1994, no such extreme storms have been seen and beach remnants were developed into gravel covers that are observed until now.

Period 2000–2005. — This period is characterised by a generally positive balance of surface area changes of terrace 1 of about 2000 m^2 (Table 2). However, more than half of the studied coastal zone lost volume. Retreat of the shoreline occurred along the whole distance of zone 1, with a maximum of 8 m and the mean of 1.9 m (Figs 7A, 11B, 12, Table 2). It was similar in the region of extra-marginal fans of Renardbreen (zone 4 and 2.3 m mean) whilst the cliffs in zone 5 also retreated with the mean of 1.9 m. The most interesting changes took place in the zones 2 and 3 between the outlet of Scottelva and Pocockodden. In both areas, the advance of the coastal zone surfaces occurred, in zone 2 by over 2700 m^2 and in zone 3 by over

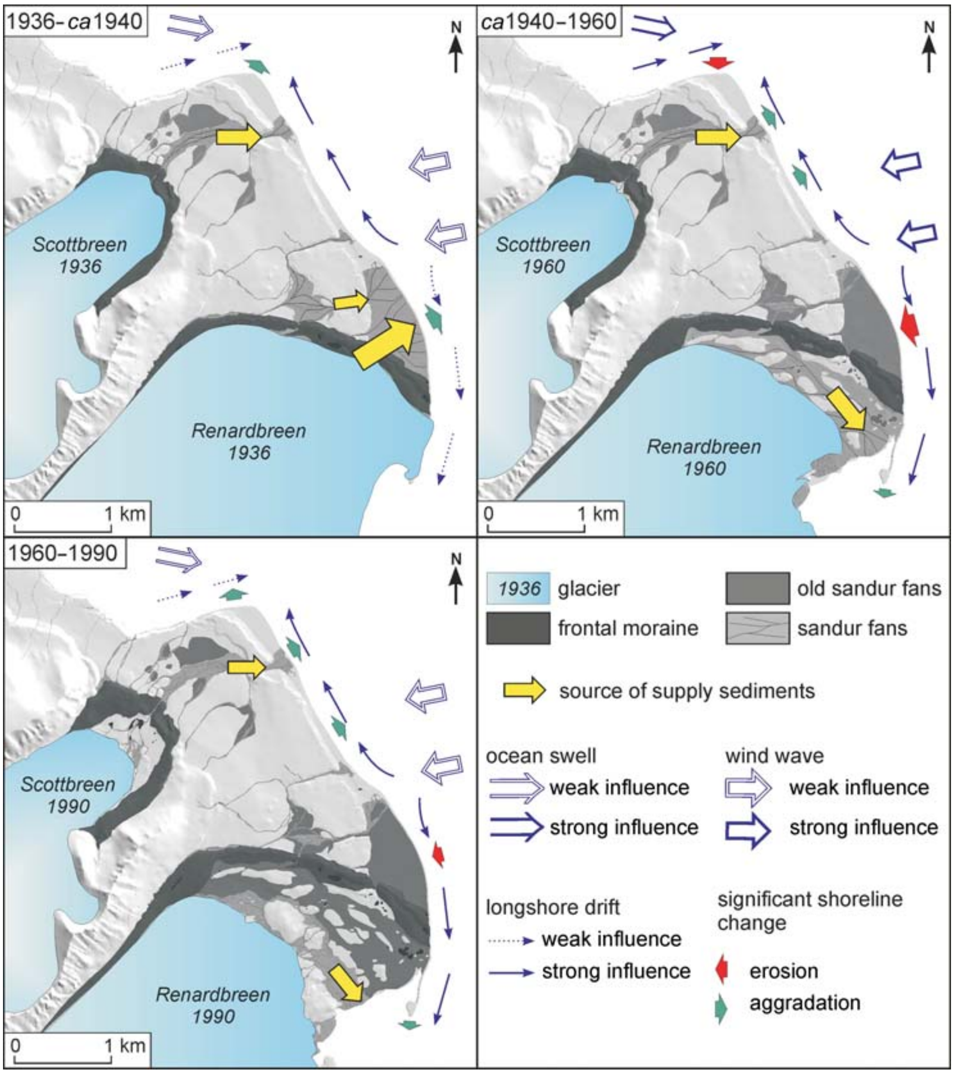

Fig. 9. The factors and processes influencing in shoreline change in selected periods. The background based on DEM made from aerial photo from 1990 (Zagórski 2002).

9800 m^2 (Table 2). But simultaneously, there were areas of erosion by 340 m^2 in zone 2 and by over 2600 m^2 in zone 3. The northern part of the outlet fan Scottelva (zone 2) was reduced by up to 8 m, while southern part expanded by storm ridge widening, by up to 15 m (Fig. 12). A similarly positive shift in shoreline was recorded in subzone 3b by up to12–16 m and in the Pocockodden region, southern part of subzone 3d, with maximum increase of 28 m (Table 2). In terrace 1 within zone 3, the shoreline propagated under the influence of two factors. The first was connected with supply of material by Scottelva (*i.e.* in 2002) and the redeposition of material, especially from zone 1 and partly from zone 2 (Fig. 11B). Because of interference

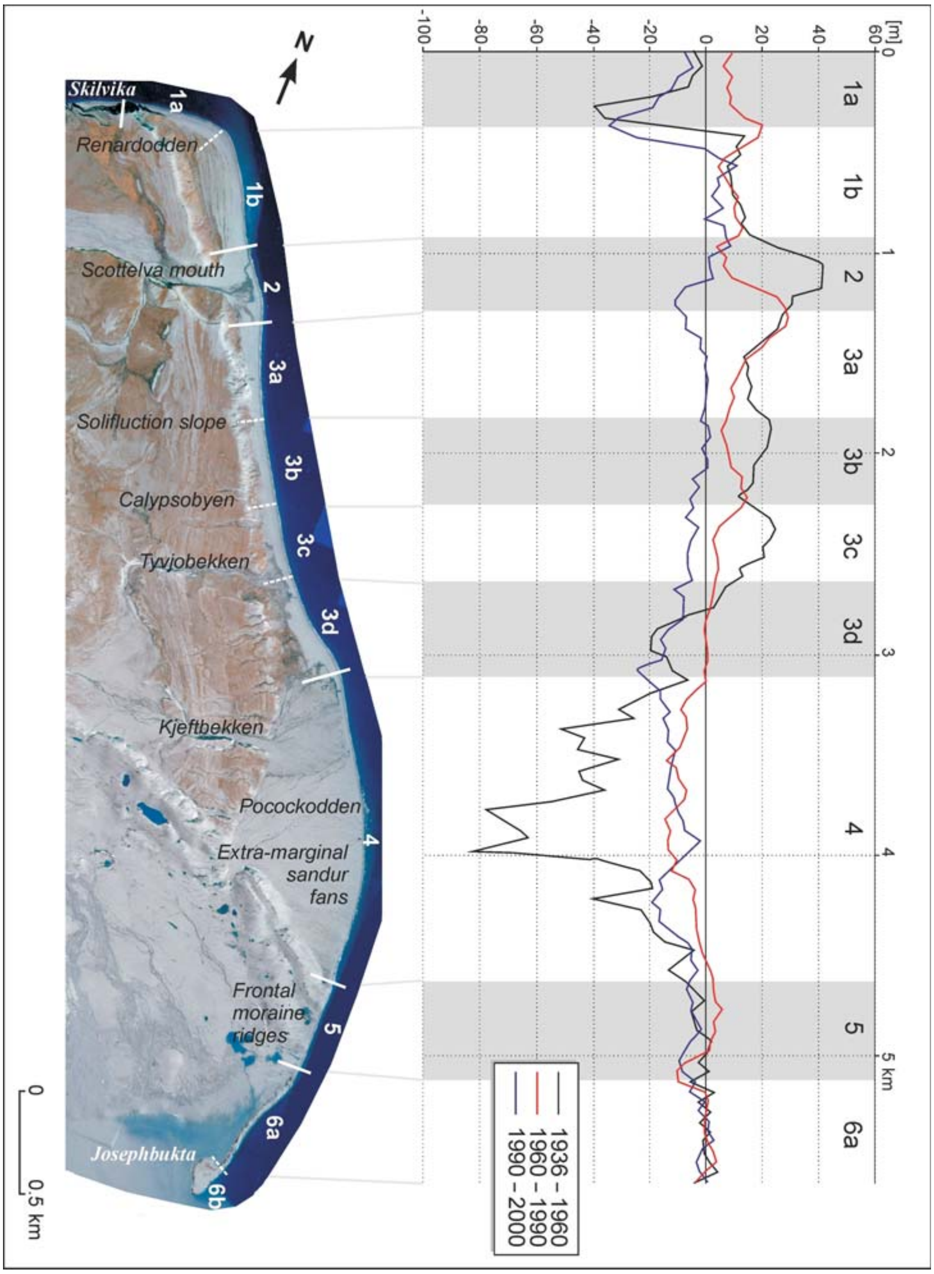

Fig. 10. Shoreline displacements in individual zones and subzones during three periods: 1936–1960, 1960–1990, 1990–2000.

waves of oceanic origin that enter Recherchefjorden from the west, sediment was spread along the coastal zone. This process was not continuous and zones of intensive deposition (subzones 2/3a, 3b, southern part of 3b) and weaker deposition or

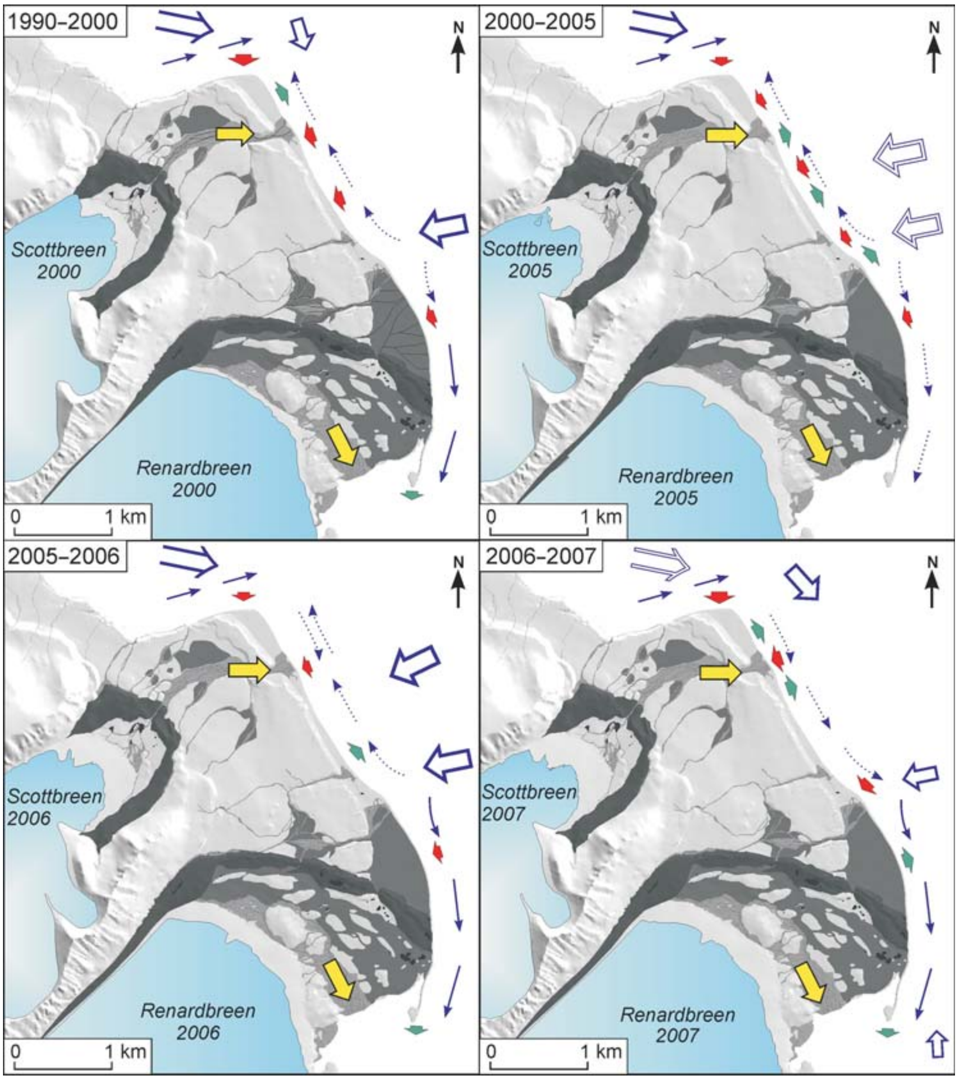

Fig. 11. The factors and processes influencing in shoreline change in selected periods. The background based on DEM made from aerial photo from 1990 (Zagórski 2002). For legend, see Fig. 9.

even erosion (subzones 3a, 3c) were distinguished. Secondly, in season 2004/2005, the polygenetic shore ice persisted until the beginning of August 2005, limiting the impact of storm waves caused mainly by winds from WNW and ENE (Fig. 13).

Period 2005–2006. — The autumn storm conditions, between the end of August and the beginning of September 2005, caused by strong winds from ENE and E (Przybylak *et al.* 2006) and a lack of polygenetic shore ice contributed to a generally negative balance of the shoreline zone (Rodzik and Zagórski 2009). Additionally, the spring-summer season of 2006 began in the middle of June with early

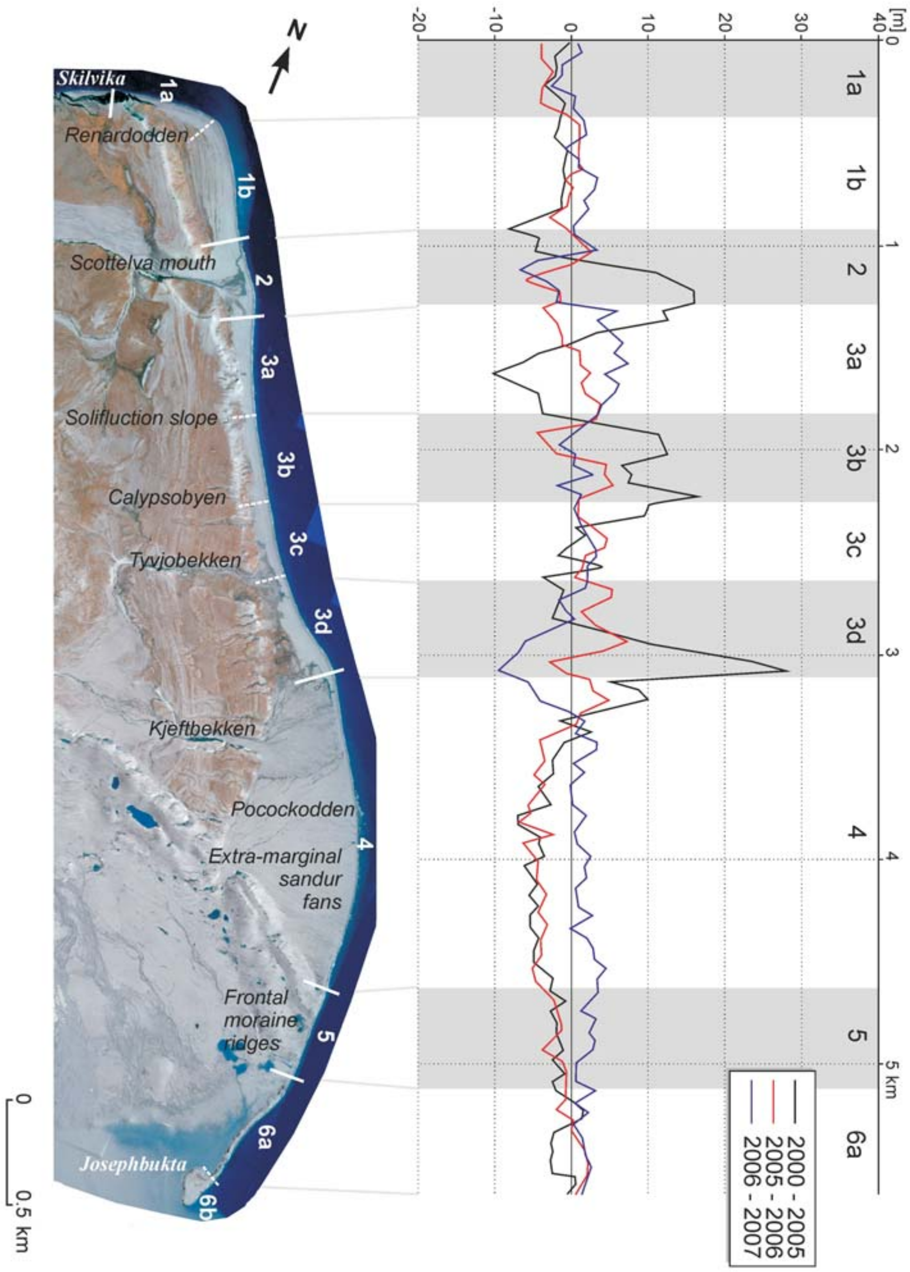

Fig. 12. Shoreline displacements in individual zones and subzones during three periods: 2000–2005, 2005–2006, 2006–2007.

snow melt and ablation of Scottbreen. About 10 000 m^2 of beach surface disappeared, with its simultaneous progradation elsewhere in the system by about 5 800 m^2. The retreat of the shoreline took place in zones 1 (mean 1.3 m), 4 (mean

Fig. 13. The polygenetic shore ice near Calypsobyen, half of July 2005 (Photo by P. Zagórski, 2007).

over 3 m) and 5 (mean nearly 2 m) (Fig. 12, Table 2). The southern part of the ridge (zone 2), limiting the alluvial fan of Scottelva, was reduced, similarly as the northern part of subzone 3a. The rest of subzone 3 propagated by 1.5 m. Some areas of erosion were seen in subzone 3b and in the Pocockodden region (subzone 3d) (Figs 11C, 12). During this period the dominant process in controlling that part of the studied shore was played by interfering waves from the west with some help from the east (Fig. 11C). Part of the sediment lost from zones 1 and 2 was moved south by longshore drift while in zone 3 the shoreline stabilised. Areas of progradation in 2000–2005 were destroyed and areas of previously negative balance were filled with beach material. The shore spit arm (zone 6a) increased its area by 230 m^2, while subzone 6b lost sediment giving a mass reduction of about 560 m^3 from the tidal zone (Figs 7D, 12, Tables 2, 4). At the same time, the spit lengthened in the axial part of subzone 6b by about 6 m (2.9%) (Table 5).

Period 2006–2007. — The weather conditions in the autumn/winter period of 2006 were relatively stable without notable storms. It allowed a comparatively early and rapid development of ice ridge on the shore and sea ice on the fiord, that obstructed sea waves approaching the shore. In the spring period (June 2007), this shore ice degraded quickly. However, its disappearance did not affect the shoreline retreat. Winds from the NW sector dominated, creating interfering waves that entered the fiord. Winds from the east sector directly influenced waves over the area north from Pocockodden, and somewhat weaker from the south sector (Fig. 11D). Such conditions caused nearly the whole length of the studied shore to prograde by 1 meter on average, equally to an area of about 5 700 m^2 of surface and 10 000 m^3 of material in the tidal zone (Tables 2, 3).

A small increase in area (940 m^2) occurred in zone 1 especially in the eastern part, subzone 1b (Table 2). However, some fragments of the coastal zone, which had developed in 2000–2005, were destroyed (Fig. 12). Shoreline "smoothing" continued in zones 2 and 3. The southern part of the ridge limiting the Scottelva alluvial fan retreated by about 5–6 m with surface loss of 820 m^2. The material of about 1900 m^3 was redeposited by west interfering waves, to the south to subzone 3a, which prograded on average by 5 m (Figs 11D, 12, Tables 2, 3). In a similar direction, terrigenous material was discharged by Scottelva, which had only one outlet, in the southern part of its alluvial fan. In subzone 3b, a small advance of 0.7 m of the coastal zone was noticed. It was much greater in subzone 3c with the mean of 1.45 m. Subzone 3d was still being reduced, by a maximum of about 10 m (mean 2.8 m) (Fig. 12, Tables 2, 3). Such big losses in that region influence zone 4, enclosing the extra-marginal sandur fans of Renardbreen. Because of longshore drift created by waves from west and north-east, for the first time since 1940s, aggradations of area of more than 2000 m^2 occurred (Fig. 11D, Table 2). The shoreline prograded by up to 3 m and 1 m mean. A similar situation took place in zones 5 (mean over 2 m) and subzone 6a (mean about 1.3 m). The end of spit (subzone 6b) lengthened in axial part by 6 m and increased in volume by 10% compared to the previous year. In 2007, that zone reached its largest area ever of over 17 200 m^2 (Fig. 7D, Tables 4, 5).

Discussion

Shoreline development before 1936 is uncertain. Existing archival materials, like maps have large inaccuracies. Indirect data are provided by archeological-geomorphological studies in the Renardodden region – site Renardodden 1 (Krawczyk and Reder 1989; Jasinski and Starkov 1993; Jasinski 1994; Jasinski and Zavyalov 1995; Jasinski and Zagórski 1996; Jasinski *et al.* 1997; Zagórski 2007b) (Fig. 2). Archaeological data reveal intensive exploitation of that area since the end of the 16th century. The nearest archaeological sites to the contemporary coastal zone are located at Renardodden 1. They are remnants of the Russian walrus hunters' station, which dates back to the first half of 19th century (Fig. 4A). Probably the building was beyond the reach of storm waves, but the higher activity of erosion (subzone 1a), destroyed old storm ridges and waves dragged fragments of bricks and organic remnants over the surface of the tidal zone (Jasinski and Zagórski 1996; Zagórski 2007b). The second oldest archaeological site Renardbreen 1 was constructed on beaches that formed at the end of 19th and at the beginning of 20th century (Figs 2,

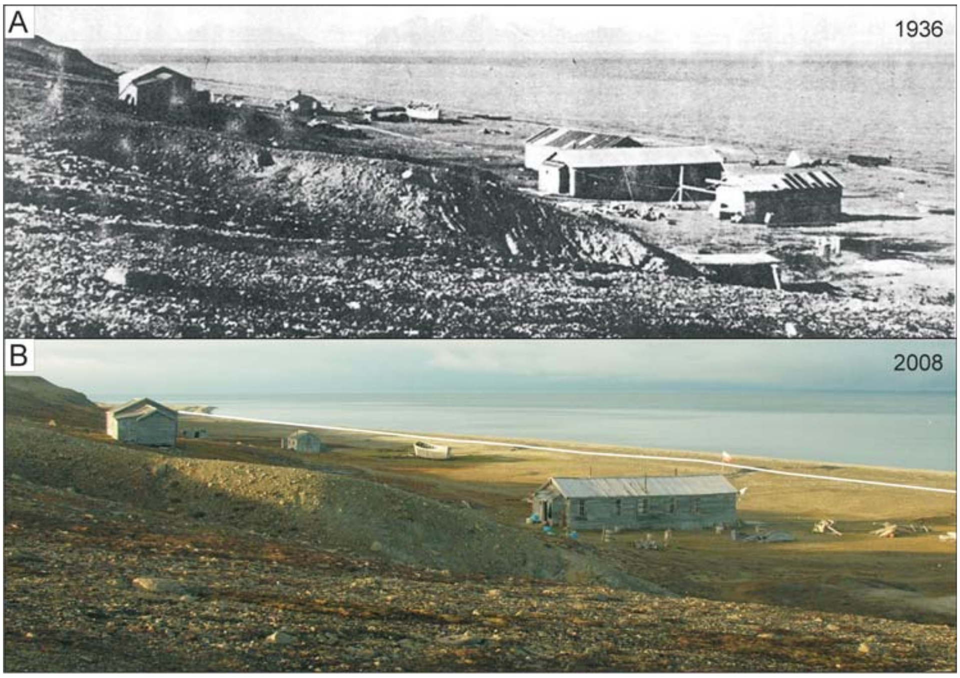

Fig. 14. Shoreline change near Calypsobyen (zone 3). **A**. 1936 (Photo by A.K.Orvin, Norwegian Polar Institute). **B**. 2008 (Photo by P. Zagórski), white line shows the shoreline position in 1936.

3B). The direct advance of Renardbreen during the LIA caused redeposition of traces of colonization from the 16th century (Jasinski, Starkov 1993; Jasinski 1994). Beneath the moraine fragments of the 16th century, a building was found with a foundation unmoved by the glacier, which was 20 cm below contemporary high sea level. Some erosion of archaeological sites, situated at the level of terrace 1, was observed also on the eastern side of Recherchefjorden (Jasinski *et al.* 1997).

The advance of glaciers during the LIA could have caused, with delay, glacio-isostatic subsidence giving marine transgression and a reduction of the area of terrace 1. The zone of sandur fans (zone 4) was being developed on the distal side of the frontal moraine of Renardbreen, but it was not able to compensate the resulting losses of the studied section as a whole. Such a condition persisted until 1936 and was visible on oblique air photos which were the basis for the 1:100 000 topographic map (B11 Keulenfjorden 1952) (Figs 8, 14).

Comparing the extension of shoreline between 1936 and 2007 permits the description of the general changes over 71 years. It is clear that erosion has been the dominated process with a *ca* 110 000 m^2 reduction in the area of terrace 1, set against an expansion of *ca* 77 000 m^2. The general balance for 1936–2007 was about -32 700 m^2, and on average, over its entire length, the shoreline retreated by 5.7 m (0.08 m a^{-1}). The greatest recession took place in zone 4, whereas zone 2 and subzones 3a, 3b, 3c witnessed coastal buildup (Fig. 15, Table 6).

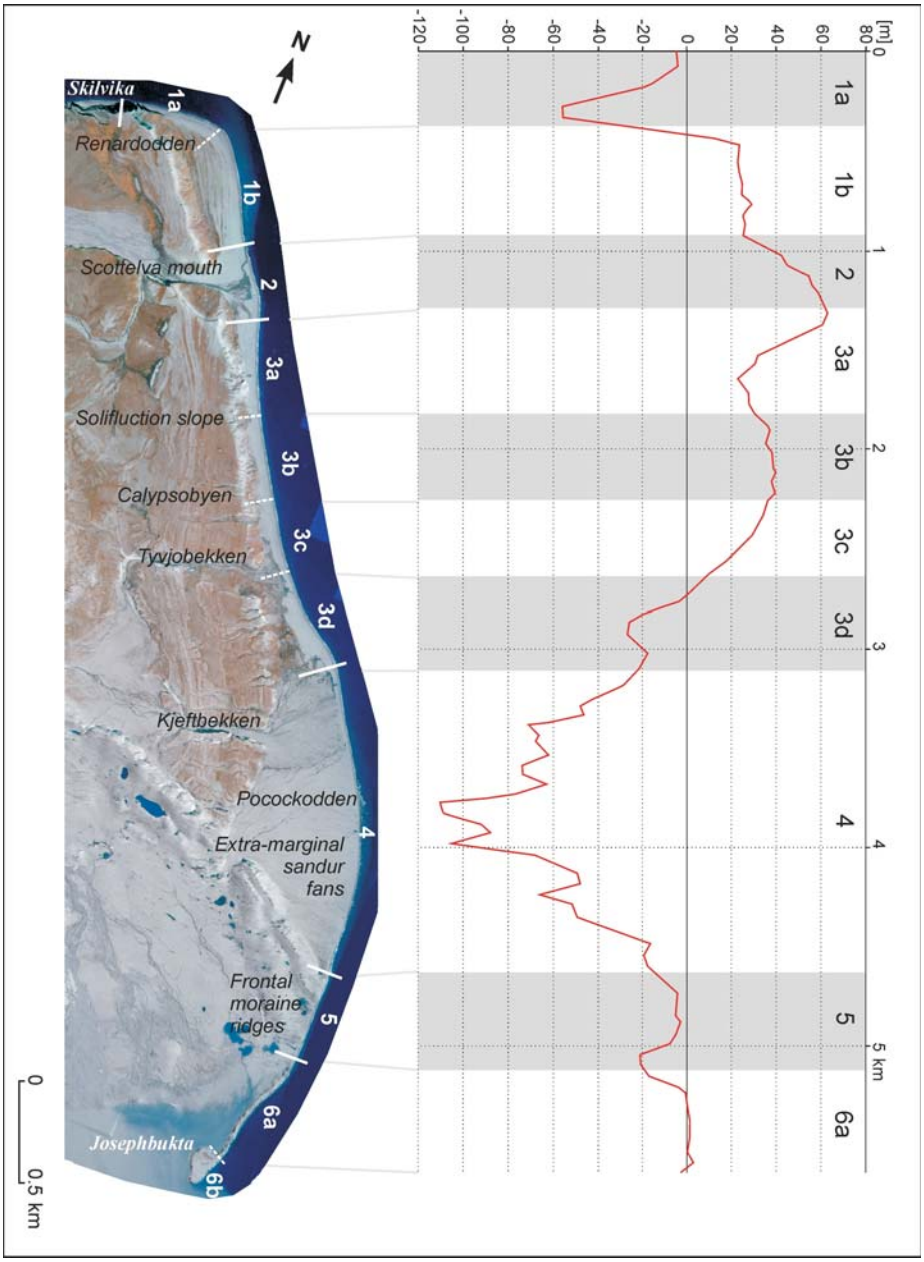

Fig. 15. Shoreline displacements over the period of 1936–2007.

These results on coastal zone dynamics between Skilvika and Josephbukta were based on analysis of archival materials and direct field measurements. They show mutual interaction between marine and terrestrial processes modified by local and regional weather conditions. Overlapping processes of marine and fluvial

Table 6

Area, shoreline and volume changes over the 1936–2007 period

Zone/ subzone	1936–2007							
	Area			Mean value of shoreline change		Sediment volume		
	Decrease [m^2]	Increase [m^2]	Balance [m^2]	[m]	[$m\ a^{-1}$]	Decrease [m^3]	Increase [m^3]	Balance [m^3]
1	10 650	14 820	4 170	4.17	0.06	20 000	27 900	7 900
1a	10 650	0	-10 650	-23.67	-0.33	20 000	0	-20 000
1b	0	14 820	14 820	26.95	0.38	0	27 900	27 900
2	0	15 860	15 860	45.31	0.64	0	29 800	29 800
3	6 740	46 100	39 360	21.28	0.30	12 700	86 600	73 900
3a	0	18 850	18 850	37.70	0.53	0	35 400	35 400
3b	0	14 760	14 760	32.80	0.46	0	27 700	27 700
3c	0	10 760	10 760	26.90	0.38	0	20 200	20 200
3d	6 740	1 740	-5 000	-10.00	-0.14	12 700	3 300	-9 400
4	87 560	0	-87 560	-60.39	-0.85	164 600	0	-164 600
5	3 440	0	-3 440	-6.88	-0.10	6 500	0	-6 500
6a	3 240	340	-2 900	-3.87	-0.05	6 100	600	-5 500
Total	111 630	77 100	-34 530	-6.06	-0.09	209 900	144 900	-65 000

accumulation and longshore transport in tidal conditions were also recorded in other parts of Spitsbergen, *i.e.* Hornsund (S Spitsbergen) and Kaffiøyra (NW Spitsbergen) by Jahn (1959), Niewiarowski and Myzyk (1983), and Kowalska and Sroka (2008). Connections of that type are typical for high-energy polar shores. On Spitsbergen, well developed progradation, coastal and forms are rare. They depend on certain bathymetric conditions and sources of material delivery (Niewiarowski and Myzyk 1983; Marsz 1996). In that range, the most important role is played by glacial catchments influencing the supply of sediment to the coastal zone (Bartoszewski *et al.* 2007, 2009; Zagórski *et al.* 2008c).

Wave action is among main process that shape coastal zone development (Davis and Fitzgerald 2004). In polar areas, Marsz (1996) identified three main types: windy, swell and single long length waves. On Spitsbergen, wind waves are the most powerful, and vary with the speed and time of wind action and the length of wave run-up. Also the arrangement and topography of fiords play an important role. Bellsund is connected with other fiords, that are open towards it: Van Mijen (from ENE), Van Keulen (from E) and Recherche (from S). Wind directions are strongly modified by local orography. In summer, meteorological data from Calypsobyen demonstrate that the dominant winds blow from E and NW, rarely from S (Brázdil *et al.* 1991; Kejna *et al.* 2000; Przybylak *et al.* 2006) (Fig. 1). Swell waves reach Spitsbergen from the open sea. The about 40 km wide open mouth of Bellsund faces into the Greenland Sea and permits long period ocean waves to penetrate the fiord. However, these waves have difficult access to Van

Mijenfjorden, Van Keulenfjorden and Recherchefjorden that branch out from Bellsund (Fig. 1). They reach Calypsostranda (the western shore of Recherchefjorden) indirectly, as a result of refraction and diffraction. The Skilvika region is influenced by both ocean swell waves and short wind waves from the western sector. Very often, overlapping or interference of long and short waves of different directions occurs here (Harasimiuk and Jezierski 1991). Observations conducted in 2007 show that the resultant interfered wave is directed into the Recherchefjorden. Such view is supported by the southward movement of the mouth of the Scottelva (Superson and Zagórski 2007).

Over the last 71 years, through the effects of various types of waves, the western part of zone 1 has been reduced significantly, especially in the Renardodden region (Figs 4A, 15). South of Renardodden short wind waves from the E and NE play an important role. They influence the coastal zone between Skilvika and Pocockodden directly, but the southern part of the section studied (zones 4, 5 and 6) remains in the shadow of mountain massifs east of the Recherchefjorden. When the waves approach the shoreline perpendicularly (±10°), material is transported to offshore or moved inland and deposited on the backshore zone. As an example, in extreme wave conditions, storm remnants from Autumn 1993 were transported 40 m inland from the high water mark (Zagórski 1996, 2004).

On the base of studies conducted at the end of 1980s, it is known that longshore drift is produced during weather by short waves from the NE and E sectors (Harasimiuk and Jezierski 1991). In the Pocockodden region, they divide and one of them heads north while the other heads south. It was acknowledged that their role was decisive in shaping the evolution of zones 2, 3, 4 and 6 especially until the 1990s (Harasimiuk 1987; Zagórski 2004). They were responsible for the spread of material from the extra-marginal sandur fans from Renardbreen (zone 4) and for its subsequent deposition in zone 3 and 6, especially until the beginning of 1990s (Fig. 7B, D). However, in last dozen or so years, the role of longshore drifts heading north has weakened considerably. The stronger influence of open ocean swell, together with the occurrence of wind waves from NW sector, led to excessive transport of material south from mouth of Scottelva. A certain role could be played by rip currents caused by oblique wave approach (MacMahan *et al.* 2006).

In the following seasons of 2006 and 2007, the direction and influence of waves and longshore drift was unchanged. However, shoreline changes included greater erosion of some fragments of terrace 1 because the supply of terrigenous sediment was reduced (Fig. 11D). In 2007, redeposition of material from zone 3 to zones 4 and 6 took place as the shoreline was “smoothed” (Fig. 12). Observations and measurements of gravel diameter on the beach face show that sediments fine in the southern direction from the mouth of Scottelva.

The intensity and direction of marine processes combine with sediment supply influence coastal zone development. Accumulation occurs mainly where terrigenous sediment supply exceeds the transport capacity of longshore drift. For the highly energetic shores of southern Bellsund, the variability of all these factors in longitudinal and cross-section might lead to accumulation or erosion.

For prograding shores in the Calypsostranda region, proglacial rivers from Scottbreen and Renardbeen were the main source of sediment supply. Up until the 1940s, two zones of terrigenous sediments supply were dominant (Figs 8, 9A). Primarly, connected with the Renardbeen, they were extensive extra-marginal sandur fans located at distal side of frontal moraine ridges (Fig. 2). From outflows located near Bohlinryggen (Bohlin Mountain), the proglacial waters divided and partly drained through gorges cut in the system of raised marine terraces, Tyvjobekken (Tyvjo Brook) among others. The surface area of the sandur fans, excluding the outlet fan of Tyvjobekken, was about 0.66 km^2 in 1936. The second and lesser zone of material delivery was the river flowing from Scottbreen, which made a fan 0.04 km^2 in area (Fig. 4B).

In the second half of 20th century, the glacio-fluvial system, that determined material delivery, was rebuilt. As the result of frontal recession of Renardbreen, proglacial water outflow was redirected toward Josephbukta and the extra-marginal fans became inactive (Harasimiuk 1987; Zagórski 2007a; Zagórski *et al.* 2008a) (Fig. 9B). Since then, the sandur fans has been remodelled by marine erosion only (Figs 5A, 7C). By 1960, their surface area had decreased by about 8% (0.61 km^2), while the other supplying zone of Scottelva became the main source of terrigenous material, as it is now (Fig. 4B). Nowadays, marginal lake appears in the outlet zones of Scottelva during spring tides and high water levels in the river, on the landward side of a gravel ridge of about 5 m wide. Whereas, in the tidal zone at river mouths, ephemeral delta developes (Fig. 16). Bathymetric measurements undertaken in 2008 did not show any extension of these delta in the offshore zone, which soon reaches a depth of 4–6 m. Calm marine conditions are conducive to delta development. Storms destroy them, removing or spreading the material along the shore. In the summer season, conditions favourable to delta cones development occur a few times, depending on hydro-meteorological conditions.

The data set of ten study seasons (1986–1990, 1993, 2001, 2002 and 2005) show that mean outflow in Scottelva was 0.89 m^3s^{-1} (Bartoszewski 2007). In June and the first decade of July, when snow melt water from the Calypsostranda area was dominant, the flow increased from 0.78 to 0.94 m^3s^{-1}. The highest flows, of about 1.5 m^3s^{-1}, took place in the second and third decades of July and the first decade of August, when the main flow component was proglacial.

Analysis of separate measurement seasons gives an insight into the transport abilities of Scottelva. The 2002 summer season was unusual. From 8th July to 10th September, the mean discharge was 1.4 m^3s^{-1} (Krawczyk and Bartoszewski 2008). The maximum discharge was in August, with two peak discharges of 2.8 and 3.8 m^3s^{-1}. The total volume of water discharged by Scottelva during the recording period was 7.92 million m^3, 22% more than the mean for 1986–2001

Fig. 16. Ephemeral delta cone at the mouth of Scottelva (Photo by P. Zagórski, 2006).

(6.46 million m^3) (Krawczyk and Bartoszewski 2008). Such a big discharge resulted from intensive ablation of Scottbreen, associated with heavy precipitation between 16th and 27th August (23 mm) and higher air temperatures than usual (5.5–7.5°C). Major remodelling of the forefield of Scottbreen occurred with large areas of ground moraine eroded and transformed into gravel-stony sandur (Reder and Zagórski 2007). Considerable amounts of terrigenous material were discharged by proglacial waters into coastal zones 2 and 3.

The transporting capacity of river grows logarithmically as discharge increases (Bartoszewski 1998). The more often higher water levels occur, the more material can be transported, but this requires a huge contribution of glacial waters. However, the amount of material reaching the coastal zone depends also on the length of the transit zone and how much material in stored in this zone. The front of Scottbreen from the end of the LIA to 2006 was under continuous recession, at a mean rate of 4–5 ma^{-1} (14.3 m a^{-1} in 1990–2006), and its area decreased by about 23% (Zagórski *et al.* 2008b). This recession lengthened the outflow routes of proglacial waters from about 1.4 km in 1936, to 2.1 km in 1990 and 2.5 km in 2006 (Zagórski *et al.* 2008c). It also increased channel and floodplain storage area.

As in many other polar areas, an important role in transformation of the studied shore section of Recherchefjorden was played by ice occurring both in the coastal zone and in the fiord (Jahn 1977; Everson and Cohn 1979; Giżejewski and

Rudowski 1994; Rodzik and Zagórski 2009). An indirect factor resulting from meteorological conditions is wind wave energy, which also influences the ice pack on open water (Marsz 1996). Ice is most effective in suppressing short waves, rather than swell. It fundamentally modifies the influence of waves on the shore (Forbes and Taylor 1994; Zagórski 2004). In its initial and moderately developed phases, shore ice facilitates the erosion of sediment from the foreshore and its transport to the storm ridge and beyond (Fig. 13). During spring and summer thawing, this material create various *e.g.* micro land-forms such as "beach creating on ice", the majority of which are ephemeral (Nichols 1961; Jahn 1977; Zagórski 2004). In general, shore ice protects the coast from the action of storm waves, but tall ice cliffs facilitate erosion and transportation of material along the shoreline (Dionne 1973; Rodzik and Zagórski 2009). The influence of shore ice was the greatest during 1994–1995 and 2004–2005, crucially modifying the shoreline course.

Conclusions

Changes of shoreline in the Calypsostranda region in the last century were the result of interactions of marine and terrigenous processes, modified by climate change. The influence of marine processes was determined mainly by meteorological conditions, especially anemometric relationships. At the beginning of second half of the 20th century, longshore drift had a dominant role (1960–1990), but since 1990 intensification of short waves (period 1990–2000) or swell (period 2000–2005) took place. Comparing the extension of shoreline between 1936 and 2007 showed that there was more erosion than accumulation. Nearly 110 000 m^2 of the area of terrace 1 decreased, whereas about 77 000 m^2 appeared. The net balance for 1936–2007 was about -32 700 m^2, on average over the whole length of the shoreline retreated by 5.7 m (0.08 m a^{-1}). However, the analysis of each divided periods showed a much more complex picture of the changes. There were three periods of negative area balance (1936–1960, 1990–2000, 2005–2006) and three periods of positive area balance (1960–1990, 2000–2005, 2006–2007). In shaping the coastal zone, marine processes took an important role, especially wind waves and swell. Strong wind waves connected with the Autumn storms in 1994 led to a considerable area reduction of terrace 1, averaging 6.55 m. Swell waves influenced the changes of shoreline geometry in the period 2000–2005, especially in the Calypsobyen region (zones 2 and 3), with a general positive area balance (2 060 m^2). On the contrary, lack of a clearly dominant direction and type of wave as in the period 2005–2006, produced a positive area balance. The annual advances and retreats in shoreline position are frequent, but that major phases of beach progradation only occur when sediment supply substantially exceeds the processes of sea level rise and wind wave effects that seek to redistribute this sediment. Recession of Renardbreen reduced the amount of coarse sediment delivered to the coastal zone, whilst extra-marginal sandur fans became sources of sediment as they eroded. The glacial catchment of Scottelva remained active during this period, considerably influencing shoreline development between Renardodden and Calypsobyen. Polygenic shore ice (*i.e.* period 2000– 2005) was the only process that reduced the otherwise general tendency for erosion of terrace 1. Scottelva was the only source of delivery, but it was too limited to compensate the negative balance of the whole studied sections of the shore resulting from intensive wave influence. Analysis of longer time spans (*i.e.* 1960–1990) gives an image of general tendencies within coastal zone. Combination of 1-year or 5-year study intervals shows the complexity and variability of phenomena that are characteristic for such high-energy Arctic shores.

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