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ANCIENT GLACIATIONS IN THE NORTH-WESTERN PART OF NORDENSKIÖLD LAND AND THEIR EXTENT IN THE LIGHT OF CHARACTERISTIC OCCURRENCE OF ERRATICS

The north-western fragment of Nordenskiöld Land represents in itself a vast peninsula situated in the central part of the Spitsbergen--West Island between Isfjorden, Grönfjorden, Orustdalen and the Greenland Sea. Linnefjella with its culmination at Griegfjellet (778 m above sea level) and the Starostinaksla-Quigstadfjellet (770 m above sea level) form dominating ridges of the territory, being parallel in their configuration and spreading from north-north-west to south-south-east. They are separated by Linnedalen whose bottom fragment is occupied by Linnevatnet.

The above-mentioned part of Nordenskiöld Land is situated on the outskirts of a tectonic syncline stretching out to the south-east of Isfjorden which itself is full of the Tertiary formations (Flood, Nagy, Winsnes, 1971). The eastern flank of the Linnefjella is marking out the line of contract between Hoecla Hoek and the Palaeozoic rock agglomerations, (Fig. 1). Parallel with this line go bassets of the remaining sedimentary series: Palaeozoic, Mezozoic and Cainozoic (Worsley, Mork, 1980). Clearly distinguishable, glacial and maritime, sediments form terraces noticeable up to a height of 150 m above sea level. Higher than that one can reveal nothing else but denudations and alluvial cover of local material (Troitski, Zinger, Koriakin, 1975).

Muttonized fragments of crests above the morainic banks of these days; the presence of glacial undercuts in the rocky walls, in the passes in particular; surfaces of the glacial shoulders, glacial notches, detersive niches cut out in the structural sills, glacial overdepth basins and pot-holes, glacial levels and flattenings, glacial brown-red clays: all of them represent a record of the old-time glacial processes in this part of the island.

Erratic boulders can often be found among the scattered fragments of rocks in the north-western part of Nordenskiöld Land. Streaky configuration of the narrow rock-outcrops varying in their age and external features helped us to follow up the way made by the material since the emergence of parent rocks. Erratics found within the area under study are well diversified in their forms. The largest ones, often weighing a couple of tons, feature sharp edges not affected so far by processes of the environmental action. Another group includes the well- and very-well-rounded, sea-water-worn cobbles from two to eighty centimetres in size; also smaller fragments of rocks with only slightly or hardly rounded edges, varying in size, are in abundance in this place.

Huge erratic boulders occur in the eastern morainic bank of Linnebreen and on its surface. They represent, in fact, blocks of the grey quartzite sandstones from the Carboniferous Period, measuring $2\times3\times3$ metres. Spatial analysis to establish the path of their movement reaffirmed that they are about two kilometres away from their parent rocks (Horodyski, Lewandowska, Malanowski, 1981). Larger fragments, $1\times\times1.5\times2$ metres in size, of the hardly rounded Permian rocks with signs of fauna visible on them have been spotted at the bottom of the eastern Linnefjella slopes, within the confines of the Carboniferous sandstone outcrop.

Sea-borne cobbles of grey sandstones from the Lower Carboniferous Period, and the cherry-red and red quartzite sandstones from the Middle Carboniferous Period, represent the most numerous group of erratics. Their large agglomerations occur at Vardeborgsletta over Isfjorden, along the eastern line of the Linnevatnet and at the mouth of the Tjörnskardet leading out into the Greenland Sea. At Vardeborgsletta, at the base of Vardasen, Vardeborg and Starostinaksla, the grey sandstone cobbles build up terraces at 53, 58 and 65 metres above sea level. Said terrigenic formations overlie limestones, dolomites, marlstones and calcium-silica schists of the Middle Carboniferous Period. Distance to which they have been carried most probably does not exceed one kilometre.

The grey-quartzite-sandstone cobbles from the Carboniferous Period form similar terraces, 53 to 65 metres high above sea level, at the outlet of the Tjörnskardet to the Greenland Sea. Here, they reach the size of 80 cm and are well distinguishable amid the brown and block schists of the Hoecla Hoek. They seem to have been delivered to this place from Linnèdalen, east to west, over a distance of two kilometres via a long narrow valley, and had to overcome a tall sill of rock cutting off access to the coastal plain on their way.

Erratic boulders in the form of cobbles have also been found on the western slope of the Kalkegga, 150 metres high above sea level, the largest among them having more than twenty centimetres in diameter (A. Musiał, 1981, 1982). These included predominantly well- and very-well-rounded, Lower Carboniferous, grey quartzite-sandstone fragments whose place of origin is to be sought at Linnèdalen, i.e. 50 to 60 metres below their present site of occurrence.

More abundant proves to be the agglomeration of cobbles at the culminating point of the elevation, 187 metres above sea level on the western side of Linnevatnet between Vardasen and Sokolovtoppen. The largest cobble found in this place exceeded 40 cm in size. In addition to pieces of the grey quartzite sandstones also cobbles, cherry-red and red in colour from the Lower Carboniferous Period, were found at the Kalkegga base and east of Linnèbreen, their nearest outcrop being supposedly about one kilometre south of Linnevatnet. Individual, rounded fragments of the dolerites could have been identified at this place, too. In the particular case under consideration, erratic material was found some 140 mtrs above the parent rocks.

The third group of erratic boulders in the north-western part of Nordenskiöld Land includes fragments of rocks varying in their size and having only slightly or hardly rounded edges. They tend to be found up to a height of 270 metres above sea level, predominantly accompanied by huge erratic blocks, as e.g. at the crest cutting off Linnèbreen from its western side (Ryżyk, 1981). Easy to identify are fragments of the Permian limestones, whose traces can be followed when proceeding from east to west along the Tjörnskardet side. They occur right on the Carboniferous quartzite sandstones and on the Hoecla Hoek schists. The distance between the outcrop of these rocks and the last-found erratic is almost four kilometres.

From facts presented herein it will be evident that in analyzing the ways via which erratic material under consideration has arrived to these places due attention must be given to the glacial factor in the first place. This has been corroborated by geological studies and geomorphological research based on aerial photography. It is especially the size of sea-borne cobbles, the level on which they tend to occur, and the distance to which they have been brought, which preclude the possibility that these erratics might have been delivered to this place by sea.

Geomorphic and petrographic documentation accummulated so far is convincing enough to make an attempt at a palaeogeographic reconstruction of the ancient glaciations in Nordenskiöld Land together with their extents between Grönfjorden, Isfjorden and the Greenland Sea (Fig. 2). Spatial arrangements of forms and deposits may be regarded as a proof that glacial oscillations, and sea transgressions in between them, had to occur more than once in the past. It would be difficult to say without hesitation how old relevant glacial forms are likely to be (Riss?, Würm?, Holocen?). Recurrent redeposition of material in the marine and glacial media clearly speaks for the periodicity of such processes, and as a consequence the present-day relief may be seen as an outcome of these and similar factors having been forced to act more than once (Troitsky, Zinger, Koriakin, 1975; Lindner, Marks, 1983). Accordingly, the present attempt to reconstruct the extent of glaciations in that part of the archipelago must be considered as a preliminary step in this direction.

The degree to which the area under investigation has undergone a process of glaciation makes us concentrate on the assymetry observed in the position of glacial sheet. The least surface areas have been those of glaciers at the Greenland Sea coastline, between Orustdalen and Kap Linne. They were flowing down in the eastward direction, from the Linnefjella massif, and their length was less than two kilometres. Their névé formations occurred in the upper stretch of Orustdalen, Linnèdalen, and Griegdalen too. This was, among other things, due to an unfavourable orographic situation in the development of glaciers, such as poor relief and large angle of inclination in the Griegfjellet and Sollryggen side surfaces. Isfjordflya constituted at that time an abrasion platform flooded over by water and that is why glaciers ended here in a steep cliff and were liable to calving, thus giving rise to a number of icebergs which opposed the movement of ice-masses in the western direction.

Exposition in relation to the Greenland Sea has always had, and still continues to have, its pronounced bearing on glaciations in this part of the Nordenskiöld Land. The western Linnefjella sides have always been liable, and keep on being so nowadays, to the action of warm maritime air-masses. In the period under consideration they formed steep precipices in the rocks, washed out by the ingressing sea.

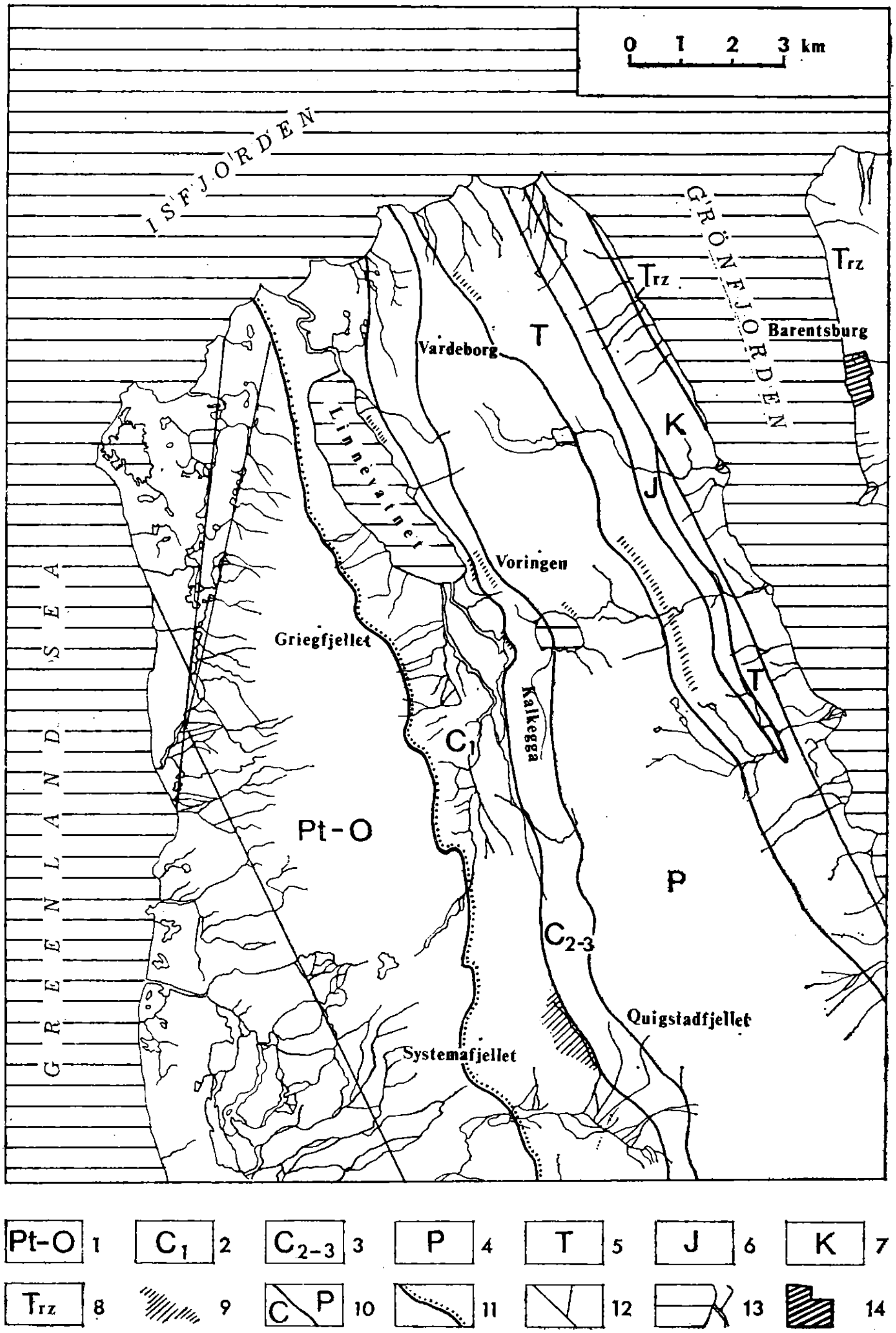
The Linnefjella ridge constituted as if a line of division between the Griegsdalen and Linnedalen glaciers, filled with ice over its entire length. In such a scenery only the nunatacs in the top parts of such peaks, as Vardeborg (588 m above sea level), Vardasen, Sokolovtoppen (541 m), Vöringen (675 m), Heftyefjellet (425 m), Flintkammen (570 m), Hermod Pettersenfjella (560 m), Productustoppen (523 m), Christensenfjella (680 m), as well as fragments of the Quigstadfjellet (770 m) and

Strandlinuten (507 m above sea level), stood out of the mountain ridges which closed the Griegdalen and Linnedalen glaciers from the east.

The surface of ice-sheet covering the said part of Nordenskiöld Land in those days was rather diversified. It came into effect as a result of a process by which separate glaciers tended to join each other. In consequence, the masses of ice lying higher in the corries and in the upper fragments of valleys began travelling slowly down the inclined planes of the land and their velocity was a function of both the angle of land inclination and the weight of ice itself. Some of the ridges and elevations, especially those to the north of Christensenfjella, in the Kalkegga extension, in the neighbourhood of Lake Congress and north of the Sokolovtoppen, played the part of a barrier to the growing and expanding glaciers in the initial phase of icing, and it was only during the stage of the most intensive ice-sheet build-up that they started to disappear under its cover. The glacier Aldegona was perhaps most dynamic in its action and so it played a dominant role in the process of glaciation. With a slight increase in the mass of ice, it flowed over the low rocky step in the northern direction of Christensenfjella and while moving towards Linnedalen it pushed the Linnebreen tongue in the western direction. Such a picture of Aldegonda glacier was also given by Norwegian topographic map drawn in the 1940s. During oscillation of the earlier glaciers, which had to be much larger than the present ones, the flow of ice proceeded in a similar way as this is illustrated by the possition of erratics scattered throughout Tjörnsgardet and over the ridge which cuts off Linnebreen from the west.

There are signs of transgression of glaciers also in the northern direction, alongside the Linnedalen, which at their peak filled up the valley to a height of 187 metres above sea level, as illustrated by erratics found at such a height. It seems therefore highly probable that the position of ice surface must have been much higher. It would be dificult to say now with precision how far the front of glacier flowing down the Linnedalen to Isfjorden had finally proceeded, but because of the great depth of Russekeilla and Solovietskibukta (over 20 mtrs) it definitely had to end in a steep cliff. Icebergs that contributed to the process of proliferation of the erratic material were breaking off exactly here. It is also possible that, with the progressing glaciation, ice-sheet might have covered a high percentage if not the whole of Grönfjorden, whose depth is more than 100 metres.

An analysis of the present-day relief helps us to identify the oldest cracking zones of the ice-sheet and to determine or locate ancient clefts and icefalls. Such discontinuities were caused by strains inside the gla-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ciers whenever noticeable bends or ridges happened in their substrata, such as e.g. the pass north of Christensefjella, the crest sealing off Linnebreen on its western side, steep walls at the northern side of Vardeborgbreen, etc. Cracks used to develop also in those places where masses of ice after leaving the ravines and narrowings, within the confines of ice-filled valleys, were undergoing a sudden expansion process, as e.g. at the outlet of the Tjörnsgardet towards the Greenland Sea.

After the investigation of the characteristic position of erratics in the north-western part of the Nordenskiöld Land, especially in relation to their parent-rock outcrop, it has become possible to reproduce two main directions of transgression of the ice-masses in the past, from east to west and from south to north. The older-time glaciers which were greater than these of the present day had to be moving from east to west along valleys and depressions, such as Blendadalen, Kongressdalen, Stenbrohultdalen. The valley occupied by Aldegondabreen nowadays, with a depression following some distance away between Hermod Petersenfjellet and Christensenfjella and the Tjörnskardet, was another easy way open to the moving ice-masses. The proved direction of movement, from east to west, coincides with what has been said by Büdel (1960) and Szupryczyński (1963).

Another direction of transgression, from south to north, is perpendicular versus the former one and is consistent with the course of Linnedalen. This may indicate the existence of two epochs of glaciation; one earlier, when the glacier was flowing towards the north, and another one, later and smaller (?), when the glaciers travelled from east to west.

In the light of our considerations on the history of the north-western glaciation in this part of Nordenskiöld Land it is possible to explain how the ice-sheet covering this land has been undergoing the process of degradation. Because of ablation and decreasing thickness of glaciers it came first to an "expansion" of the nunatacs and then to an "agglomeration" process by which the Linnefjella and Starostinaksla-Quig-

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Fig. 1. Geological map of the north-western part of Nordenskiöld Land by G. A. Kowalowa and A. Musiał

1 — limestones, dolomites, tillites, green and black Cambrian and Ordovician shales (Hoecla Hoek formation); 2 — grey conglomerates and quartzite sandstones with hard coal inclusions (Lower Carboniferous Period); 3 — cherry-red and red quartzite sandstones, grey limestones, dolomites, marly slate, rottensones (Medium and Upper Carboniferous Period); 4 — grey limestones and siliceous limestones with rich fauna (Permian Period); 5 — sandstones (Triassic); 6 — black clay shales with siderite concretions (Jurassic); 7 — sandstones and mudstones (Cretaceous); 8 — sandstones (Palaeogene); 9 — greenish-grey dolerites (Jurassic and Cretaceous); 10 — stratigrraphic boundaries; 11 — stratigraphic discontinuity lines; 12 — tectonic lines; 13 — surface waters; 14 — housing estate.

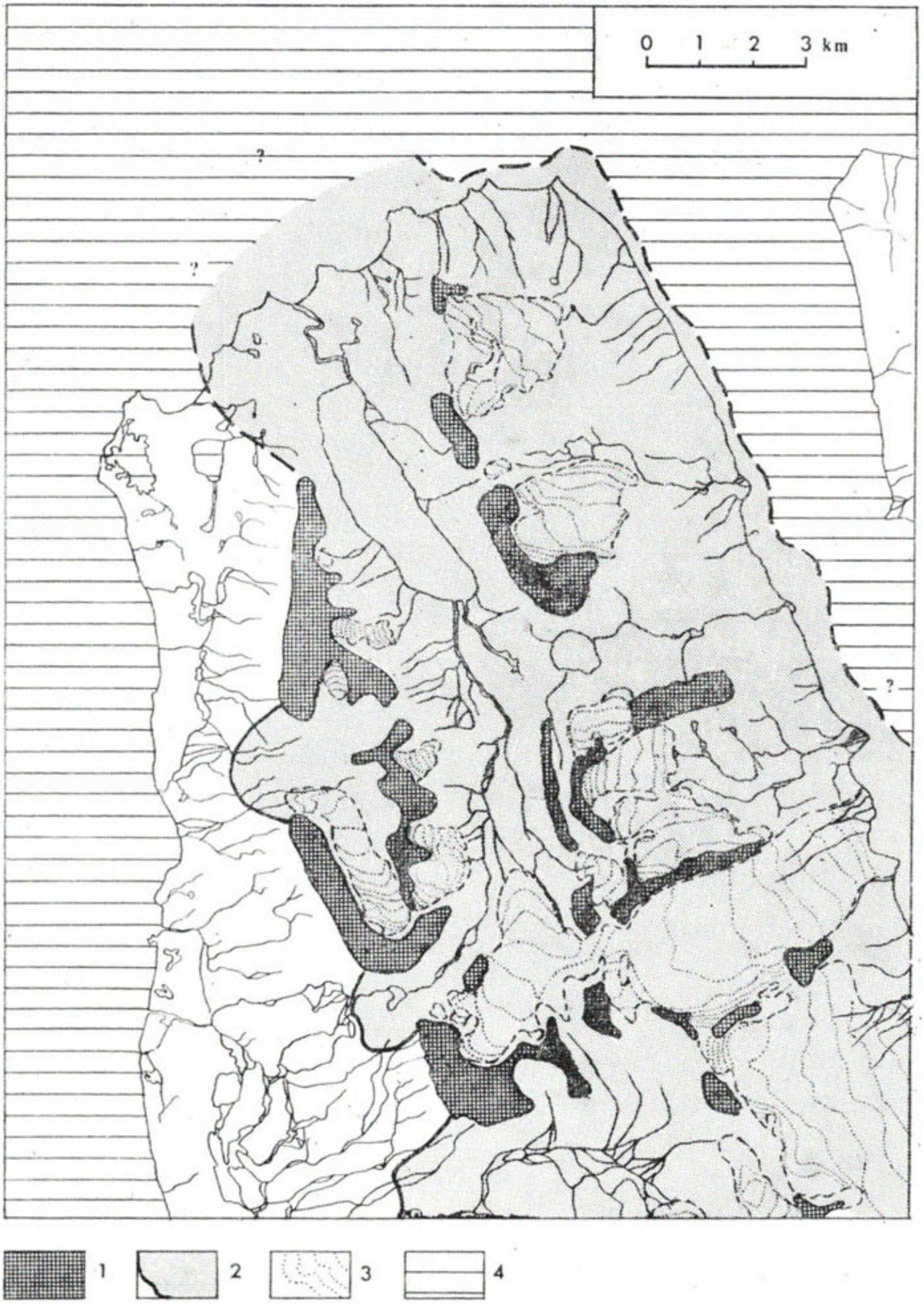

Fig. 2. Map of ancient glaciations in the north-western part of Nordenskiöld Land and their extents

1 — rocky nunatacs; 2 — ancient (maximum?) extent of the ice-cover; 3 — contemporary glaciers; 4 — surface waters.

stadfjellet ridges consolidated into mountain ranges. When the rocky iceshed was formed, large fragments of glaciers remained cut off from their firn areas (névé) and were changing into dead ice patches, melting with the lapse of time. The rate at which glaciers were decaying in the Linnedalen must have been fast enough as there have remained hardly any glacial kars noticeable within its boundaries in the form of vast névé reservoirs.

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