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

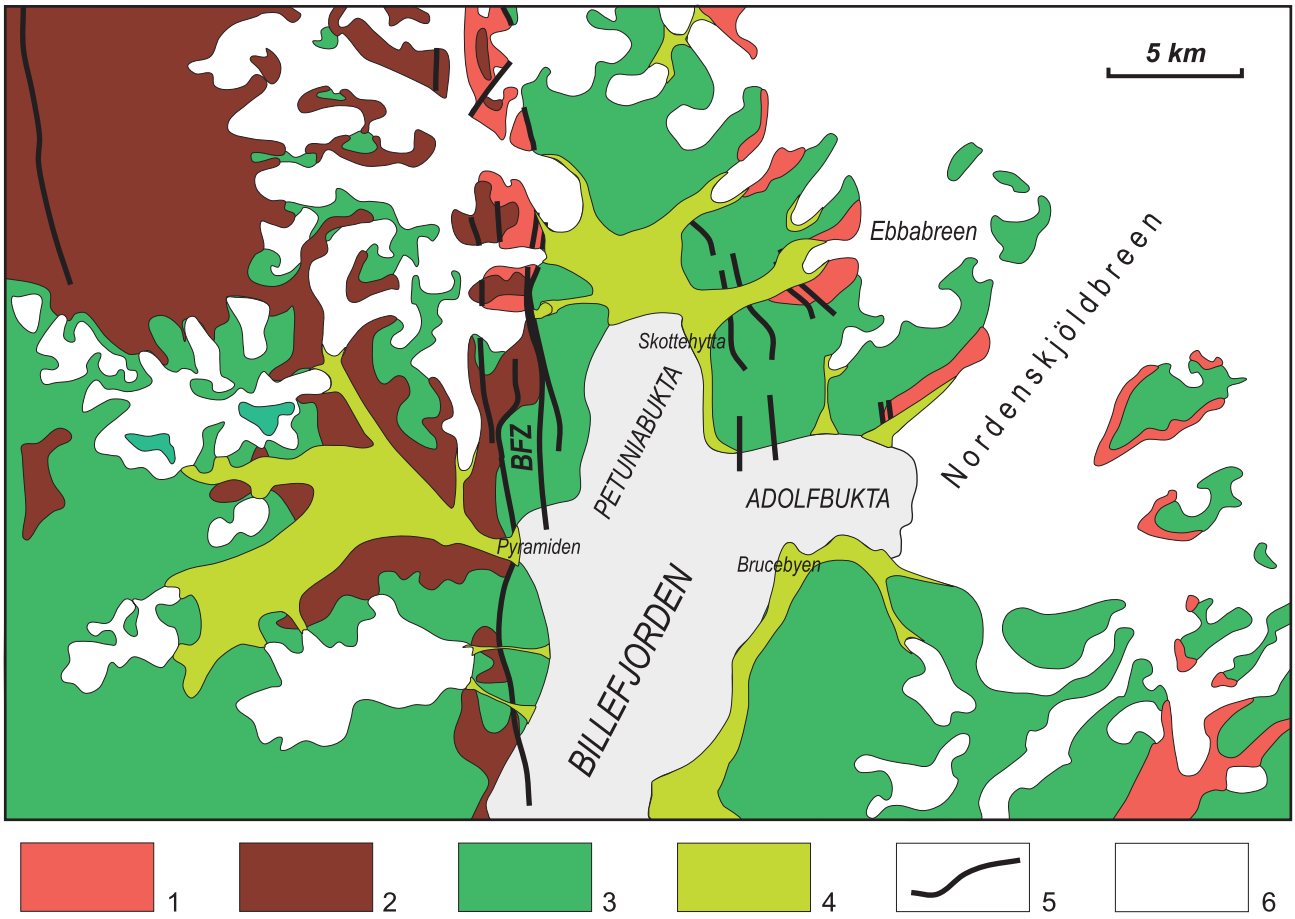

Fig. 4. Simplified geological sketch of Billefjorden, after Dallmann et al. (1999)
1 – Precambrian crystalline basement; 2 – Devonian sedimentary rocks; 3 – Carboniferous-Permian sedimentary rocks; 4 – Quaternary covers; 5 – main faults; 6 – glaciers; BFZ – Billefjorden Fault Zone.

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

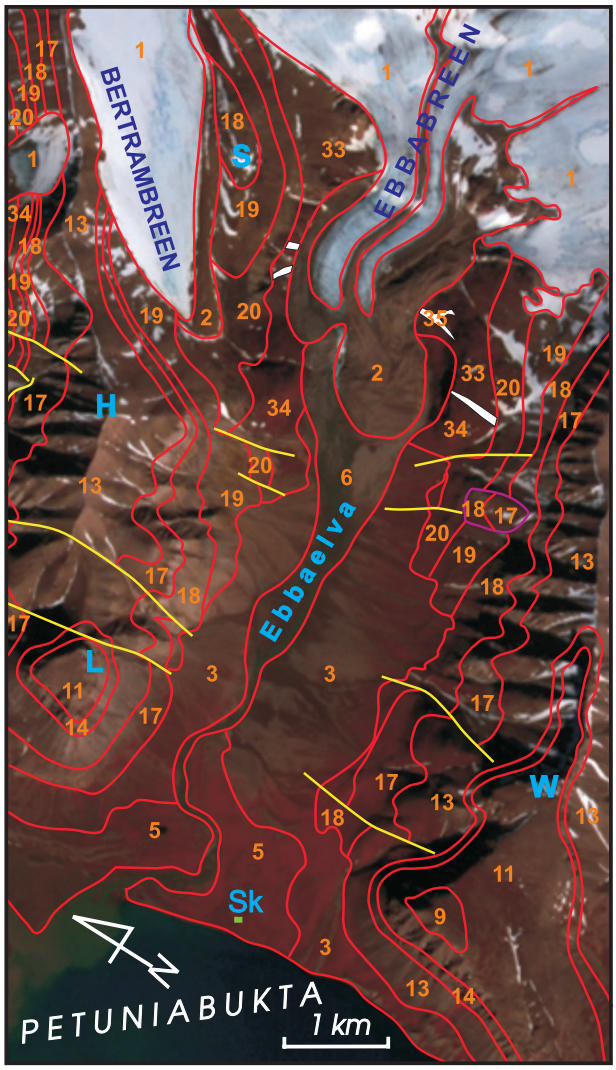

Fig. 5. Geology of Ebbadalen (after Dallmann et al. 2004) on the background of a part of TERRA/ASTER satellite image from 2002-07–13

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-

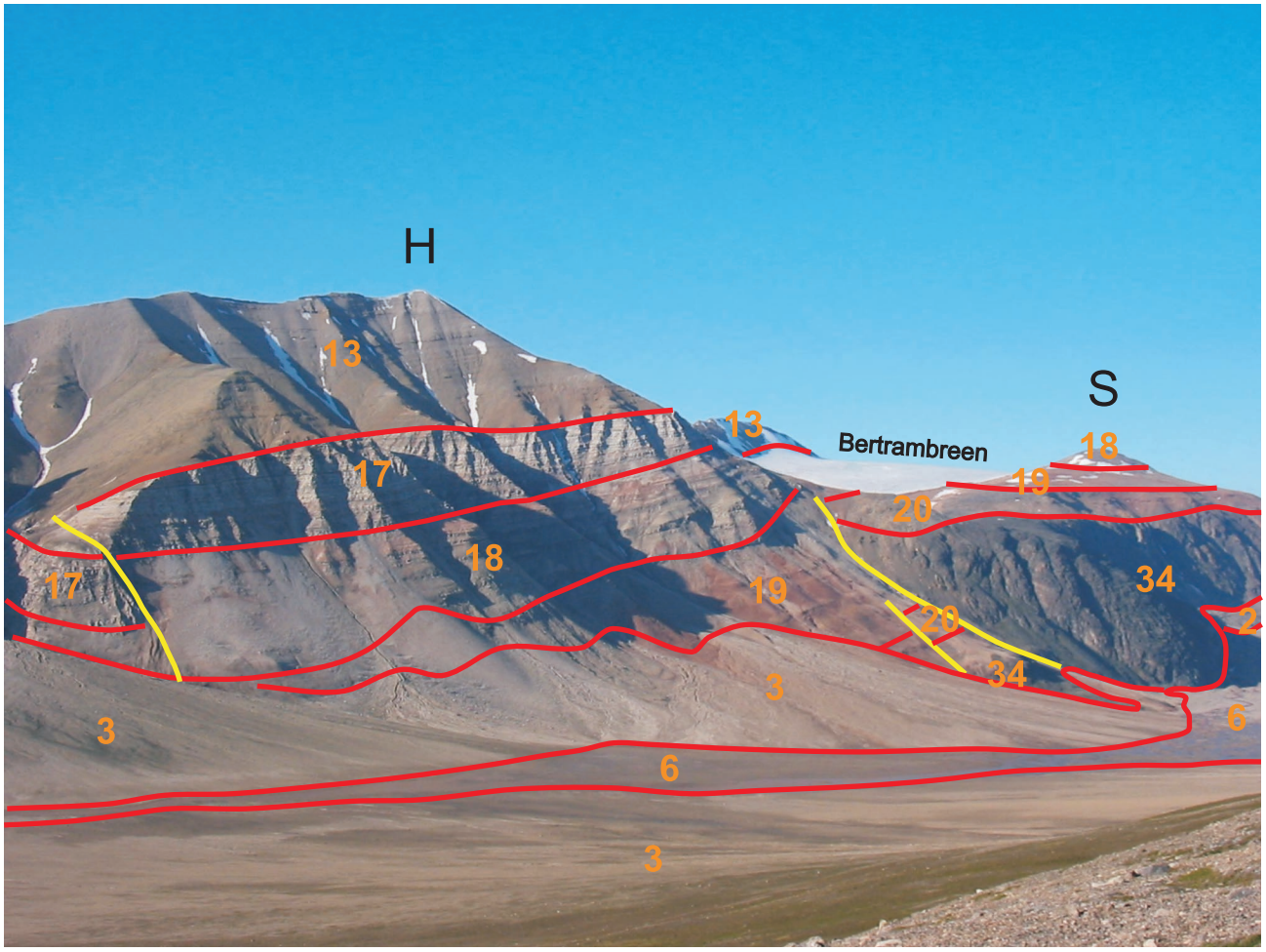

Fig. 7. Northern slopes of Ebbadalen: Hultberget and Sporehøgda massifs. Explanations on fig. 5

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)