Kazimierz Pękala
Janina Repelewska-Pękalowa
Piotr Zagórski

2.2. Quaternary deposits and stratigraphy

Genetic classification

In contrast to the southern tip of Spitsbergen the NW part of Wedel Jarlsberg Land has been relatively poorly explored region. Scientific interest in this region dates back to the second half of the 20th century (e.g. Różycki 1957; Marcinkiewicz 1961, Troitsky *et al.* 1979; Salvigsen *et al.* 1991; Landvik *et al.* 1992).

The intensive scientific exploration of the area by members of Maria Curie-Skłodowska University Polar Expeditions has initiated in 1986. The comprehensive programme of environmental studies included also investigations of the genetic diversity and age of deposits in the context of the Quaternary stratigraphy of Spitsbergen. Quaternary deposits found in the Bellsund region are of various age and origin: glacial, fluvial and fluvioglacial, marine, slope and aeolian (e.g. Flood *et al.* 1971; Szczęsny 1987; Ozimkowski & Merta 1988; Szczęsny *et al.* 1989; Dallmann *et al.* 1990; Merta *et al.* 1990). The list of academic papers has been presented in the bibliographic index by Repelewska-Pękalowa & Pękala (1997) and Zagórski (1998).

Glacial deposits. Currently glacial deposits are represented by glacial tills, rock blocks and boulders mixed with gravels and form frontal, lateral and ground moraines in forefields of retreating glaciers (Chlebowski 1989b; Zagórski *et al.* 2012). The ground moraines composed of tills, sands and rock blocks were exposed between the frontal moraines and glacier front covered with ablation moraines (Merta 1988abc, 1989).

Two Holocene series of frontal moraines were distinguished: the belt of older moraines composed predominantly by till blocks and the belt of younger moraines in the form of ice-cored moraines associated with the Little Ice Age (LIA) advance. The older moraines are deposited on regolith or directly on bedrock, that has been reshaped into roches moutonnées by glaciers passing the area during several Pleistocene and LIA advances. Whereas, the younger moraines are often deposited over relict soils and fossilised tundra covers (Pękala & Repelewska-Pękalowa 1990; Dzierżek *et al.* 1990ab). In many cases the frontal and ablation moraines of present-day glaciers are evolving into glacier-derived rock glaciers (Dzierżek & Nitychoruk 1987ab, 1990).

The lithological characteristics, age and stratigraphic position of local tills were determined in several sites spread across the study area:

- in trenches excavated in raised marine terraces in Dyrstaddalen (Reder 1990) (Figs. 2.2.1 and 2.2.2);
- in coastal cliffs of Skilvika (Pękala & Repelewska-Pękalowa 1990; Landvik *et al.* 1992) (Fig. 2.2.3);
- in trenches excavated across Calypsostranda (Troitsky *et al.* 1979; Pękala & Repelewska-Pękalowa 1990) (Fig. 2.2.4);
- in exposures digged in Renardbreen moraines (Dzierżek *et al.* 1990a; Pękala & Repelewska-Pękalowa 1990) (Fig. 2.2.5, Photo 2.2.1A);
- and from pingos formed in Chamberlindalen (Pękala & Repelewska-Pękalowa 1990) (Fig. 2.2.6).

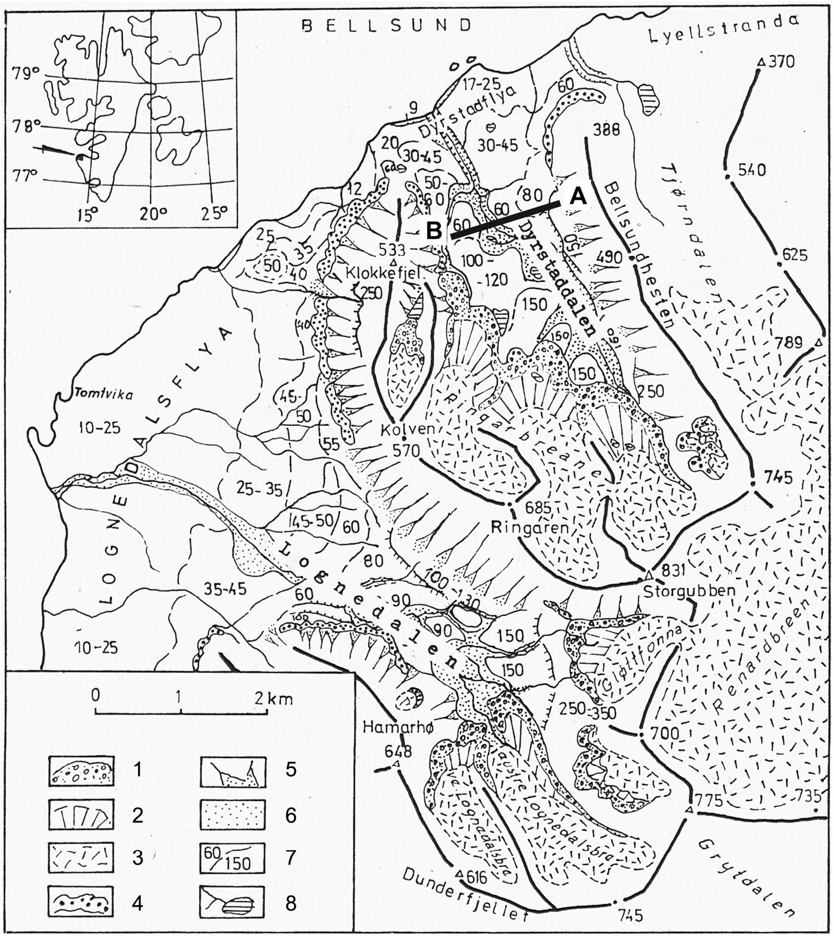


Fig. 2.2.1. Geomorphological map of the Dyrstaddalen and Lognedalen (Pękala & Reder 1989): 1- terminal moraines, 2- ground and ablation moraines, 3- glaciers, 4- nival moraines and rock glaciers, 5- talus fans, 6- outwash plains, 7- marine terraces and denudation levels, 8- streams and lakes; A-B- cross section (see: Fig. 2.2.2).

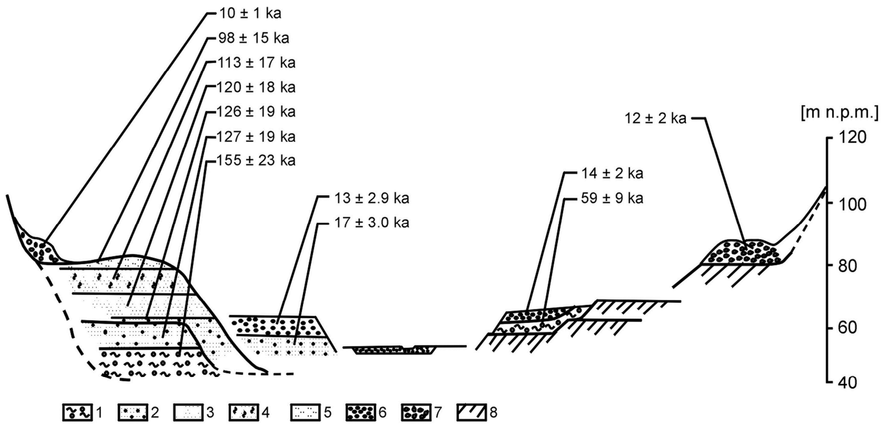


Fig. 2.2.2. Schematic geological section of Dyrstaddalen (Reder 1990): 1- till, 2- sands with coal, 3- sands, 4- sands and dusts, 5- stratified sands, 6- gravels, 7- nival moraine, 8- rocky bases.

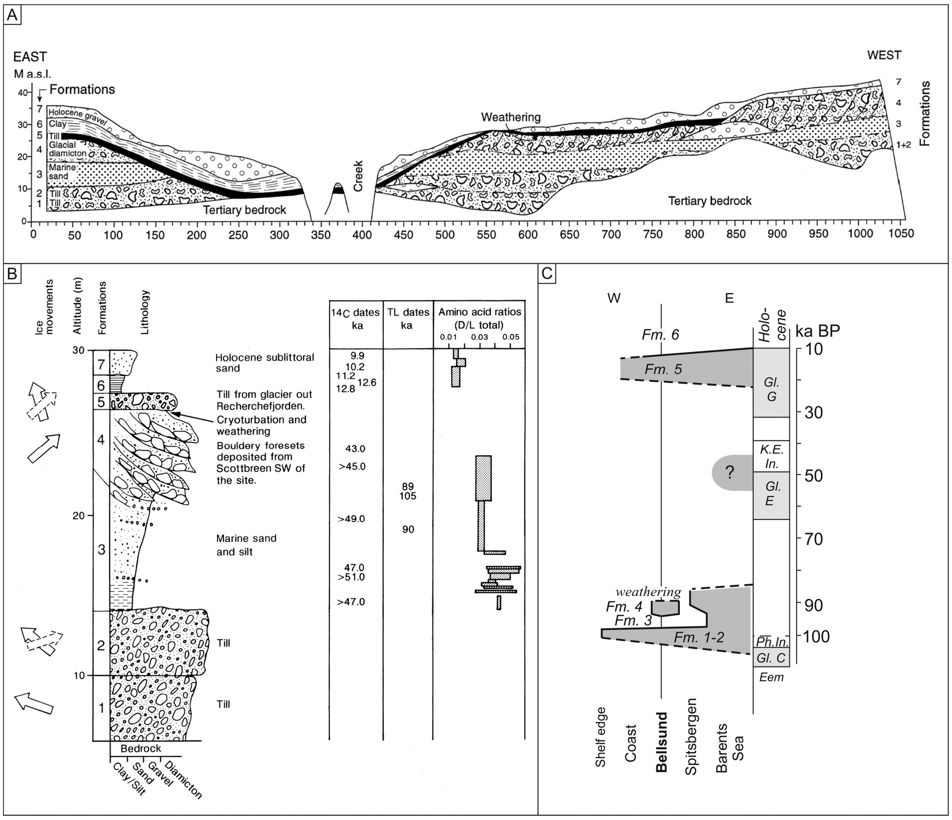


Fig. 2.2.3. A- Cross-section along the shore at Skilvika (after: Landvik *et al.* 1992; Mangerud *et al.* 1998); B- composite stratigraphy for Skilvika, slightly modified from Landvik *et al.* (1992); amino acid D/L ratios are plotted as the mean with one standard deviation for samples from each bed (Mangerud *et al.* 1998); C- the main glacial episodes based on the interpretation of deposits in the Skilvika cliff: Gl.- glaciation, K.E In.- Kapp Ekholm Interstadial, Ph. In.- Phantomodden Interstadial, Fm – formations (Landvik *et al.* 1992).

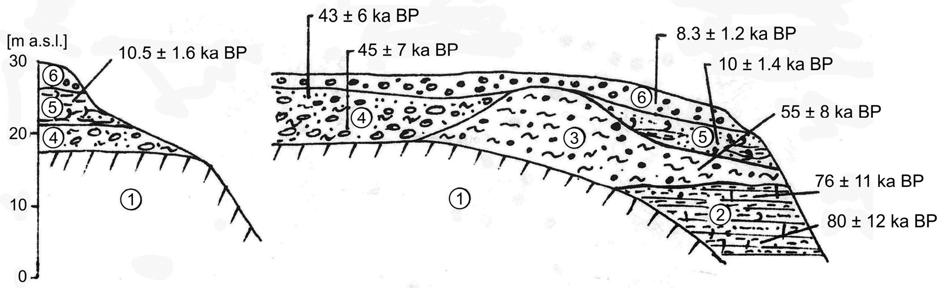


Fig. 2.2.4. Profiles and TL age of Quaternary deposits in the erosive cut of the Tyvjobekken in Calypsobyen (Pękala & Repelewska-Pękalowa 1990): 1- bedrock (Tertiary), 2- marine deposits (loams and dusts with strongly crumbled shells), 3- boulder clay, 4- gravels and fluvioglacial sands, 5- sands and marine loams with shells, 6- beach gravels.

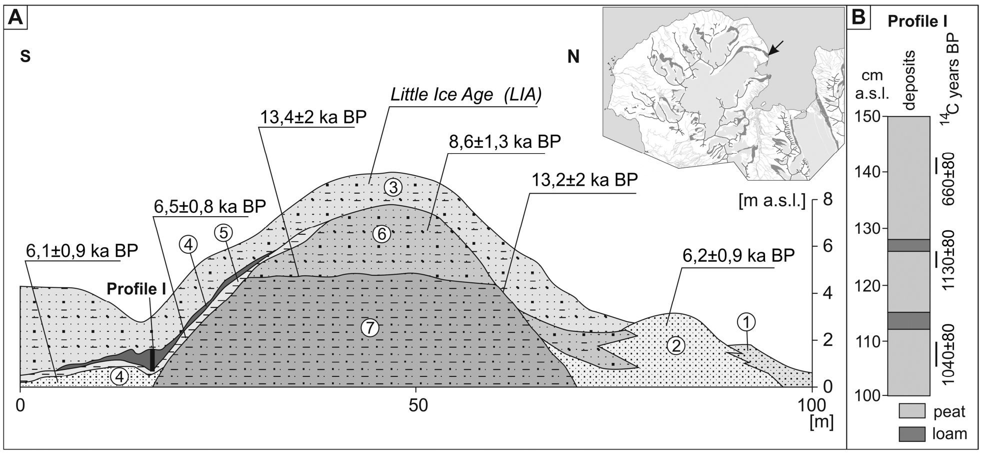


Fig. 2.2.5. A - the geological cross-section of frontal moraine of the Renardbreen (Pękala & Repelewska-Pękalowa 1990): 1- present storm ridge 2- fossil storm ridge, 3- glacial till (Little Ice Age), 4- pushed occupation level of whale settlement with fossil flora (profile 1), 5- clay, 6- glacial till, 7- glacio-marine deposits; B- profile of organic sediments of the Renardbreen-1 site (Dzierżek *et al.* 1990a).

Fluvial and fluvioglacial deposits. They are characterised by high lithological variability and ascribed to specific landforms: inner and outer outwash plains, eskers and kames composed of mixed gravel and sand deposits and tidal flats and deltas composed mainly by sands and muds (Łanczont 1988ab; Warowna 1994) (Photo 2.2.1B). Sediments from outer outwash plains are often interlocked with or superimposed on alluvial and deltaic sediments as observed in Vestervågen tidal flat (Vestervågøyra, Chamberlindalen) (Photo 2.2.1C). The diversity of those forms is dependent on the dynamics of fluvial processes (Zagórski *et al.* 2012). Fluvial and fluvioglacial deposits are important stratigraphic members.

Marine deposits. They form a low present-day marine terrace (0-5 m a.s.l), and are often superimposed on shore platforms preserved on higher, old marine terraces (Zagórski 2002) (Appendix 2, Photo 2.2.2A). Due to the changing character of coastal dynamics most of the marine sediments are characterised by high lithological variability. The lower marine terrace is usually composed of pebbles and gravels or gravels, whereas the raised terraces are often made of clays, sands with marine fauna and mixed sand and gravel. Deposits on raised marine terraces represent various stages and conditions of coastal zone evolution that occurred during the Quaternary (Harasimiuk 1987; Harasimiuk & Jezierski 1991; Jezierski 1992, 1993; Zagórski 2002, 2004a, 2007ab). In some of the sites the marine deposits were mixed with glacial tills (Landvik *et al.* 1992) (Photo 2.2.2B).

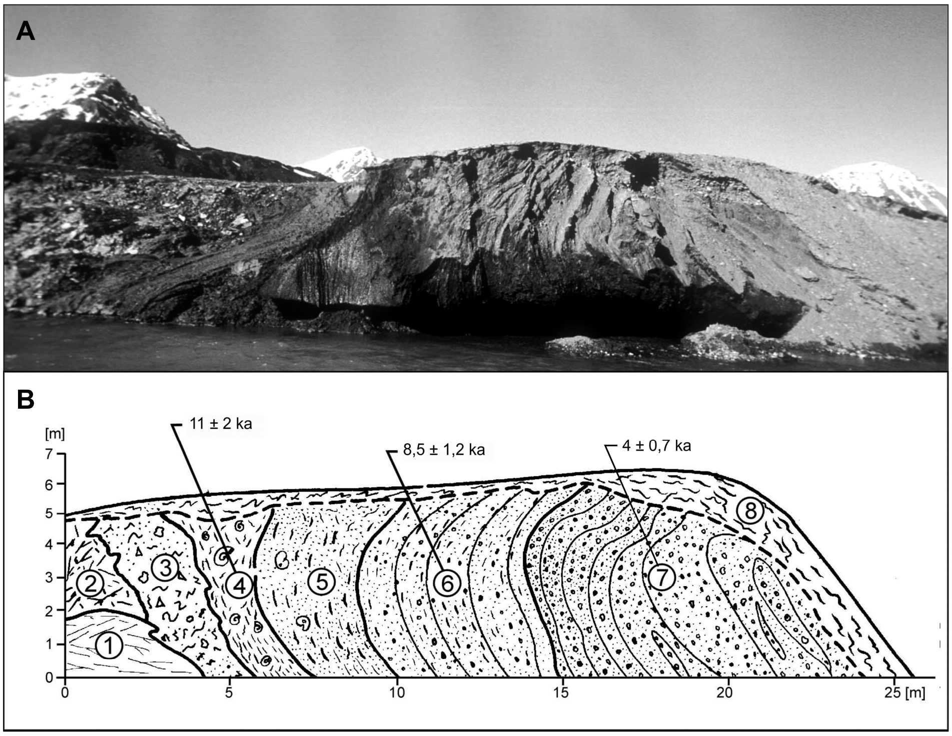


Fig. 2.2.6. A- pingo of the Mackenzie delta type at Chamberlindalen – location see: Fig. 5.3.16, pingo No. 9 (Photo K. Pękala); B- profile and TL data of the Quaternary deposits dislocated in consequence of the development of pingo (Pękala & Repelewska-Pękalowa 1988b): 1- ice, 2- crushed metamorphical silts, 3- boulder clay, 4- marine silts with shells, 5- sands and marine silts with shells, 6- sands with gravels, 7- sandy gravels and gravel lenticles (delta sediments), 8- solifluctional cover.

Present-day bays and lagoons are filled with rhythmically layered varves e.g. Fagerbukta lagoon and bay in front of Renardbreen. Varves cover older deposits of predominantly glacial origin. The detailed study of recent sedimentation in Recherchefjorden were conducted in 2011 and 2012 and focused on lagoon in front of Recherchebreen, Vestervågen and Josephbukta (Photo 2.2.1C).

Slope deposits. The origin of slope deposits is linked with the operation of weathering and gravitational processes on steep slopes and with solifluction on gentle slopes. Steep slopes are covered with rocky blocks, coarse talus fans, landslides and rock glaciers described in detail in Chapter 5.1.

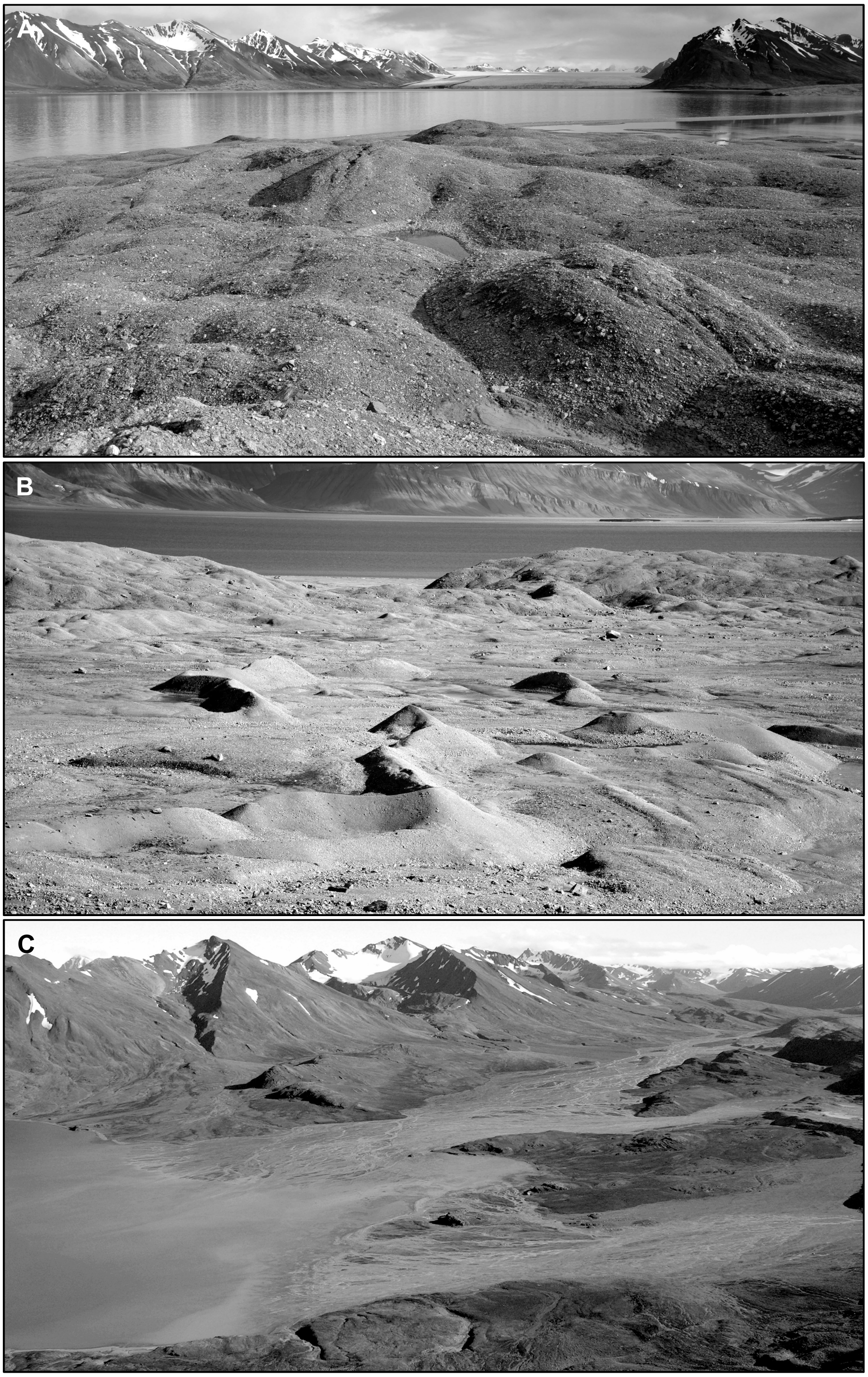


Photo 2.2.1. A- frontal moraines of Renardbreen (Photo P. Zagórski 2012), B- forefield of Renardbreen – eskers (Photo P. Zagórski 2011), C- fluvial and fluvioglacial deposits – Chamberlindalen (Photo P. Zagórski 2006).

Photo 2.2.2. A- coastal deposits – terrace I in Calypsobyen (Photo P. Zagórski 2011), B- glacial and marine deposits – cliff in Skilvika (Photo P. Zagórski 2011).

Gentle slopes are covered by solifluction deposits and shaped by permafrost-related processes (Repelewska-Pękalowa & Pękala 1992; Zybała 1994). Deposits are characterised by high textural and structural variability associated with the weatering and frost segregation of and gravitational mixing of marine, glacial and fluvial deposits. In flat areas covered with those mixed deposits various types of patterned grounds are formed. In humid areas covered with tundra and with high concentrations of clays and silts in surface deposits the characteristic micro-relief including: earth hummocks, palsas and ice wedges are formed. On the coastal plains covered with tundra, the solifluction covers are characterised by three-fold division (Fig. 2.2.7, Photo 2.2.3). The different activity phases are separated by fossil soils with traces of vegetation from the warm phase of the so-called Viking period, which was followed by the cooling episode of the LIA (Baranowski & Karlen 1976; Pękala 1980ab; Dzierżek & Nitychoruk 1987ab; Lindner *et al.* 1987; Repelewska-Pękalowa & Pękala 1993) The existence of these two phases of climate (the Viking Period and the LIA) is clearly reflected in the proglacial relief of Renardbreen (Pękala 1987; Pękala & Repelewska-Pękalowa 1990; Dzierżek *et al.* 1990b; Jasinski & Starkov 1992).

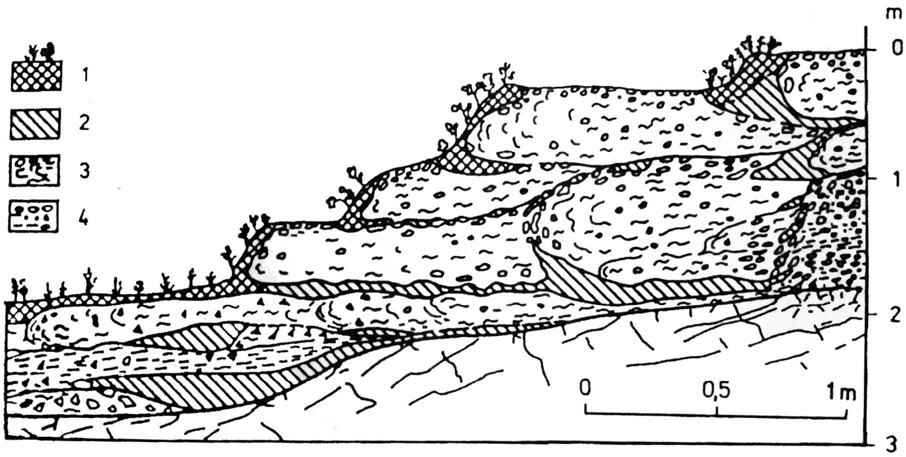


Fig. 2.2.7. Fagerbukta region – garland terrace: 1- vegetation cover and recent soil, 2- peat and fossil soil, 3- solifluction deposits, 4- marine deposits (Repelewska-Pękalowa & Pękala 1993).

Photo 2.2.3. Garland terrace – slope of Tyvjobekken valley (Photo K. Pękala 2005).

Aeolian deposits. The aeolian deposits are formed in a consequence of the operation of wind-derived processes such as deflation, transport and accumulation. The high frequency of strong winds is favourable to deflation of fine deposits from extensive outwash plains, alluvial plains and beaches. Particularly active are niveo-aeolian processes, which cause the corrasion of the edges of raised marine terraces, erode the surface of relict storm ridges and reshape the rocky monadnocks (Photo 2.2.4). The result of the operation of niveo-aeolian processes is the erosion of snow cover, vegetation cover and soil cover and their exposure to the action of meltwaters and rainfalls (Pękala & Wojtanowicz 1987; Wojtanowicz 1990, 2010).

The area surrounding the Recherchefjorden is characterised by the occurrence of favourable conditions for the formation of aeolian sandy and silty deposits. The largest accumulations of aeolian deposits are found in the Reinsletta, the surrounding of Malbukta, the forefields of Recherchebreen and coastal plains of Calypsostranda (Wojtanowicz 1990, 1991).

The accumulation of deflated sand and silt occurs in small hollows, along open slopes, moraine surfaces, and marine terraces and on glacier surfaces. The rate of aeolian accumulation depends on the local relief, geology and the distance from sediment sources. The accumulation rates vary from 6.4-17.7 $g{\cdot}m^{-2}$ on coastal plains, 15.8-36.2 $g{\cdot}m^{-2}$ on frontal moraines, 41.8-167$g{\cdot}m^{-2}$ on beaches to 328 $g{\cdot}m^{-2}$ over eskers kames and outwash plains (Pękala & Repelewska-Pękalowa 1988a, Wojtanowicz 1990, Repelewska-Pękalowa 1996). The highest accumulation rates were measured on eskers in front of Recherchebreen and reached 655 $g{\cdot}m^{-2}$. Observed values are comparable with the results of studies on aeolian transport and accumulation carried out in Hornsund (Jahn 1961; Pękala 1980a; Baranowski & Pękala 1982).

Photo 2.2.4. Aeolian processes on the surface of raised marine terrace – Skilvika (Photo P. Zagórski 2007).

Aeolian deposits are characterised by high variability of grain size dependent on the transport distance. In case of local transport the dominant fraction is sand (over

50%) with large portion of skeleton fractions (up to 40%) and tundra detritus. Deposits from longer transport are composed predominantly by finer fractions with dominant role of silts (Repelewska-Pękalowa & Pękala 1991).

Outline of Quaternary stratigraphy

The Quaternary stratigraphy of Spitsbergen is an implication of Pleistocene glaciations. The traces of Saalian and Weichselian glaciations on Svalbard are relatively well-documented (Mangerud *et al.* 1998; Ingólfsson and Landvik 2013) (Figs. 2.2.8 and 2.2.9). The glacial deposits associated with Saalian glaciation are commonly found across SW Spitsbergen. Pękala *et al.* (1985) and Szczęsny *et al.* (1985) documented them in Torellbreen pushed moraines on the western coast of Wedel Jarlsberg Land. The Saalian deposits was preceded by the accumulation of marine clays which were TL dated at 413-383 ka BP (Lindner *et al.* 1984, 1986, 1987; Pękala *et al.* 1985; Lindner & Marks 1993b). The period of clay deposition has been called the Torellkjegla interglacial (Pękala *et al.* 1985; Lindner *et al.* 1987; Lindner & Marks 1993a). The older part of Saalian in the Torellkjegla profile is represented by glacial till TL-dated at 313-284 ka BP and the younger part is represented by tills TL-dated at 189 ka BP and fluvioglacjal deposits TL dated at 161-143 ka BP (Pękala *et al.* 1985; Marks & Pękala 1986; Lindner & Marks 1993ab). The glacial tills are divided by fluvioglacial sands and gravels TL-dated at 222-190 ka BP (Lindner *et al.* 1987). The younger part of Saalian is also documented by morainic deposits found in western Sørkapp Land TL-dated at 217 ka and 141 ka BP (Butrym *et al.* 1987) and in the famous profile at Kapp Ekholm (in Billefjorden) TL-dated at 116 ka and 120 ka BP (Boulton 1979a; Troitsky *et al.* 1979).

The interstadial deposits from Saalian glaciation found in the southern part of Bellsund region were TL-dated at 181 ka BP (Pękala & Repelewska-Pękalowa 1990). The deposits from younger part of Saalian were found in Dyrstaddalen and TL-dated at 155 ka BP (Pękala & Reder 1989; Reder 1990, 1996). The bipartite glacial tills found in Skilvika were TL-dated at 156 and 130 ka BP (Pękala & Repelewska-Pękalowa 1990) (Figs. 2.2.2 and 2.2.8).

During the Saalian the Svalbard-Barents Sea Ice Sheet was very extensive (Mangerud *et al.* 1998; Knies *et al.* 1999, 2000; Ingólfsson & Landvik 2013) (Figs. 2.2.8 and 2.2.9). According to Arkipov *et al.* (1995) the ice-sheet was supplied in deposits from Spitsbergen and western shelf of Siberia. However, the Saalian deposits have not been found on the western shelf of Spitsbergen. It may suggest that the ice-sheet was drained by ice-streams flowing in Isfjorden, Bellsund and Hornsund (Lindner & Marks 1993a) and that the extent of glacial deposits is limited to the mouth of fjords (Nitychoruk & Dzierżek 1994).

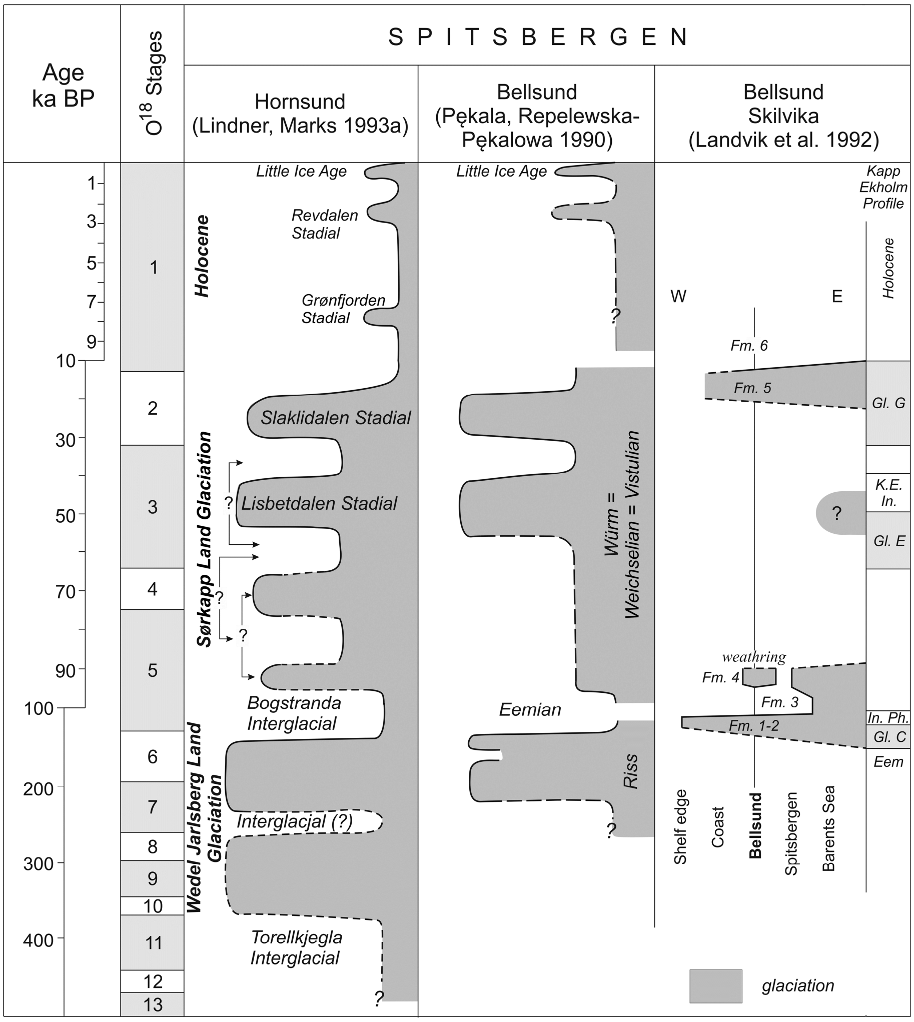


Fig. 2.2.8. Correlation of the main glacial episodes and phases of glaciers recession (interglacial, interstadial) for southern Spitsbergen: Hornsund (Lindner & Marks 1993a), Bellsund (Pękala & Repelewska-Pękalowa 1990), Bellsund – Skilvika (Landvik *et al.* 1992).

During the Eemian Interglacial the ice-sheet retreated from Svalbard and the Barents Sea and Gulfstream influence extended further north than currently (Sancetta *et al.* 1972; Ruddiman & McIntyre 1977; Ruddiman *et al.* 1980). In southern Bellsund the Eemian interglacial is represented by glacimarine deposits found in Calypsostranda and TL-dated at 76-102 ka BP (and raised marine terraces located in Dyrstaddalen at 80-95 m a.s.l and 56-75 m a.s.l and TL dated 98-127 ka BP (Pękala & Repelewska-Pękalowa 1990; Reder 1990) (Fig. 2.2.2).

The best recognised and documented glaciation on Spitsbergen is the Weichselian glaciation which has been divided into several glacials and interstadials associated with the formation of raised marine terraces. The first of distinguished glacial episodes is represented by morainic deposits found in various parts of Spitsbergen

(Fig. 2.2.8) including Bellsund, Hornsund and Billefjorden (Mangerud & Salvigsen 1984; Butrym et.al 1987; Kłysz *et al.* 1988ab; Mangerud & Svendsen 1992; Landvik *et al.* 1992; Lindner & Marks 1993ab; Mangerud *et al.* 1998) (Fig. 2.2.8).

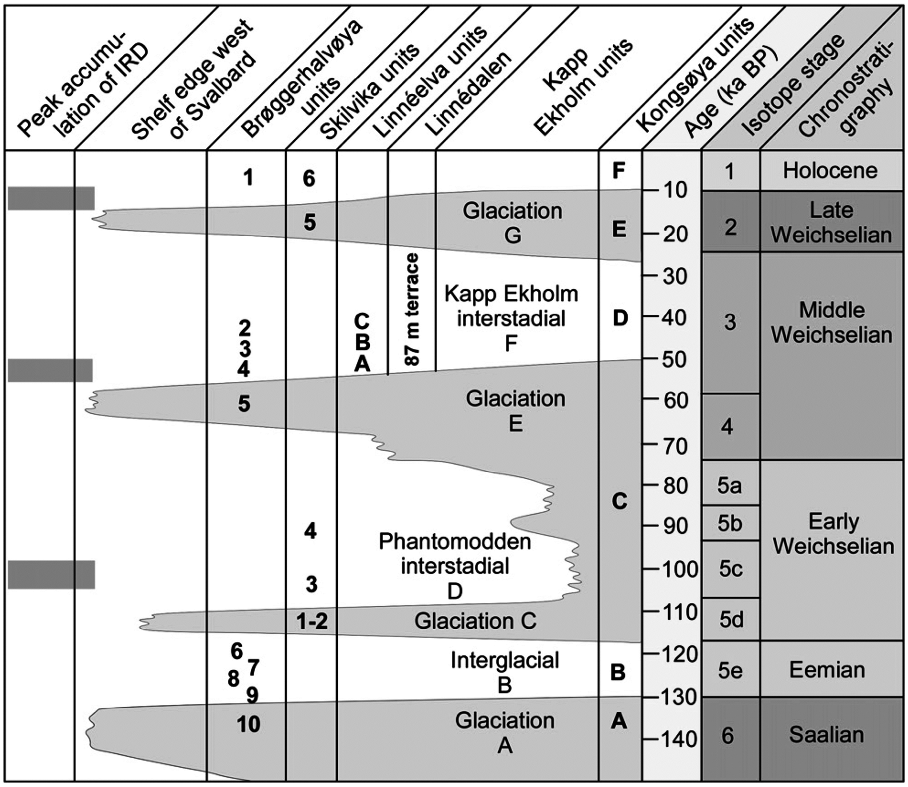
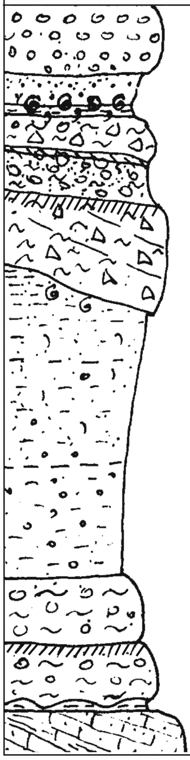


Fig. 2.2.9. Time-distance diagram (glaciation curve) based on correlations along a transect from Kongsøya (northern Barents Sea) in the east to the shelf edge west of Svalbard. (after: Ingólfsson & Landvik 2013).

Glacial deposits from second glacial episode are represented by tills TL-dated at 73 ka BP and found in front of Torellbreen in northern part of Hornsund region (Pękala *et al.* 1985; Lindner *et al.* 1986, 1987; Lindner & Marks 1990). Niewiarowski *et al.* (1993) found similar deposits in Kaffiøyra in NW Spitsbergen. In Bellsund area the deposits from this episode were found in Skilvika (Landvik *et al.* 1992; Mangerud *et al.* 1998; Ingólfsson and Landvik 2013) (Figs. 2.2.8 and 2.2.9).

The third glacial episode of Weichselian that occurred on Spitsbergen between 56-31 ka BP covered the whole island (Fig. 2.2.8). Deposits representing this period were found in Bellsund region in several sites. Reder (1990) excavated glacial tills TL-dated at 59 ka BP in Dyrstaddalen (Fig. 2.2.2). Pękala & Repelewska-Pękalowa (1990) found tills (TL-dated at 55 ka BP) covered with fluvioglacial deposits (TL-dated at 43-45 ka BP) in the vicinity of Tyvjobekken (Calypsostranda) (Figs. 2.2.4 and 2.2.10).



Deposits	Laboratory No	TL age	Strat.
shingle	Lub - 1819	8.3 ± 1.2 ka	HOLOCENE
sand, clay (shells)	Lub - 1818	10 ± 1.4 ka	HOLOCENE
till	Tnl - Tl - 31	26 ka	WÜRM
sand, gravel	Lub - 1842 Lub - 1823	43 ± 6 ka 45 ± 7 ka	WÜRM
till	Lub - 1817	55 ± 8 ka	WÜRM
	Lub - 1816	76 ± 11 ka	EEM
silt and mud	Lub - 1815	80 ± 12 ka	EEM
(marine depidits, shells)			EEM
glacio-marine deposits	Lub - 1850	102 ± 15 ka	EEM
silt, mud, gravels			EEM
till	Lub - 1849	130 ± 20 ka	RISS
till	Lub - 1848	156 ± 23 ka	RISS
clay	Lub - 1847	181 ± 27 ka	RISS
bedrock			TERTIARY

Fig. 2.2.10. Synthetic profile and stratigraphy of Quaternary deposits in the region of Recherchefjorden and southern Bellsund (Pękala & Repelewska-Pękalowa 1990).

According to several researchers, during the youngest glacial episodes of Weichselian (the Last Glacial Maximum – LGM) Spitsbergen glacier reached their maximum extent (e.g. Baranowski 1977c; Boulton 1979b; Troitsky *et al.* 1979; Boulton *et al.* 1982; Butrym *et al.* 1987; Kłysz *et al.* 1988ab; Karczewski & Rygielski 1989; Stankowski *et al.* 1989; Lindner & Marks 1991). Landvik *et al.* (1998) made an extensive review of existing geological observations and interpretations regarding oscillations of the LateWeichselian Svalbard-Barents Sea ice sheet in time and space, and used those for defining boundary conditions for numerical modelling of the ice sheet. They also took advantage of the isostatic record, which shows a centre of postglacial uplift in the north-central Barents Sea and they suggested that LGM ice-free areas in west Spitsbergen were unlikely, except for some high-altitude coastal nunataks (Ingólfsson & Landvik 2013) (Fig. 2.2.11).

In Calypsostranda the LGM is represented by glacial tills TL-dated at 26 ka BP (Troitsky *et al.* 1979). The reconstructions of ice-cover extent for Bellsund area suggest that around 12.6-12.8 ka BP Bellsund was a bay filled with icebergs from calving glaciers. Around 11 ka BP glaciers retreated to the mouths of Van Mijenfjorden, Van Keulenfjorden, Recherchefjorden (Landvik *et al.* 1987; Mangerud *et al.* 1992; Nitychoruk &

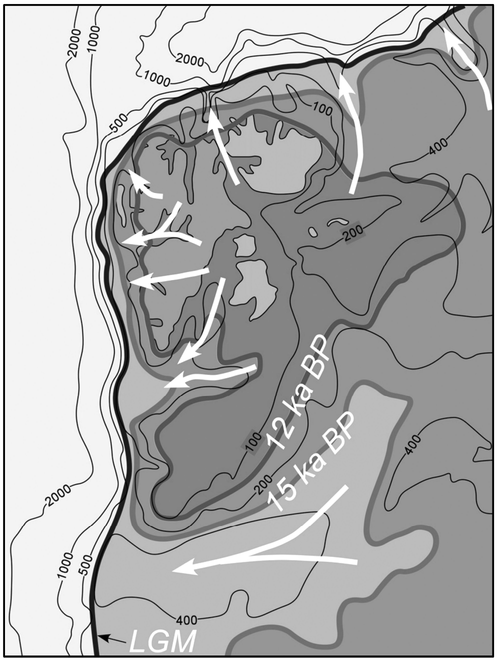


Fig. 2.2.11. Reconstruction of the margins of the Late Weichselian Svalbard-Barents ice sheet at LGM and stages during the deglaciation at 15 and 12 ^{14}C ka BP, respectively (after: Ingólfsson & Landvik 2013).

Dzierżek 1994, Mangerud & Landvik 2007) (Fig. 2.2.11). The deposits from this period found on the shelf of Bellsund have similar features to those found in Isfjorden.

Samples collected from a sediment layer covering the diamictites were interpreted as subglacial tills that have been ^{14}C-dated at 16.4-13.9 ka BP (Landvik *et al.* 1998) and TL-dated at 13.4- 11.2 ka BP (Pękala & Repelewska-Pękalowa 1990). According to Pękala & Repelewska-Pękalowa (1990) the Late Weichselian deglaciation of Bellsund started after 16.4 ka BP.

The beginning of Holocene on Spitsbergen is associated with progressive warming of climate, consistent with global trends (Broecker & Denton 1990). Svendsen & Mangerud (1997) claimed that the Early Holocene was characterised by strong seasonal temperature contrast, which were approx. 4-5°C warmer in summers and 5-6°C colder in winters than observed currently. According to Lindner & Marks (1997) the Early Holocene advances of local glaciers cannot be excluded.

The terrestrial and marine records suggest the occurrence of climate warming preceding the last glacial episode – the Little Ice Age (LIA). This warming episode is often called the Viking period (the Medieval Warm Period) which lasted between 1,150-750 BP (Baranowski 1977bc; Pękala 1980ab, 1984; Lindner *et al.* 1984, 1986, 1987; Miller *et al.* 1989; Dzierżek *et al.* 1990ab; Grove & Switsur 1994; Bianchi & McCave 1999).

Spitsbergen glaciers reached the LIA maximum at the end of the 19th century. In Bellsund the LIA period was documented in series of geological and archaeological studies (Dzierżek *et al.* 1990ab; Jasinski 1994; Jasinski & Starkov 1992, 1993; Jasinski & Zagórski 1996). The LIA moraines were documented and investigated across entire Spitsbergen (Baranowski 1977a; Liestøl 1969; Lindner & Marks 1993a; Niewiarowski *et al.* 1993; Werner 1993; Wójcik & Ziaja 1993; Reder 1996; Birkenmajer & Łuczkowska 1997; Birkenmajer & Olsson 1997; Svendsen & Mangerud 1997).

Streszczenie

Osady i stratygrafia czwartorzędu

W północno-zachodniej części Wedel Jarlsberg Land występują czwartorzędowe osady różnej genezy: glacjalne, fluwialne i fluwioglacjalne, morskie, stokowe oraz eoliczne (Pękala, Repelewska-Pękalowa 1990). Tworzą one zwarte pokrywy w dnach dolin, w dolnych odcinkach stoków, na podniesionych terasach morskich oraz na przedpolach lodowców.

Osady te są zróżnicowane pod względem litologicznym i wiekowym i reprezentują różne ogniwa stratygraficzne. Osady glacjalne: gliny, bloki skalne i głazy wymieszane ze żwirami, budują moreny czołowe, boczne i denne przedpoli współczesnych lodowców, będących w stadium recesji. Wydziela się dwie holoceńskie serie moren czołowych: starsze, blokowo-gliniaste i młodsze – wały lodowo-morenowe, związane z Małą Epoką Lodową (LIA). Z kolei osady moren plejstoceńskich zalegają na pokrywach zwietrzelinowych lub skałach podłoża oraz przedzielają inne ogniwa stratygraficzne osadów budujących podniesione terasy morskie (Pękala, Repelewska-Pękalowa 1990; Dzierżek i in. 1990ab). Osady fluwialne i fluwioglacjalne są reprezentowane przez żwiry i piaski, budujące sandry zewnętrzne i wewnętrzne, ozy i kemy oraz przez piaski i iły, występujące w obrębie równi pływowych i delt. W basenach sedymentacyjnych zatok i lagun współcześnie tworzą się iły warwowe. Klasyczne osady morskie, jako serie iłów i piasków z fauną morską oraz żwirów, tworzą terasy akumulacyjne i nadbudowują platformy abrazyjne. Osady stokowe powstały z przeobrażenia utworów różnej genezy wskutek wietrzenia, segregacji mrozowej i procesów grawitacyjnych. Na stokach stromych tworzą rumowiska skalne, stożki usypiskowo-niwalne i lodowce gruzowe. W obrębie stoków łagodnych mają one postać gliniastych pokryw soliflukcyjnych (Pękala, Repelewska-Pekalowa 1988a). Osady eoliczne, pochodzące z miejsc skupisk drobnego materiału: przedpoli lodowców, sandrów, stożków rzecznych i plaż morskich, akumulowane są w zagłębieniach, na otwartych stokach, powierzchniach moren i teras oraz na lodowcach. Wielkość akumulacji jest zróżnicowana – 6,4-17,7 $g{\cdot}m^{-2}$ w obrębie równin nadmorskich – 15,8-36,2 $g{\cdot}m^{-2}$ w strefie moren czołowych, do 328 $g{\cdot}m^{-2}$ w obrębie ozów, kemów i sandrów (Wojtanowicz 1990).

W rejonie południowego obrzeża Bellsundu stwierdzono osady interstadialne zlodowacenia saalian datowane na 181 ka BP (Skilvika) i 155 ka BP (Dyrstaddalen) oraz dwudzielne gliny zwałowe (Skilvika) datowane na 156 i 130 ka BP (Pękala, Reder 1989) (ryc. 2.2.1). Interglacjał eemski reprezentowany jest przez osady glacjalnomorskie Calypsostrandy, datowane metodą TL na 102-76 ka BP oraz piaski i żwiry podniesionych teras morskich (127-98 ka BP). Wydzielono kilka epizodów glacjalnych zlodowacenia weichselian, przedzielonych okresami interstadialnymi. Pierwszy i drugi epizod dokumentuje profil Skilvika (daty TL: 88-30 ka BP). Trzeci epizod reprezentują gliny zwałowe z Dyrstadalen, datowane TL na 59 ka BP, z Calypsostrandy (TL 55 ka BP) oraz osady fluwioglacjalne (TL 45-43 ka BP). Najmłodsze osady glacjalne na Calypsostrandzie, to gliny zwałowe datowane na 26 ka BP (Troitsky i in. 1979; Pękala, Repelewska-Pękalowa 1990; Mangerud i in. 1998).

W zapisie osadów lądowych i głębokomorskich zaznaczył się wikingowski okres ocieplenia poprzedzający ostatni epizod glacjalny Małej Epoki Lodowej, udokumentowany badaniami geologicznymi i archeologicznymi. Na przedpolach lodowców przeważają współcześnie deponowane osady glacjalne i fluwioglacjalne (schyłku LIA) (Reder, Zagórski 2007ab; Zagórski i in. 2012).

Objaśnienia

Ryciny

Ryc. 2.2.1. Mapa geomorfologiczna Dyrstaddalen i Lognedalen (Pękala, Reder 1989); 1- moreny czołowe, 2- moreny denne i ablacyjne 3- lodowce, 4- moreny niwalne i lodowce gruzowe, 5- stożki usypiskowe, 6- sandry, 7- terasy morskie i poziomy denudacyjne, 8- potoki i jeziora; A-B – przekrój poprzeczny (patrz: ryc. 2.2.2).

Ryc. 2.2.2. Schematyczny przekrój geologiczny Dyrstaddalen (Reder 1990): 1- glina zwałowa, 2- piaski z węglem, 3- piaski, 4- piaski i pyły, 5- piaski warstwowane, 6- żwiry, 7- moreny niwalne, 8- podłoże skalne.

Ryc. 2.2.3. A- Profil wzdłuż wybrzeża Skilviki (Landvik i in. 1992, Mangerud i in. 1998); B- zestawienie stratygrafii dla Skilviki, nieco zmodyfikowanej przez Landvika i in. (1992); wskaźnik aminokwasów D/L - wykres średniej odchylenia standardowego dla próbek podłoża (Mangerud i in. 1998); C- główne epizody glacjalne w oparciu o interpretację osadów klifu Skilviki: Gl.- zlodowacenia, K.E In.- interstadiał Kapp Ekholm, Ph. In.- interstadiał Phantomodden, Fm – formacje (Landvik i in. 1992).

Ryc. 2.2.4. Profil i wiek TL osadów czwartorzędowych na zboczach Tyvjobekken w Calypsobyen (Pękala, Repelewska-Pękalowa 1990): 1- podłoże (Trzeciorzęd), 2- osady morskie (mułkowo-ilaste z silnie pokruszonymi muszelkami), 3- glina zwałowa, 4- żwiry i piaski fluwioglacjalne, 5- piaski i mułki morskie z muszelkami, 6- żwiry plażowe.

Ryc. 2.2.5. A- przekrój geologiczny przez moreny czołowe Renardbreen (Pękala, Repelewska-Pękalowa 1990): współczesny wał sztormowy, 2- fosylny wał sztormowy, 3- glina zwałowa (Mała Epoka Lodowa), 4- przemieszczona warstwa kulturowa stanowiska wielorybniczego z florą kopalną (profil 1), 5- glina, 6- glina zwałowa, 7- osady glacjalno-morskie; B- profil osadów organicznych stanowiska Renardbreen-1 (Dzierżek i in. 1990a).

Ryc. 2.2.6. A- pingo typu Mackenzie delta w Chamberlindalen (lokalizacja patrz: ryc. 5.3.16, pingo nr 9); B- profil i datowanie TL osadów czwartorzędowych przemieszczonych w wyniku rozwoju pingo (Pękala, Repelewska-Pękalowa 1988b): 1- lód, 2- mułki metamorficzne, 3- glina zwałowa, 4- mułki morskie z muszelkami, 5- piaski i mułki morskie z muszelkami, 6- piaski ze żwirami, 7- żwiry piaszczyste z soczewkami żwirowymi (osady deltowe), 8- pokrywy soliflukcyjne.

Ryc. 2.2.7. Rejon Fagerbukty – terasy girlandowe: 1- pokrywa roślinna i współczesna gleba, 2- torfy i fosylna gleba, 3- osady soliflukcyjne, 4- osady morskie (Repelewska-Pękalowa, Pękala 1993).

Ryc. 2.2.8. Korelacja głównych epizodów glacjalnych i faz recesji lodowców (interglacjał, interstadiał) dla południowego Spitsbergenu: Hornsund (Lindner, Marks 1993a), Bellsund (Pękala, Repelewska-Pękalowa 1990), Bellsund-Skilvika (Landvik i in. 1992).

Ryc. 2.2.9. Czasowo-przestrzenny diagram (krzywa zlodowaceń) na podstawie korelacji stanowisk wzdłuż transektu od Kongsøyi (północne Morze Barentsa) na wschodzie, po krawędź szelfu na zachodzie Svalbardu (Ingólfsson, Landvik 2013).

Ryc. 2.2.10. Syntetyczny profil i stratygrafia osadów czwartorzędowych w rejonie Recherchefjorden i południowego Bellsundu (Pękala, Repelewska-Pękalowa 1990).

Ryc. 2.2.11. Rekonstrukcja zasięgu lądolodu Svalbard-Barents w czasie ostatniego maksimum glacjalnego i etapy deglacjacji w odpowiednio 15 i 12 ka BP ^{14}C (Ingólfsson, Landvik 2013)

Fotografie

Fot. 2.2.1. A- morena czołowa Renardbreen (fot. P. Zagórski 2012), B- przedpole Renardbreen – ozy (fot. P. Zagórski 2012), C- osady fluwialne i fluwioglacjalne wypelnijące dno Chamberlindalen (fot. P. Zagórski 2006).

Fot. 2.2.2. A- osady wybrzeżowe – terasa I w Calypsobyen (fot. P. Zagórski 2011), B- osady glacjalne i morskie – klif w Skilvice (fot. P. Zagórski 1998).

Fot. 2.2.3. Terasy girlandowe – stok doliny Tyvjobekken (fot. P. Zagórski 2011).

Fot. 2.2.4. Procesy eoliczne na krawędzi terasy morskiej – Skilvika (fot. P. Zagórski 2007).