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Marine terraces in Kaffiøyra and Hermansenøya (Oscar II Land, NW Spitsbergen)

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Abstract: The main relief elements which document the sea level changes on the Kaffiøyra Plain and the Isle of Hermansenøya, including the sea transgressions, are both abrasive (marine terraces) and accumulative (raised beaches). Such landforms have been relatively well preserved in the area of Kaffiøyra. However, the issues relating to the number of such forms and their age remain questionable. They refer to the number of glacial episodes, the extension of the glaciers during these periods as well as the limit of the sea transgressions during and after the deglaciation of the NW Spitsbergen during the Weichselian and Holocene periods.
The first detailed geomorphological research which was conducted in Kaffiøyra and its vicinity and included geomorphological mapping, was carried out by Niewiarowski and Sinkiewicz during the Toruń Polar Expeditions to Spitsbergen in 1978 and 1985 (Niewiarowski et al. 1993). The authors listed the exact number and extension of the old marine terraces as well as the Late Weichselian marine limit. According to these studies, the Kaffiøyra's marine terraces are of two generations. The Isle of Hermansenøya, located four km off the Kaffiøyra's shores, has one generation of former marine terraces. The maximum Late Weichselian marine limit in Kaffiøyra reached 46–48 m a.s.l., while in Hermansenøya it reached about 33 m a.s.l. On both the Kaffiøyra Plain and the Isle of Hermansenøya there is evidence of the Holocene sea level changes.

Key words: marine terraces, raised beaches, Late Weichselian marine limit, Svalbard, Kaffiøyra, Hermansenøya

Introduction

The north western part of Spitsbergen is taken by the Oscar II Land. It is located to the east of Forlansundet Passage, between Isfjorden to the south and Kongsfjorden to the north. The main landforms in this area, besides glaciers and mountain ranges and massifs, include terraced coastal plains (strandflats). Kaffiøyra is one of such plains (Fig. 1, Photo 1). It developed due to an isostatic uplift during Late Glacial and Holocene. The Kaffiøyra Plain is about 14 km long and 1.5 to 4 km wide, and is located between 78°42' N and 78°35' N. It generally stretches from NNW to SSE, between the Aavatsmarkbreen Glacier and Hornbaekbukta Bay as well as the Dahlbreen Glacier and Dahlbrebukta Bay with Farmsundet Passage. To the west it borders Forlandsundet Passage, while to the east the mountains from which glaciers flow out: the outlet ones down to the sea (Aavatsmarkbreen and Dahlbreen), the Kaffiøyra ones terminating on the plain itself (Elisebreen and Andreasbreen) as well as the ones of the Alpine type (Waldemarbreen, Irenebreen, Agnorbreen, Eivindbreen and Oliverbreen) which terminate in the valleys within the mountain massifs. The Kaffiøyra Plain, together with the surrounding mountain chains and valley glaciers with their marginal zones, takes up slightly over 100 km^2. To the south of Kaffiøyra, 4 km south of Cape Snippen, the Isle of Hermansenøya is located. It is a small terraced island of 2.7 km^2 and the maximum height of 39 m a.s.l. (Photo 2).

The isostatically uplifted beaches and abrasive marine terraces of both the Kaffiøyra Plain and the Isle of Hermansenøya are relatively well preserved. Their amount and age, however, are still under discussion. The questioned issues refer to the number of glacial episodes, the extensions of glaciers during those episodes as well as the limits of marine transgressions during and after the deglaciation of the

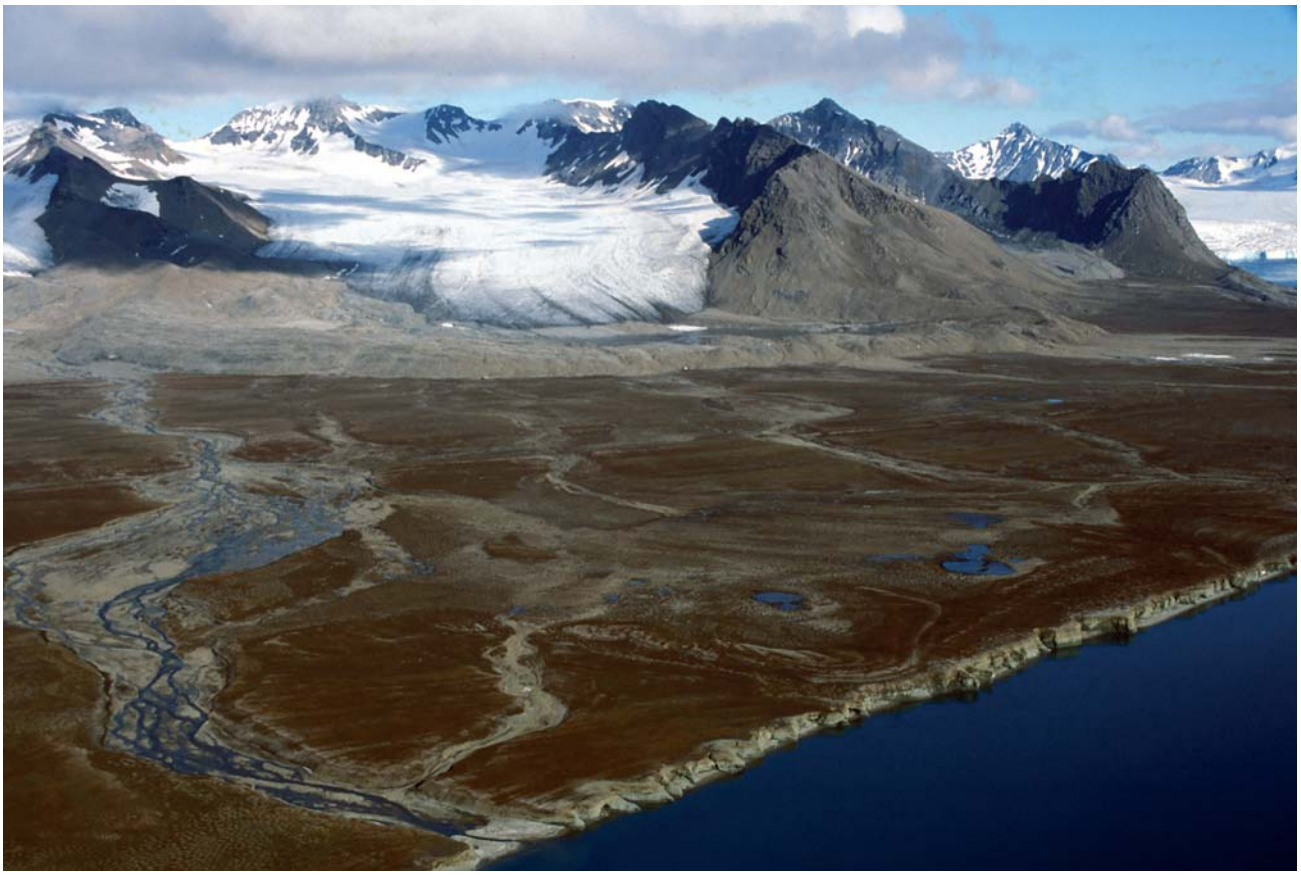
Fig. 1. Location of Kaffiøyra and Hermansenøya

NW Spitsbergen in the Weichselian and Holocene periods (incl. Boulton 1979, Forman 1989, Forman et al. 2004, Niewiarowski et al. 1993, Landvik at al. 1998). The first general research on the marine terraces of the Kaffiøyra Plain was conducted in 1938 by Klimaszewski (1960) during the first Polish Glaciological Expedition to Spitsbergen. The studies included the area located along the west coast of Spitsbergen between Kongsfjorden and Eidembukta. Since 1975 physiogeography, including geomorphology, of the Kaffiøyra Plain and its vicinity have been studied by the Toruń Polar Expeditions based on the research station purposely built by the University of Nicolaus Copernicus in Toruń.

The first thorough geomorphological studies, which included geomorphological mapping, of the Kaffiøyra Plain and its nearest surroundings were conducted in 1978 and 1985 by Niewiarowski and Sinkiewicz (Niewiarowski 1982, Sinkiewicz 1982, Niewiarowski et al. 1993). As a result, a detailed geomorphological map of the Kaffiøyra Plain and its vicinity at the scale of 1:30 000 was made (Niewiarowski & Sinkiewicz 1993). It was based on field research, aerial photographs and numerous geodetic measurements. The topographic map of this area at the scale of 1:25 000 was made by Lankauf (2002). It was party based on the earlier measurements of Zapolski (1977a, b) as well as the author's own measurements (incl. Lankauf 1982).

Marine terraces and their age

The main relief elements which register the changes in the sea level, including marine transgres-



Phot. 1. The southern part of Kaffiøyra with the marine terraces; the Andreasbreen Glacier and its marginal zone at the distance (Photo M. Grześ)

sions, are both abrasive (marine terraces) and accumulative (raised beaches). It is possible to distinguish relatively well preserved forms of the old coastal zones, which include former cliffs, abrasion platforms, beach ridges and former lagoons, as well as deposits, such as sublittoral, littoral and beach ones with marine molluscan shells. Marine terraces, former abrasion platforms, are being gradually degraded by both denudation (levelled and gentle scarps) and erosive processes (valleys of proglacial rivers as well as meltwater and niveofluvial valleys). Thus, the level of degradation of these relic forms is a result of the passing time. As a result, the youngest coastal forms, which are generally located at lower levels, are in most cases best preserved.

The first data on raised marine terraces of the Kaffiøyra Plain are found in the dissertation by Klimaszewski (1960). He delimited five levels of marine terraces (either accumulative or erosive) at the altitudes of 10–12 m, 14–15 m, 23 m, 37–40 m and 50–55 m a.s.l. However, this delimitation was based on only two simplified hypsometric profiles, conducted in the northern and southern parts of the plain. As a result, they do not reflect the actual situation in those terms. It is also important to consider the outcomes of Forman's research (1989, 1990). Besides terraces and raised beaches of Late Weichselian origin for which he did not give the number and limits, he also delimited two earlier terraces at the altitudes from about 46 m to about 60 m a.s.l. Forman dated them as pre-Late Weichselian forms.

Further thorough research accompanied by geomorphological mapping was conducted by Niewiarowski and Sinkiewicz (1993). The authors gave an exact number and limits of the former marine terraces as well as the maximum Late Weichselian marine limit. In accordance with these studies, the Kaffiøyra Plain has sections of 12 marine terraces at the altitudes of 4–6 m, 7–9 m, 10–12 m, 12–14 m, 18–19 m, 22–24, 26–29 m, 30–33 m, 37–40 m, 42–46 m, 52–58 m and 62–65 m a.s.l. (Fig. 2). On the Isle of Hermansenøya, located about four km off the Kaffiøyra's south shore, Sinkiewicz delimited five marine terraces at the altitudes of 4–6 m, 7–9 m, 10–12 m, 15–17 m and 21–24 m a.s.l. (Niewiarowski et al., 1993). Additionally, Forman (1989) delimited one higher level of marine terrace at the altitude of about 33 m a.s.l. It must be stressed that the maximum altitude of the Isle of Hermansenøya is only 39 m a.s.l., and its surface is flat and devoid of beach deposits. The thorough analyses of both topographic maps and aerial photographs indicate the existence of two more flattened areas found on the mountain sloped bordering with the Kaffiøyra Plain, such as the one on the side of the ridge which separates the Elisebreen Glacier from the Eivindbreen Glacier,

Phot. 2. Isle of Hermansenøya as seen from the Kaffiøyra Plain. In the foreground there is the marginal zone of the Andreasbreen Glacier; rocky Cape Snippen at the distance (Photo M. Król)

found at the altitude of about 160 m and 110 m a.s.l. Their genesis, however, has not been completely explained. It is supposed that the level 110 m a.s.l. might be concordant with the level 120 m a.s.l. of the Sarsøyra Plain located to the north of the Kaffiøyra Plain. There beach deposits were recorded (Klimaszewski 1960, Moign 1974, Forman 1990). A distinct flattened area is also found on the slope of Gråfjellet, which separates the Waldemarbreen Glacier from the Irenebreen Glacier. These might be structural flatnesses or pediments. Another distinct flat level exists at the altitude of 110 m a.s.l. on the slope of Prins Heinrichfjella which borders the Aavatsmarkbreen Glacier from the south. This level lacks beach deposits.

In Holocene some marine terraces and raised beaches were partly damaged and covered with forms and deposits of the transgressing glaciers. First time such a situation took possibly place during the glacial episode at about 3.0–2.5 ka BP and the second time during the Little Ice Age. The oldest Pleistocene deposits on the Kaffiøyra Plain which have been recorded so far are located in the sea cliff in its southern end (Niewiarowski et al. 1993). These are glacio-marine deposits represented by the stratified dark grey clays and grey silts with marine molluscan shells and the admixture of organic matter. They are interbedded with sandy-gravel deposits with a large amount of pebbles and boulders which originated from melting icebergs. These deposits are well over five m thick. They are sheared and covered discordantly by beach gravels from the end of Late Weichselian or from the beginning of Holocene. In accordance with the results of the radiocarbon dating, the age of the organic matter is over 35 ka BP (Niewiarowski et al. 1993). Boulton (1979) observed similar glacio-marine deposits in the cliff of the Sarsøyra Plain, where the molluscs *Mya truncata* were dated to over 34 ka BP. On this basis he concludes that the underlying till originated during the Middle Weichselian glacial episode (glaciation). Similarly developed glacio-marine deposits, found in the push-end moraine of the Elisebreen Glacier and described by Olszewski (1977), might have originated at the same time. The moraine itself developed during the Little Ice Age and today is located on a marine terrace at the altitude of 10–13 m and 14–15 m a.s.l.

Due to relative scarcity of the data on Pleistocene deposits on marine terraces, including absolute dating, as well as on the limits of Weichselian marine transgressions related directly to the Kaffiøyra Plain, there is a need to review the neighbouring areas in those terms. Such areas mainly include the Brøggerhalvøya Peninsula, about 20–30 km to the north, as well as the Isle of Prins Karls Forland, which is located about 15–20 km to the west of the Kaffiøyra Plain, as much more information is available for them (incl. Andersson 2000, Andersson et al. 1999, 2000, Bergsten et al. 1998, Forman 1989, 1990, Forman & Miller 1984, Forman et al. 1987, Landvik et al. 1998, Miller et al. 1989, Salvigsen 1984).

Forman and Miller (1984) described a complex of isostatically uplifted beaches of the Brøggerhalvøya Peninsula. They correlated the highest marine deposits from 55 to 80 m a.s.l. with the so called episode C (130–290 ka BP), the series found at 44–55 m a.s.l. with the episode B (60–160 ka BP), while the terraces below 44 m a.s.l. with the last 12 ka BP, i.e. with the episode A. The Kaffiøyra Plain lacks the deposits which would suggest the existence of marine terraces connected with the episode C. It is possible, though, that the marine terrace at 120 m a.s.l. on the Sarsøyra

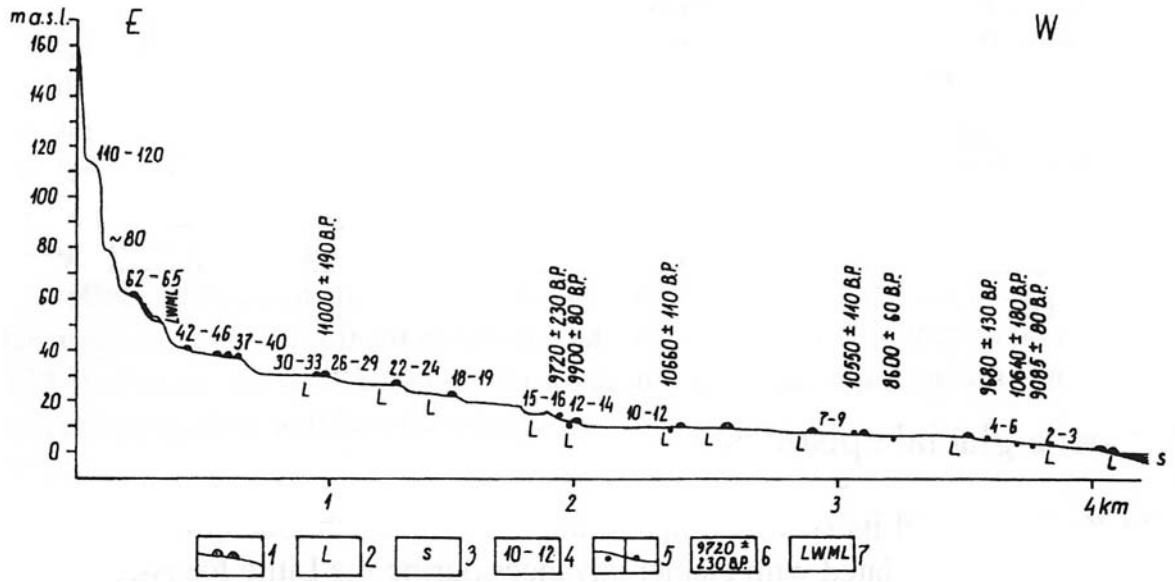


Fig. 2. Synthetic hypsographical section across Kaffiøyra (after Niewiarowski et al. 1993).
1 – beach ridges, 2 – former and recent lagoons, 3 – sea, 4 – altitude of raised marine beaches in metres a.s.l., 5 – sampling sites to radiocarbon datings, 6 – radiocarbon dates, 7 – Late Weichselian marine limit

Plain described by Klimaszewski (1960) and the flattened surfaces found at the mountain slopes neighbouring the Kaffiøyra Plain are related to one of the above episodes.

The highest marine terraces and raised beaches of the Kaffiøyra Plain are located at 52–58 m and 62–65 m a.s.l. The best preserved terraces are located at the foot of Prins Heinrichfjella near the end-lateral moraines of the Aavatsmarkbreen Glacier, which originated during the Little Ice Age. There is an accumulative coastal platform there, about 80 m wide, which contains beach ridges at 58–64 m a.s.l. Along its entire length the platform is cut by niveofluvial valleys. The platform is built of at least six-meter series of sands and gravels with sea pebbles up to 10 cm and marine molluscan shells (Niewiarowski et al. 1993). These deposits are discordant with the underlying Palaeogenic conglomerates.

In accordance with the outcomes of the soil research conducted on the Brøggerhalvøya Peninsula (Forman & Miller 1984), on the Isle of Prins Karls Forland (Andersson et al. 1999, 2000) and on the Kaffiøyra Plain (Plichta 1993), it can be concluded that the highest former marine terraces, i.e. those at 52–58 m and 62–65 m a.s.l., are connected with the deglaciation, marine transgression and glacio-isostatic uplift after the glacial episode B of Early Weichselian (about 70 ka BP). As Plichta (1993) observed, below the 40-cm thick horizon B of the Gelic Cambisols, at the bottom parts of the larger gravel grains found at the depth of about 50 cm there were continuous carbonate coats. They are typical for the episode B soils of the Brøggerhalvøya Peninsula, where they are found at 44–55 m a.s.l. They are not recorded, however, under the same genetic layer of the soils developed on beach deposits located at lower altitudes. Higher location of the beach deposits on the Kaffiøyra Plain is the result of its more intensive (by a few meters) glacio-isostatic uplift in relation to the Brøggerhalvøya Peninsula (Lehman & Forman 1987, Forman 1989, Landvik et al. 1998, Forman & Ingólfsson 2000, Forman et al. 2004). Similar conclusions can be drawn from the geomorphological and pedological research conducted on the Isle of Prins Karls Forland, where similar interrelations were found out (Andersson et al. 1999, 2000).

The origin of the marine terraces below 50 m a.s.l. are connected with the last Late Weichselian glaciation and the marine transgression and regression. However, the proper dating of these events has yet to be established. Most researchers agree that the recession of the Late Weichselian glaciation took place at 13–12 ka BP (Mangerud et al. 1987, 1998, Forman 1989, Hequette & Ruiz 1989, Niewiarowski et al. 1993, Landvik et al. 1998). The deglaciation was connected with the marine transgression as well as glacio-isostatic uplifting and the marine regression from the maximum Late Weichselian limit. On the Kaffiøyra Plain the limit of this maximum marine limit is visible at 46–48 m a.s.l. (Forman 1989, Niewiarowski et al. 1993). It is 2.5–3.0 km from the present sea shore. In the neighbouring areas the Late Weichselian marine limit is about 45 m a.s.l. on the Brøggerhalvøya Peninsula (Forman et al. 1987), while in the central part of the Isle of Prins Karls Forland (the surroundings of Poolepynten), i.e. directly to the west of the Kaffiøyra Plain, it is about 36 m a.s.l. There are well preserved former beach ridges, lagoons and sea cliffs below that level on the Kaffiøyra Plain. The soils developed on the coastal forms have typical features for the episode A, including the B horizon of less than 35 cm and lack of continuous carbonate covers on the bottom sides of larger gravel grains (Plichta 1993). Below the Late Weichselian marine limit there are fragments of about ten marine terraces and raised beaches which document the sea regression. They are found at the levels of 46–42, 40–37, 33–30, 29–26, 24–22, 19–18, 14–12, 12–10, 9–7 and 6–4 m a.s.l. The highest dated level (33–30 m a.s.l.) comes from about 11 ka BP (Niewiarowski et al. 1993). Radiocarbon dates (incl. the shells of *Mya truncata*, *Hiatella sp.*, *Mytilus edulis*) of the other levels indicate the age of 11–9 ka BP (Goslar & Pazdur 1985, Niewiarowski et al. 1993). Thus, at those times an average isostatic uplift was about 2 m/100 years and made up around 3/4 of the total uplift that took place during the entire Weichselian period. That value is concordant with the models presented by Landvik et al. (1998), Forman and Ingólfsson (2000) as well as Siegert and Dowdeswell (2004). In accordance with Niewiarowski et al. (1993) the deglaciation and maximum sea transgression onto the Kaffiøyra Plain took place at about 12–11.5 ka BP, while the levels from 46 m to 4 m a.s.l. developed at about 11.5–9 ka BP.

The fact that theses terraces were preserved indicates, that the Middle and Late Weichselian glaciations did not cover the entire Kaffiøyra Plain. Similarly to the Brøggerhalvøya Peninsula and the Isle of Prins Karls Forland, they had, in fact, a rather regional range. However, there do exist controversies around the character and maximum limit of the Late Weichselian glaciations (see Forman 1989, Niewiarowski et al. 1993, Andersson et al. 2000 and Lehman & Forman 1992, Landvik et al. 1998, Landvik et al. 2005).

It should be pointed out that at the depth of 2 to 10 m under sea level off the coastal zone of the Kaffiøyra Plain there is a wide underwater abrasive platform (Niewiarowski & Myzyk 1983). The part which borders the Kaffiøyra Plain from the southwest is about 2.5 km wide. It submerged after 9 ka BP due to the glacio-eustatic rise of the sea level in this area, which then reached the lowest level throughout Holocene (about 10–15 m below the modern sea

Phot. 3. Former lagoon of about 14 m a.s.l. in the southern part of the Kaffiøyra Plain. Peat bog with some frost peat mounds has developed here (Photo T. Jaworski)

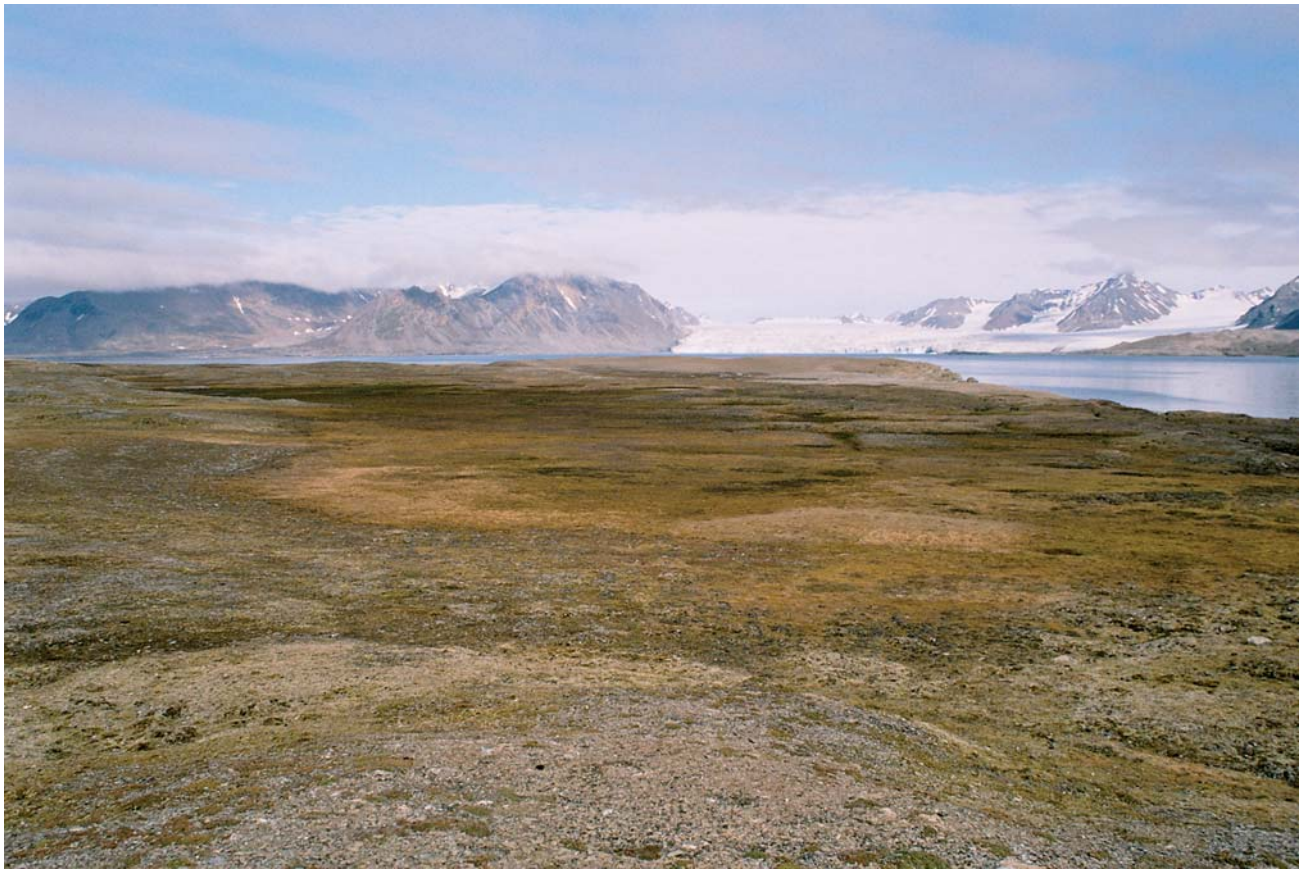
level – Héquette & Ruiz 1989) as well as the sea transgression which followed.

The Kaffiøyra Plain witnessed two glacial episodes in Holocene. The earlier one, in 3.0–2.5 ka BP, left small crescents of 3-4 m high end moraines at the foreground of the Elisebreen Glacier (Olszewski 1977) and the Aavatsmarkbreen Glacier (Niewiarowski 1982), outside of the marginal zones of the last episode. They are located on the marine terraces of 13 m and 10–12 m a.s.l. dated to be over 10.5 ka BP. The younger glacial episode, called the Little Ice Age (17th–19th c.), left very clear forms and deposits connected with the glacial advances as well as the following recessions in the 20th and the 21st c. However, no glacio-isostatic terrain lowerings and subsequent sea transgressions were connected with these glacial episodes.

Both on terraces and former marine beaches there is a variety of periglacial landforms and structures due to cryogenic processes, especially multigelation and all the phenomena related to it (Klimaszewski 1960, Niewiarowski & Sinkiewicz 1988, Plichta 1993). Stone polygons and circles as well as sorted and non-sorted nets have developed on the surfaces of the former lagoons. Landforms developed on the beach ridges and former abrasive platforms, which are built of the deposits containing less clay material, are dominated by ice-wedges polygons of various sizes. Boulder stripes and flat solifluction tongues are found on the sloping areas, while vegetative hummocks have developed within the former beach ridges or waterlogged flat areas. Furthermore, small earth hummocks are found within the ice-wedges polygons. On the surfaces of the youngest raised lagoons (up to 14 m a.s.l.), within which local peat bog has developed, frost peat mounds have originated (Niewiarowski & Sinkiewicz 1988) (Phot. 3).

Presently the coast of the Kaffiøyra Plain is shaped at the glacio-isostatic equilibrium and the stabilisation of the sea level as well as permafrost on the land and the long periods of the frozen sea. However, the shores of the sea bays which have been undergoing the process of deglaciation since the beginning of the 20th c. due to the regression of the Aavatsmarkbreen Glacier (Hornbaekbukta Bay) and the Dahlbreen Glacier (Dahlbrebukta Bay) are still unstable and prone to changes.

The Isle of Hermansenøya (Phots 2, 4), located off shore of the Kaffiøyra Plain, has five or six variously preserved marine terraces and raised beaches of 4–6 m, 7–9 m, 10–12 m, 15–17 m and 21–24 m a.s.l. (Niewiarowski et al. 1993) and possibly of about 33 m a.s.l. Their number is probably limited by the relatively low total height of the island, which is maximum 39 m a.s.l. On the other hand, on the basis of



Phot. 4. South western part of the Isle of Hermansenøya – a former lagoon of about 3–4 m a.s.l. with developed peat bog. In the background there is a marine terrace of 6 m a.s.l. and the Dahlbreen Glacier terminating in the sea (Photo T. Jaworski)

the general research results Forman (1989) delimited the Late Weichselian marine limit at about 33 m a.s.l. Thus, the former sea terraces preserved here represent the youngest Late Weichselian generation. Similarly to the Kaffiøyra Plain, the Isle of Hermansenøya is surrounded by the submerged abrasive platform at the average depth of about 7 m. It is best developed from the NE side of the island, where it reaches over 0.5 km width.

The fact that the Late Weichselian marine terraces have been preserved on the Isle of Hermansenøya proves that it was neither covered with ice during the glacial episode of 3.0–2.5 ka BP nor during the Little Ice Age (Forman 1989, Niewiarowski et al. 1993). Such a conclusion can also be drawn from the subaqueous relief of the island's surroundings (Król et al. 2010), as well as the layers of fossil peat aged about 8 ka BP which are found in the former lagoon in the southern part of the island.

On both the Kaffiøyra Plain and the Isle of Hermansenøya there is evidence of the Holocene sea level changes. In the southern part of the Isle of Hermansenøya the Middle Holocene marine transgression is reflected by about 10-cm laver of grey organic silts developed on the peat bog in the former lagoon and aged about 6.5–5.8 ka BP. These deposits are presently found at the altitude of about 3.0–3.5 m a.s.l. between the layers of fossil peat of different ages. The evidence of the marine transgression at about 6 ka BP in the southern part of the Kaffiøyra Plain is found in the cliff of the marine terrace of about 6 m a.s.l. (Forman 1990). In the cliff, at about four m a.s.l., there is an Early Holocene fossil soil covered with a two-meter layer of beach sands and gravels. A higher sea level in this area (Hermansenøya) was also recorded at 2.0–1.0 ka BP. This is proved by the layers of beach sands and gravels of 0.5 m thickness, which overlie a layer of brown peat at about 2.0–2.5 m a.s.l., the thickness of about 30 cm and the age of 2.0–1.5 ka BP (Phot. 5). Similar evidence is found in the southern part of the Isle of Prins Karls Forland (Andersson 2000).

Conclusions

Kaffiøyra is a terraced coastal plain (*strandflat*) with two generations of marine terraces:

- pre-Late Weichselian at 52–58 m and 62–65 m a.s.l.;
- Late Weichselian at 4–6 m, 7–9 m, 10–12 m, 12–14 m, 18–19 m, (22–24?), 26–29 m, 30–33 m, 37–40 m and 42–46 m a.s.l.

The Isle of Hermansenøya, located four km south off the Kaffiøyra Plain, has one generation of former marine terraces at 4–6 m, 7–9 m, 10–12 m, 15–17 m

Phot. 5. South eastern part of the Isle of Hermansenøya – a layer of brown peat at about 2.0–2.5 m a.s.l., covered by a series of marine sandy-gravel deposits (Photo M. Król)

and 21–24 m a.s.l., as well as possibly one more at about 33 m a.s.l.

The Late Weichselian marine limit on the Kaffiøyra Plain was at 46–48 m a.s.l., while on the Isle of Hermansenøya at about 33 m a.s.l. Both the Kaffiøyra Plain and the Isle of Hermansenøya have evidence of the Holocene marine transgressions at about 6.5–5.7 ka BP and 2.0–1.0 ka BP, which reached up to 2–3 m.

References

Andersson T., 2000. Raised beach deposits and new 14C ages from Pricepynten, Prins Karls Forland, western Svalbard. *Polar Research*, 19 (2): 271–273.

Andersson T., Forman S.L., Ingólfsson Ó. & Manley W.F., 1999. Late Quaternary environmental history of central Prins Karls Forland, Svalbard. *Boreas,* 28: 292–307.

Andersson T., Forman S.L., Ingólfsson Ó. & Manley W.F., 2000. Stratigraphic and morphologic constraints on the Weichselian glacial history of northern Prins Karls Forland, western Svalbard. *Geografiska Annaler* 82 A (4): 455–470.

Bergsten H., Andersson T. & Ingólfsson Ó., 1998. Foraminiferal stratigraphy of raised marine deposits, representing isotope stage 5, Prins Karls Forland, western Svalbard. *Polar Research,* 17: 81–91.

Boulton G.S., 1979. Glacial history of the Spitsbergen archipelago and the problem of a Barents Shelf ice sheet. *Boreas,* 8: 31–57.

Forman S.L., 1989. Late Weichselian glaciation and deglaciation of Forlandsundet area, western Spitsbergen, Svalbard. *Boreas,* 18: 51–60.

Forman S.L., 1990. Post-glacial relative sea-level history of northwestern Spitsbergen, Svalbard. *Geological Society of America Bulletin,* 102: 1580–1590.

Forman S.L. & Ingólfsson Ó., 2000. Late Weichselian glacial history and postglacial emergence of Phippsøya, Sjuøyane, northern Svalbard: a comparison of modelled and empirical estimates of a glacial-rebound hinge line. *Boreas,* 29: 16–25.

Forman S.L. & Miller G.H., 1984. Time dependent soil morphologies and pedogenic processes on raised marine beaches, Bröggerhalvöya, Spitsbergen, Svalbard Archipelago. *Arctic and Alpine Research*, 16: 381–394.

Forman S.L., Lubinski D.J. Ingólfsson Ó., Zeeberg J.J., Snyder J.A., Siegert M.J. & Matishov G.G., 2004. A review of postglacial emergence on Svalbard, Franz Josef Land and Novaya Zemlya, northern Eurasia. *Quaternary Science Reviews,* 23: 1391–1434.

Forman S.L., Mann D. & Miller G.H., 1987. Late Weichselian and Holocene relative sea-level history of Bröggerhalvöya, Spitsbergen. *Quaternary Research*, 27: 41–50.

Goslar T. & Pazdur M., 1985. Contamination studies of mollucs shell samples. *Radiocarbon,* 27: 33–42.

Héquette A. & Ruiz M.H., 1989. Les variations postglaciaires de la ligne de rivage au Spitsberg nord-occidental, Svalbard, *Zeitschrift für Geomorphologie*, 33: 323–337.

Klimaszewski M., 1960. Geomorphological studies of the western part of Spitsbergen between Kongsfjorden and Eidembukta, *Zeszyty Naukowe Uniwersytetu Jagiellońskiego,* 32: 91–168.

Król M., Grześ M., Sobota I., Ćmielewski M. & Jaworski T., 2010. Submarine evidence of the Late Weichselian and Little Ice Age (LIA) glaciers limits in the St. Jonsfjorden Region (Svalbard). *Bulletin of Geography*, in press.

Landvik J.Y., Mangerud J. & Salvigsen O., 1987: The Late Weichselian and Holocene shoreline displacement on the west-central coast of Svalbard. *Polar Research,* 5: 29–44.

Landvik J.Y., Bondevik S., Elverhøi A., Fjeldskaar W., Mangerud J., Salvigsen O., Siegert M.J., Svendsen J.I. & Vorren T.O., 1998. The last glacial maximum of the Barents Sea and Svalbard area: ice sheet extent and configuration. *Quaternary Science Reviews,* 17: 43–7.

Landvik J.Y., Ingólfsson Ó., Mienert J., Lehman S.J., Solheim A., Elverhøi A. & Ottesen D., 2005. Rethinking Late Weichselian ice-sheet dynamics in coastal NW Svalbard. *Boreas*, 34: 7–24.

Lankauf K.R., 1982. Waldemar Glacier, Oscar II Land. Topographic map 1:5000, *Acta Universitatis Nicolai Copernici*, Geografia 16 [Suppl.].

Lankauf K.R., 2002. *Recesja lodowców rejonu Kaffiøyry (Ziemia Oskara II – Spitsbergen) w XX wieku*. Prace Geograficzne IG i PZ PAN 183, Warszawa: 224 pp.

Lehman, S. J. & Forman, S. L. 1992. Late Weichselian glacier retreat in Kongsfjorden, west Spitsbergen, Svalbard. *Quaternary Research*, 37: 139–154.

Miller G.H., Sejrup H.P., Lehman S.J. & Forman S.L., 1989. Glacial history and marine environmental change during the last interglacial-glacial cycle, western Spitsbergen, Svalbard: *Boreas,* 18: 273–296.

Mangerud J., Bolstad M., Elgersma A., Helliksen D., Lycke J.Y., Lönne J., Salvigsen O., Sandahl T. & Sejrup H.P., 1987. The Late Weichselian glacial maximum in western Svalbard. *Polar Research,* 5: 275–278.

Mangerud J., Dokken T., Hebbeln D., Heggen B., Ingólfsson Ó., Landvik J.V., Mejdahl V., Svendsen J.I. & Vorren T.O., 1998. Fluctuations of the Svalbard-Barents Sea ice sheet during the last 150 000 years. *Quaternary Science Reviews,* 17: 11–42.

Moign A., 1974. Géomorphologie du strandflat au Svalbard: problémes (âge, origine, processus), methodes de travail. *Inter-Nord*, 13–14: 67–72.

Niewiarowski W., 1982. Morphology of the forefield of the Aavatsmark Glacier (Oscar II Land, north-west Spitsbergen) and phases of its formation. *Acta Universitatis Nicolai Copernici*, Geografia, 16: 15–43.

Niewiarowski W. & Myzyk B., 1983. Kaffiöyra coast (Oscar II Land, NW Spitsbergen), its morphogenetic factors and processes, *Acta Universitatis Nicolai Copernici*, Geografia, 18: 17–43.

Niewiarowski W. & Sinkiewicz M., 1993. Geomorphological map of Kaffiöyra and its surroundings. [Annex to the article by W. Niewiarowski, M.F. Pazdur, M. Sinkiewicz, 1993]: *Polish Polar Research* 14 (3).

Niewiarowski W. & Sinkiewicz M., 1988. Frost mounds in Kaffiöyra and Hermansenöya, NW Spitsbergen, and their origin. In: Senneset, K. (eds.) *Permafrost Fifth Intern. Conference, Proc.*, 1. Tapir Publishers, Trondheim: 824–829.

Niewiarowski W., Pazdur M.F. & Sinkiewicz M., 1993. Glacial and marine episodes in Kaffiöyra, northwestern Spitsbergen, during the Vistulian and the Holocene. *Polish Polar Research* 14 (3): 243–258.

Olszewski A., 1977. Geomorphological investigations of the marginal zone of Elise Glacier. *Acta Universitatis Nicolai Copernici*, Geografia 13: 67–74.

Plichta W., 1993. *Gleby Kaffiöyry, Spitsbergen*. Szkic monograficzny, Wydawnictwo Naukowe UMK, Toruń.

Salvigsen O., 1984. Two observations of pumice levels from the west coast of Spitsbergen. *Polar Research,* 2: 115–116.

Siegert M.J. & Dowdeswell J.A., 2004. Numerical reconstructions of the Eurasian Ice Sheet and climate during the Late Weichselian. *Quaternary Science Reviews,* 23: 1273–1283.

Sinkiewicz M., 1982. Transformations of moraine forms under slope processes exemplified by some morains of Kaffiöyra (NW Spitsbergen). *Acta Universitatis Nicolai Copernici*, Geografia 16: 123–149.

Zapolski R., 1977a. Geodetic and topographic accomplishments of the "Toruń Polar Expedition, Spitsbergen – 1975". *Acta Universitatis Nicolai Copernici*, Geografia 13: 21–37.

Zapolski R., 1977b. Marginal zone of Elise Glaciers, Oscar II Land, West Spitsbergen. Topographic map 1:5000, *Acta Universitatis Nicolai Copernici*, Geografia 13 [Suppl.].