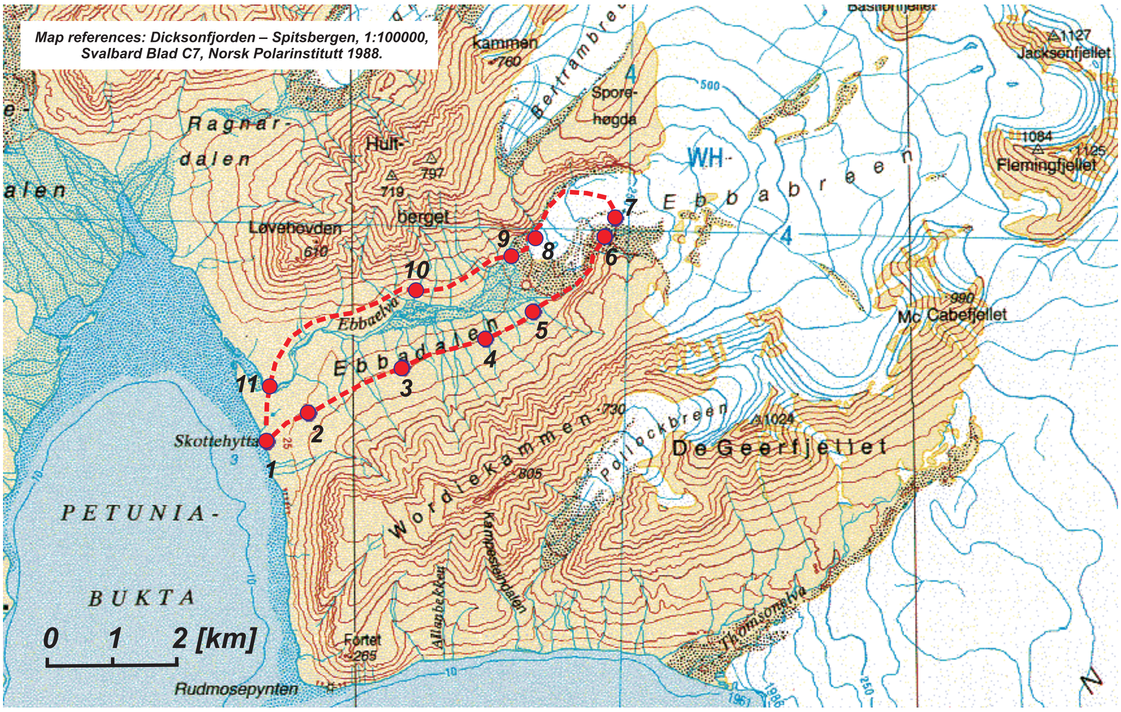
Petuniabukta: from glacial to paraglacial processes in Ebbadalen – Leader Grzegorz Rachlewicz

Grzegorz Rachlewicz*

Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poznań, Poland



Petuniabukta – excursion programme

Point 1 – Skottehytta 78°41.944'N 16°36.932'E
Introduction, environmental background

Point 2 – Terrace 78°42.143'N 16°38.428'E
Raised marine terraces, non-glacial catchments

Point 3 – Ebbadalen 78°42.458'N 16°41.790'E
Slope processes, periglacial phenomena

Point 4 – Wordiekammen W 78°42.654'N 16°44.777'E
Sedimentary rocks – Gipsdalen Group

Point 5 – Wordiekammen E 78°42.843'N 16°46.509'E
Crystalline bedrock – Hekla Hoeck Formation

Point 6 – Ebbabreen marginal zone 78°43.368'N 16°49.098'E
Glacial geomorphology and deglaciation since Little Ice Age

Point 7 – Ebbabreen 78°3.495'N 16°49.479'E
Glacial phenomena

Point 8 – Ebbabreen marginal zone, Ebbaelva waterfall 78°43.391'N 16°46.583'E
Marginal glacifluvial outflow

Point 9 – Bertilelva 78°43.219'N 16°45.736'E
Bertilbreen characteristic and glacifluvial processes

Point 10 – Hultberget 78°42.962'N 16°40.928'E
Complex view on Arctic valley system

Point 11 – Ebbaelva mouth 78°42.319'N 16°37.039'E
Catchment closing point and interferences with coastal processes

* e-mail: grzera@amu.edu.pl

Introduction to the excursion

The surroundings of Petuniabukta is an area easy-accessible from Svalbard West coast, in the inner-fiord region of Central Spitsbergen. It is the most North-Eastern tip of the Isfjorden system, what through its location determines geology, morphology and climate features.

The exploration following the search for natural resources and investigations of natural environment in this region started at the turn of 19th and 20th century with expeditions of Baron N.A.E. Nordenskjöld, who gave most of place-names in this area, and activities of Scottish Spitsbergen Syndicate. The share of the control over this territory was crowned by the establishment of settlements and coal-mines Pyramiden by Swedes in 1910 (in 1927 sold to the Soviet Union, operating until 1999) and Brucebyen by Scotts in 1919. The prospection and exploitation of mineral resources, inspite of coal, included also gypsum, uranium and petroleum. About the same age (from 1917) is the cabin Skottehytta, on the eastern coast of Petuniabukta. Later, in the 50. and 60., it was used by Cambridge Geological Expeditions and

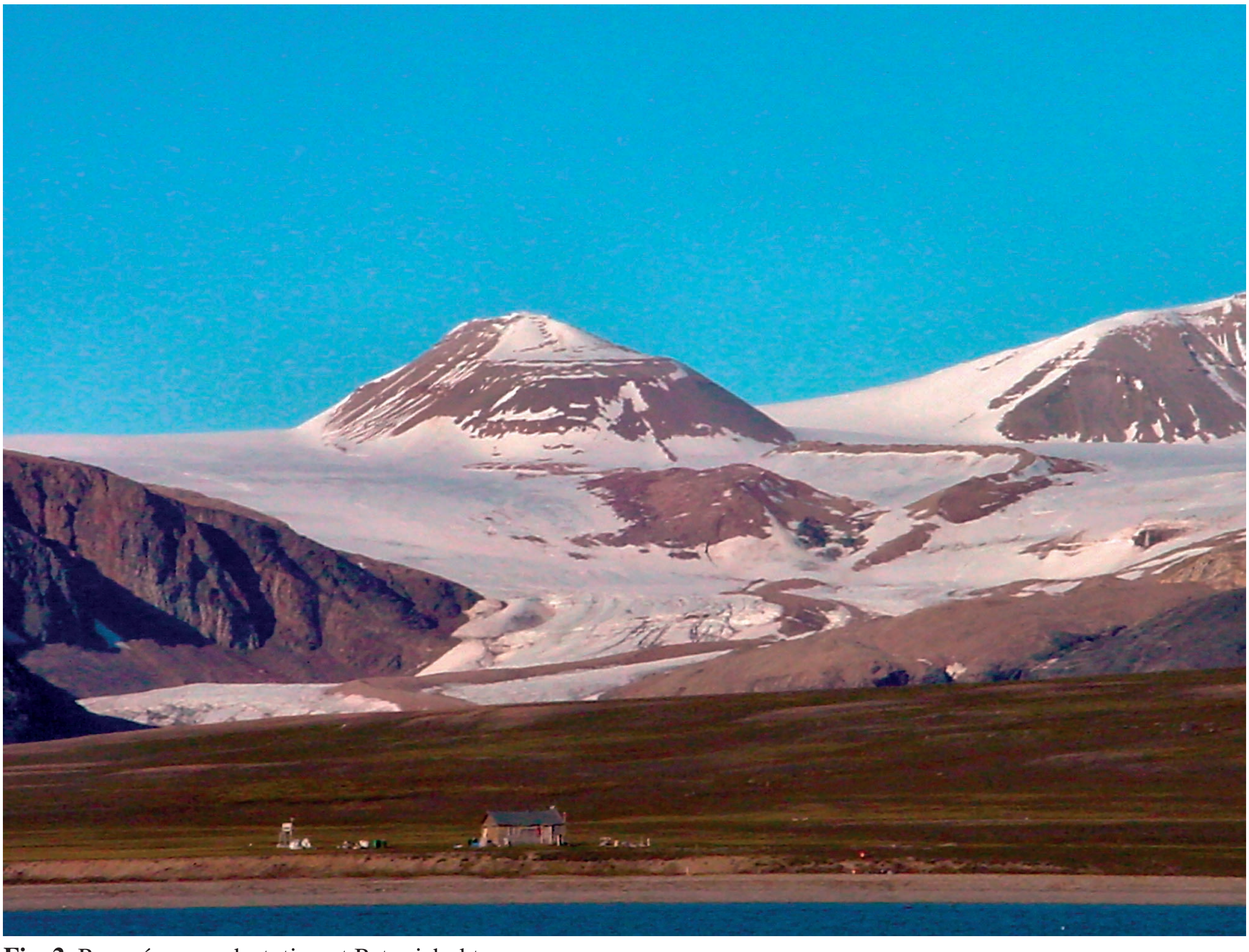


Fig. 2. Poznań research station at Petuniabukta

since the 80., "discovered" for scientific use by P. Kłysz in 1979, became a base of Polish expeditions from Adam Mickiewicz University in Poznań (Fig. 2); consecutive leaders: 1984 – W. Stankowski, 1985 – A. Kostrzewski, 1986 – A. Karczewski, 1987 – W. Stankowski, 1989 – A. Karczewski, 2000–2003 – G. Rachlewicz, 2005 – L. Kasprzak, G. Rachlewicz, 2006 – Zb. Zwoliński, 2007 – L. Kasprzak, K. Dragon.

First period of Polish investigations in Petuniabukta (1984–1989) realized geomorphological mapping around Petuniabukta and a general subject "Quaternary palaeogeography and present-day processes in an area between Billefjorden and Austfjorden, central Spitsbergen". Among other publications a map and a volume of papers cited below were published. In the year 2000 a new project "Matter circulation in the Arctic terrestrial-marine geoecosystem on the example of Billefjorden" has been started. It is continued until present days preparing and realizing a part of Polish National Project for the International Polar Year 2007–2008 "Structure, evolution and dynamics of lithosphere, cryosphere and biosphere in the European sector of the Arctic and in the Antarctic". Main topics of the current project in Petuniabukta are covering:

- geology, geomorphology and Quaternary paleogeography;
- meteorology and environment reactions to climate changes with special attention paid to glaciers and permafrost;
- morphology and functioning of glaciers marginal zones;
- spatial and temporal mass fluxes in terrestrial and marine environments.

Petuniabukta, within an area of average glaciers coverage and specific alteration of quasi-continental climate, not observed on the Western coast of the Island, offers a variety of interesting examples to study past and present features of the natural environment, like: unique and diversified geology, activity of various morphogenetic processes, unequivocal linkage between terrestrial and marine systems, limited human impact, and finally easy access to investigation sites (Fig. 3). Further investigations in the Billefjorden region, with possibilities of their expansion on neighboring areas, will continue with more detailed approach and advanced instrumentation to obtain long-term observation databases.

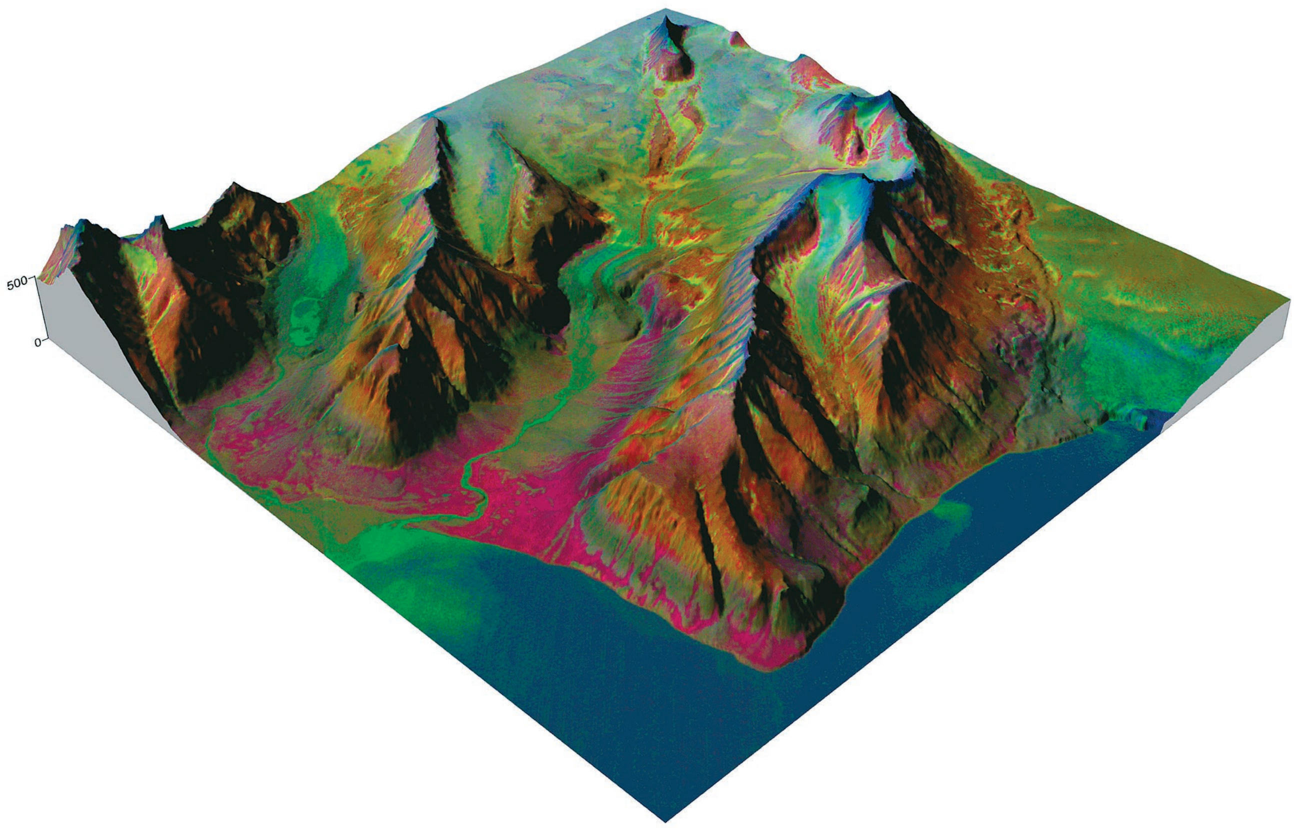


Fig. 3. Orthophotomap of Petuniabukta region – satellite (TERRA/ASTER, taken on July 13, 2002) image draped on DEM (elaborated by A. Stach)

Geological setting of the Petuniabukta Region

Witold Szczuciński
Institute of Geology, Adam Mickiewicz University, Poznań, Poland

Grzegorz Rachlewicz*
Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poznań, Poland

Surrounding of the Petuniabukta (Petunia Bay) offers a spectacular insight into geological history of Svalbard (Fig. 4) and modern geological processes. Due to being cut by one of the most important fault zones in the region – N-S trending Billefjorden Fault Zone (Fig. 5) a complex set of rocks is visible now on the earth surface. One can see old crystalline rocks next to clastic sandstones, coal measures and created in hot and dry conditions sequences of carbonates, anhydrites and gypsum. Valley floors and fjord bottom are covered by products of the youngest processes dominated in contrast to older rocks by facies typical for polar climates. These processes are still active and intensive formation of new sediments and alteration of older rocks are well visible. This region was in focus of geological investigations from the beginning of the 20th century – partly due to long lasting exploitation of coal (mainly in Pyramiden). That interest is documented by production of geological maps, books and many scientific papers related to that region (selected further reading is attached at the end).

The geological setting is dominated by N-S trending Billefjorden Fault Zone – (BFZ) and related Billefjorden Trough. The complex history of the fault zone activity caused that western and eastern coasts of Petuniabukta are dominated by different lithological units – Devonian clastic rocks on the west and carbonate Carboniferous sequences on the east. The faults of the BFZ are well visible in many places (Figs. 5–7) and sedimentary rocks adjacent to them are often also deformed due to movements along the faults. The BFZ have been active with various intensity since Precambrian times, but the most intense movements along it occurred during early Paleozoic when horizontal dislocation of rocks for several thousands of kilometers and vertical dislocation up to 20 km took place. In the recent times small and rare earthquakes and hydrothermal springs are observed along this zone. The complex tectonic history of the region resulted in four structural units, which are separated by unconformities:

- The oldest structural units is composed of Precambrian rocks often called the Hecla Hoek Succession (or Pre-Old Red rocks), which were engaged in the Caledonian Orogeny. They are represented mainly by various crystalline (igneous and metamorphic) rocks;
- Next unit is of Devonian age and comprise of sedimentary rocks – mainly sandstones and mudstones. It is preserved only on the western side of BFZ;
- Carboniferous-Permian rocks are represented by various sedimentary rocks: conglomerates, sandstones, mudstones, limestones, coal (exploited till 1998), gypsum, anhydrites and dolomites. The lateral and vertical variety of rock types in the unit is due to BFZ activity during that time;
- The youngest structural unit is of Quaternary age. It consists of various sediments: glacimarine muds, beach sands and gravels, intertidal deposits, glacial and glacifluvial terrestrial deposits in marginal zones of glaciers and sedimentary covers on slopes.

* e-mail: grzera@amu.edu.pl

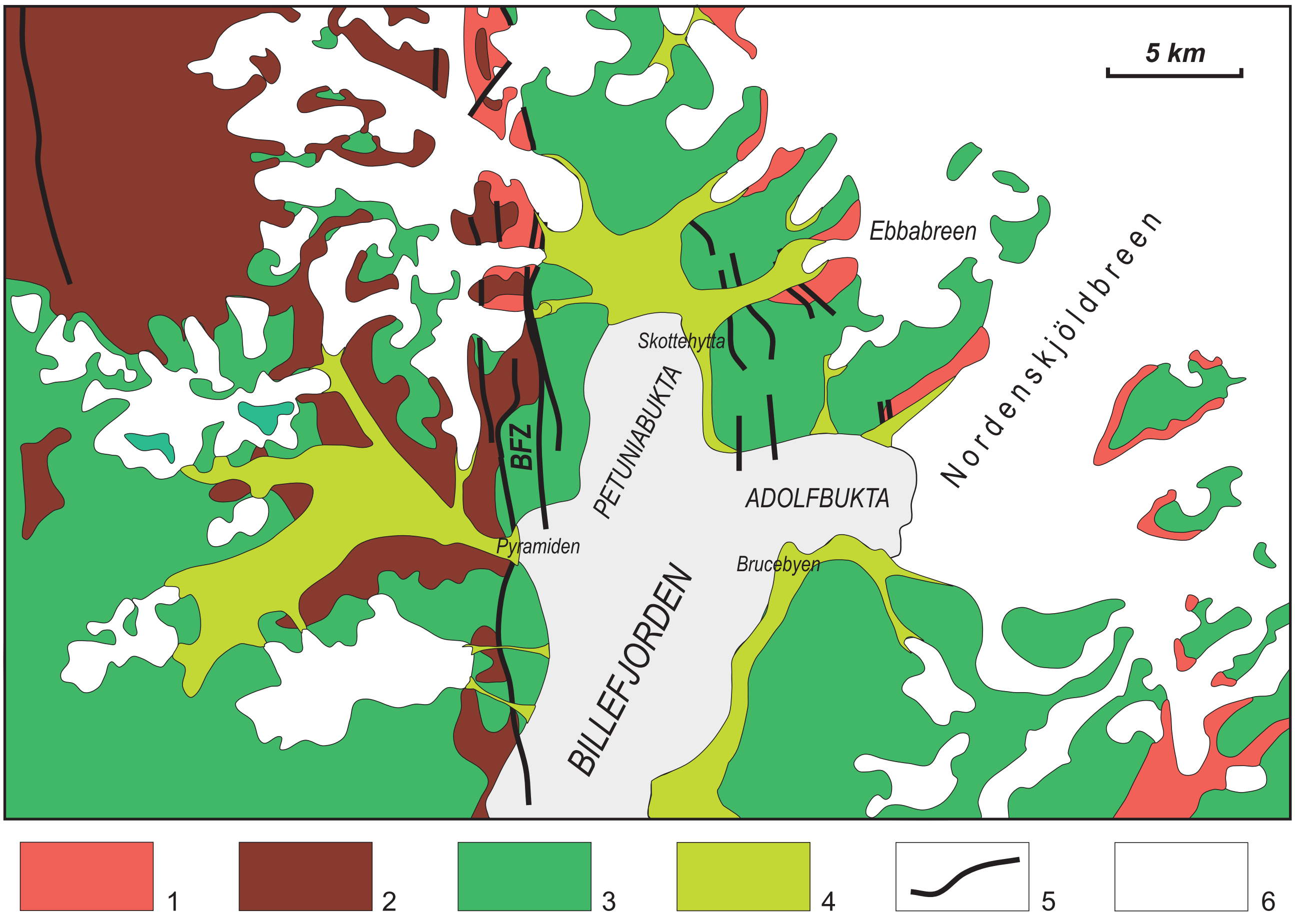


Fig. 4. Simplified geological sketch of Billefjorden, after Dallmann et al. (1999)
1 – Precambrian crystalline basement; 2 – Devonian sedimentary rocks; 3 – Carboniferous-Permian sedimentary rocks; 4 – Quaternary covers; 5 – main faults; 6 – glaciers; BFZ – Billefjorden Fault Zone.

Pre-Old Red rocks are visible as isolated outcrops of usually dark and resistent rocks. The most common rock types are: gneiss, schist, phyllite, amphibolite and syenite, but granite, quartzite and marble are also documented. The pre-Devonian formations were subjected to block tectonics and multiple folding. The whole complex formed for about a billion of years, reaching thickness up to 18 km . The complex starts with transformed into amphibolites former volcanic rocks (the lowest 12 km) covered with clastic rocks (gneisses, schists, phyllites, quartzites), carbonate rocks (marbles), tillites and finally carbonate-dominated layer. At the time of their formation and after that several igneous intrusions took place (granites, syenites). Isolated outcrops of the Pre-Old Red rocks offered an opportunity to use them as indicators of the direction of glacial transport. Erratic boulders derived from them were found on mountain fields (built of younger sedimentary rocks) in valleys and in fjord sediments (drop stones).

The next structural unit is composed of Devonian clastic rocks with admixture of carbonates and coals. Most of them belong to Wood Bay Formation, which consists of typical 'old red facies' – red shales intercalated with sandstones and conglomerates. They are famous because of common fish fossils. In the late Devonian rocks appear coal seems, sandstones with common fossil plants and rare limestones.

Most of the rocks visible around Petuniabukta is of late Devonian – Carboniferous – early Pemian age and belong to Billefjorden and Gipshuken (or Gipsdalen) Group. They consist of several formations, which are represented by clastic rocks (conglomerates, sandstones and mudstones) with coal seams (mined in Pyramiden) and the most common carbonate rocks (limestones, dolomites) with anhydrite and gypsum strata. Most of these rock types are represented in Ebbadalen Formation, which has its stratotype on the northern slopes of Wordiekammen in Ebbadalen (Ebba valley). The age of this formation was established on the base of brachiopoda and foraminifera fossils to the mid-Carboniferous (Bashkirian or even slightly earlier). The thickness is from 0 to 550 m, of which 280 m is present in the stratotype. The formation lies in an asymmetric basin, about 18 km wide, elongated parallel to the BFZ. Its largest thickness is observed in the near-fault area and is thinning eastward. Facies in the Ebbadalen Formation are variable and their

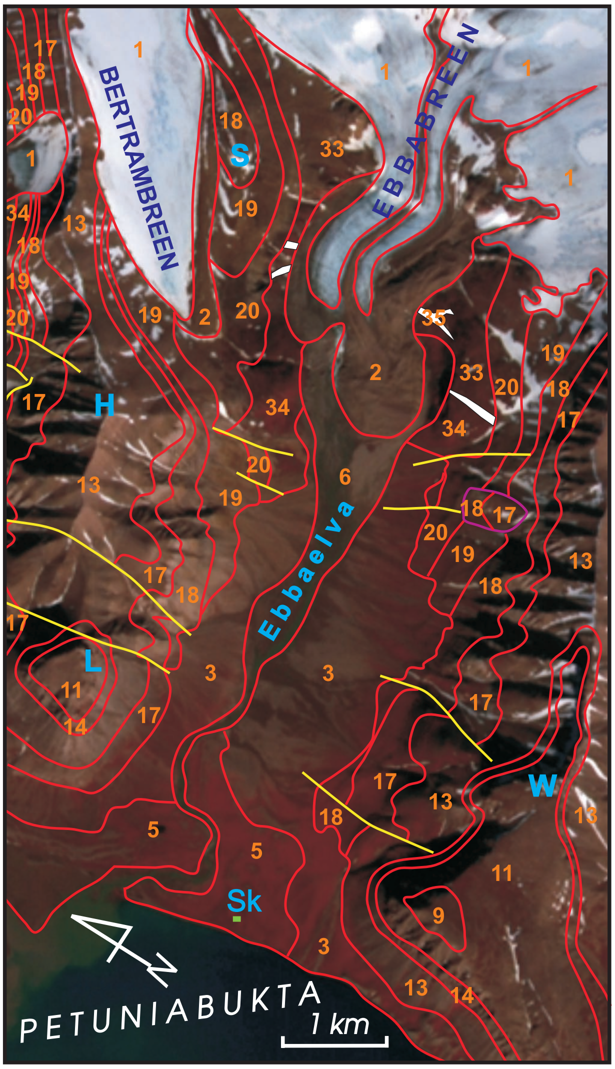


Fig. 5. Geology of Ebbadalen (after Dallmann et al. 2004) on the background of a part of TERRA/ASTER satellite image from 2002-07–13

Red lines – rock boundaries; yellow lines – faults; magenta lines – boundary of landslides. QUATERNARY: 1 – glaciers; 2 – moraines (Holocene); 3 – slope deposits (talus and undifferentiated material, Holocene); 5 – marine shore deposits (Holocene); 6 – Fluvial and glacifluvial deposits (Holocene); Carboniferous: Gipsdalen Group – Dickson Land Subgroup: 9 – Gipshuken Fm. (gypsum/anhydrite, dolomite breccia, dolomite and limestone); 11 – Wordiekammen Fm. (limestone and dolomite, sandstone, mudstone); Campbellryggen Subgroup: 13 – Minkinfjellet Fm. (sandstone, dolomite, gypsum/anhydrite); 14 – Fortet Mb. (dolomite solution breccia); Ebbadalen Fm.: 17 – Trikolorfjellet Mb. (gypsum/anhydrite, dark limestone); 18 – Ebbaelva Mb. (multicolored sandstone, shale, limestone, dolomite, gypsum/anhydrite); 19 – Hultberget Fm. (red sandstone, shale and conglomerate); Billefjorden Group: 20 – Hörbyebreen and Mumien Fms. (sandstone, conglomerate, shale and coal); Paleo- and Mesoproterozoic: 33 – Smutsbreen Unit (garnet-mica schist, calc-peltic schist and marble); 34 – Eskolabreen Unit (biotite (amphibole) gneiss, amphibolite, granitic gneiss); 35 – distinct marble layers within other basement units. S – Sporehøgda; H – Hultberget; L – Løvehovden; W – Wordiekammen; Sk – Skottehytta.

Fig. 6. Billefjorden Fault Zone – a pronounce fault separating Proterozoic rocks (on the left on slopes of Faraonfjellet) from light Carboniferous carbonate rocks (Cheopsfjellet) In the very back, a snow covered Devonian sedimentary rocks (Karnakfjellet)

probable sedimentary environments were lakes, alluvial fans, braided rivers, estuaries, deltas, sebkhas, lagoons and beaches. Its lower part is composed of gray and yellow sandstones interbedded with grayish-green schists, anhydrites, conglomerates and red sandstones. The upper part is mainly consists of carbonate and sulphate rocks formed probably in sebkha environment. Due to its relatively higher resistance they are very well visible on mountain slopes forming cliffs. Within the carbonate and sulphate rocks karst forms have developed (Fig. 8).

The youngest unit is represented by Quaternary sediments. They are mainly from the Holocene period because the fjord was deglaciated about 10,000 years ago. Only in few places older sediments are preserved in raised marine terraces (in Hörbyedalen, Ebbadalen and in well known Kapp Ekholm section in the middle part of Billefjorden). During the early Holocene the whole region was glacioisostatically uplifted and associated relative sea level fall was more than 90 m. Due to that along the coast of Petuniabukta are well preserved raised marine terraces composed mostly of sand and gravels, but locally also of finer deposits. Their thickness is usually within 1 to 2 m, but in some cases even about 20 m high paleo-spits are preserved. During the Holocene extensive slope covers and alluvial fans have developed. Several erosional cuts show that their thickness is up to 10 m. They are composed of poorly sorted debris, which is locally intercalated by well sorted finer material. Paleosoil found within them suggest complex evolution with periods of slope stabilization. It is believed that during most of the Holocene glaciers were much smaller than now. Their advance started probably around 3000 years ago and maximum extent was reached during the Little Ice Age, which terminated at the end of 19th century. Since that time the glaciers are continuously retreating with rates from few to about 50 m per year. Their recession is associated with deposition of glacial sediments forming ice-cored terminal moraines and lat-

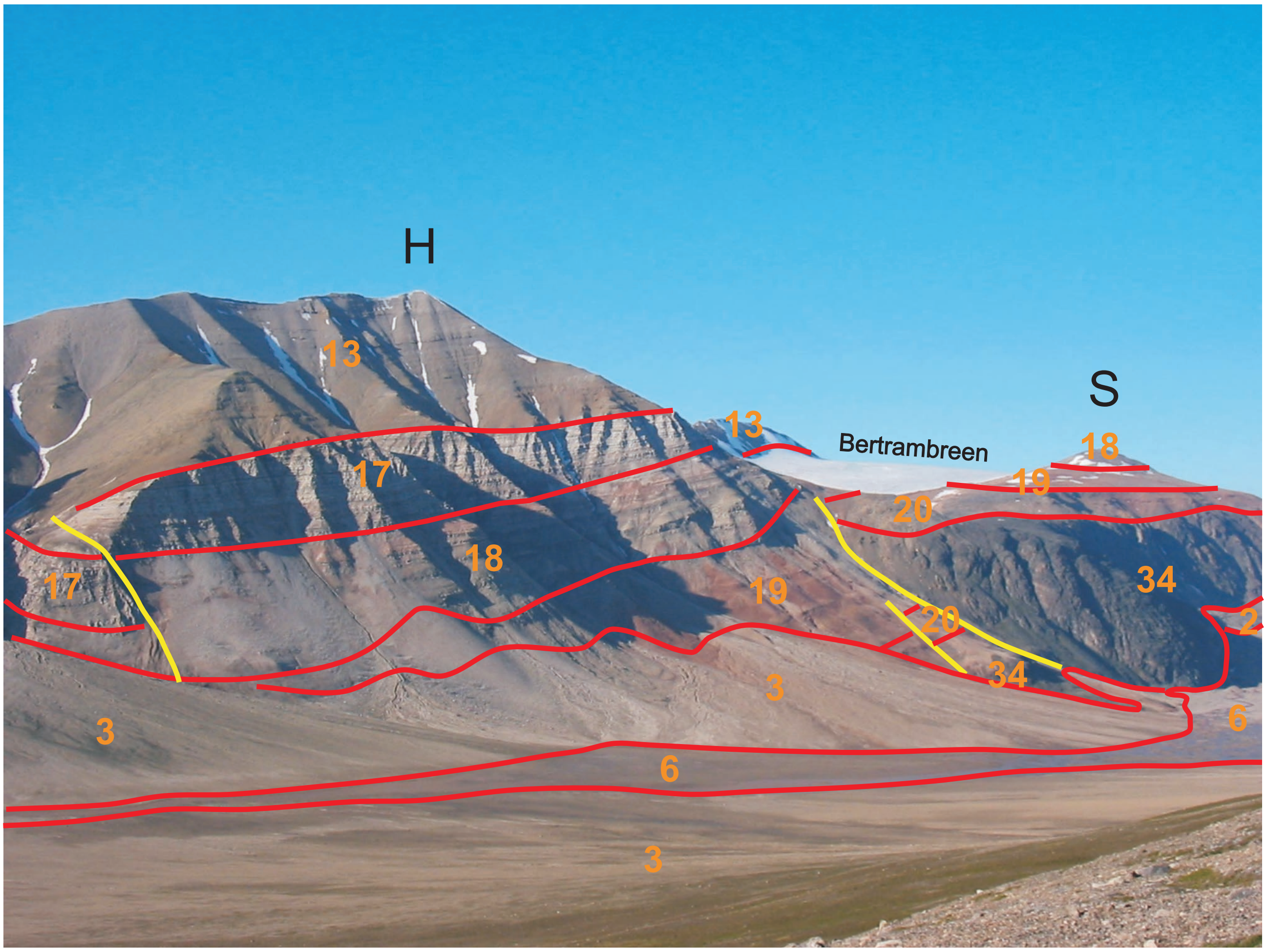


Fig. 7. Northern slopes of Ebbadalen: Hultberget and Sporehøgda massifs. Explanations on fig. 5

eral moraines covered by about 2.5 m thick debris mantle. There are also deposits related to basal deposition (lodgement till) and push moraines. Due to meltwater circulation sediments were left in form of eskers, kames and extensive outwash plains. The latter contain up to 20 m of sediments, so they play important role in sediment storage in a glacial system. Glaciers around Petuniabukta are land terminating and glacial rivers enter the fjord through up to 2 km wide tidal flat. It serves as transfer and storage zone for sediments and is shaped by tidal action (tidal amplitude up to 1.5 m), waves, shore ice, and glacial rivers. The intertidal zone is built mostly of silts and sands and most of sedimentation occurs at its margin (with particulate matter flux up to 90 $gm^{-2}hour^{-1}$) causing its successive progradation. Further in the bay the accumulation rate is much lower and the annual average sediment accumulation is in order of mm per year in the main fjord basin. The fjord floor is covered with glacimarine muds and their maximum thickness is in Adolfbukta (next to tidewater glacier – Nordenskiöldbreen) and reach up to 25 m.

Fig. 8. Weathered surface of Carboniferous anhydrite from Ebbadalen Formation (Ebbadalen)

Geomorphology outline of the vicinity of Petuniabukta

Grzegorz Rachlewicz*

Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poznań, Poland

The relief of coasts, valleys and mountain massifs around Petuniabukta reveals a variety of interesting and unique features. Landscape associations are diversified according to their genesis, intensity of geomorphic processes and age. Main stream of this branch of research arose here as the aftermath from Poznań University expeditions in the last three decades.

Main agents in shaping primary features of landscape were associated with extensive Quaternary glaciations finished ultimately 10 ka BP. The traces of at least four major advances of Spitsbergen – Barents Sea ice-sheet were detected in the not far Kapp Ekholm section. The most spectacular effects of their activity are large valleys and fiords. The last, widespread episode of glaciers advances during the Little Ice Age (LIA – 600–100 BP) was responsible only for the architecture of valley marginal zones.

In Billefjorden, which is glaciated in about 44%, among 23 existing glaciers only one (Skansdalsbreen) was reported to surge after the LIA. Some premises within the wide area of sharp, non ice-cored ramparts, suggest also a possible surge in the case of Hörbyebreen. Non-surging glaciers commonly leave marginal zones in form of a set of ice-cored morainic ridges. Their setting is closely connected with the layout of the hard-rock basement. In Petuniabukta it can be observed on examples of Svenbreen and Ebbabreen, terminating next to hardly resistant crystalline thresholds. The Ebbabreen LIA marginal zone is located beneath a 50 m high gneiss step, transverse to the valley axis. Valley slopes are dominated by egzaration relief with polished surfaces, striae and glacial undercuts at the height of 50 m above the valley floor. In the upper part this level is marked by belts of lateral moraines. The marginal zone is shaped in form of an asymmetric oval. Maximum heights of frontal moranic rampart, elevated 20–25 m above the valley floor, lined with outwash sediments, are located in the southern wing. Mass movements on slopes of ice-cored moraines are the most intensive here, filling up englacial voids and crevasses with debris-slides and melt-water derived material. Central part of marginal zone is occupied by a depression with small lakes, drained through a system of ice-cracks, to the springs on the edge of the marginal zone. The central part of terminal moraine continues up the glacier in the form of supraglacial belt, connecting the Bastion nunatak in the central part of accumulation area with the edge of ice. The northern part of marginal zone reveals confined amount of morainic material, as a discontinuous cover on roches moutonné of the crystalline threshold. A spectacular waterfall of the main subglacial outflow from the glacier margin is located beneath it. This outflow generates in majority outwash series at the bottom of the valley. Some smaller hillocks in this part may suggest earlier abrupt slide of ice in the steeper part of the basement rocks. Another type of marginal zone can be observed in the case of of Ragnarbreen, showing erosional features in the form of vast depression, taken by the proglacial lake framed by a garland of ice-cored moraines.

Rock walls dominating over valleys, glacieted mostly in upper parts, undergo intensive weathering processes. Beneath flat field surfaces develop structural features of hardness dependent rock outcrops

* e-mail: grzera@amu.edu.pl

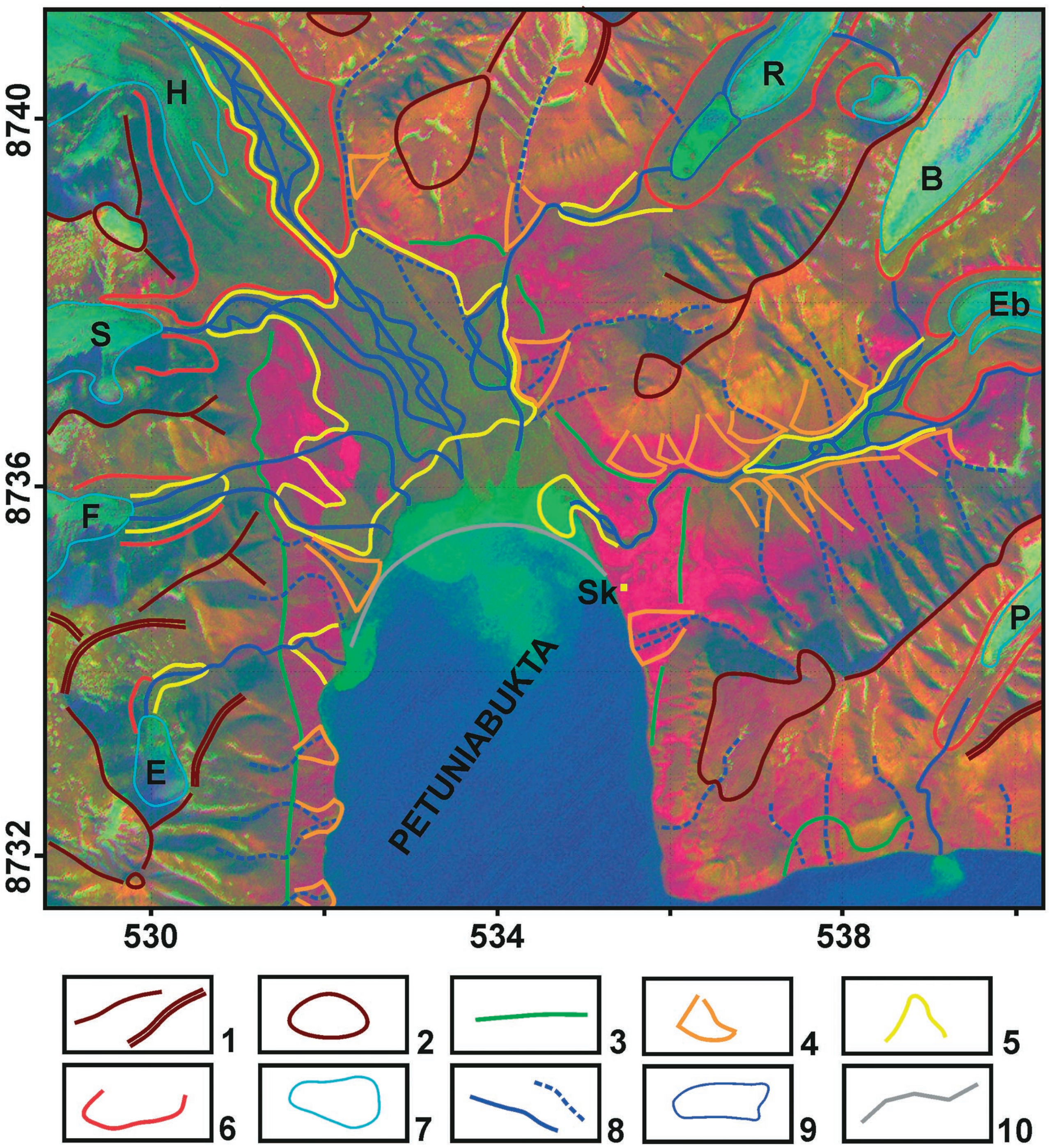


Fig. 9. Main features of geomorphology of Petuniabukta (updated after Karczewski et al. 1990)
1 – Narrow and rounded mountain crests; 2 – Flat top structural surfaces; 3 – Extent of raised marine forms; 4 – Alluvial fans; 5 – Outwash planes; 6 – Marginal zones of glaciers; 7 – Glaciers; 8 – Periodic (proglacial) and episodic streams; 9 – Lakes; 10 – tidal flat. E – Elsabreen; F – Ferdinandbreen; S – Svenbreen; H – Hörbyebreen; R – Ragnarbreen; B – Bertrambreen; Eb – Ebbabreen; P – Pollockbreen; Sk – Skottehytta.
The background satellite (TERRA/ASTER, taken on July 13, 2002) ortophotomap prepared by A. Stach.

underlined by talus cones and solifluction slopes. Their boulder and debris cover is transformed by mass movements associated with snow and rock avalanches and locally by episodic streams.

Lower parts of valleys, especially on the eastern coast of Petuniabukta are developed in form of raised marine terraces to the level of about 80 m a.s.l. The highest terraces in Ebbadalen, where associations with Pleistocene glaciations are visible, were 14C dated for 37860±1000 yBP. Younger terraces sequence descending from 45 m a.s.l. to the actual coast-line is associated with sea level changes since mid-Holocene. During the younger Holocene, with a progressing warming, central part of the valley was flooded by a sea transgression, recorded in form of a lagoon in the Ebba river mouth. Outflowing glacial

Fig. 10. Mountain walls built of carbonate rocks, talus slopes and raised marine forms (terrace, spit) on the Eastern coast of Petuniabukta (Wordiekammen massive)

rivers in the tide zone accumulate part of bedload and suspended material forming broad tidal flat coupling with outwash cones and planes revealing the greatest intensity of eolian processes.

In Petuniabukta there is a small, although visible range of human-induced landscape changes. Most of them are effects of mining and explorative activity around the settlement Pyramiden as roads and mine waste dumps.

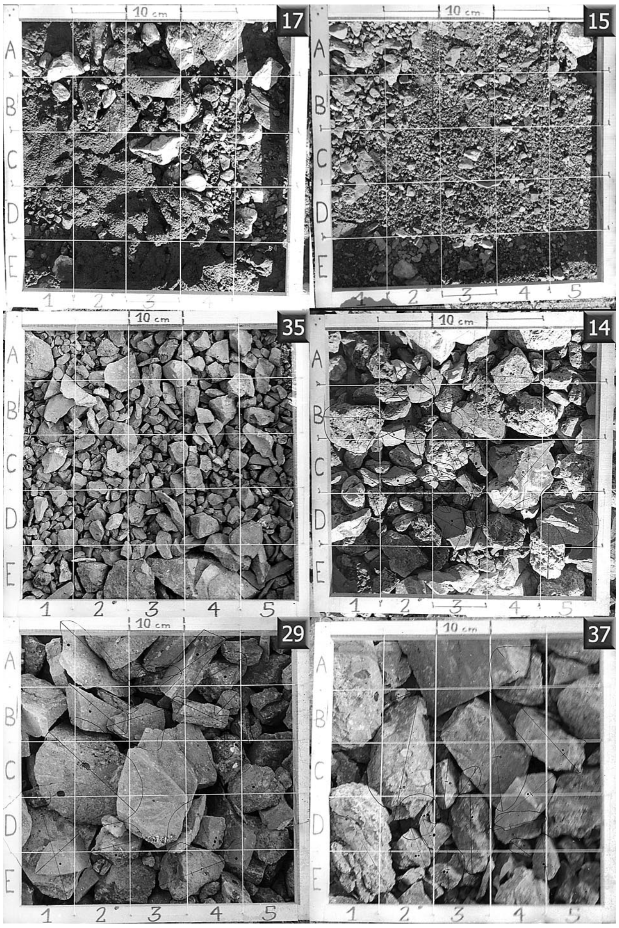


Fig. 11. Facies of slope deposits on western side of Wordiekammen massive (photo Zb. Zwoliński)
sample 17 – incorporation of debris facies into mud facies, sample 15 – fine debris facies, samples 35 and 14 – medium debris facies, samples 29 and 37 – coarse debris facies.

Fig. 12. Upper part of Ebbadalen with the marginal zone of Ebbabreen, higher located Bertrambreen and Mittag-Lefflerbreen in the back

Fig. 13. The front of Ragnarbreen with a marginal lake, seen from the morainic ridge of Little Ice Age

Fig. 14. Tidal flat and outwash plain of the inner part of Petuniabukta. Ebbadalen visible in the front and valley glacier Hörbye in the back

Fig. 15. Fifth level of raised marine terrace near Skottehytta, 20–25 m a.s.l. (photo Zb. Zwoliński)

Fig. 16. Supraglacial stream on the Ebbabreen (photo Zb. Zwoliński)

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