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Glacial and marine episodes in Kaffiöyra, northwestern Spitsbergen, during the Vistulian and the Holocene

ABSTRACT: Geological and geomorphological studies in Kaffiöyra and Hermansenöya (Oscar II Land, northwestern Spitsbergen), completed with radiocarbon datings, indicated that the Early Vistulian (Weichselian) Glaciation of presumable regional significance, occupied the whole area. Marine transgression during and after deglaciation reached at least to 65 m a.s.l. Glacioisostatic uplift and marine regression in Kaffiöyra resulted in development of older raised beaches at 52-65 m a.s.l. During the Late Vistulian, Kaffiöyra was occupied partly by outlet glaciers (Aavatsmark, Elise and Andreas), while the Dahl Glacier covered Hermansenöya. Extents of these glaciers were much greater than during the Little Ice Age. Marine transgression during deglaciation reached to 46-48 m a.s.l. at about 12-11.5 ka B.P. During glacioisostatic emergence at 11.5-9 ka B.P., ten younger raised marine beaches were formed in Kaffiöyra. Traces of a probable glacial episode at 3-2.5 ka B.P. were noted in forefields of the Aavatsmark and the Elise glaciers only. In forefields of all glaciers in Kaffiöyra there are deposits and landforms formed during glacial advances of the Little Ice Age and the following continuous retreat. The Aavatsmark Glacier was the only one to indicate surge type readvances at that time.

K e y w o r d s: Arctic, Spitsbergen, Kaffiöyra, Quaternary, glaciations, marine transgressions.

In spite of considerable research a number and extents of glacial episodes, as well as of marine transgressions during and after deglaciation of fiords and strandflats in northwestern Spitsbergen during the Vistulian (Weichselian) and the Holocene are still controversial. It results also from the fact that no landforms represent older glacial episodes, whereas deposits from these episodes are very scarce. Only glacial landforms and sediments of the Little Ice Age and the

deglaciation since the end of the 19th century are very clear and well preserved. Sediments of older marine transgressions and regressions are also relatively poor. In some fiords and strandflats there are, however comparatively well preserved, raised marine beaches and terraces, but their number and age are also an object of much controversy.

The first, more thorough geomorphological studies in Kaffiöyra were carried out in 1938 by Klimaszewski (1960). Since 1975 large-scale physico-geographical studies have been conducted in Kaffiöyra and its surroundings by the Toruń polar expeditions, organized mainly by the Institute of Geography, Nicholas Copernicus University (so far there have been 8 expeditions). During the 3rd Toruń Polar Expedition in 1978 and the 7th one in 1985, the authors (W. Niewiarowski and M. Sinkiewicz) carried out detailed geomorphological mapping of Kaffiöyra and its surroundings. Geomorphological mapping was based on Norwegian air photos of 1966 and 1969 in scale of 1:54,000 and 1:20,000 respectively. It was supplemented with maps of glaciers and their forefields in scale of 1:5,000 of the Elise (Zapolski 1977) and Waldemar (Lankauf 1982) glaciers, and with geodetic measurements in Kaffiöyra (mainly by K.R. Lankauf who also established glacial snouts in 1985 or 1989). All these studies resulted in a detailed geomorphological map in scale of about 1:30,000. During field works, data on the Quaternary deposits and samples with organic matter and marine mollusc shells were also collected. The samples were submitted to radiocarbon dating in the Radiocarbon Laboratory of the Silesian Technical University in Gliwice. Some samples of marine molluscs, collected in 1975 by J. Szupryczyński in this region, have been also dated in the same laboratory previously (Goslar and Pazdur 1985a). The present coast of Kaffiöyra was described by Niewiarowski and Myzyk (1983), while new information on the pre-Quaternary bedrock in Kaffiöyra are to be found in Wójcik (1982).

Laboratory method

Samples of organic matter were subjected to chemical pre-treatment with diluted hydrochloric acid at ambient temperature to remove carbonates, then charred in nitrogen stream and combusted to CO_2. Samples of mollusc shells were preliminary washed in distilled water to remove mineral admixture and to obtain clean surfaces. A surface layer was then removed by treating with 8% HCl. Amount of the latter was evaluated as such to remove *ca* 30-40% of carbonates from the outermost layer which, according to Goslar and Pazdur (1985b), may provide with erroneous dates due to contamination with younger carbonates. Remaining inner part of shells was similarly treated with 8% HCl in a vacuum apparatus and the evolved carbon dioxide was quantitatively collected, cleaned and stored for at least four weeks to enable a complete decay of radioactive gas ^{222}Rn. All radiocarbon datings were performed with proportional counters, filled with pure CO_2 from

dated samples. Small aliquots of CO_2 were used to determine $\delta^{13}C$ values of shell carbonates, necessary to account for isotopic fractionation effects.

The value of $\delta^{13}C$ of shell carbonates may be used as important indicator of contamination with foreign carbon in isotopic exchange (*cf.* Goslar and Pazdur 1985b). According to Mangerud (1972), contamination of shell carbonates is significant if the value $\delta^{13}C$ is lower than -3 permille wrt PDB standard. In all samples from Kaffiöyra dated for this study, measured values of $\delta^{13}C$ were much higher, from +1.2 to +2.2 permille wrt PDB. Therefore, any contamination of shell carbonates seems highly improbable. All radiocarbon dates for the studied area are listed (Table 1). Dates of shells were normalized for isotopic fractionation with a use of measured values of $\delta^{13}C$ and corrected for a reservoir effect, assuming some value of apparent age of 510±20 yr for all the samples (Goslar and Pazdur 1985a; *cf.* also Mangerud 1972, Olsson and Osadebe 1974, Mangerud and Gulliksen 1975). For organic samples, a fractionation and reservoir corrections are assumed to be neglectable.

General description of Kaffiöyra

Kaffiöyra is located in the Oscar II Land of northwestern Spitsbergen (Fig. 1). It forms a strandflat delimited in the north by Hornbaekbukta and the Aavatsmark Glacier, whereas in the south by the fiord-like bay of Farmsundet and the Dahl Glacier. In the west, it adjoins the Forlandsundet and in the east - the mountains. From the latter, outlet glaciers (Aavatsmark, Elise, Andreas and Dahl) flow down onto Kaffiöyra but there are also mountain glaciers of Alpine type (Waldemar, Irene, Agnor, Eivind and Oliver) which terminate in intra-montane valleys.

Mountains which adjoin Kaffiöyra, are of medium heights, rising from about 400 to 935 m a.s.l. They are built of rocks of the Hecla Hoek Succession: dolomites, quartzites, pegmatites, marbles and schists. These rocks outcrop in Kaffiöyra to the east of the main fault which runs from foot of the Prins Heinrichfjella to the Cape Snippen. The same rocks occur on Hermansenöya, about 4 km to the south. West of the fault there are the Palaeogene rocks with prevailing conglomerates and sandstones, but also with siltstones and clayey shales. These rocks are cut by joints and faults, running WSW-ENE (Wójcik 1982).

The bedrock of Kaffiöyra is covered mostly with a thin (up to 6.3 m) layer of Quaternary deposits. In many places however, especially on abrasive marine terraces, the bedrock is exposed. The Quaternary sediments on the marine terrace 22-24 m a.s.l. on Hermansenöya are to 14 m thick.

Raised marine beaches are among the most significant geomorphological elements that testify sea transgressions and regressions. Ancient marine cliffs, abrasive platforms, beach ridges, old lagoons as well as sublittoral, littoral and beach deposits with marine mollusc shells are preserved (*Annex*). Klimaszewski (1960) distinguished in Kaffiöyra five marine beaches: 50-55, 37-40, 23, 14-15 and 10-

Radiocarbon dates from Kaffiöyra, Sarsöyra and Hermansenöya Table 1.

Locality	Landforms, sediments	Altitude m a.s.l	Material dated	Age [B.P.]	Lab. - ID	References
Kaffiöyra	coastal cliff, glaciomarine sediments	0.5	organic matter	>30 ka	Gd - 4283	
		2.0		>35 ka	Gd - 2862	
	raised beach, ridge sediments	33.0	marine mollusc shells	11,000 ± 190	Gd - 4296	
	marine terrace surface sediments	12.9-13.6	shells *Mya truncata* Lam., inner part	9,720 ± 110	Gd - 1253	Goslar and Pazdur (1985a,b)
	coastal cliff, raised beach	12.0-13.0	marine mollusc shells	9,990 ± 80	Gd - 5351	
	moraine ridge	11.0		10,660 ± 110	Gd - 5348	
	raised beach surface sediments	7.0-8.0		10,550 ± 110	Gd - 5349	
	coastal cliff, beach sediments	7.0	organic matter	8,600 ± 60	Gd - 5329	
	raised beach, surface sediments	5.0-6.5	shells *Mytilus edulis* Lam., inner part	9,540 ± 110	Gd - 1258	Goslar and Pazdur (1985a,b)
		5.6-6.5		9,630 ± 130	Gd - 1255	
	raised beach, subsurface	4.0-5.0		10,640 ± 180	Gd - 2861	
	raised beach, glaciomarine	4.5	shells *Mya truncata* L.	9,085 ± 80	DIC - 2904	Forman (1989)
Hermansenöya	c. cliff, sublittoral sediments	15-17	shells *Mya truncata* L.	9,980 ± 120	Gd - 788	Goslar and Pazdur (1985a,b)
		15-17	shells *Hiatella sp.*	10,060 ± 10	Gd - 1254	
		17	shells *Hiatella arctica*	9,825 ± 90	DIC - 2905	Forman (1989)
Sarsöyra	marine terrace surface sediments	21.5-24	shells *Mya truncata* L.	10,000 ± 150	Gd - 1234	Goslar and Pazdur (1985a,b)
		22		10,130 ± 160	Gd - 789	
	c. cliff sublittoral/littoral sediments	22		9,255 ± 100	DIC - 2906	Forman (1989)

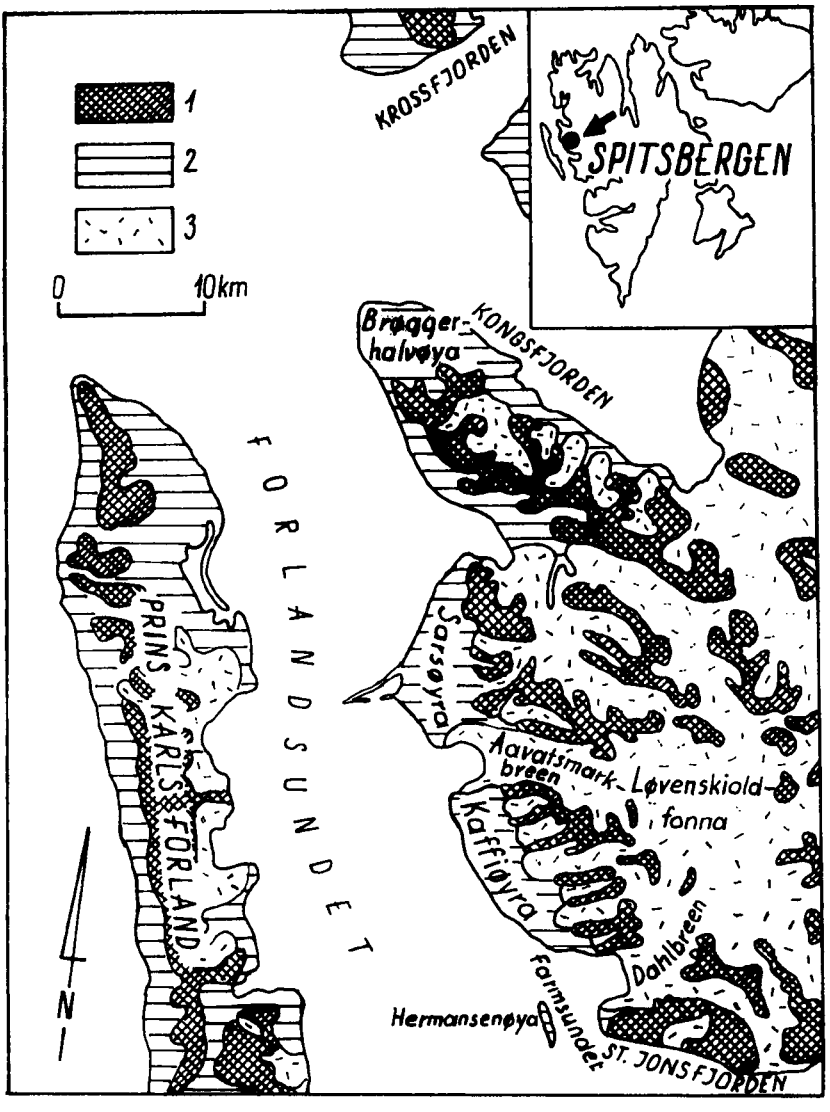

Fig. 1. Location sketch
1 - mountains, 2 - strandflat, 3 - glaciers

12 m a.s.l. Such beaches have been then cited in many papers, *e.g.* by Moign (1974). These estimates were based on 2 hypsometric sections only and are not true to reality. During detailed geomorphological mapping, the highest shelves were noted on slopes of Jarlbergryggen between the Elise and the Eivind glaciers at 160 and 110 m a.s.l. The shelves have not been thoroughly explored and it is still uncertain whether they are fragments of either marine terraces or structural/ denudation flatnesses (pediments). Likewise, at foot of the Prins Heinrichfjella at

about 110 m a.s.l., there is a shelf 100-200 m wide, developed on schists of the Hecla Hoek Succession which get easily weathered and moved about due to solifluction. No beach deposits were found on this shelf. However, in Sarsöyra (north of Kaffiöyra) beach deposits have been found on the terrace 120 m a.s.l. (Klimaszewski 1960, Moign 1974). The highest Quaternary marine limit is therefore highly probable to have reached to over 120 m a.s.l. (Klimaszewski 1960, Moign 1974) and it seems to have occurred also above this altitude. Fragments of undoubted raised marine beaches occur in Kaffiöyra at 62-65, 52-58, 42-46, 37-40, 30-33, 26-29, 18-19, 12-14, 10-12, 7-9 and 4-6 m a.s.l. On Hermansenöya with its maximum altitudes of 39 m a.s.l., there are more or less clearly distinguishable raised marine beaches at 21-24, 15-17, 10-12, 7-9 and 4-6 m a.s.l.

Some of the raised marine beaches in Kaffiöyra have been partially transformed and covered with landforms and depostis of advancing glaciers during the Little Ice Age and at the time of their shrinkage in the 20th century. There are also faint traces of glaciation, dating probably to about 2-2.5 ka B.P. (Niewiarowski 1982). Raised marine beaches are cut by outwashes, meltwater and niveofluvial valleys formed during these glacial episodes. Great variety of periglacial forms and structures are noted on them (Klimaszewski 1960, Niewiarowski and Sinkiewicz 1988, and others) but they are not to be considered here.

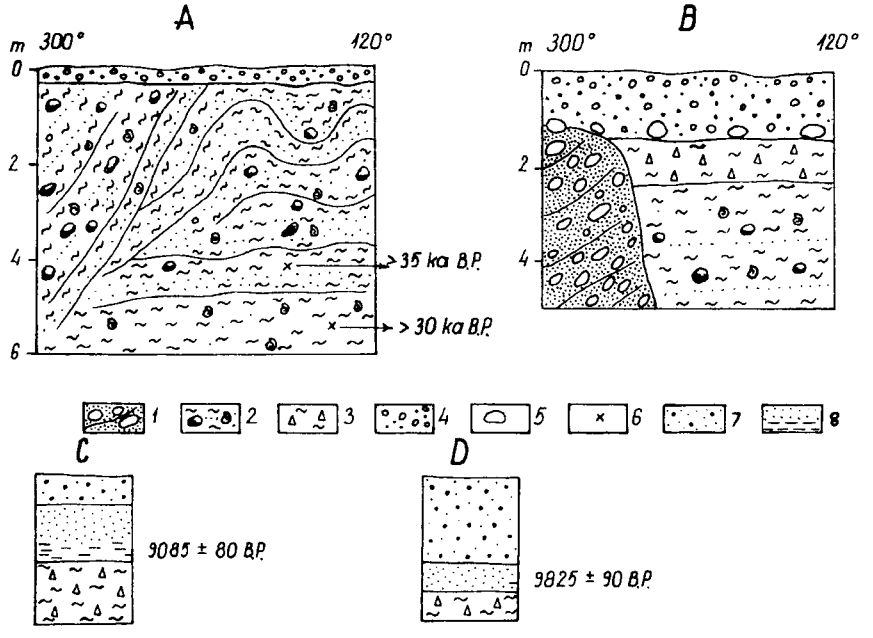

Fig. 2. Outcrops in a coastal cliff of Kaffiöyra (A, B), and geological sections after Forman (1989) from Hermansenöya (C) and Kaffiöyra (D)

1 - Palaeogene conglomerates, 2 - glaciomarine sediments, 3 - till, 4 - beach gravels, 5 - large erratics, 6 - sampling site to radiocarbon dating, 7 - beach sediments, 8 - sublittoral sediments

Problem of older Vistulian episodes

The oldest Pleistocene sediments found so far in Kaffiöyra are exposed in a marine cliff between Öyrness and Snipeodden. They are glaciomarine stratified darkgrey clays and grey silts with marine mollusc shells and admixture of organic matter. These deposits are interbedded with sand and gravel, and contain a large number of dropstones (pebbles and boulders) derived from melting icebergs (Fig. 2A). They are locally disturbed, probably by stranded icebergs or a glacier. Over 5 m thick in a cliff, they are truncated in top and discordantly overlain by beach gravels of the Late Vistulian or the Early Holocene. Radiocarbon dates of organic matter point out to over 30 ka and over 35 ka B.P. (Table 1). Similar glaciomarine deposits in a similar stratigraphical location are exposed in a cliff of Sarsöyra, about 6 km to the north of Kaffiöyra. They have been studied by Boulton (1979): shells of *Mya truncata* were dated at over 34 ka B.P. Boulton found a till beneath these deposits. He suggested the till was deposited by a glacier during a glacial episode shortly prior to 40-45 ka B.P. whereas glaciomarine sediments should be related to a glacier retreat at that time. Glaciomarine sediments occurring in a push end moraine of the Elise Glacier from the Little Ice Age on the marine beaches 10-13 and 14-15 m a.s.l., are probably of the same age.

On Hermasenöya, Szupryczyński (1983) found a lower till which probably dates from the Saalian; it overlies rocks of the Hecla Hoek Succession and occurs at depth of 12.7-13.35 m a.s.l. in the marine terrace 22-24 m a.s.l. The age presumption is not supported however by any evidence. The till is overlain at depth of 7.6-12.7 m by coarse gravel with large pebbles and fine-grained sands, containing sparse remains of marine mollusc shells. At 7-7.6 m depth there is the upper till, overlain with sands and gravels. This till is mantled, according to Forman (1989), by sublittoral sediments with shells of *Hiatella arctica*, radiocarbon-dated at 9825±90 B.P. A similar age for these deposits was obtained by Goslar and Pazdur (1985b; *cf.* Table 1).

Much more information about the Pleistocene deposits in northwestern Spitsbergen has been obtained on Bröggerhalvöya, *i.e.* a dozen or so kilometres to the north of Kaffiöyra. Forman and Miller (1984) found there a complex sequence of raised marine beaches, subdivided into a bipartite age series on the ground of their altitude, geomorphic preservation, radiocarbon dates and amino-acid ratios of mollusc shells. The uppermost beach sediments at 55-80 m a.s.l. were deposited during the episode C (130-290 ka B.P.). The intermediate beach series at 44-55 m a.s.l. is tentatively correlated to the episode B (60-160 ka B.P.), whereas the ones below 44 m a.s.l. were formed during the last 12 ka (episode A). Later Miller *et al.* (1989) discovered that superimposed glacial and marine sediments in coastal cliffs of Bröggerhalvöya contain four emergence cycles (episodes D-A), related to glacioisostatic subsidence and subsequent recovery of the Earth crust. Tills are noted for the episodes C and B. In each case, a glaciation began with advance of local glaciers, followed by a regional glaciation. Marine transgression after the

deglaciation episode C reached up to 70-80 m a.s.l. Glaciomarine sublittoral and littoral sands within the episode C contain a diverse and abundant microfauna, requiring more favourable marine conditions than during the Holocene. This interval is named the Leinstranda Interglacial and it corresponds to the Eemian Interglacial in Europe.

We have not found, so far, any deposits in Kaffiöyra that may be related to the episodes C or D. It is possible however, that the marine terrace 120 m a.s.l., noted by Klimaszewski (1960) and Moign (1974) in Sarsöyra close to the end moraines of the Aavatsmark Glacier, is related to one of these episodes and so may be the shelves found by us at about 110 m a.s.l. on slopes adjacent to Kaffiöyra. Age of the raised marine beaches in Sarsöyra at 90 and 106 m a.s.l. (Moign 1974) is not clear either. She suggested that beaches at about 100 m a.s.l. in Sarsöyra were formed during the Alleröd and the Younger Dryas. However, in light of Forman and Miller's (1984) pedological studies on Bröggerhalvöya as well as our own datings of terraces in Kaffiöyra, this suggestion does not find any confirmation.

Miller *et al.* (1989) claim the deglaciation episode B on Bröggerhalvöya to have occurred during the isotope stage 5 (*ca* 70±10 ka B.P.), and was followed by a marine transgression to about 50 m a.s.l. Associated foraminifers, molluscs and vertebrates require seasonally ice-free conditions, similar to the ones during the Holocene but worse than during the Leinstranda Interglacial. They also claim no evidence on Bröggerhalvöya for major glacier activity during the Middle Vistulian (isotope stages 4 and 3), and conclude that ice margins were not significantly different from the ones of the Late Vistulian; however, records for this interval are scant.

In light of the above conclusions, a problem arises which episodes of deglaciation and glacioisostatic subsidence are represented by glaciomarine sediments exposed in a cliff of Kaffiöyra and older than 35 ka B.P. (Table 1). Were they deposited during the Early Vistulian deglaciation about 70±10 ka B.P. which occurred on Bröggerhalvöya (Miller *et al.* 1989), or during the Middle Vistulian prior to 40-45 ka B.P. as suggested by Boulton (1979) for Sarsöyra?

The problem of older Vistulian glacial episodes in Spitsbergen is complex and difficult to solve. Some authors postulate that both the Early and the Middle glacial episodes occurred there. For example Lindner *et al.* (1987) assume that in the Sörkapp Land there is evidence for the Early Vistulian (about 73 ka B.P.) and the Middle Vistulian (about 50-41 ka and 29.5-22 ka B.P.) glacial episodes. Kłysz *et al.* (1988) suggest that in the northwestern Billefjorden Region, there were two glacial episodes (about 87 ka and 40-56 ka B.P.). Also Boulton *et al.* (1982) assume glacial episodes about 70 ka B.P. and 35-45 ka B.P. on western coast of Spitsbergen. In the case of Kaffiöyra it is difficult to answer this question, since there is no direct age evidence so far for glaciomarine deposits and the older till on Hermansenöya. There is however, some indirect evidence in Kaffiöyra as undoubted raised marine beaches at 52-58 and 62-65 m a.s.l. The best preserved beach sediments occur at foot of Heinrichfjella, not far from the Little Ice Age end-lateral moraines of the Aavatsmark Glacier. They are exposed

on a slope of a marginal valley: 6.3 m thick sands and gravels with marine pebbles up to 10 cm in diameter and with fragments of marine mollusc shells. These sediments lie discordantly on the Palaeogene conglomerates and form accumulative platform about 80 m wide and with poorly developed beach ridges at 58-63 m a.s.l., deeply cut by niveofluvial valleys. Pedological studies by dr. W. Plichta (Department of Pedology, N. Copernicus University, Toruń) indicated that a soil horizon B is 40 cm thick, with larger clasts in the lower part and continuous carbonate coats on them at depth of 50 cm. He did not find such coats on clasts in beach deposits at lower altitudes. Soil sections exhibit then many soil morphologies, typical for soils of the episode B on Bröggerhalvöya (Forman and Miller 1984), developed on beach deposits of the so-called intermediate beach series at 44-55 m a.s.l. More elevated beach deposits in Kaffiöyra result from the fact that this area indicates glacioisostatic uplift several metres higher than Bröggerhalvöya (Lehman and Forman 1987, Forman 1989). The episode B on Bröggerhalvöya, as already mentioned, is considered to have been older than 60 ka B.P. It can be assumed therefore that glaciomarine sediments older than 35 ka B.P. and raised beaches between 52 and 65 m a.s.l. on Kaffiöyra represent deglaciation, marine transgression and emergence due to glacioisostatic uplift after the Early Vistulian glacial episode (*ca* 70±10 ka B.P.). This glaciation occupied probably the whole Kaffiöyra and Hermansenöya, since large erratics are to be found all over the former. After deglaciation and emergence, a long glacier-less period occurred which also comprises the Middle Vistulian interstadial (40-25 ka B.P.), distinguished by Salvigsen (1977) in northwestern Spitsbergen.

Late Vistulian glacial episode, subsequent marine transgression and regression in Kaffiöyra

There are different opinions regarding glaciation of northwestern Spitsbergen during the Late Vistulian, its exact date and extents. Grosswald (1980), Denton and Hughes (1981) claimed that it occupied a vast area and occurred at the same time as the last Scandinavian glaciation. Conversely many authors *e.g.* Boulton (1979) suggest that this glacial episode took place during the Younger Dryas and was of very limited extent: glaciers did not expand further than during the Little Ice Age. In Kaffiöyra and Hermansenöya there is evidence to estimate such opinions with some criticism.

We found in a marine cliff a thin layer of till, overlying the already described marine sediments (Fig. 2B) and covered by beach deposits. In some other places abrasive platforms are mantled with a till. Szupryczyński (1983) found the upper till on Hermansenöya. Goslar and Pazdur (1985) as well as Forman (1989) dated a lower part of marine sediments (Fig. 2D) over a till at about 10 ka B.P: (Table 1). With such information, Forman (1989) claims, that during this glacial episode, the Dahl Glacier expanded at least as far as the Hermansenöya. Basing on the

fact that a till was found in forefield of the Elise Glacier (Fig. 2C), he concludes that the glacier reached the Forlandsundet. We noted a till in a marine cliff and therefore, found that also the Aavatsmark Glacier, at least in its southern part, occupied a vaster area at this time and reached the Forlandsundet at about 100 m b.s.l. Fragments of raised marine beaches (52-58 and 62-65 m a.s.l.), older than this glacial episode, are preserved in Kaffiöyra and thus indicate that this area was only partly occupied by glaciers. Alpine-type glaciers do not seem to have advanced beyond the mountains; only outlet glaciers - in particular the Aavatsmark, Elise, and Dahl glaciers (presumably also the Andreas Glacier) - expanded to the Forlandsundet. The glaciation was then of a regional character.

There is no direct evidence to date a beginning of the Late Vistulian glacial episode and a moment of the glacial maximum. Salvigsen and Nydal (1981) suggested earlier that maximum of the Late Vistulian glaciation in western Spitsbergen occurred at about 18 ka B.P. but *e.g.* Mangerud *et al.* (1987) found it to have been somewhat later. Forman (1989) assumes duration of this glacial episode from 15 to 10 ka B.P.

More compatible opinions concern a beginning of the Late Vistulian deglaciation in western Spitsbergen. A deglaciation is generally accepted to have started about 13-12 ka B.P. (Mangerud *et al.* 1987, Lehman and Forman 1987, Héquette and Ruiz 1989, Forman 1989) and coincided in time with marine transgression and glacioisostatic uplift, resulting in marine regression. Forman (1989) defined the maximum Late Vistulian Marine Limit in Kaffiöyra at about 46-48 m a.s.l. Our observations confirm this opinion as below this level there are quite well preserved beach ridges, former lagoons and marine cliffs, whereas soils exhibit properties typical for the episode A (last 12 ka) *i.e.* horizon B is less than 35 cm thick and without a continuous carbonate coating on lower sides of clasts, etc. Below the Late Vistulian Marine Limit, there are in Kaffiöyra fragments of ten raised marine beaches: 42-46, 37-40, 30-33, 26-29, 22-24, 18-19, 12-14, 10-12, 7-9 and 4-6 m a.s.l. which document a marine regression. A synthetic section across Kaffiöyra is presented (Fig. 3). Unfortunately, there are no radiocarbon dates from the two uppermost raised beaches yet. Mainly shells of *Mya truncata* and *Hiatella arctica* were dated on raised beaches but some of them were undoubtedly redeposited. The highest dated level (30-33 m a.s.l.) has about 11 ka B.P. (Table 1, Fig. 3). Only the date 8600±60 B.P. comes from organic matter in sediments of a marine beach 7-9 m a.s.l. but this date is probably too young. Remaining dates indicate radiocarbon ages between 11 and 9 ka B.P. Considering them, a mean glacioisostatic uplift seems to have been of about 2 m per 100 years.

On the ground of mean rate of glacioisostatic uplift, though most rapid during at the very beginning, deglaciation and maximum marine transgression in Kaffiöyra took place about 12-11.5 ka B.P. Basing on datings of raised marine beaches in Kaffiöyra (Table 1, Fig. 3), the levels between 46 and 4 m a.s.l. seem to have developed from about 11.5 to 9 ka B.P. and ever since that time Kaffiöyra has been under subaerial conditions. Earlier suggestions on raised marine beaches younger than 9 ka B.P. (Klimaszewski 1960, Moign 1974, and others) have not

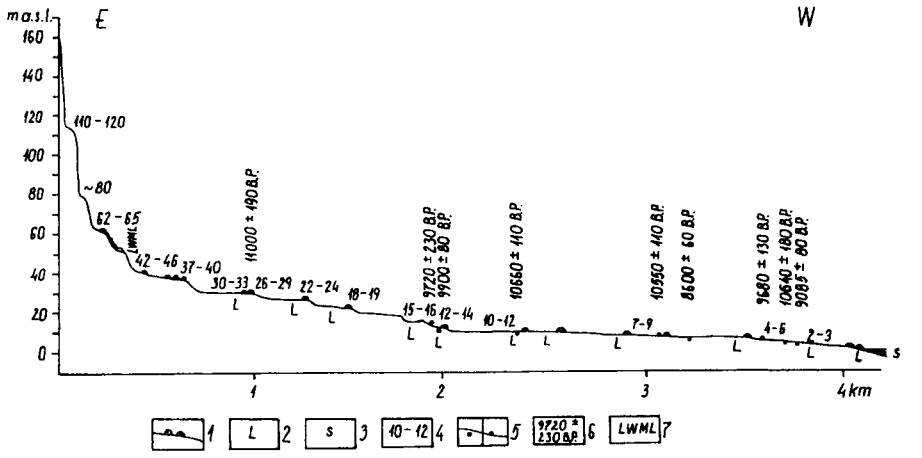

Fig. 3. Synthetic hypsographical section across Kaffiöyra
1 - beach ridges, 2 - former and recent lagoons, 3 - sea, 4 - altitude of raised marine beaches in metres a.s.l., 5 - sampling sites to radiocarbon datings, 6 - radiocarbon dates, 7 - Late Vistulian Marine Limit

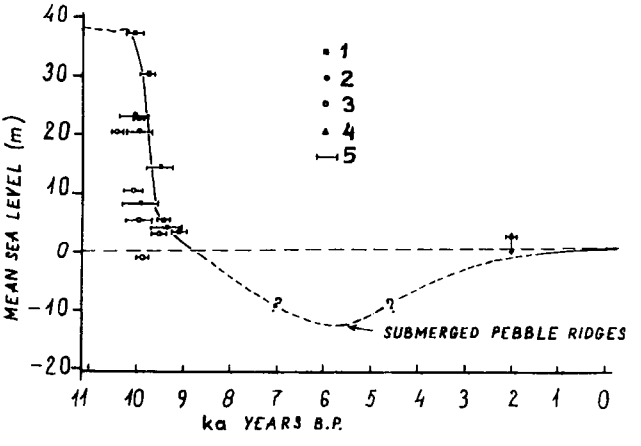

Fig. 4. Relative sea-level curve in the Kongsfjorden during the Holocene after Héquette and Ruiz (1989)
1 - whalebones; marine shells in: 2 - littoral sediments, 3 - sublittoral sediments; 4 - moss, 5 - error of radiocarbon age

been confirmed. Results from Kaffiöyra are different from those obtained in other areas of Spitsbergen but agree with results by Héquette and Ruiz (1989) from the Kongsfjorden. The only difference is that the uppermost marine limit is there somewhat older (13 ka B.P.) but it may be due to regional differences, especially to greater extent of glaciers in Kaffiöyra during the Late Vistulian.

Our results indicate that sea level after 9 ka B.P. was lower than at present. This suggestion is based on fact that along the western coast of Kaffiöyra, a submerged strandflat at 2-10 m b.s.l. occurs (Niewiarowski and Myzyk 1983). A simi-

lar submerged strandflat with polygons on beach ridges was noted in Kongsfjorden (Moign 1974). Basing on these facts, Héquette and Ruiz (1989) suggested that the lowest Holocene sea level in northwestern Spitsbergen was about 10-15 m below the present one (Fig. 4). Such picture, different from the known in other parts of Spitsbergen, is accounted by specificity of glacioisostatic movements. Results from Kaffiöyra confirm in general the shoreline displacements after 12-13 ka B.P., suggested by Héquette and Ruiz (1989) for northwestern Spitsbergen.

Holocene glacial episodes

In Kaffiöyra and its surroundings, there are very fresh glacial and glaciofluvial landforms associated with glacier advances during the Little Ice Age, but also their thinning and shrinkage since the end of the 19th century. Maximum extents as well as their retreat up to 1985, in some cases even to 1989, are presented (*Annex*). From research in forefields of the Irene (Wronkowski and Olszewski 1977), Elise (Olszewski 1977), Aavatsmark (Niewiarowski 1982), Waldemar (Lankauf and Preisner 1982), Dahl (Sendobry and Sinkiewicz 1983) and partially Andreas (Drozdowski 1985) glaciers, all they are known to have been shrinking continuously during the 20th century. The Aavatsmark Glacier is the only exception as in the thirties and fifties indicated surge-type readvances (Niewiarowski 1982).

A problem of the older Holocene glacial advances is more complicated. At foot of a push end moraine from the Little Ice Age in forefield of the Elise Glacier, there are older moraines 1-3 m high, at about 13 m a.s.l. (Olszewski 1977). Niewiarowski (1982) also noted older moraines (2-4 m high, 5-10 m wide and 80 m long) at foot of southern end moraines of the Aavatsmark Glacier from the Little Ice Age. These older moraines occur on the marine beach 10-12 m a.s.l., and their deposits comprise mollusc shells dated at 10,660±110 B.P. (Table 1). These moraines are associated with older outwash cones, almost reaching a sea-level. They are therefore younger than the lowest raised beaches *i.e.* younger than 9 ka B.P. In a push end moraine of the Elise Glacier from the Little Ice Age there is, besides glaciomarine sediments, an older brown till disturbed by periglacial processes with fragments of soil and peat, covered by a grey till from the Little Ice age (Olszewski 1977). Behind these push end moraines but in forefield of the Elise Glacier, the 5 cm thick layer of peat dated at 1655±130 B.P. (Gd-660) was found under a thin (60 cm) fresh lodgement till and on brown loamy gravels and a till. These gravels and the till are to be connected probably with the already mentioned older moraines. Considering the Holocene glacial episodes in Spitsbergen (Szupryczyński 1962, Troitsky *et al.* 1975, Baranowski 1977), these older moraines in Kaffiöyra seem to be associated with a glacial episode 3-2.5 ka B.P. when glaciers in this region (except for the Elise Glacier and locally the Aavatsmark Glacier) occupied a smaller area than during the Little Ice Age.

Glacioisostatic subsidence and subsequent marine transgressions are not associated with these glacial episodes. However, as demonstrated by studies in Kaffiöyra (Niewiarowski and Myzyk 1983), on coasts of the Hornbaekbukta and the Farmsundet, ice-free in the 20th century, sea waves destructed deposits and glacial landforms relatively quickly, and sea encroached a low lying coast.

Comparison of air photographs from 1966 and 1969 with the present state demonstrates that coastal lakes have considerably increased their extents, and shorelines have been shifted inland. In either of the two bays the present shoreline has not reached a limit from before the Little Ice Age yet (Niewiarowski and Myzyk 1983). Hence, even at a stable sea-level and isostatic equilibrium, the observed sea transgression will be continued.

Conclusions

New geological and geomorphological data point out that the whole Kaffiöyra and Hermansenöya were glaciated during the Early Vistulian about 70±10 ka B.P. This glaciation can be correlated with the episode B on Bröggerhalvöya (Miller *et al.* 1989). Glacioisostatic subsidence associated with this glaciation was conducive to marine transgression up to about 65 m a.s.l. The following glacioisostatic emergence resulted in development of raised marine beaches 52-58 and 62-65 m a.s.l. After emergence, there was a long glacier-less interval. So far, no evidence of the Middle Vistulian glaciation is known what of course does not rule out its existence.

There are well preserved traces (till) of the Late Vistulian glaciation. However, glaciers probably occupied a smaller area than during the Early Vistulian but much greater than suggested *e.g.* by Boulton (1979). A marine transgression during deglaciation reached up to 46-48 m a.s.l. at about 12-11.5 ka B.P. During the glacioisostatic uplift (about 11.5-9 ka B.P.) numerous raised marine beaches were formed at 4-46 m a.s.l.

There are only few traces of the Holocene glacial episode of a limited extent in Kaffiöyra, dated most probably at 3-2.5 ka B.P. Very clear landforms and deposits associated with glacier advances during the Little Ice Age and their subsequent shrinkage in the 20th century are known. Against a general retreat of glaciers, the Aavatsmark Glacier indicated at least two well marked surge-type readvances.

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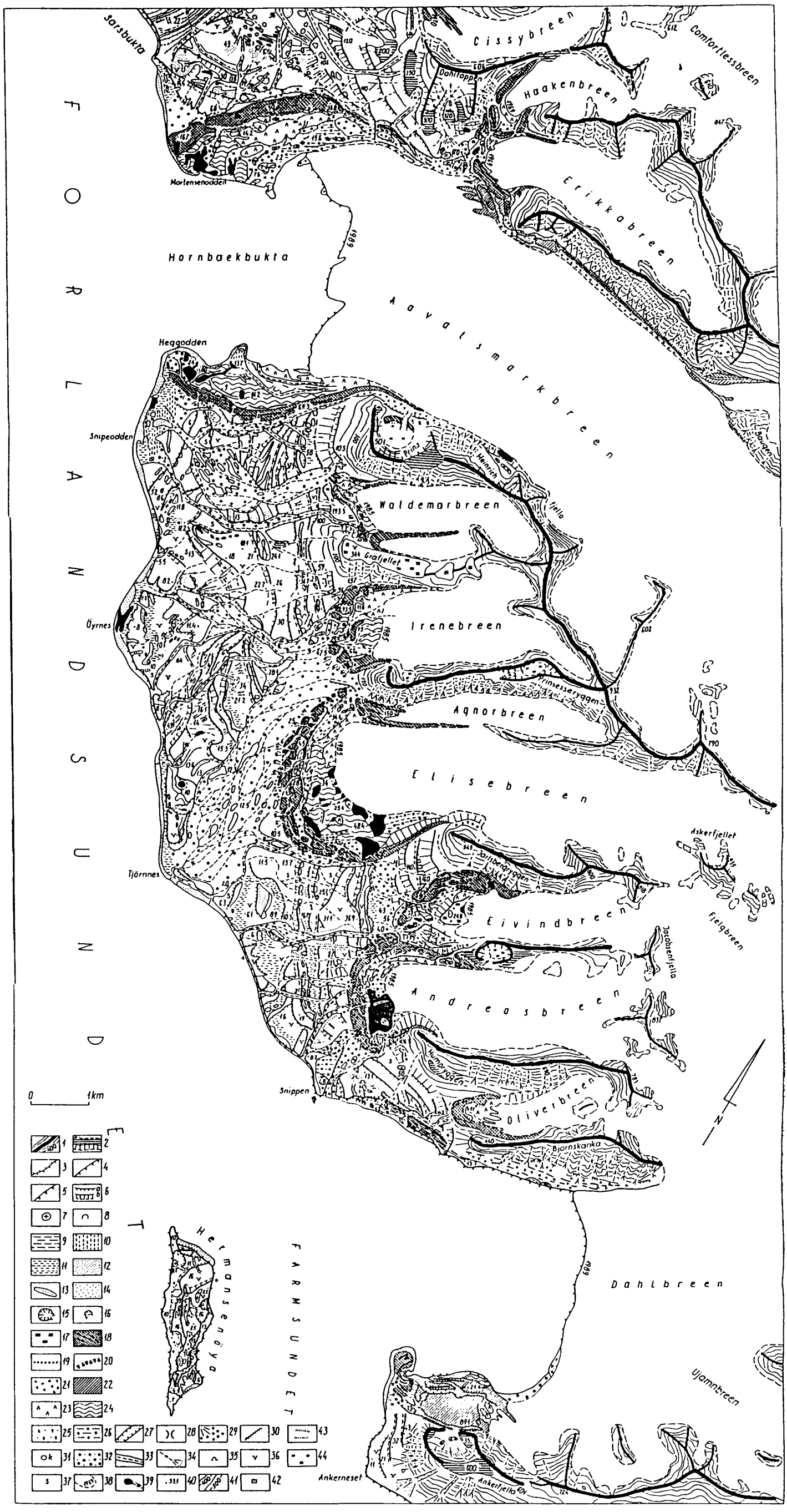
W. Niewiarowski, M. Sinkiewicz

Geomorphological map of Kaffiöyra and its surroundings



1 - mountain ridges, contour interval at every 50 m, 2 - slope flattenings and steps, 3 - structural ridges on the abrasive platform, 4 - active sea cliffs, 5 - inactive (dead) cliffs, 6 - marine beach edges, a - distinct, b - undistinct, 7 - stacks, 8 - abrasive niches, 9 - abrasion platform, 10 - tidal plain, 11 - recent and former lagoons, 12 - recent and raised beach plain, 13 - recent and raised beach ridges, 14 - berms, 15 - glacial cirques and erosion channels, 16 - nival niches, 17 - roches moutonnées, 18 - moraine ridges and ice-cored moraines (recent and from the Little Ice Age), 19 - moraines of the glacial episode at 3.0-2.5 ka BP, 20-former lateral moraines, 21 - till cover up to 1 m thick on bedrock, 22 - ablation till up to 1 m thick on stagnant ice, 23 - hummocky moraine, 24 - ground moraine plain, 25 - washed moraine and morainic pavement, 26 - meltwater erosive plains, 27 - marginal and lateral valleys, 28 - meltwater gaps, 29 - outwash fans and plains, 30 - eskers, 31 - kames, 32 - ice dam lake plains, 33 - niveofluvial valleys, 34 - chutes and talus or alluvial cones, 35 - larger frost mounds, 36 - patterned ground areas, 37 - intensive solifluction areas, 38 - glacier snouts at definite year, 39 - lakes and streams, 40 - altitude points, 41 - contour lines, 42 - large eratics, 43 - overflow channels, 44 - large perenial snow patches.

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Streszczenie

Kaffiöyra - nadmorska równina abrazyjna (strandflat) i sąsiadująca z nią wyspa Hermansena, położone są na Ziemi Oskara II w NW Spitsbergenie (fig. 1). Autorzy (W. Niewiarowski i M. Sinkiewicz) prowadzili tam w czasie Toruńskich Wypraw Polarnych w 1975 i 1985 roku, badania geologiczne i kartowanie geomorfologiczne (*zał.*), a pobrane próbki osadów ze szczątkami organicznymi oraz muszle mięczaków morskich zostały wydatowane metodą radiowęglową przez Goslara i Pazdura (1985a, b). Te i datowania metodą radiowęgla innych autorów zostały zestawione (tab. 1).

Na podstawie przeprowadzonych badań autorzy stwierdzają, że zlodowacenie (prawdopodobnie o znaczeniu regionalnym) w czasie wczesnego vistulianu (Weichselian) około 70±10 ka B.P. przykryło całą Kaffiöyrę i wyspę Hermansena. W czasie i po deglacjacji nastąpiła transgresja morza, sięgająca co najmniej do 65 m n.p.m. Pozostałością z tej transgresji są osady glacjalno-morskie (fig. 2A). Z glacjoizostatycznym wynurzeniem obszaru i regresją morza związana jest na Kaffiöyra starsza sekwencja podniesionych plaż, o wysokości 52-65 m n.p.m. Potem nastąpił długotrwały okres bezlodowcowy.

W kolejnym epizodzie glacjalnym - w późnym vistulianie (około 12-15 ka B.P.) - nie cała Kaffiöyra była zlodowacona a pokrywały ją częściowo lodowce Aavatsmarka, Elizy i Andreasa, zaś lodowiec Dahla pokrył także wyspę Hermansena. Pozostałością tego zlodowacenia są częściowo zachowane osady morenowe (fig. 2B-D). Postępująca w czasie deglacjacji transgresja morza dotarła do wysokości 46-48 m n.p.m. około 11,5-12 ka B.P. W czasie podniesienia glacioizostatycznego powstała na Kaffiöyra w okresie 9-11,5 ka B.P. młodsza sekwencja 10 podniesionych plaż lub tarasów morskich (fig. 3). Wahania poziomu morza w tym regionie w holocenioe są zbliżone do sytuacji w Kongsfiordzie (fig. 4).

Jedynie na przedpolu lodowców Aavatsmarka i Elizy stwierdzono dotychczas ślady epizodu glacjalnego, prawdopodobnie z okresu 2,5-3 ka B.P., a na przedpolu wszystkich istniejących tu lodowców występują osady i fromy związane z Małą Epoką Lodową i późniejszym (w XX wieku) ciągłym kurczeniem się lodowców. Jedynie lodowiec Aavatsmarka wykazywał co najmniej 2 krótkotrwałe nasunięcia typu zerwania–*surge* (*zał.*).