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RELIEF-FORMING PROCESSES IN THE POLAR ZONE. EXAMPLE FROM NORDENSKIÖLD LAND (WEST SPITSBERGEN)

The relief of the Svalbard Archipelago was formed by different morphogenetic processes both exo- and endogeneous.The effect of external processes connected with the polar climate is here particularly distinct. The degree of dismemberment of the relief depends on the activity of morphogenetic factors and first of all on its morphometric features. The geological structure has also a great influence on the differentiation of the archipelago surface, particularly its lithology and the activating effect of crustal movements due to neotectonic and glaciotectonic processes.

In the NW part of Nordenskiöld Land (West Spitsbergen) a number of geological units can be distinguished. The oldest among them form strongly folded and metamorphosed rocks of the Upper pre-Cambrian; they were rejuvented in the Neogene and the Quaternary, which led to the formation of young horst structures. Younger structural units, from the Palaeozoic era to the Tertiary were not metamorphosed and they are inclined eastwards. Rock series dip here at the angle of 60—70° toward the centre of the West Spitsbergen island. The main structural units run parallelly to the Greenland Sea coast, from NNW to SSE.

The oldest rocks of the Hecla Hoek formation which occur here come from the pre-Cambrian and outcrop in the West (Y. Ohta, 1987). They consist of strongly metamorphosed shales, tillites, dolomites and metamorphosed limestones (A. Musiał 1985). No Devonian deposits have been found here up to now. Directly on the Hecla Hoek rocks, Carboniferous deposits occur discordantly as hard, grey conglomerates. Farther to the East quartzite sandstones outcrop; they are light-grey, very resistant to weathering, with many floral remnants; farther there occur cherry-red and red sandstones.

Carbonate series come from the Upper Carboniferous, they are mainly dark limestones with fauna, gypsum and anhydrites. Permian deposits are represented by dark limestones with large numbers of brachiopods (*Productus and Spirifer*). Limestones with fauna and sandstones were deposited in the Triassic, sandstones and siltstones in the Cretaceous. Tertiary sediments

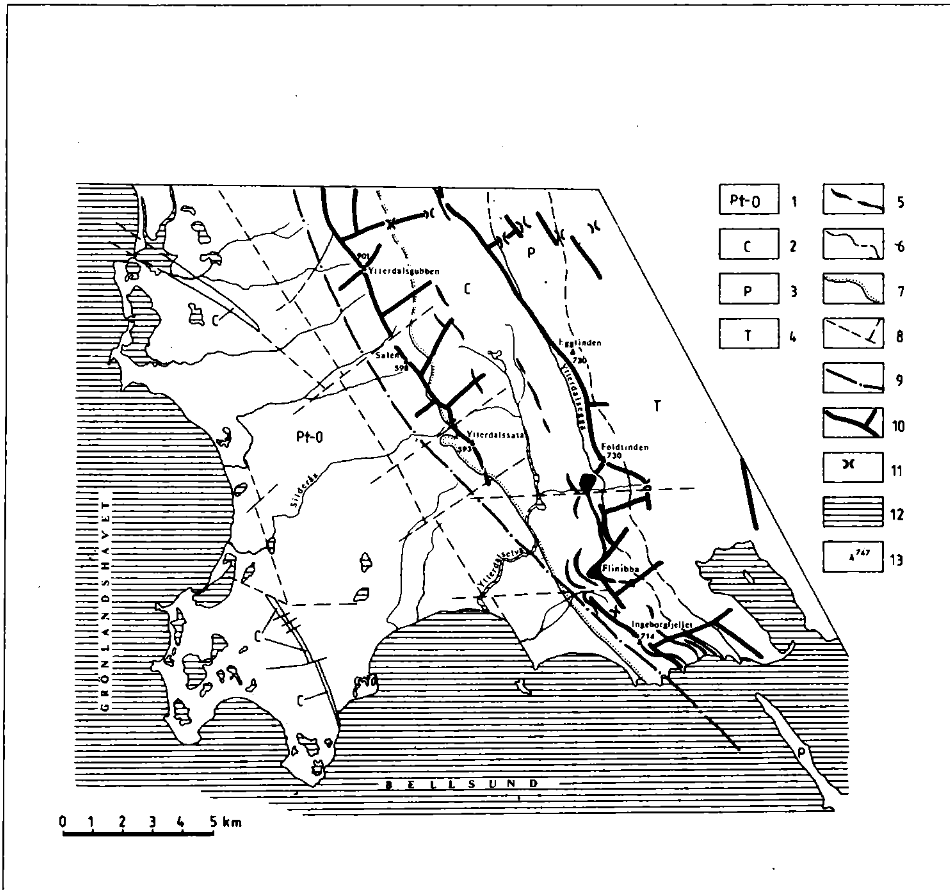

Fig. 1. Geological and structural map of the SW part of Nordenskiöld Land.
1 — limestones, dolomites, tillites, rust—coloured and brown shales of the Cambrian and the Ordovician (Hecla Hoek formation), 2 — grey quartzite sandstones with coal interbeddings (Lower Carboniferous), cherry-red and red quartzite sandstones, grey limestones, dolomites, marly shales, siliceous limy shales, gypsum and anhydrites (Middle and Upper Carboniferous), 3 — grey limestones and siliceous limestones with rich Brachiopod fauna (the Permian), 4 — grey sandstones and limestones (the Triassic), 5 — green-grey dolerites (the Jurassic, the Cretaceous?), 6 — stratigraphic border-lines, 7 — lines of stratigraphic discontinuousness, 8 — tectonic lines, 9 — distinct rifts active in the Quaternary, 10 — main ridges, 11 — distinct passes, 12 — surface water, 13 — distinct peaks

outcrop on the coast along the Grönfjord. Among Palaeozoic and Mesozoic series, parallelly to the outcropping strata there occur green-grey dolerites which are very resistant and proof against destructive processes.

Glacio-marine and fluvial deposits extend over large areas in Nordenskiöld Land. Most of them are younger than 11,000 years (A. Hjelle et al. 1986). The foreland of glaciers is covered with glacial and fluvio-glacial deposits.

The present-day glaciation of this part of the Svalbard Archipelago is not large and, except the Fridtjof and Grönfjord glaciers, it is limited to the upper sections of valleys.

The role and magnitude of neotectonic movements in the formation of the West Spitsbergen relief are not quite clear yet. According to D.V. Semevskij (1967), the whole Svalbard undergoes uplifting due to neotectonic or glacioisostatic movements. J. Kvitković (1971) stated unequal uplifting of different parts of the archipelago when he compared the height of the marine terraces occurring around the Bellsund fiord.

The tectonic activity of that area can also be proved by Quaternary volcanic forms and by hot springs located mainly in the north of West Spitsbergen.

Instead, some authors deny the participation of neotectonic processes in the relief formation of Svalbard or they attribute a minor role to them; e.g. O. Salvigsen and R. Nydal (1981) attach first-rate importance to glacioisostatic movements, which occurred in the Holocene after the withdrawal of Pleistocene ice-sheets. At the present stage of investigations it is still difficult to determine univocally the role of neotectonic and glacioisostatic processes in the modelling of the archipelago relief. To treat them separately would be a mistake since they acted simultaneously. Glacioisostatic uplifting affected the course of neotectonic movements and due to it the archipelago was undergoing unequal uplifting during the whole Holocene. According to G.S. Boulton, (1979) the greatest intensity of those processes took place some 6,500 years ago when the ice shield disappeared from the Barents Sea. At present, uplifting movements are weakening (Salvigsen, 1984).

A manifestation of the activity of isostatic processes and of level changes of the word ocean is the system of marine terraces which can be observed in many places (K. Birkenmajer and J. V. Olsson 1970; A. Karczewski et al. 1981).

Intensive tectonic movements occurred on the Spitsbergen after the Palaeogene. Numerous rifts and faults were then formed cutting older and Palaeogene deposits. On those tectonic lines Isfjorden and Van Mijenfjorden have developed among others, reaching far into the West Spitsbergen island. The rifts have been active during the whole Quaternary, as J. Kvitković (1971) observed.

As a result of the activity of tectonic processes, a sharp geomorphological border-line was created between the little differentiated coastal plain and the greatly dismembered mountain chains. Those processes continue to occur, as it is proved by frequent earthquakes recorded in this area. Those phenomena should be connected with the immediate neighbourhood of the middle-Atlantic ridge the end of which is situated near the West Spitsbergen island.

The concordance between the run of the main geological structures and the occurrence of ridges and valleys is well visible. Ytterdalen and the valleys of the Fridtjof, Grönfjord and Dahlfonna glaciers have a subsequent character and generally they follow the direction of rock layers: NNW-SSE. Mountain ridges with Ytterdalsgubben (901 m above sea level) and Ytterdalsegga (730 m above sea level) are similarly oriented. Instead, the Ingeborgfjellet massif (714 m above s.l.) is more complicated. The main ridge is cut in two places by vast valleys: Fold and Orust, running along transverse tectonic cleavages. These valleys and the small Jarn valley are obsequent while the hanging Kleiv valley is subsequent but its lower section is obsequent. The valleys of the Saga, Gränut and Sartorius glaciers are resequent.

The differentiation of the geological structure is recorded in the character and run of mountain ridges. Many of them have an asymmetric transverse profile. Steep rock walls have developed on outcrops of resistant threshold-forming strata while the opposite sloping mountain-sides are conformable with the dip of beds. Ytterdalsegga (730 m above s.l.) is an example of such an asymmetrical ridge which conforms with the features of a monoclimal ridge. The analysis of the cross-section outcropping in the Fold valley proves univocally the complexity of its structure. In the surrounding rock walls near the fault zones, distinct fold structures can be observed.

Lithologic conditions have played a great role in the relief development of this part of the archipelago. The rich complex of rock occuring here differ in th degree of resistance against weathering (quartzite sandstones, marbles, dolerites, limestones, conglomerates, gypsum, shales). As a result of the selective activity of external processes hard rock were uncovered and soft rocks—destroyed. The thick beds of Lower Carboniferous quartzite sandstones proved to be the most resistant to outer factors. On the outcrops of yellow-grey Spirifer Permian limestones steep rock walls were formed such as can be observed in the Ytterdalsegga ridge (730 m a.s.l.) and in the Ingeborgfjellet massif (714 m a.s.l.). Single peaks, hummocks, structural nickpoints and banks can be found on dolerite outcrops. Many of these banks were cut by river which formed deep gaps, e.g. in the Fold valley.

The kind and intensity of external processes on the Svalbard archipelago depends, in the first place, on climate conditions. Accordingo to L.C. Peltier's morphoclimatic classification (1950), the described area is situated on the border-line of the periglacial and glacial regions.

The part of Nordenskiöld Land under study is numbered among the warmest areas in the whole West Spitsbergen. The mean yearly temperature reaches here -6° C. There is a distinct difference in climatic conditions between the coastal lowland plain and the mountain massif where glaciers occur.

Over the glaciated areas definite relief-forming processes take place which permits to distinguish a separate — glacial — morphoclimatic domain. Changes in the glaciers extent cause the movement of the border-line between the glacial and periglacial zones. This is proved by deposits and forms built during older glaciations (erratics, moutonnees ridges, glacial undercuts, etc.). Former glaciers covered all the coastal plain and the coastal part of the Greenland Sea (A. Musiał 1984). During the past several decades a considerable recession of glaciers has been observed in these latitudes. Hence the extent of the glacial zone is shrinking to the advantage of the periglacial zone. New relief-forming proccesses develop on areas which are free of ice.

The main relief-forming factors in the glacial zone are processes of which the intensity and character depend on the type of glaciers and on the total balance of their mass. In the western part of Nordenskiöld Land, valley glaciers prevail which have a small gradient, not exceeding 6°.

Their erosive capacity is also small. Small-sized firn and car glaciers do not erode the basement very hard because of their small mass.

Owing to their lack of erosive strength these glaciers transport little morainic material; its quantity grows visibly near to the front and in the lateral zones. Ice-and-moraine ramparts formed here maintain their morphologic distinctess for a long time owing to the presence of the ice core.

Glacifluvial and cryogenetic processes play an important relief-forming role in glaciated regions. Water circulating inside the glaciers has a particular importance since it shapes their basement.

The largest part of Nordenskiöld Land is occupied by the periglacial zone. According to J. Büdel (1948), processes of denudation are most intensive in periglacial regions. That is why older glacial forms are hardly preserved here.

Beside climatic conditions also the differentiation of relief and the geological structure determine the intensity and character of relief-forming exogenetic processes. Accordingly, some areas can be distinguished in the periglacial zone, where definite relief-forming processes prevail (Fig. 2). Thus the largest surface in the studied area is occupied by a poorly differentiated coastal plain and the flat bottom of the Ytter valley, where cryogenetic processes prevail while nival processes are weaker.

Within the young coastal plain, which was glacioisostatically uplifted in the Holocene, distinct traces of the activity of littoral processes have been preserved. The flat, illdrained Holocene marine terraces occuring here gather yearly, on their surface, a lot of water from thawing snow, which favours the development of cryogenetic processes. Complexes of structural soils of various shape and size are formed here, built of most varied rock material. On peat plains *tufurs* and initial pingo hills arise. During dry periods the terrace are surfaces shaped by aeolic processes though no dunes are formed. Material brought by debouching rivers is accumulated in coastal lakes. Similar processes may be observed in the Ytter valley bottom, which is additionally shaped by glacifluvial processes.

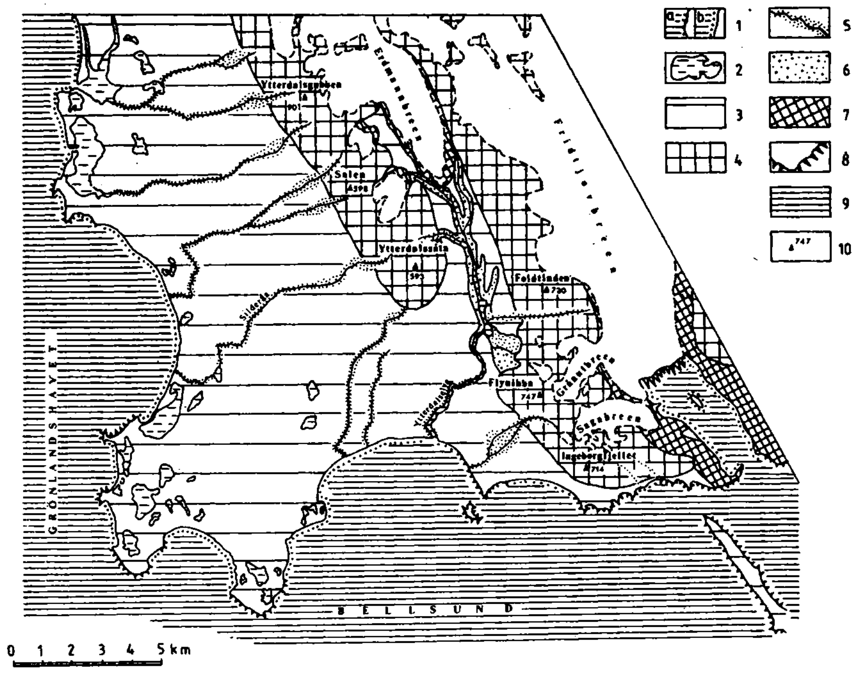

Fig. 2. Map of contemporary exogenous processes shaping the relief of the SW part of Nordenskiöld Land with prevalence of:
1 — littoral processes a — of intensive abrasion, b — of intensive accumulation, 2 — limnetic processes (lacustrine accumulation), 3 — cryogenetic, gravitational and nival processes (regelation gelivation, partial solifluction, nival erosion, etc.), 4 — mass movements, 5 — fluvial processes, 6 — glacifluvial processes, 7 — glacial-gravitational processes, 8 — glacial processes, 9 — surface water, 10 — distinct peaks

The reach of the influence of littoral processes depends mainly on the geological structure and on the coast type. On a high, rocky coast the activity of the sea is limited to a narrow zone of riparian rocks which are destroyed through intensive abrasion. On a flat coast the abrasion is inconsiderable, while accumulation is important and reaches far into the land. This is evidenced by the systems of storm banks, whale bones and pieces of drift wood found several hundred meters off the shoreline. Rows of storm banks are an obstacle for streams flowing towards the sea, which causes violent changes of their run and the formation of gaps.

The intensity of gravitational processes grows on steep slopes. At a gradient of 3—4° circular polygones of structural soils undergo deformation and at 6° stony strips and streaks appear. The most intensive gravitational processes occur in the marginal zones of glaciers. Their development and intensity depends on the activity of the nearest glacier and on the presence of dead ice in the basement. Ice blocks inside glacial and glacifluvial forms have sliding surfaces on which much flowage, landslips, stone-falls etc. occur. A characteristic phenomenon in ice-moraine banks is thermokarst, owing to which large depressions filled with water as well as hills and hummocks are formed.

Fluvial and glacifluvial processes are concentrated along river channels, while larger surfaces are at the border-line of the lowland plain and mountains or on the foreland of glaciers, where systems of taluses and outwash cones are formed. Along gaps, the zone of river activity grow narrower and processes of erosion gain in importance. Because of small gradients, accumulation and lateral erosion prevail over bottom erosion in the river channels of western Nordenskiöld Land.

Great dynamics characterises morphogenetic processes occuring on steep rock walls. Various gravitational processes depend here, in the first place, on the geological structure and the situation of mountain. massifs.

In consequence of intensive frost weathering, rock material is brought into circulation. A part of the weathered material forms eluvial covers and block fields on the spot. In areas where the relief is highly differentiated intensive degradation occurs and a fast transport of material (falling-off, saltation, creeping, sliding, etc.) takes place. The character of those processes is mainly erosive and gravitational. A system of gullies and clints is the result of their activity.

In the low parts of slopes aggradation prevails. Taluses and talus-alluvial cones are formed at the outlet of gullies. Nival processes play here an essential role. The long-lasting snow cover facilitates the saltation of large blocks over sloping surfaces.

Biogenetic processes do not play any important role in the formation of relief of West Spitsbergen.

The influence of human activity on the Svalbard archipelago is, as yet, limited. Operations leading to changes of relief are of a local character and may be most frequently observed in the immediate vicinity of mines.

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The relief shaping of the NW part of Nordenskiöld Land and of the whole Svalbard proceeds due to the activity of both constructive endogenous and destructive exogenous processes. The structural relief is, first of all, the result of crustal movements which occurred and occur with various intensity. Those processes and the geological structure were the main foundation of the little diversified coastal plain in the West and the differentiated mountainous part in the East. The run of the main valleys and mountain ridges is connected with the elements of the structural relief.

The differentiated mountain relief is due to endogenous processes. Its dismemberment highly conditions the character and intensity of exogenous processes which shape small elements of the relief.

In the western part of Nordenskiöld Land the decrease of the glacial zone to the advantage of the periglacial zone has been proceeding now for a long time. Over areas free from the ice cover there occur rapid changes of the kind and intensity of exogenous processes and, in consequence, homogenous relief forms acquire new features and become polycyclic.

The intensity and character of exogenous relief-forming processes in the Arctic zone have a specific course adapted to the rhythm of the polar night and day. During the polar night lasting many months most of the relief-forming processes are stopped. Very large quantities of water are accumullated in the form of ice and snow on the surface and underground (permafrost, needle ice).

When the polar day arrives, huge quantities of water are freed and a violent, though of short duration (2—3 months) developmet of relief-forming exogenous processes follows, frequently with a disastrous result. In spite of their relatively short period of activity, those processes bring about rapid and great changes in the morphology of the area.

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