Geomorphology of the southern side of Bellsund – Leader Piotr Zagórski

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Since 1986 the Bellsund Region (NW part of Wedel Jarlsberg Land), has been explored by the members of Polar Expeditions organised by M.C. Skłodowska University in Lublin. The main base was located in Calypsobyen, the western coast of the Recherche Fiord.

Within the programme of Expeditions some interdisciplinary researches of polar environment have been done. Among them there are Earth Science (geomorphology, geology, meteorology, soil science, environment protection) and Biology (botany, biochemistry) and radiochemistry. As the reflection a lot of scientists of various fields have been present in Expeditions.

The interest was the relief, cover formations and paleogeography of Pleistocene, the functioning of glacial and periglacial geoecosystems in local and global conditions of climate changes and the influence of anthropogenesis. The introduction of the latest computer technology and method of positioning allow making cartographical view of the relief.

The effect of 18th Expeditions has been numerous publications in national and international magazines, as the examples below confirm:

- Zalewski M.S. (ed.) 2000. *Bibliography of Polish Research in Spitsbergen Archipelago 1930–1996, part I*, Publications of the Institute of Geophysics Polish Academy of Sciences, Warszawa;
- Zagórski P., 1998. *Spitsbergen Bibliography: Geomorphology, Glaciology and Quaternary Geology*. IV Conference of Polish Geomorphologists II, Spitsbergen Geographical Expeditions, (ed.) J. Repelewska-Pękalowa, Wyd. UMCS, Lublin, 291–314.

The results of the studies were presented in many conferences and national sessions as well as internationally, for example International Conferences on Permafrost: Trondheim (1988), Beijing (1993), Zurich (2003), and in conferences: Frankfurt/Main (1989), Mainz (1992) and Potsdam (2005).

Introduction to guide

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The presented area covers western borders of Recherche Fiord from the spit in Josephbukta to Skilvika (Fig. 1). The main elements are there: extensive plain (Calypsostranda) made by the system of raised marine terraces and the forefield of Renard and Scott Glaciers. The whole makes unique and picturesque tundra landscape, extremely interesting from cognitive and scientific points of view.

The aim of first two points of the terrain session (points: 1, 2/2A) is to show the evolution of marginal zone and stages of fluctuations (advance and recession) of Renard Glacier and its influence on transformation of the shore on the base of geomorphological and archaeological studies. At the next point (3) the issues of periglacial phenomena and monitoring of dynamics of active layer of permafrost are going to be shown. A break and a short rest will be expected at Polar Station of M.C. Skłodowska University in Calypsobyen (point 4). It will also be a chance to acquaint with a history of that place, its present function and scientific programmes. The point 5 is connected with glacial issues of the Scott Glacier, which is much smaller than the Renard Glacier. At the last two points of the terrain session, it is expected to be presented the issues related to Late Weichselian and Holocene morphogenesis of Calypsostranda (point 6), with the special attention paid on conversion of shore zone at the historical time and present (point 6A).

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Calypso – excursion programme

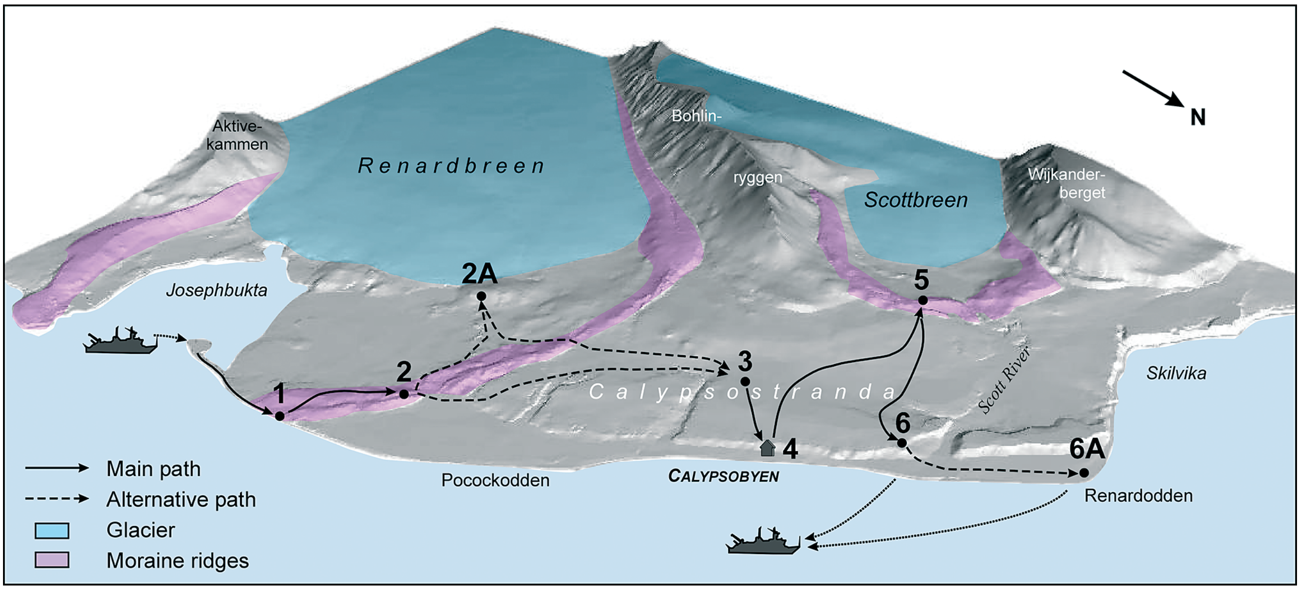

Fig. 1. The landing point, the passage path and the location of points. 3D model of the Calypsostranda Region (Zagórski 2002)

Point 1 – THE FRONTAL MORAINE OF THE RENARD GLACIER 77° 32' 22" N, 14° 34' 06" E
Piotr Zagórski, Kazimierz Pękala, Janina Repelewska-Pękalowa – The role of the Renard Glacier in forming of shore zone

Point 2/Point 2A – FOREFIELD OF THE RENARD GLACIER
2 – 77° 32' 37" N, 14° 32' 41" E; 2A – 77° 32' 23" N, 14° 29' 47" E
Jan Reder, Piotr Zagórski – Recession and development of marginal zone of the Renard Glacier

Point 3 – PERIGLACIAL POLYGON 77° 33' 20" N, 14° 29' 52" E
Kazimierz Pękala, Janina Repelewska-Pękalowa – Dynamics of active layer of permafrost

Point 4 – CALYPSOBYEN 77° 33' 31" N, 14° 31' 01" E
Kazimierz Pękala, Janina Repelewska-Pękalowa – Calypsobyen - history and the present day

Point 5 – PUSH MORAINE OF THE SCOTT GLACIER 77° 33' 36" N, 14° 26' 11" E
Jan Reder, Piotr Zagórski – Recession and development of marginal zone of the Scott Glacier

Point 6 – CALYPSOSTRANDA 77° 33' 55" N, 14° 29' 41" E
Piotr Zagórski – Relief and development of Calypsostranda

Point 6A – RENARDODDEN 77° 34' 21" N, 14° 28' 49" E
Piotr Zagórski – Present morphogenesis of the shore and the importance of archaeological sites for reconstructing the stages of development

Point 1 – The frontal moraine of the Renard Glacier 77° 32' 22" N, 14° 34' 06" E

The role of the Renard Glacier in forming of shore zone

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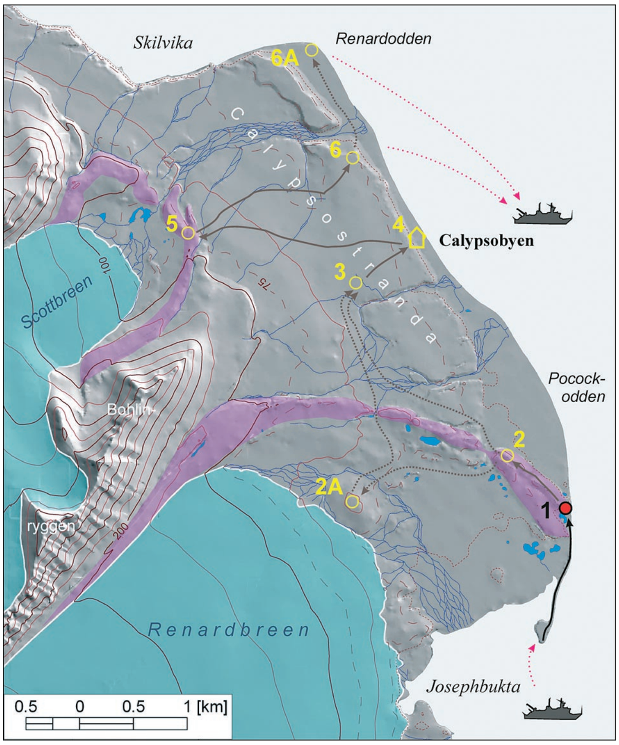

The coast of NW part of the Wedel Jarlsberg Land is exposed to various morphogenetical factors. One of the most important can be numbered among glaciers that can influence directly (destruction and transform of existing forms of relief, accumulation of moraine covers) and indirectly (with the cooperation of different factors: tectonic, fluvial, marine).

The present relief shown at point 1 was shaped fundamentally at the end of XIX and at the beginning of XX century, but the ridge of frontal moraine is built of some moraine layers of different age, that show the advance of glacier of the surge type during Holocene (Pękala, Repelewska-Pękalowa 1990, Reder 1996) (Fig. 2). The direct influence of the Renard Glacier, correlated with the advance during the Little Ice Age, caused for example redeposition of sediments and fossil flora which was dated on 660 ± 80, 1 040 ± 80 and 1 130 ± 80 BP with ^{14}C method (Dzierżek et al. 1990) (Fig. 2). Those layers are disturbed glaciotectonically and contain some fragments of woollen fabric, whalebone, animal's bones and wood – archaeological site Renardbreen 1 (Krawczyk, Reder 1989, Jasinski, Starkov 1993, Jasinski 1994). Furthermore, under the moraine, there were found some fragments of buildings from XVI century, which constitution remained intact by glacier, they were 20 cm under present sea level (Fig. 3, 4, 5). This site was studied in 1986–1993 and it is the only one in Spitsbergen where the leftovers of whale fishing buildings were covered with till. It allows us to date the activity of glaciers and changes of sea level at historical time. The terrace I was also aggradated, and the marine materials of fossil storm ridge were dated on 6.2 ± 0.9 ka BP with TL method (Pękala, Repelewska-Pękalowa 1990) (Fig. 2).

The decisive role in forming of a section of accumulative shore located on the south of abrasively cut frontal moraine of the Renard Glacier plays longshore currents (Fig. 6). At the region of the Pocockodden, there are distinguished two longshore currents; one flows northwest and the other south (Harasimiuk, Jezierski 1988, 1991). The other one is supplied with the material from conversion of sandur fans and influences the origin and remodelling of the spit developing in the shade of shore ledge – moraine ridge of the Renard Glacier (Fig. 6). Its development was also enabled in the presence of glacial sediments of marginal zone of the Renard Glacier at that part of the shore. The shape and geometry of widen, final

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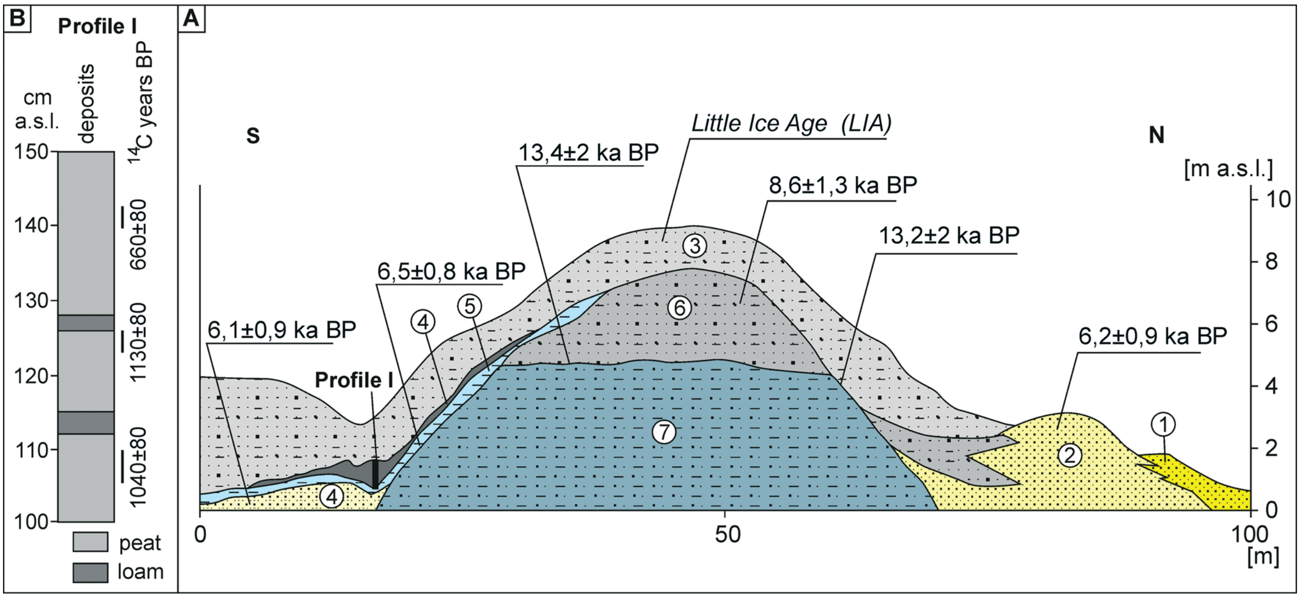

Fig. 2. The geological structure of frontal moraine of the Renard Glacier (Pękala, Repelewska-Pękalowa 1990)
A: 1 – present storm ridge 2 – fossil storm ridge, 3 – glacial till (Little Ice Age), 4 – pushed occupation level of whale settlement with fossil flora (profile 1), 5 – clay, 6 – glacial till, 7 – glacio-marine sediments; B – profile of organic sediments of the Renardbreen site (Dzierżek et al. 1990).

Fig. 3. Archaeological works at Renardbreen site 1. (photo Kazimierz Pękala, 1991)

Fig. 4. The occupation layer still visible in the northern margin of the trench (photo Kazimierz Pękala, 1991)

part of spit was and is still changing quickly. It is supported by the analysis of available cartographical materials and GPS measurements (Zagórski 2007) (Fig. 6).

Indirect role of the Renard Glacier in remodelling the shore with the help of fluvial and marine processes has been appeared fully in the section between Pocockodden and ridges of the frontal moraine of the Renard Glacier (Fig. 6). At the time of maximum range of the Renard Glacier at the Little Ice Age, the glacier waters caused the origin of gorge in the mouth where plain fluvioglacial sandur fans were developed that aggradated terrace I. Thanks to that, slightly slanting area of semi-circular outline was arisen. It is closed in the shore zone by the storm ridge. The origin of such a form shows clearly considerable advantage of fluvioglacial accumulation over the possibilities of spreading the material by waving and longshore current. Broad surfaces of fluvioglacial cones, after the recession of the Renard Glacier from the push moraine lines, became the fossil forms. Disappearance of delivery of the terrestrial material caused the increase of activity of marine processes that as an effect made gravel ridge that brought to a stop the destruction of the cone.

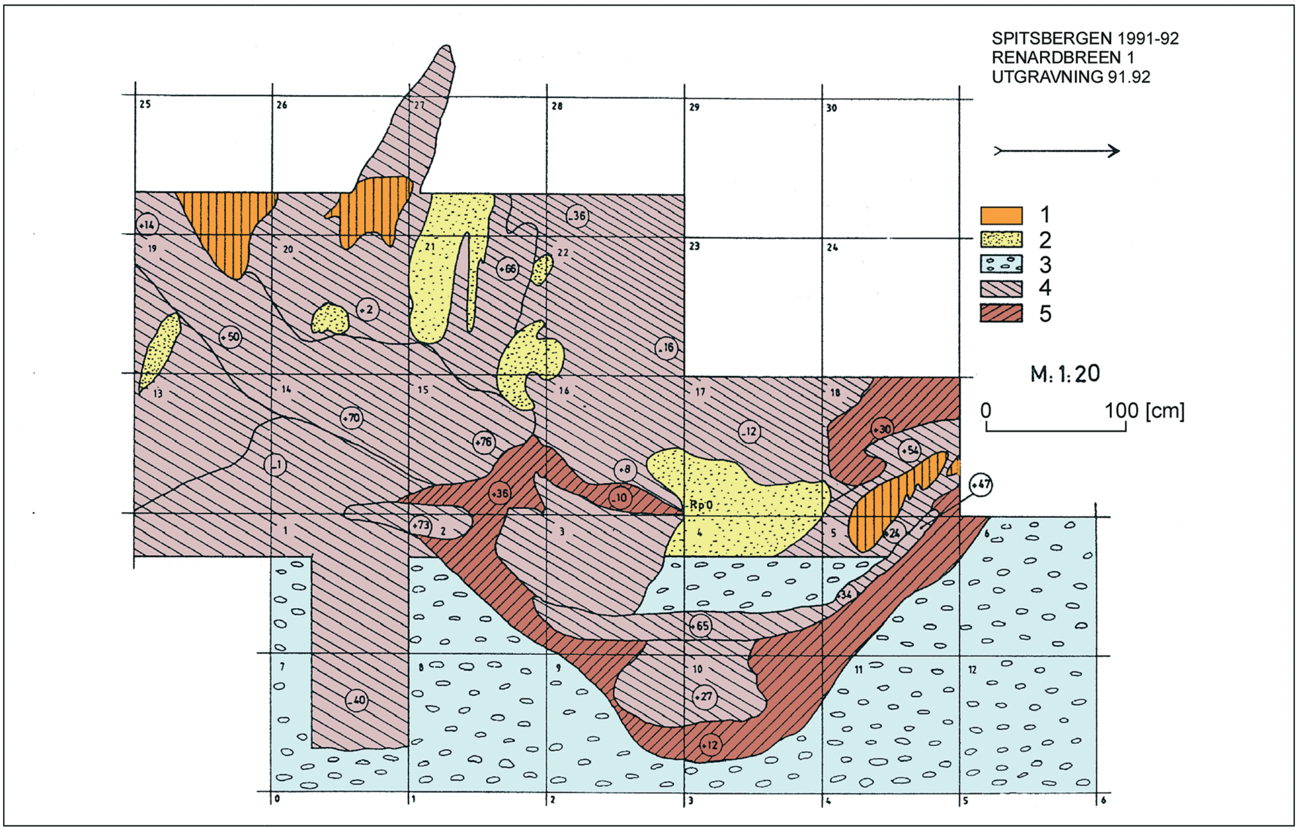

Fig. 5. The archaeological site Renardbreen 1. Excavations 1991–1992
1 – marine sediments, 2 – sand, 3 – marine gravel, 4 – brown/black occupation layer, 5 – the wall-like construction (after Jasinski, Starkov 1993)

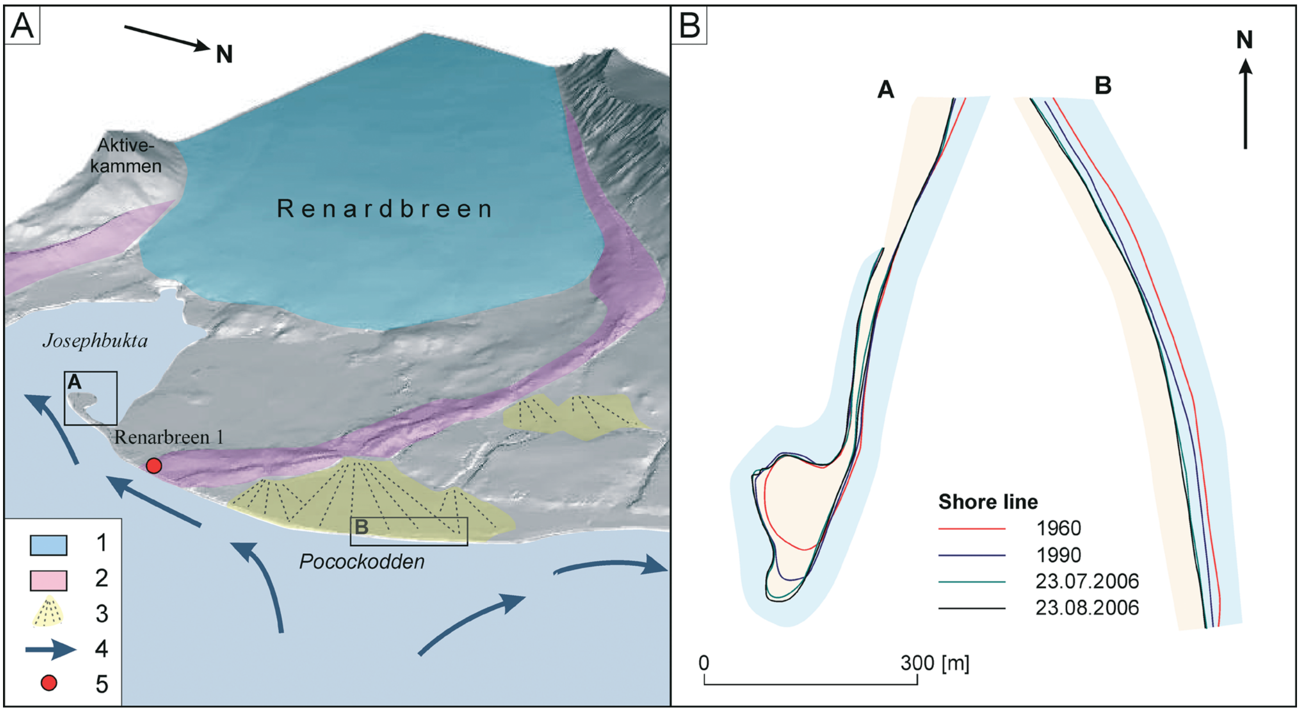

Fig. 6. A – Main factors that influence the shape of the shore in the section from Pocockodden to Josephbukta
1 – glacier surface, from 1990, 2 – frontal moraine ridge, 3 – extramarginal sandur fans, 4 – directions of the longshore currents (after Harasimiuk, Jezierski 1988, 1991), 5 – location of archaeological site Renardbreen 1. B – Changes of geometry of the shoreline made on the basis of analysis of cartographical materials and GPS measurement (Zagórski 2007).

Point 2/Point 2A – Forefield of the Renard Glacier

2 – 77° 32' 37" N, 14° 32' 41" E
2A – 77° 32' 23" N, 14° 29' 47" E

Recession and development of marginal zone of the Renard Glacier

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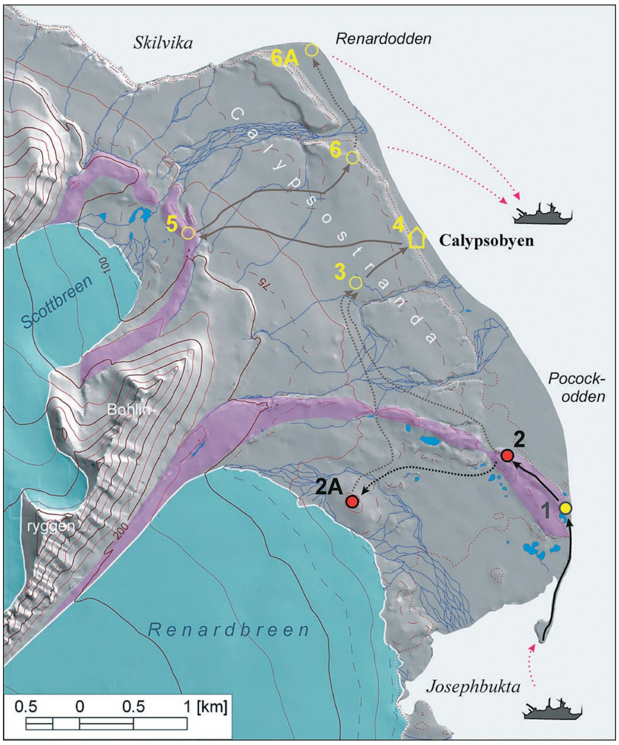

The Renard Glacier, the biggest in the NW part of Wedel Jarlsberg Land region; its area in 2006 was a little over 31 km². Its length in axis was about 8.3 km, the width is various, from 2.5 km at the lower part, 7–8 km at the central firn field and its side arms. Tongue of the Renard Glacier covers the valley limited from NW by the Bohlinryggen and Activekammen from SE (Fig. 7, 8).

The largest size of the Renard Glacier was during its maximum spread at the end of XIX century when the glacier front was staying on the line of frontal moraine range and finally formed during the Little Ice Age (Fig. 9). Then the glacier filled the whole area of Josephbukta and its area was 38 km². Till 1936 on that area, there was no major change. The glacier was still filling the whole area to the inner side of moraine range. The part escaping right into the fiord underwent the significant recession of nearly 1000 m and exposed a considerable part of the Josephbukta (Fig. 9). In the following period of 1936–1960 the much quicker recession began especially in the land part without direct contact with fiord water (Reder 1996). That recession occurred by frontal receding of the glacier front of 780 m (33 m a^{-1}), and on the southern side of the bay – 1200 m (50 m a^{-1}). Also the receding of 560 m (23 m a^{-1}) was present in the Josephbukta revealing almost all of it. Between 1936 and 1960 the direction of the proglacial water outflow changed. Till that time active outside wide sandur fans became dead and the outflow made directly for Josephbukta (Harasimiuk 1987, Reder 1996, Zagórski 2004).

In the following years, till 1990 the quicker recession of the glacier front underwent mainly land part of maximally 720 m (24 m a^{-1}), while much slower was the recession of the part connected with the bay mouth – maximum up to 450 m (15 m a^{-1}). The Renard Glacier had a mouth to the fiord in the Josephbukta and its front made some metres high ice cliff (Fig. 7, 9). Now the deglaciation of the Renard Glacier has generally a frontal character. Based on observations and GPS measurements from 1990–2006 the glacier front receded of maximum almost 340 m (21 m a^{-1}). Starting from the end of XIX century till 2006, area of 7 km² was exposed

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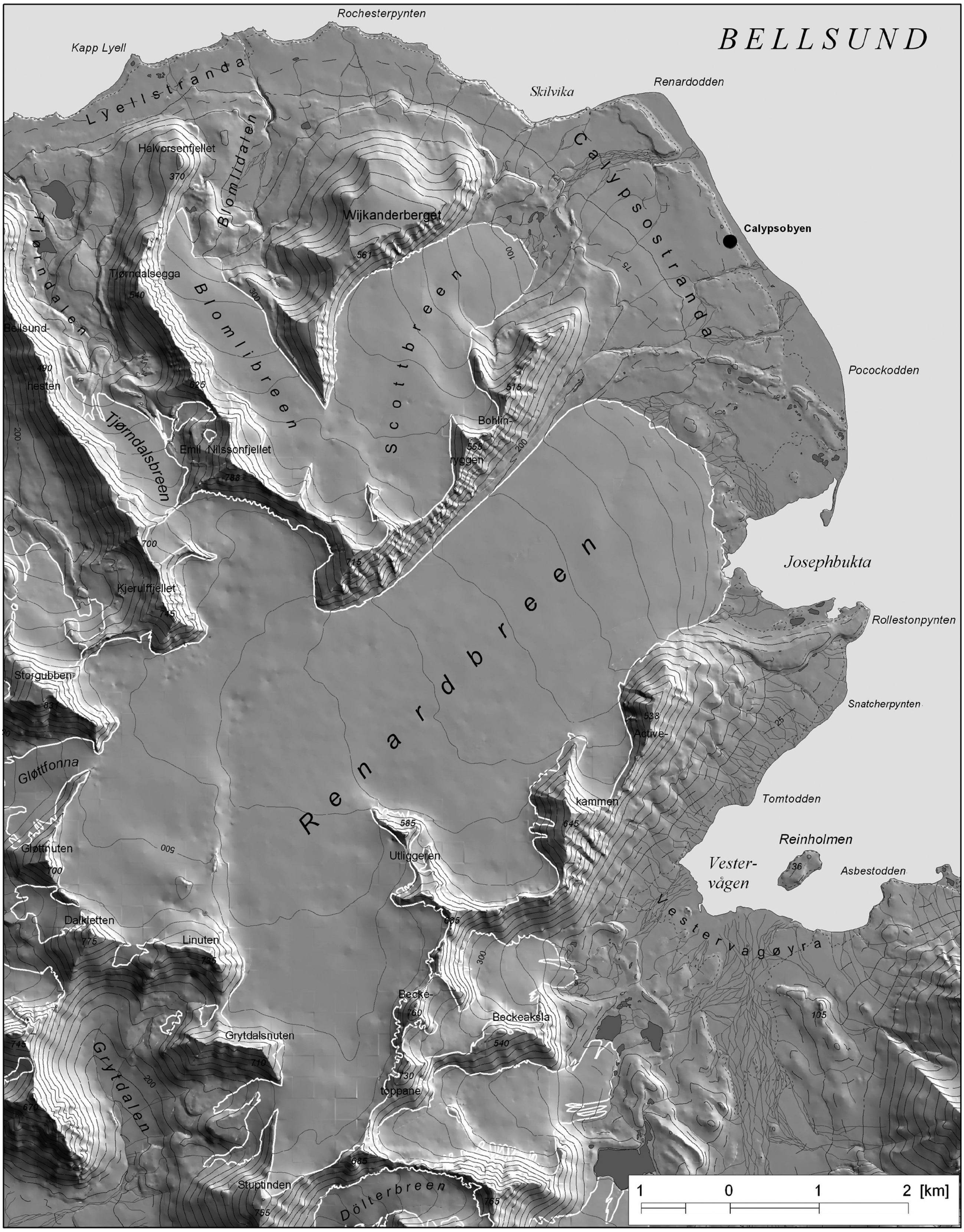

Fig. 7. The Renard Glacier and Calypsostranda Region. The shade map made using the Digital Terrain Model (DTM) obtained from the aerial photos from 1990 (Zagórski 2002)

where 1.5 km^2 was Josephbukta. It has its consequences in the origin and formation of the surface of the forefield of the Renard Glacier limited by frontal moraine ridges (Fig. 9).

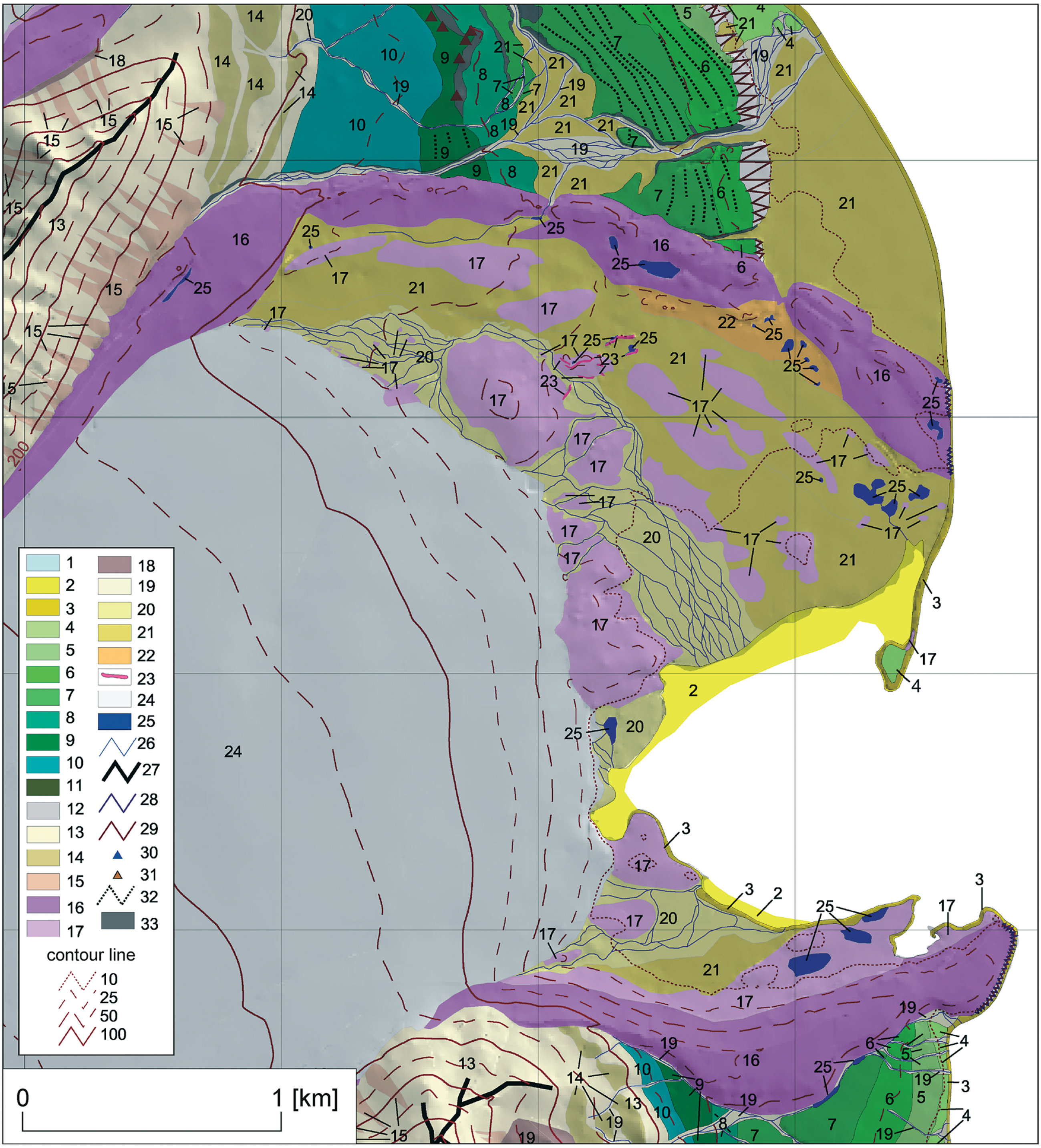

Fig. 8. Geomorphological map of the forefield of the Renard Glacier (Zagórski 2002)
1 – contemporary abrasion platform, 2 – tidal flat, cone of delta, 3 – contemporary storm ridge, 4 – terrace I (2–8 m), 5 – terrace II (10–20 m), 6 – terrace III (25–30 m), 7 – terrace IV (30–40 m), 8-terrace V (40–50 m), 9 – terrace VI (50–65 m), 10 – terrace VII (70–85 m), 11 – terrace VIII (105–120 m), 12 – superficial flattening, 13 – slopes, 14 – denudation-structure level, 15 – talus cones, 16 – ice-cored moraine ridges, push and lateral moraines, 17 – ground and ablation moraines, 18 – rock glaciers (nival), 19 – floors of pronival valleys, 20 – contemporary sandur plains and fans, alluvial cones, 22 – kame, 23 – esker, 24 – glaciers, 25 – lakes, 26 – rivers, 27 – ridges, 28 – active marine cliffs, 29 – dead marine cliffs, 30 – skerries, 31 – paleoskerries, 32 – old storm ridges, 33 – edges.

The frontal moraine of Renard Glacier consists of two genetically and age-old distinct parts: inside of push moraine character and inside neighbouring ice-cored moraine ridges (Fig. 2, 8). The push moraine at N and NW part of the forefield has the surface of mild character, slopes are mild and the tops are not marked sharply. The more varied is southern area with that is only fragmentally preserved part of the moraine. Its surface is characterised by very intensive line of relief in the shape of longitudinal parallel swellings and lowerings. Similar morphological features show frontal moraines of glaciers accumu-

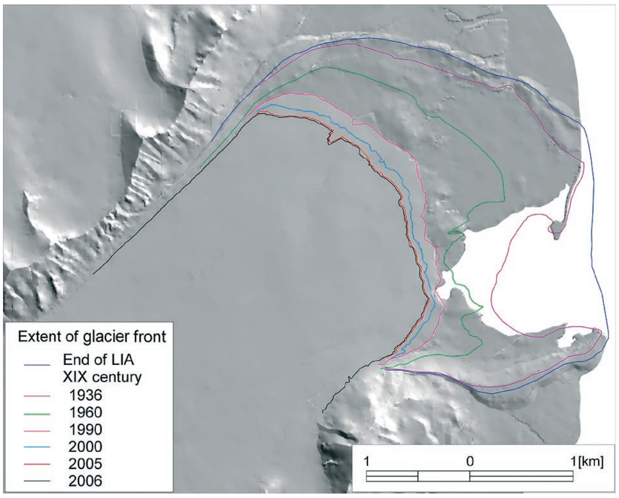

Fig. 9. The extent of the Renard Glacier fronts combined on the basis of archival data (Reder 1996, Szczęsny et al. 1989, Zagórski 2005) and GPS measurement

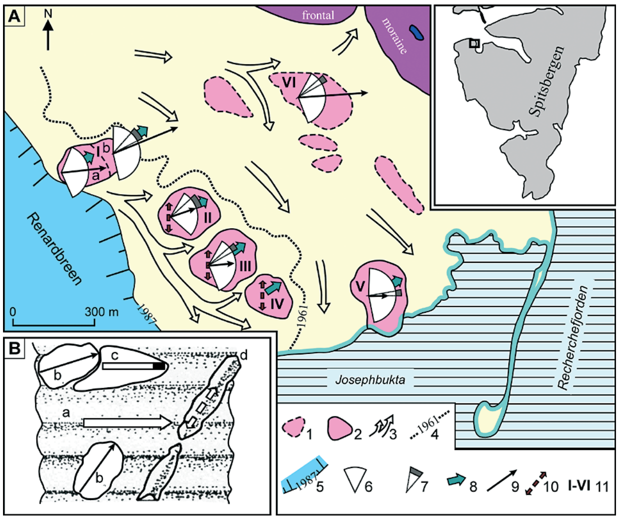

Fig. 10. The sketch of the forefield of the Renard Glacier (Merta 1988)
1 – patches of erosive moraine of compact texture of “fluted” type, 2 – patches of fresh relief of ”fluted type”, 3 – directions of outflow of proglacial water, 4 – location of the glacier front in 1961, 5 – location of the glacier front in the study season, 6 – the range of orientation of the longer axis of free stones (type b2), 7 – the range of orientation of extension of moraine accumulates of type c, 8 – directions of setting of moraine ridges and grooves of the fluted type, 9 – resultant factor of orientation of the longer axis of stones (type b1), 10 – location of uncompleted ridges, 11 – measurement domains I–VI, B: scheme of location of respective types of directional elements, their symbolic and the way of measurement: a – ridges and grooves, b1 – stones with the sediment at their hinterland, b2 – free stones, c – moraine deposits in the shade of stones b1, d – uncompleted ridges.

lated in the conditions of strong compression, so at the surge stage. At the area of ice-cored moraine ridges, even huge denivelations can be seen. Sharp, pyramidal tops and considerable number of cracks and lowerings of thermokarst character (often filled with water) prove the existence occurrence of relict ice inside (Reder 1996).

At the first stage of the recession of the glacier the outflow from moraine ridges was blocked and at its internal side some marginal troughs begin their kelter. Ablation water was taking them to Josephbukta direction (it was parallel to the glacier front). With the growing distance from the glacier tongue in the SW direction, in the lowering between its edge and ice-cored moraine ridges some intensive accumulation processes of the material carried by ablation water began to happen. Then, the kame terrace was formed made of sandy deposits with some gravel infillings and ablation till (Fig. 8). The total obstruction of the outflow in northern direction through the frontal moraine and kame terraces, caused creation of the marginal river, flowing along glacier front in direction of Josephbukta. On the hinterland of moraine series and kame terrace the ablation waters have cut down the deep valley, which present dry floor is covered with sandy-gravel sediments. As the result of progressive recession the set of ground moraine of fluted type was made. That set is on the outcrop of bedrocks of roche moutonnée type (Merta 1988, Reder 1996) (Fig. 10, 11).

The inside set of marginal sandurs consists of three layers correspond with the stages of recession of the glacier. Two upper layers, not active now, compose the forms of the shelf type or terraces connected to the inner slopes of ice-cored moraine ridges. Single packs of sediments that belong to the upper system of cones are universally met at lowerings of the fluted moraine. The third, contemporary sandur layer is made of the series of cones that are in the lowerings between roche moutonnée on the hinterland of the glacier tongue edge. The surface of that sandur is formed by proglacial water of marginal rivers (Fig. 8). At the direct neighbourhood of tongue they have concentrated confluence, huge fall and considerable erosive abilities. Due to a progressive recession of the glacier causes the marginal rivers to move towards the glacier front that receding every year. The traces of older flows recorded as dead, hung riverbeds which location can reconstruct the advance of the glacier front with high probability (Fig. 8).

During the last thirty years the large island mountains of roche moutonnée character were unveiled from the ice, as well as moraine cover of fluted type, which was on. The glacier gradually recedes towards West lost the contact with the water of Josephbukta (Fig. 8, 9, 10). At the direct forefield of the glaciers, between the taking back tongues and frontal moraines (ice-cored moraine ridges) that mark the maximum extend of the last transgression, there were created the zones of ground and ablation moraines, similar to drumlins forms, inner sandurs and sometimes concurrent crevasse forms. Ground moraines, often fully developed as the moraine of the fluted type, stay mainly on the roche moutonnée (Merta

Fig. 11. The fluted moraine covers the proximal slope of roche moutonnée (photo Piotr Zagórski 2006)

Fig. 12. Covers of naledi and the lump of dead ice buried in the sandur sediments (photo Piotr Zagórski 2006)

1988, Reder 1996) (Fig. 11). Proglacial rivers that aggrade and cut sandur surface use the lowerings between them. On the distal side of roche moutonnée, from time to time the ridges of eskers are preserved that were formed in the middle of XX century and their orientation correspond to the direction of crevasses on the glacier and the directions of grooves of the ground moraines on its forefield (Fig. 8). Hypsometric domination of moraine ridges was softened by neighbouring from inside kame terraces. In that zone big morphological importance has universally appeared vast covers of naledi and rarely present clods of dead ice buried in sandur sediments (Fig 12).

Point 3 – Periglacial polygon *Localization: 77° 33' 20" N, 14° 29' 52" E*

Dynamics of active layer of permafrost

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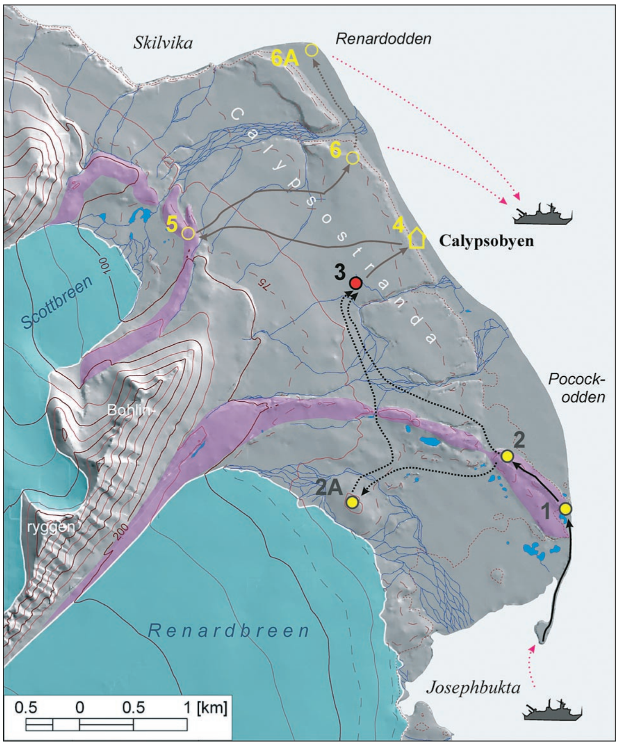

The fragment of Calypsostranda that was formed by cryogenic processes connected with frost segregation in different moisture conditions is characterised by the presence of structure soil (garland terraces, stone circle) of different size, shape and present active processes. That area is the polygon of periglacial study and monitoring of active layer of permafrost (Fig. 13, Table 1).

Within the confines of scientific programme of polar expeditions of M.C. Skłodowska University, during almost twenty seasons (1986–2005) the measurements of thickness of active layer were conducted. The main study polygon was Calypsostranda, the moraine plain located in the neighbour of Renard and Scott Glaciers (Fig. 13). The thickness of active layer of permafrost was stated with the use of the method of sounding with the metal rod and some Danilin's frostmeters were used, too. The measurement point's representative for tundra survey were located in various places of different degree of water mobility in covers, flora cover, inclination and exposition. They were on the surface of raised marine terrace of the height to 20–40 m a.s.l., and on the slopes of valleys cutting that terrace and on inclinated surfaces of dead cliff transformed by periglacial processes (Fig. 13). The maximum of Summer ground thaw were diverse (Table 1).

The maximum sizes of thawing were noticed at the point with movable water in covers (225 cm) while minimum – at the peat island (45 cm). For the inclined surface it was stated that except for obvious thermal privilege of the south exposed slope, also warming up was influenced by winds of foehn type which effect touched the slope III (S exposition). The speed of thaw was diverse, at the range from 0.25 to 6.0 cm per 24h. The biggest – at the first stage.

The studies on Calypsostranda show that diverse amounts of Summer thaw of the ground have also some local factors, like foehn phenomenon, mobility of non-permafrost water, flora, exposition and snow cover (Repelewska-Pękalowa et al. 1988).

The data from Calypsostranda area are included into International Monitoring System of permafrost active layer: CALM (*Circumpolar Active Layer Monitoring – Site P1 Calypsostranda*) and can be found in the database of *National Snow and Ice Data Center,*

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Table 1. Maximum thickness of active layer in Calypsostranda in chosen points (in cm)

Point Year	1	2	3	4	5	I	II	III	IV
1986	90	125	120	–	60	130	–	145	122
1987	111	175	175	175	68	124	150	165	130
1988	108	163	168	193	70	121	180	177	135
1989	145	165	157	180	83	135	160	186	139
1990	130	165	165	165	56	118	135	170	122
1991	127	148	163	170	75	141	150	165	121
1992	140	170	165	180	70	140	180	155	125
1993	112	180	180	196	70	130	180	180	140
1995	125	176	180	174	68	135	170	160	160
1996	125	154	178	168	65	132	160	151	128
1998	130	124	121	170	75	–	–	160	–
2000	108	175	155	130	45	126	135	160	150
2001	116	131	180	165	73	150	170	132	155
2002	130	155	170	154	81	139	160	150	143
2005	150	225	220	210	115	157	195	200	145

Points 1–5 along the NS and WE transects WE: 1 – flat marine terrace (sands and gravels, dry tundra), 2 – structure soils with movable water, sandy-gravel cover, moss on the peat surface, 3 – and 4 – patterned ground with movable water in covers, sands and gavels, without flora, 5 – peat island on little water basin.
Slopes: I – N exposition, I – S exposition, III – E exposition, IV – W exposition.

Boulder, Colorado (Repelewska-Pękalowa 2002, Repelewska-Pękalowa, Pękala 2003, Christiansen et al. 2003) (Fig. 14). The aim of CALM programme is to collect and share data which document the process of Summer thaw of the ground in zones of occurrence of permafrost on both hemispheres. The measurements are done in 117 areas and 15 countries are involved. Only two areas, not long ago did represent Spitsbergen: Kapp Linnee (S1) and Calypsostranda (P1). In 2000 the measurements were begun in Longyearbyen and Ny Ålesund, and very recently site P2 (Kaffiøyra). The CALM programme is designed for observation the reaction of active layer of permafrost to climate changes and by the decision of IPA it will be executed within the confines of projects of International Polar Year 2007–2008.

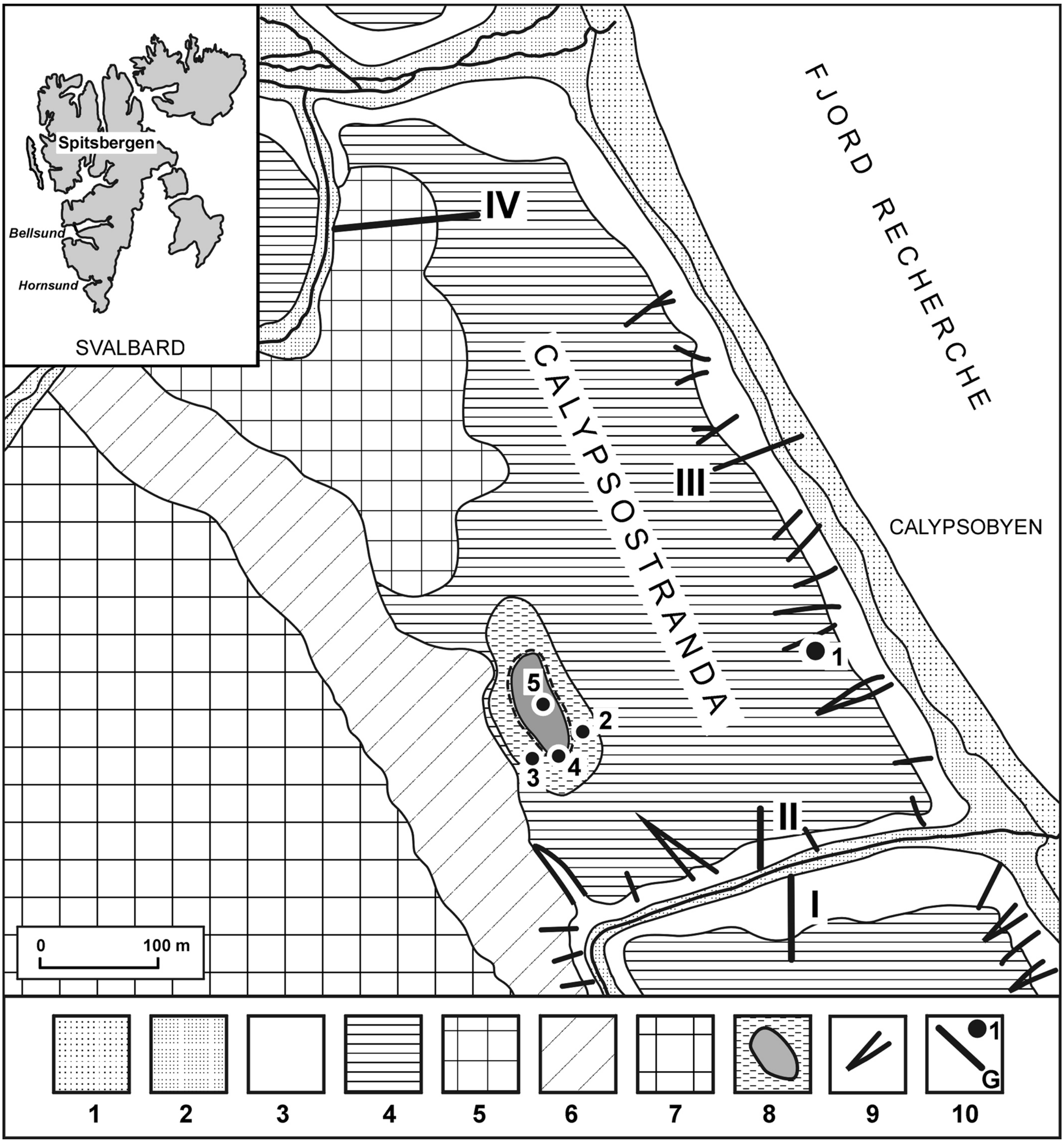

Fig. 13. Main sets of forms and localization of measurement points of active layer of permafrost (Repelewska-Pękalowa, Pękala, 2003)
1 – beach, 2 – floors of valleys and zones of alluvial cones at the cliff base, 3 – cliff and erosive edges of valleys, 4 – dry surfaces of marine terraces, 5 – zones of active solifluction, 6 – periodically wet terraces aggradated with alluvial cones, 7 – slopes and high marine terraces converted by weathering, cryoplanation and erosive processes, 8 – seasonal lake, 9 – erosive dissection, 10 – measurement points.

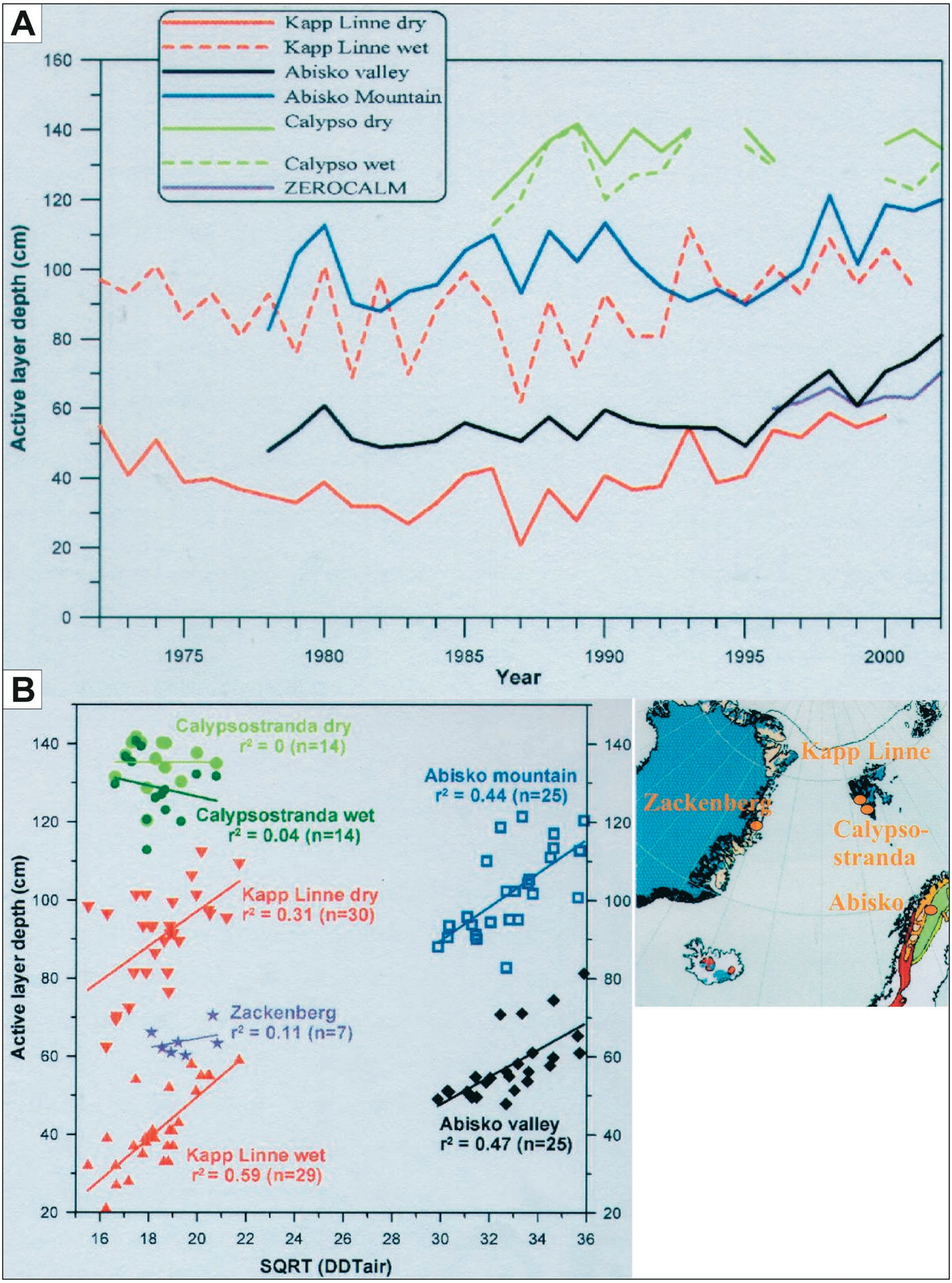

Fig. 14. Thickness of active layer of permafrost in dry and wet conditions, B: Correlation between thickness and air temperature (DDT – Daily Degree Thaw) (Christiansen et al. 2003)

Point 4 – Calypsobyen *77° 33’ 31" N, 14° 31’ 01" E*

Calypsobyen – history and the present day

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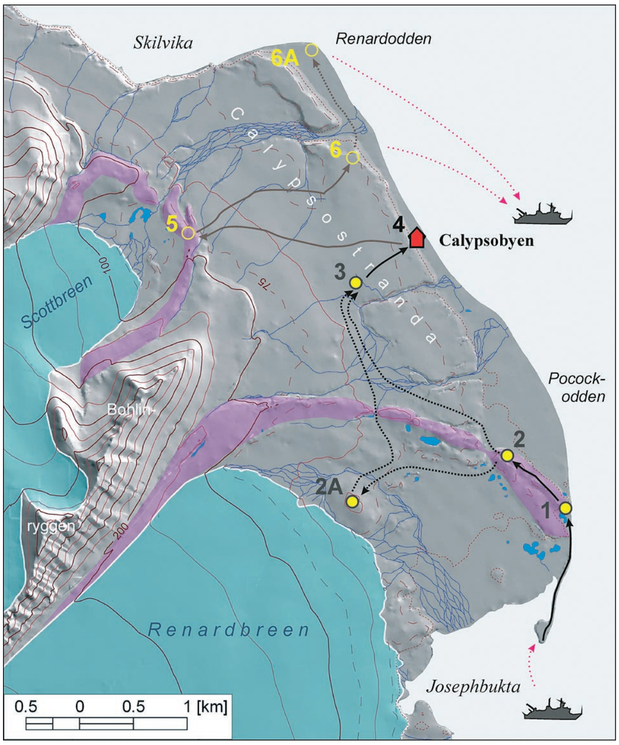

A mining settlement Calypsobyen is situated opposite the mouth of Van Keulen Fiord to Bellsund (Krawczyk, Reder 1989, Roll 1993). It consists of wooden buildings preserved in different conditions (Fig. 1, 7, 15). The oldest buildings reach date back to first years of XX century. They are not big but covered with a ridge roof. That generation of buildings is represented by house on the slope near the mouth of Wydrzyca Stream (E). It was once covered with birch bark and some buildings in the “centre” of the village. Only one of those with two rooms (C) is suitable to live in. The rest (D) were used as the farm buildings.

A bit latter, after 1911 the London company: “*The Northern Exploration Company*” began the economic activity. It planned to exploit out coal and marble in the Bellsund region. Up till now it is possible to find the signs with ‘NEC’ on. They were used do mark the area that belonged to the company. At the end of First World War, some big buildings were built for mine needs. Quite quickly the mine activity was stopped and trappers used existing buildings. Their presence is still noticeable by equipment and traces they had left behind.

Till present only one building on the beach has been preserved. The longer axis is perpendicular to the shore and now it is usable to live in (A) and two-part building that is a bit higher on the slope (B), which has been turned into a store (Fig. 15). At the near surroundings of the buildings there are still some traces to the entrance to the mining shaft, track, coal truck and some mine tools. The relict from that epoch is a big wooden transport boat called “*Maria Teresa”*. There is also a partly ruined building on the raised marine terrace (F). There is a very good view over the fiords, so during the Second World War Germans built a broadcasting station. Its fallen aerial mast has been here near the entrance (Fig. 16).

The buildings in Calypsobyen have been left untouched because according to law all traces of human activity, from before 1946 year, are under legal protection (Roll 1993). They are the heritage park of industrial buildings from the beginning of XX century. The Calypsobyen and the whole NW part of Wedel Jarlsberg Land are within the border of the National

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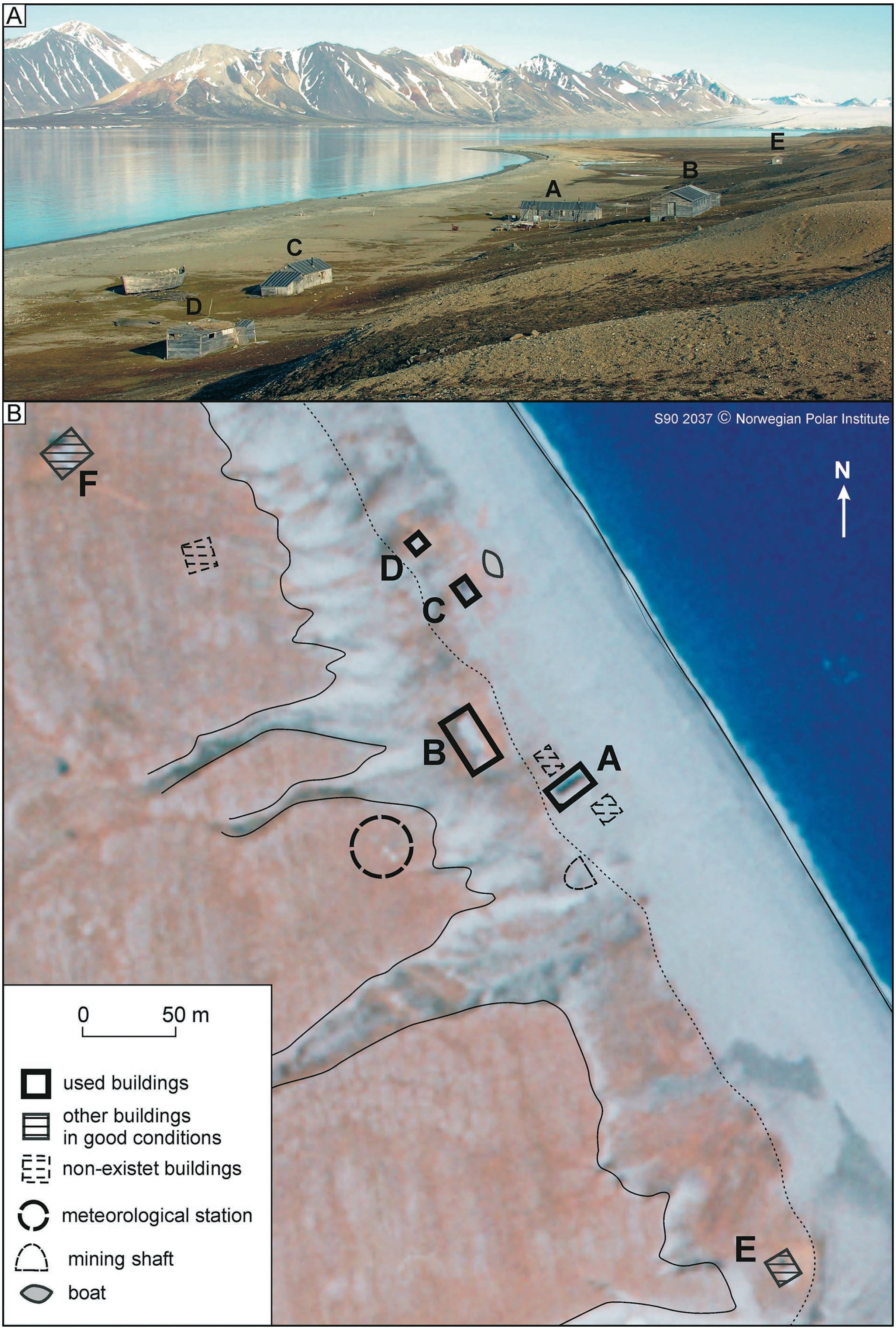

Fig. 15. Calypsobyen. A – general view (photo Piotr Zagórski 2005), B – localisation of buildings (Orthophotomap, Zagórski 2005)

Fig. 16. The building of broadcast station (F) from the Second World War (photo Piotr Zagórski 2006)

Fig. 17. The repair works on the building C (photo Janina Repelewska-Pękalowa 1986)

Park formed in 1973. Because of it there are some important limits for staying and working there.

Under the permit of Governor of Svalbard, since 1986 the buildings in Calypsobyen have been the main bases for Polar Expeditions of M. C. Skłodowska University. The participants of 16 expeditions who have worked here did a lot of necessary repair work to live and work here (Fig. 17). All work was done with a great care to preserve the original look. For a few years the Norwegian administration is responsible for all renovation.

Point 5 – Push moraine of the Scott Glacier *77° 33' 36" N, 14° 26' 11" E*

Recession and development of marginal zone of the Scott Glacier

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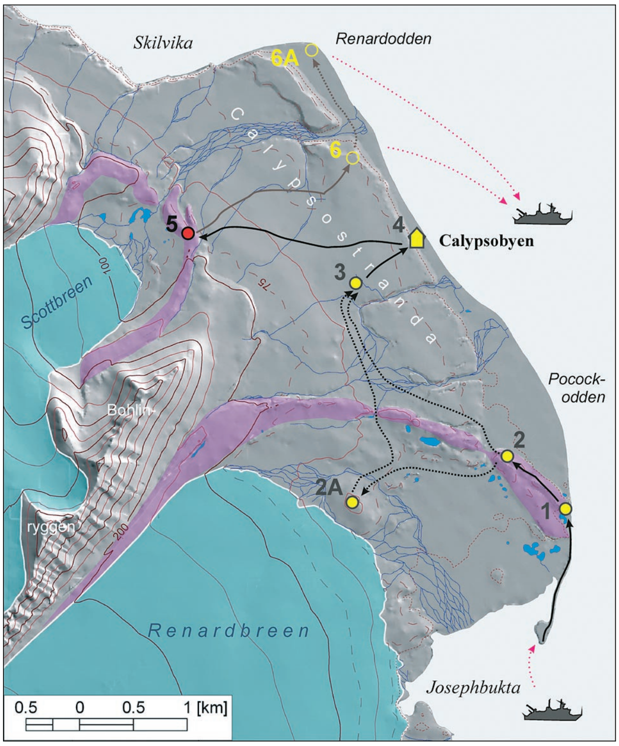

The Scott Glacier filled the valley of NW-SE direction at the lower part and higher – meridional one. From East the Scott Glacier is limited by Bohlinryggen range while from West – Wijkanderberget (Fig. 18). From Southwest, in the zone of low passes it connects with the Blomli Glacier, which fills the upper part of the Blomli Valley. The mouth of the valley of the Scott Glacier closes a few meters' push moraine ridge (ice-cored moraine ridges) cut by the gorge made by outflow of proglacial water. In axial parts its length was about 3.5 km and the wideness at the lower part exceeded 1 km when in the zone of firnfield reached about 1.5 km (Fig. 7).

The Scott Glacier in 2006 included the area of 4.7 km^2, but the largest area was at the end of XIX century (decline of Little Ice Age), and the episode of the surge is dated on 1880 (Liestøl 1993). Within the reach of it was probably all present inside part of the forefield to push moraines, and its area could have been over 6 km^2 (Zagórski, Bartoszewski 2004) (Fig. 19, 20). Since the Little Ice Age till 1936 the average for the whole length of the glacier front the distance of recession was 57 m – maximum 148 m. For the period of 1936–1960 the speed of recession was 1.8 m a^{-1}, as the mean recession – 44 m (maximum 120m – 5 m a^{-1}).

For the period 1960–1987 the mean recession of the glacier front on its whole distance was 162 m, (6–7 m a^{-1}), maximum 400 m (15 m a^{-1}). Those data can be incompleted because according to some archival data (the photo taken in 1963 and published in the book by J.Landvik et el. 1992, page 337), the Scott Glacier was just after the stage of advance (surge type). So in fact since 1960s we can talk about the beginning of the fast recession of the Scott Glacier and revealing inside part of the forefield. The following period 1987–1990 was characterised by the acceleration of the recession for the whole length up to 28 m, what corresponds to 9.3 m a^{-1} (maximum 68 m, 23 m a^{-1}). Since the end of XIX century till 1990 the surface of the Scott Glacier was reduced by 13% of the primary area (Zagórski, Bartoszewski, 2004).

Systematic studies and measurements of the Scott Glacier are conducted since 2000 and show that its front during the period of 1990–2006 moved back on

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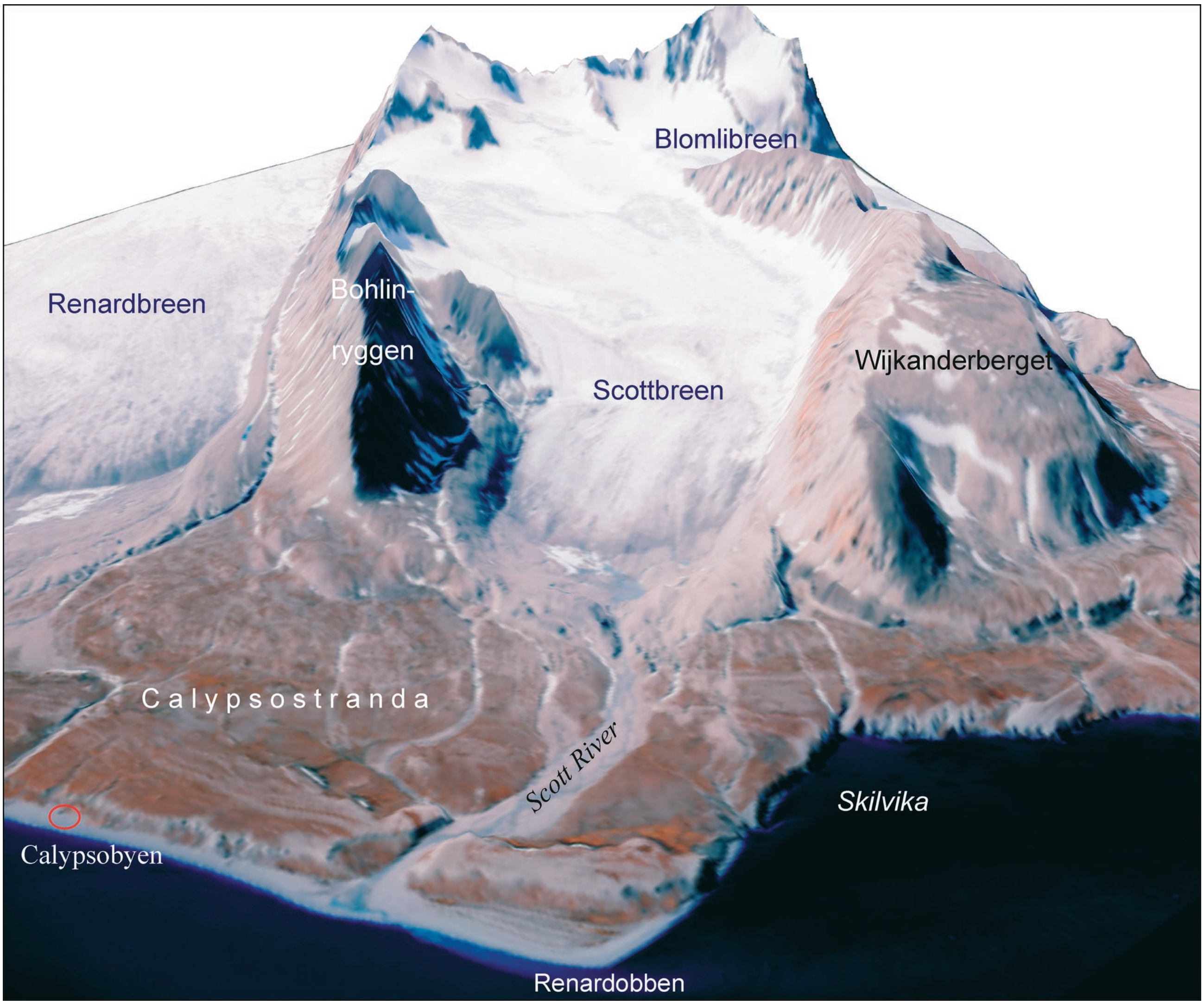

Fig. 18. Spatial model of the Scott Glacier and Calypsostranda made on the basis of combined the digital model of the terrain with aerial photo from 1990' (Zagórski 2002)

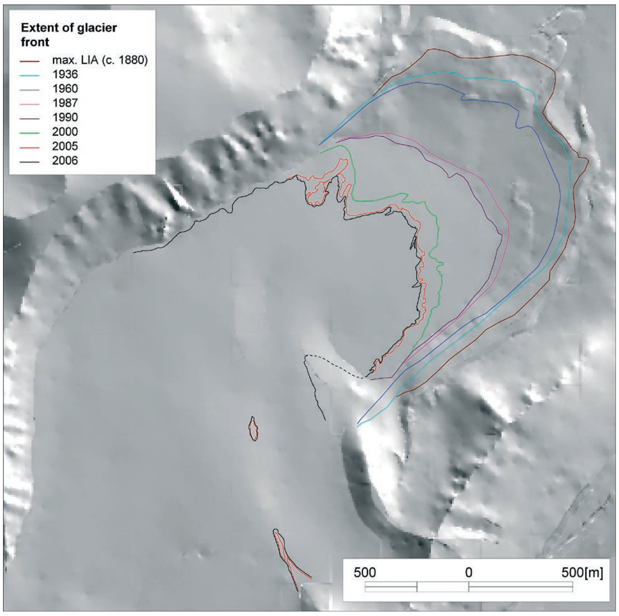

Fig. 19. The extent of the Scott Glacier fronts combined on the basis of archival data and GPS measurements (Szczęsny et al. 1989, Merta et al. 1990, Zagórski, Bartoszewski 2004, Zagórski 2005)

average 230 m on its whole distance, while the maximum was 440 m (28 m a^{-1}). The last measure period is marked especially clearly when the mean speed of recession of the glacier front reached 21 m, and maximum even 140 m. The main reason for quick decrease of the thickness of the glacier ice is the relief of the bedrock with the zone of rocky steps at the bottom of the Wijkanderberget (Fig. 19, 20).

The relief of the forefield of the Scott Glacier is much less diverse than the forefield of the Renard Glacier. The dominant element is frontal moraine ridge (Fig. 18, 21). The material of the moraine is on the bedrock of former denudation-structure layers of roche moutonnée character. The ridge of the lateral moraine accompanying the glacier tongue from southeast rises 60 m above the surface of the glacier.

The frontal moraine, but especially the lateral one deposited along the slopes of Bohlinryggen are compound forms came into being in two different phases

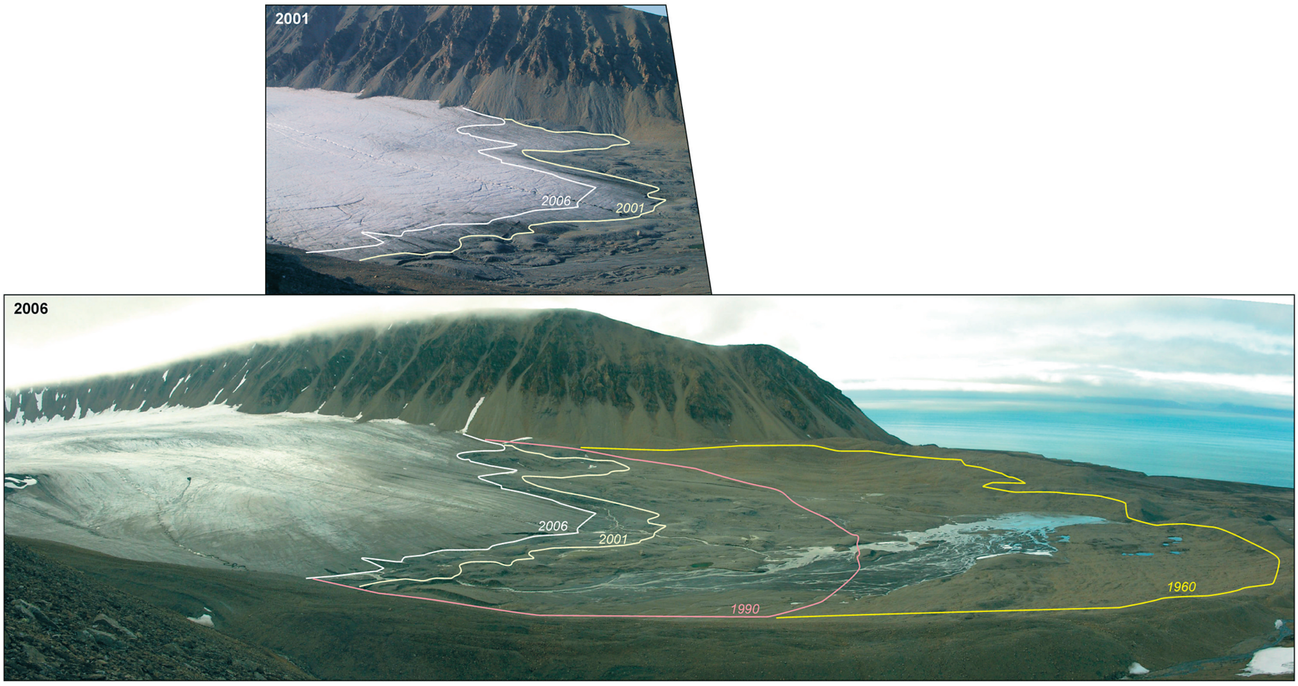

Fig. 20. The forefield of the Scott Glacier. The view from Bohlinryggen (photo Stefan Bartoszewski 2001, Piotr Zagórski 2006)

of the glacier transgression. The young ice-moraine sediments, partially pushed, were accumulated during the fast advance of the glacier onto its forefield in XIX century. They cover here a bit older moraine series, which probably arose during the advance of the Scott Glacier in the earlier phase of the Little Ice Age (Fig. 20). The frontal moraine from inside gradually and softly came onto the ground moraine with the traces of flow in the direction of the only active gorge. The more distinct element of the relief here is only the course of little hills that marks one of stages of the glacier recession (Fig. 21).

The internal marginal zone looks like a hollow: south-east part of the area is lower and a lot of it is flooded with water, north-east part is some meters higher from about the line of the gorge (Fig. 21, 22). This zone is made of mainly ground moraine, locally distinctly fluted. Some active riverbeds of the 2–4 m

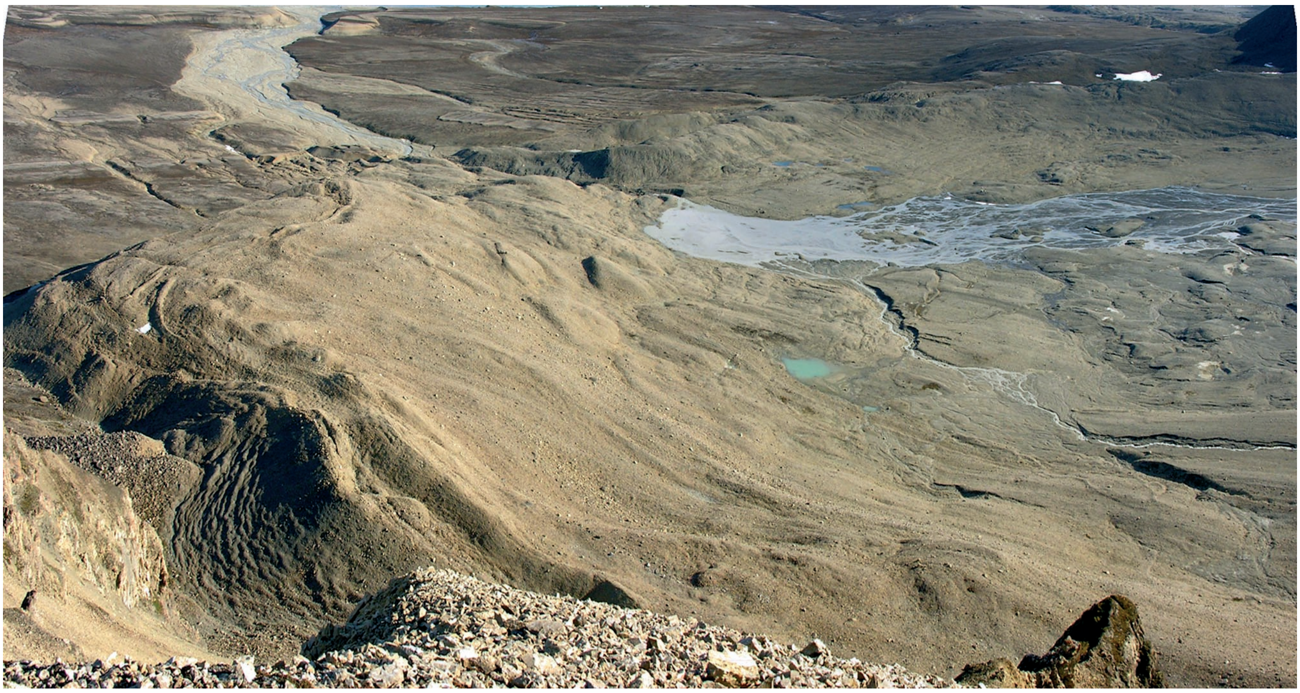

Fig. 21. The forefield of the Scott Glacier – the view from Wijkanderberget. Varied zone of the push moraine and the area of contemporary forming inner sandur (photo Piotr Zagórski 2006)

Fig. 22. The marginal zone of the Scott Glacier (photo Piotr Zagórski 2006)

depth cut it. The grooves of fluted moraine in this region are of different character than those observed on the forefield of the Renard Glacier. They are much bigger, and the height of single ridges reaches 50–60 cm. The orientation of the grooves follows the axis of the valley and the main direction of the glacier recession. The orientation, material layout and size can show that in that forefield Renard Glacier region they came into being as the result of filling former supraglacial troughs with material from ablation moraine. The depressions on the surface of the moraine are filled with stagnating water, which is the result of melt out phase. Sometimes the thin layer of silt is accumulated. The other fragments of moraine do not have signs of washout.

In the central part of the forefield, in the axial part of the valley the floodwaters exist where fine-grained material is sedimented. In the zone between frontal moraine and the glacier the typical sandur has not been developed yet (Fig. 20, 21). This is rather the zone of cut and washout of the ground moraine and sand little cons.

At the final part of the glacier tongue some ridges were observed. They are large and accumulative, similar to kame, made of fluvioglacial material and deposited on ice that melts out slowly. They are transverse to the axis and movement of the glacier. Their height is from some centimetres to about 2 m. They are built with fine-grained, irregular stratified material originated from the washout of the ablation moraine. They have significant asymmetric structure: proximal slope is a very gentle continuation of the slope, the distal slope is steep and falls at the angle of 30°–45° into the direction of the inside sandur. The similar set of forms of similar topographic layout due to glacier front is observed on the distance of some tens of metres on the northwest from the present edge of ice. Their origin should be connected with some phenomena that are noticed only sporadically. It is probable they are of extreme character as the result of unusually dynamic and efficient morphologically water flow on the surface of the glacier. It accompanies the beginning stage of ablation during Spring and early Summer. The steep distal slope could arise as the result of damming the outside part of the ridge against the thick cover of naledi or thick cover of snow on the glacier forefield.

As it was marked earlier the main outflow from the glacier takes place from the SE side. Between the glacier and the lateral moraine the kame terrace was made. In the middle part of the forefield, there is a large sandur fan located aslant to the glacier front and only periodically active. The flowing river in the edge zone of the cone cut into the moraine sediments and now the cone rises 40–50 cm higher than the level of the ground moraine.

Relief and development of Calypsostranda

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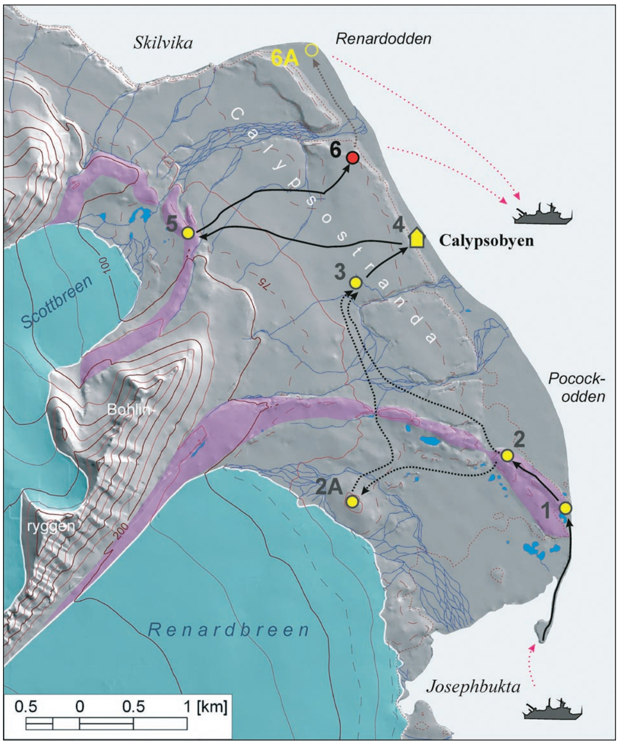

The direct effect of sea level changes connected with glacial-interglacial cycles and glacioisostasy are the raised marine terraces. Very often they develop systems of steps within which there are characteristic storm ridges marking former shoreline, dead cliffs and paleoskerries related to marine abrasion. On Calypsostranda area seven terraces can be distinguished. The range of their height is between 2 and 85 m a.s.l. (Zagórski 2002, Zagórski et al. 2006) (Fig. 23).

The highest is the terrace VII (70–85 m) developed as slightly slanting abrasion platform. In the region of the Bohlinryggen, it neighbours to denudation level (80–90 m and 125–140 m) and shows clear traces of glacial remodelling. On the forefield of the Scott Glacier it was aggradated partly with ice-cored moraine ridges (Fig. 24). The abrasive character belongs to the terrace VI (height 50–60 cm). The age of those terraces is difficult to state due to a lack or vestigial occurrence of accumulative sediments. Their surfaces show traces of distinct glacial remodelling so the guess of pre-Weichselian age.

The marine terraces (V–I), which are located lower, are of accumulative character. They are made of various sediments as regards genesis and stratigraphy. It indicates multistage of development of the surfaces in Late Pleistocene when the periods of marine inundation interlaced with the advances of glaciers.

The marine terrace V (40–50 cm) probably marks the maximum limit of sea inundation from about 12 ka BP, what means after the last maximum Weichselian deglaciation (Fig. 25). That is the slightly slanting plain in the lower part accumulative changing into abrasive-accumulative one. In its morphology it can clearly distinguished the storm ridge of maximum width 60 m. Its length is at the foot of a denudation level 110–130 m (Wijkanderberget region) to Skilvika where it was cut abrasively.

The dominant terrace IV (30–40 m) is accumulative, nearly flat with fossil storm ridges and covered by fluvioglacial and marine sediments (Pleistocene and Holocene), which are lying on Palaeogene and Precambrian bedrock. Glacial sediments (medial moraine) are connected with the conjunction of glacier tongues from the region: Recherche Fiord and Van Keulen Fiord (Fig. 25). Near the Renardodden the terrace IV is limited by dead marine cliff modelling by solifluction. From the Skilvika terrace IV is

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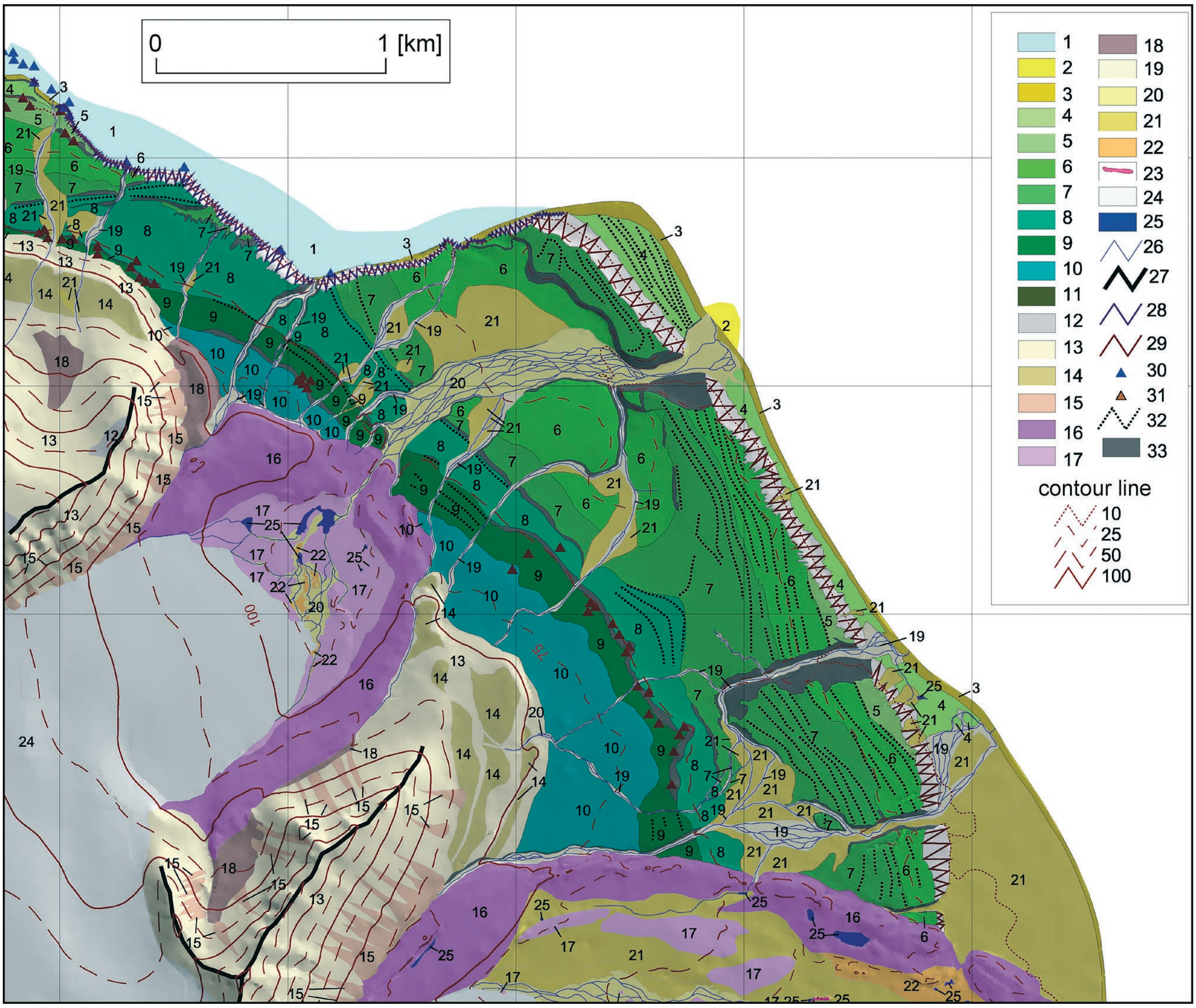

Fig. 23. Geomorphological map of the forefield of the Renard Glacier (Zagórski 2002)
1 – contemporary abrasion platform, 2 – tidal flat, delta cons, 3 – contemporary storm ridge, 4-terrace I (2–8 m), 5 – terrace II (10–20 m), 6 – terrace III (25–30 m), 7 – terrace IV (30–40 m), 8 – terrace V (40–50 m), 9 – terrace VI (50–65 m), 10 – terrace VII (70–85 m), 11 – terrace VIII (105–120 m), 12 – superficial flattening, 13 – slopes, 14 – denudation-structure level, 15 – talus cones, 16 – ice-cored moraine ridges, push and lateral moraines, 17 – ground and ablation moraines, 18 – rock glaciers (nival), 19 – floors of pronival valleys, 20 – contemporary sandur plains and fans, alluvial cones, 22 – kame, 23 – esker, 24 – glaciers, 25 – lakes, 26 – rivers, 27 – ridges, 28 – active marine cliffs, 29 – dead marine cliffs, 30 – skerries, 31 – paleoskerries, 32 – old storm ridges, 33 – edges.

Fig. 24. The view of Calypsostranda from Wijkanderberget (Photo Piotr Zagórski 2006)

destroyed intensely by abrasion. In that part of Calypsostranda it surrounds circularly distinct plain depression within which the lower terrace III of 25–30 m height was distinguished. Its fragments occur also between the valley of the Scott River and moraine ridges of the Renard Glacier and have character of slightly inclined accumulative surface with fossil storm ridges (Fig. 23, 25). On the distance from the Calypsobyen to extramarginal sandur fans of the Renard Glacier the terrace III merge into the lower terrace II (10–20 m). The dead cliff from east of Calypsostranda proves the intensity of abrasion of both terraces III and II in early Holocene.

The lowest terrace I (2–8 m) is a beach around the whole shore between Josephbukta and the Renardodden (Fig. 23). On the distance from the vast extramarginal sandur fans of the Renard Gla-

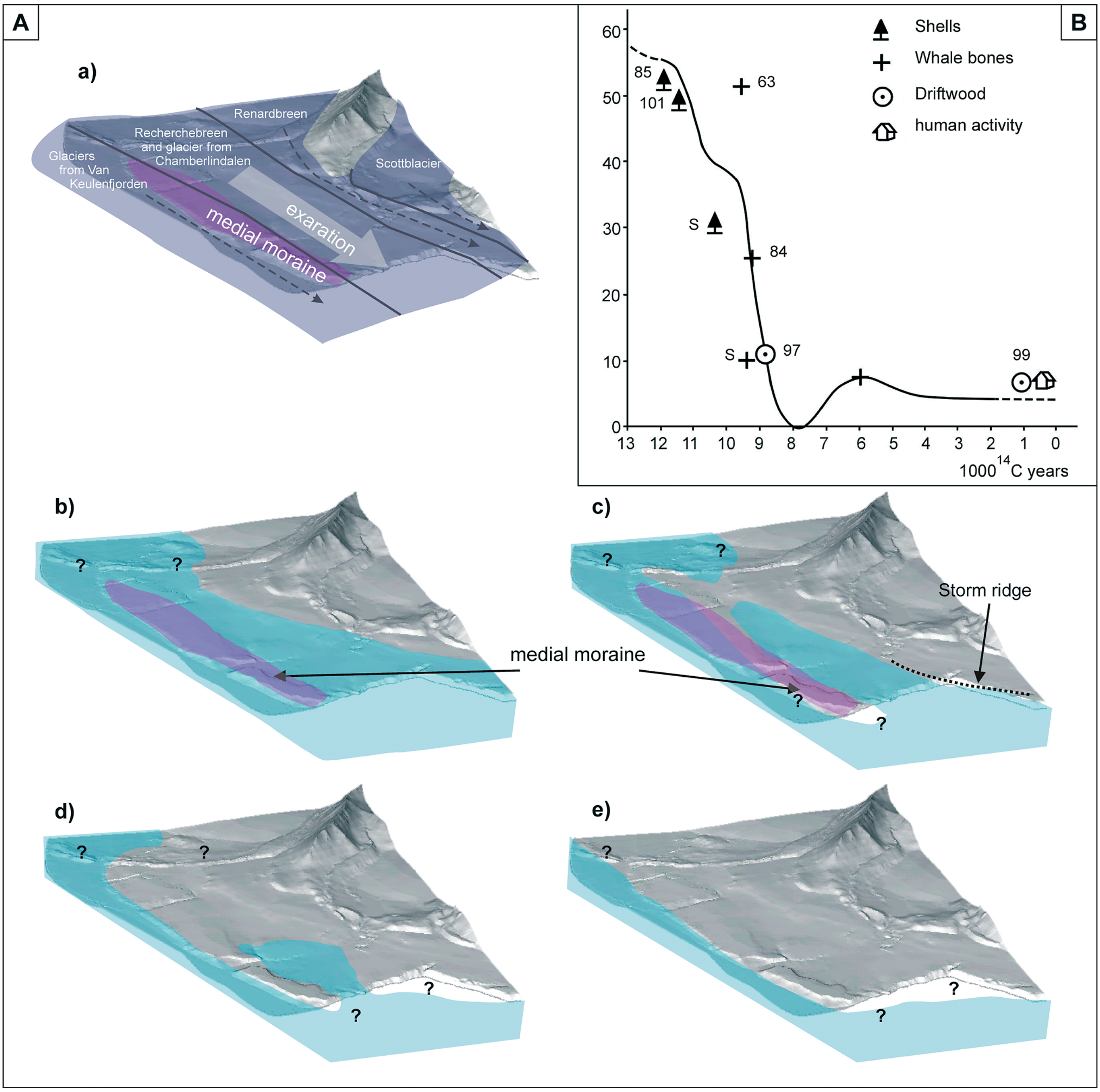

Fig. 25. A. Phases of development of Calypsostranda at the decline of Weichselian and in Holocene (Zagórski 2002) a – the zone of influences of the glaciers during the glacial maximum of the Late Weichselian (about 20 ka BP), b – shoreline at 12 ka BP (development of terrace V), c – shoreline at 11–10 ka BP (development of terrace IV), d – shoreline at 10–9 ka BP (development of terrace III), e – shoreline at 8 ka BP (development of terrace II); B. Shoreline displacement curve for north-western Wedel Jarlsberg Land (Lognedallen) (after: Salvigsen et al. 1991)

cier in the Pocockodden region to the mouth of the Scott River, the terrace I is build of two old storm ridges divided by two depressions developed as lagoons. In the neighbourhood of the Renardodden, as the result of intensive accumulation some now fossil ridges were made. On their surface there are numerous settlements sites from XVII and XIX century (Krawczyk, Reder 1989).

Point 6A – Renardodden *77° 34' 21" N, 14° 28' 49" E*

Present morphogenesis of the shore and the importance of archaeological sites for reconstructing the stages of development

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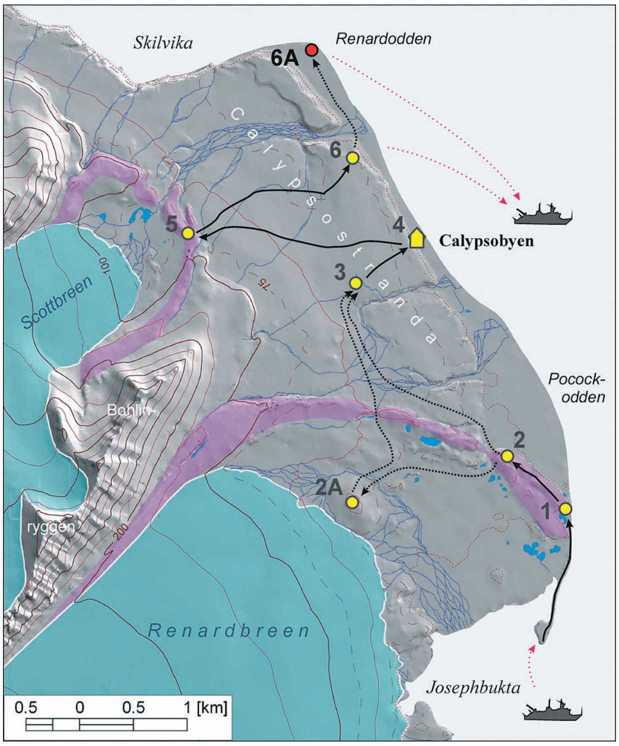

The Renardodden Region is unique example of the influence of marine factors on development and conversion of shore zone of accumulative character. The development of terrace I (2–8 m) was connected with the rise of the delivery of the material by the proglacial river of the Scott Glacier during the Little Ice Age. The additional reason of so big deposition could have been the change of the angle of the pass of the waves to the shore, which force accumulation. Here, longshore currents play the important role. Their zone of convergence exists in the section of the highest bend of the shore (Harasimiuk 1987, Harasimiuk, Jezierski 1991, Harasimiuk, Król 1992, Jezierski 1992, Zagórski 2004) (Fig. 26). The old storm ridges are well developed in that part of the shore are cut abrasively from the north and are aggradated with present storm ridge.

To estimate the role of marine processes in the Renardodden region it was crucial to recognise numerous archaeological sites here (Krawczyk, Reder 1989, Jasinski et al. 1993). Archaeological data show intensive exploration of this area since XVII century. The nearest to the shoreline zone is located the site Renardodden 1 (Fig. 27). It is remain of the Russian station of walrus hunters dated on the first half of XIX century. Probably, the building was out of reach of storm waving, but after the latter rise of activity of the abrasive processes caused the most probably by the changes of the sea level, the old storm ridge was destroyed and storm waves dragged pieces of bricks and organic remnants over the tidal flat zone (Jasinski, Zagórski 1996). The sediments of the following storm ridge, now intensively transformed, cover traces of the dragged occupation layer. Such conditions was kept till the beginning of 60s, so since the moment of start of quick recession of the Scott Glacier (Reder 1996, Zagórski, Bartoszewski 2004). Till 1990 the intensification of the delivery of the material caused aggradation of the cape of over 20 cm (Fig. 26). Yet the last years show that the delivery of

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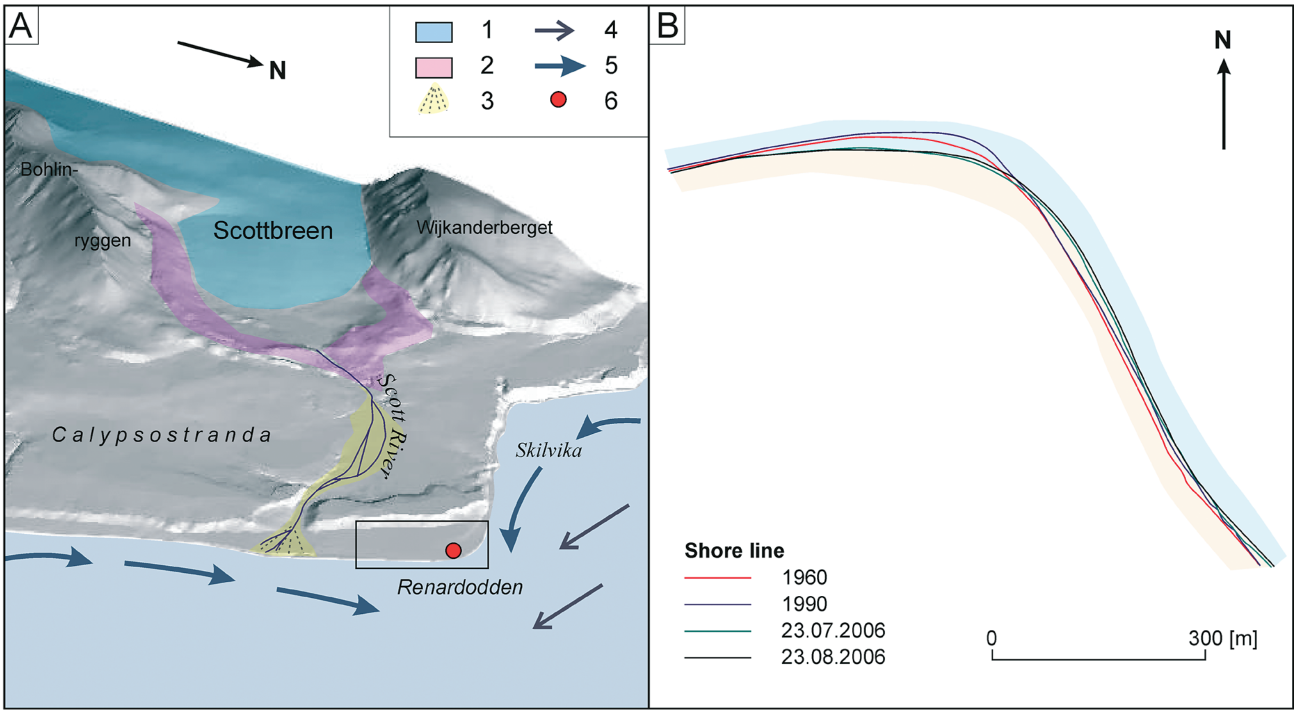

Fig. 26. A. Main factors that influence on formation of the shore in the Renardodden region
1 – glacier surface in 1990, 2 – frontal moraine ridges, 3 – sandurs, 4 – drift of western winds, 5 – directions of displacement of the long-shore currents (after: Harasimiuk, Jezierski 1998, 1991), 6 – localisation of the archaeological site Renardodden 1.
B. Changes of geometry of the shoreline combined on the basis of archival data and GPS measurement (Zagórski 2007)

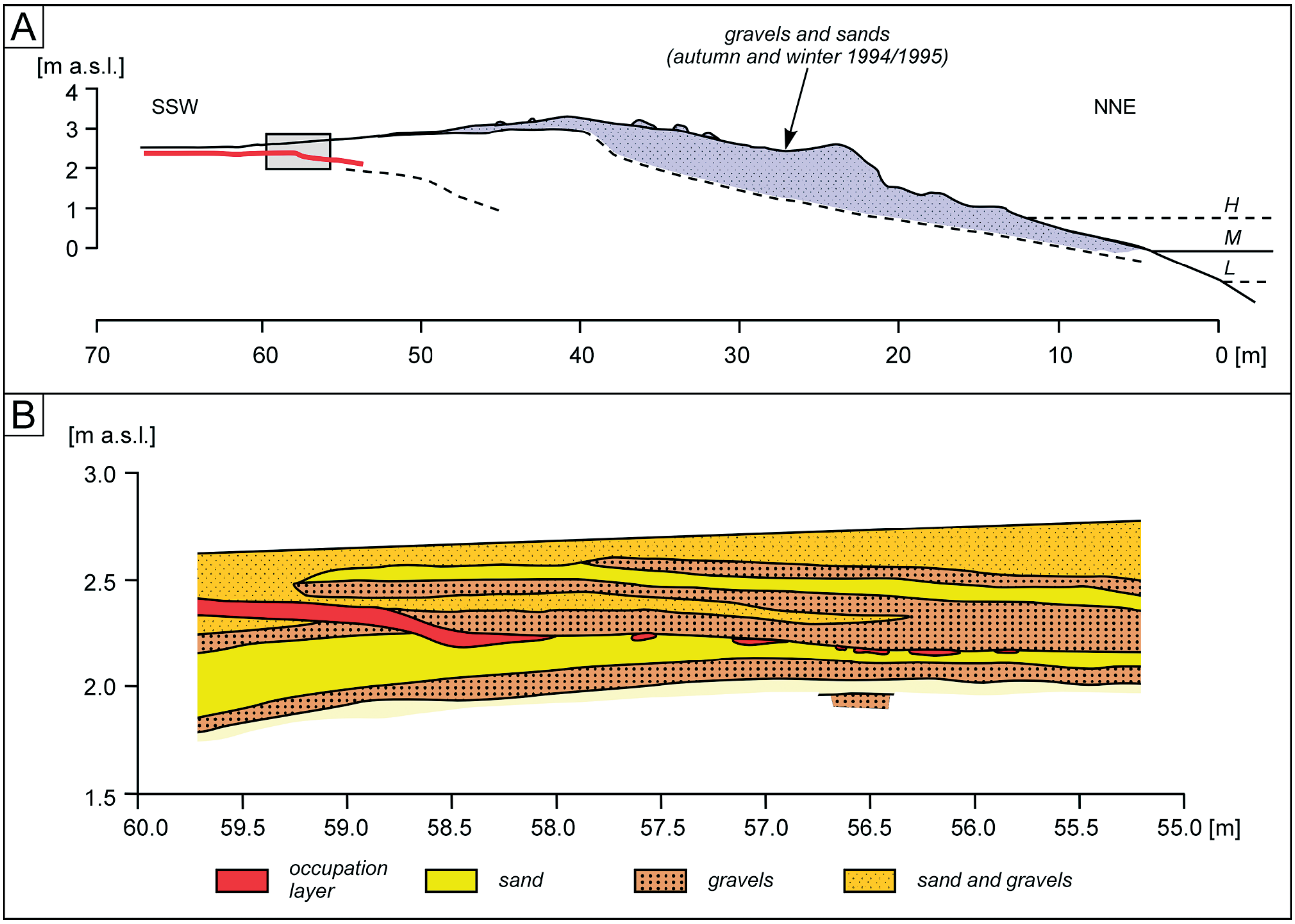

Fig. 27. Archaeological site Renardodden 1
A – Geological profile across the storm ridge, B – Geological profile across the fragment of storm ridge with dragged occupation layer (after: Jasinski, Zagórski 1996).

the material from the marginal zone of the Scott Glacier falls but the importance of marine processes rises (waving, longshore currents). The archival data (maps, air photos) and GPS measurement show the changes of geometry of the Renardodden. Strong cut of the part from the Skilvika is noticed but the section in the direction of the mouth of the Scott River is aggradated (Zagórski 2007).

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