PROBLEMS OF MORAINE STRATIGRAPHY

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Abstract. The paper deals with morainic deposits near to glacial margins and at subglacial thresholds. Five problem fields are treated:

1. *Moraine materials of mountain summits and upper slopes of the northern Caledonides.* The frequency of erratics is high along the eastern marginal slopes of the central high massifs of Norway and Sweden and on slopes facing east or opening in easterly directions. These morainic materials were transported to summit regions from very much lower levels within or with the aid of ascending strata of the inland ice. The direction of transport was normal for the region, roughly from E. to W. The amount of vertical transport, from 1000 m to nearly 2000 m, is significant in many problem fields.
2. *Anomalous moraine transports.* During the deglaciation, a number of mountain glaciers were in action in the high western massifs and tectonic ranges of the northern Caledonides. The directions of flow of these glaciers were in many cases anomalous, as compared with the preceding stages. It is likely that a large fraction of the deposited morainic materials was transported in more than one direction before final sedimentation.
3. *Combinations of moraines and sediments.* Submorainic sediments and morainic windows in sediments occur in certain Archaean districts of Västerbotten County.
4. *Moraines of the coastal drumlin district of Västerbotten.* Early investigators of this area suggested that transversal moraines (end moraines) do not occur in the same areas as the longitudinal drumlins. However, in some areas, drumlins and swarms of transversal moraines are found together. These transversal moraines seem to be younger than the drumlin strata of the coastal district. In this district the author has analysed (1) the contact surfaces of deep moraine sheets and underlying rock, (2) moraine *in statu nascendi,* with boulders oriented in the divisional planes of the underlying rock, although resting in the local weathering soil, and (3) exposed strata of boulders in crag-and-tails with imbrication and preferred orientation about the mean strike of local drumlin ridges.
5. *Glacial tectonics, disturbed sediments and ice wedges.* In the sediments of southwestern Skåne and especially in the cliffs of Ven, the author recognized silty strata which were obviously tilted, thrusted and folded by the Öresund glacier ice. In 1953 the author started a systematic investigation of glacial tectonics and autotectonics in all sorts of glacigenic sediments. In 1956 ice wedges were included in the Västerbotten research program. Ice wedges are very rare in the Archaean district. Glacial tectonic phenomena occur at certain sites, whereas contortion and thrust phenomena of fine strata, mostly due to compaction and/or autotectonic movements, are common features, especially in the glacifluvial and littoral sediments of Västerbotten. Finally, the author suggests that investigations of the glacial tectonics of marginal sites may aid research into glacial history and into the quantitative stratigraphy of the central parts of the glaciated areas.

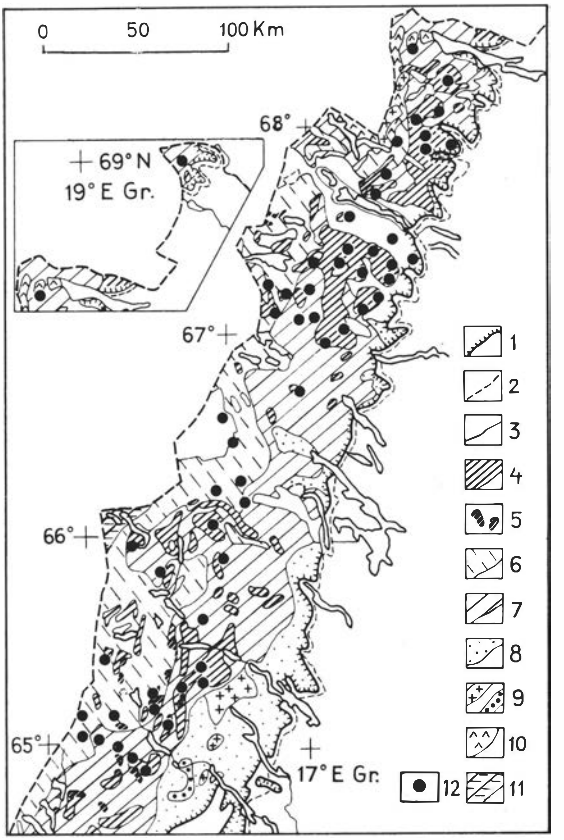

Fig. 1. Centres of areas in the northern Swedish part of the Caledonides, where chute slopes, glacial forms and deposits are investigated. Modified from 1964, 1, Overthrust. 2, Eastern Cambro-Silurian. 3, Granites and syenites, mostly Archaean. 4, Greenstones. 5, Peridotites. 6, Köli schists. 7, Seve schists. 8, Sparagmites and quartzites of the eastern marginal zone. 9, Gabbros and diorites (xx), Sorsele granites (...). 10, Lina granites in the NW. 11, The Rödingsfjöll nappe. 12, Centres of areas investigated. Maps: *Atlas över Sverige* and SGU, Ca 37.

INTRODUCTION

During the last 30 years, there has been great research activity in the problem fields of Cenozoic history and geomorphology. As regards the investigations of the Quaternary system in Denmark and Fennoscandia, improved methods of dating and correlating sequences of Pleistocene sediments and beds of glacial drifts have come into frequent use in both local research projects and systematic investigations for survey maps.

This tendency is evident in the publications of the national survey series for the period in question (see, for example, Milthers, 1942; Holtedahl, 1953; G. Lundqvist, 1951, 1959, 1961, 1963; J. Lundqvist, 1958, 1967, 1969*a*, 1969*b*, 1971*a*, 1971*b*; Nilsson, 1959, 1964; Okko, 1960; Fromm, 1965, and the literature quoted in these papers).

During the period mentioned, we have also witnessed a growing understanding of the significance of Quaternary research in human history, economy and ecology and of its bearing upon the future control of fundamental resources, such as ground-water and soil. Any kind of research in the field of Quaternary problems may thus, in time, prove to be of interest to planners of human ecology, although its primary aim may be merely the solution of certain interesting problems.

The present paper does not actually provide the proper answers to certain questions. It deals with a systematic series or group of moraine problems, which the author has met with frequently during his field work. He wishes to describe certain aspects of these problems to other field investigators.

Primarily, the scope of this series of problems is the interaction between the glacier, its basal load and the subglacial materials, together with the resulting deposits in extreme parts of the glacier, near its margins and at subglacial thresholds.

A very remote aim is to determine the quantities of preglacial and glacial rock waste transported and sedimented. However, the immediate aim is to discuss certain limited problems in the series mentioned above, firstly some moraine problems on the summits of the Fennoscandian Caledonides.

1. Moraine problems on mountain summits and slopes

This heading refers to problems concerning the summits and slopes of the high mountains of the Caledonides and certain pre-Caledonian areas in northern Fennoscandia. Some 30 years ago, it was a common view that certain summits and high mountain areas of the northern Caledonides of Norway and Sweden had persisted as nunataks during the Pleistocene glaciation. Consequently, no morainic materials should be found on the tops of these mountains. As a matter of fact, moraine is very rare on several summits of this part of the Caledonides. However, the writer did not come across one high mountain, where moraine, erratic boulders, glacial striae or other signs of glaciation were entirely lacking in northernmost Norway, Sweden or Finland (see Markgren, 1954 and 1964:A). The result of the investigation of possible nunataks may be summarized by saying that there were no persisting nunataks in northern Fennoscandia, including the Varanger Peninsula.

Erratic boulders and/or glacial striae were found, for instance, on the summits of the highest mountains of the Varanger Peninsula, including the Raggo Peninsula, in northeastern Arctic Norway, the Mageröya and Seiland Islands in northernmost and northwestern Arctic Norway, on the summits on both sides of the Kvænangen Fjord, on the high Lyngen mountains, on the islands of Værøy and Røst to the SSW. of Lofoten, and on the summits of the high mountain massifs on both sides of the border between arctic and sub-Arctic Norway and Sweden. Erratic boulders were thus found on the highest summits of the Caledonides from about 71°11′N. to about 65°N. These results are exemplified in Table 1.

On the upper slopes of the mountain areas mentioned, the existing erratic materials were studied in a random way. Thus, the erratics, found along a horizontal zone about 25 m in breadth, were analysed and counted per 2500 m of horizontal length of slope. In Norway, Sweden and Finland, 92 slopes were studied in this way during the period 1948–64. Although some of the investigated slopes are short, the number of erratics/2500 m is always $\geqslant 1$ and ranges from 1 to 50. The slopes are classified according to the frequency of erratic materials in the following way:

1. Poor slopes = slopes with 1–5 erratics/2500 m.
2. Moderate slopes = slopes with 5–10 erratics/2500 m.
3. Rich slopes = slopes with 10–50 erratics/2500 m.

Some of these slopes are presented in tables in Markgren (1962–63). There are certain trends in the composition and distribution of erratic materials on the slopes in question. It is possible to recognize regional variations in the distribution of the quantity of moraine (see, for example, Granlund and Lundqvist, 1937, p. 12; Svensson, 1959, p. 192). This variation is probably due to several factors, one of which is the preglacial morphology. High mountain areas have obviously lost

Fig. 2. Survey map of the central Caledonian amphibolitic massifs of Swedish Lapland (part of *Generalstabens höjdkarta,* northern Sweden, sheet II). Scale about 1:380 000.

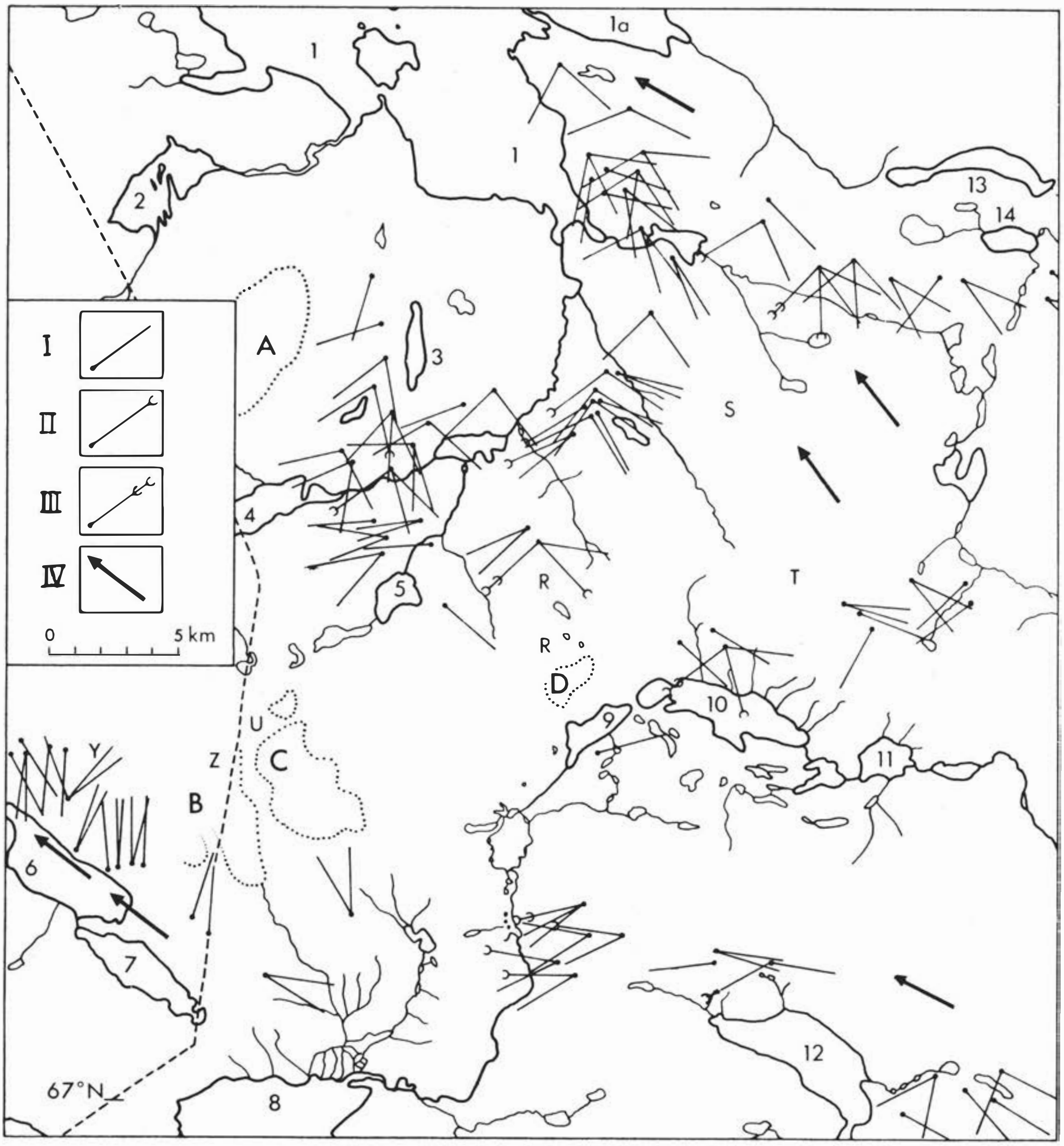

Fig. 3. Ice movements according to glacial striae between Lake Virihaure the Ålmajalos-Sulitelma Massifs in the N. and W., and the Sarek-Tarrekaise and Staika Massifs in the E. and SE. Striae occurrences according to A. GAVELIN (1906) were checked by the author. Occurrences on higher levels were added. A—D: Glaciers. A, Ålmajalosjägna. B, Salajekna. C, Stuorajekna. D, Jäknafojägna. S, Mts. Kerkevare and Passevare, 1565 and 1581 m. T, Mt Silbakvare-Silpatjåkko. U, 1889 m (1877 in *Sw. Fjällk.,* 3). Y, 1830 m. Z, Suliskongen, 1913 m (GLEDITSCH 1960; 1914 m in most maps). 1—14: Lakes, modified according to aerial photographs. 1, Virihaure. 1*a,* Arasluokta. 2, Gasakjaure. 3, Kappajaure. 4, Sårjåsjaure = Sårjusj. 5, Lower Staddaj. 6, Låmivatn. 7, Eidevatn. 8, Peskehaure = Pjeskej. 9, Haddet = Hadit. 10, Rovejaure = Råvej. 11, Skalo. 12, Vaimok. 13, Allajaure. 14, Rissajaure. I, Striae, not very divergent. II, Younger striae system. III, Youngest system in a locality. IV, Predominant directions of old striation in the area.

Table 1. Erratics and striae on summits of the northern Caledonides and the Varanger Peninsula.

Mountains				Erratic boulders	Striae
Name	Slope	Height, m	Site, m		
		The Sarek Massifs			
Palkattjåkko	SE.	2042	2005	1 quartzite, 1 granite-gneiss, red 1 syenite, grey	
Pårtetjåkko	W.	2039	<2000	1 granite, red, coarse 1 gneiss, grey	
St. Järta	NE.	1840	1820	1 gneiss, 2 syenites (red)	N.23°W.
St. Järta		1840	<1750	—	N.54°E.
Kåtotjåkko		1888	1880	1 syenite, red 1 gneiss, grey 1 sparagmite	
Akatjåkko	NE.	2010	1980	1 quartzite, grey 1 "Archaean", red	
Kanalberget	S.	1960	1920	1 phyllite, largely folded	
Äpartjåkko		1925	<1900	1 gneiss, red	N.61°W.
Äpartjåkko	SE.	1925	>1900	—	N.12°E ± 180°
Äpartjåkko	NW.	1925	1850	1 slate, grey	S.10°W.
Sarektjåkko	W.	2125	2020	3 "Archaean" boulders	N.36°E. ± 180°
Sarektjåkko	N.	2125	2085	—	Glacial surface
Sydtoppen	NE.	2037	<2020	1 gneiss, red, weathered	
		The Akka Massif			
Stortoppen	N.	2013	<2000	1 quartzite, red 1 syenite-granite	
Mattotjåkko	E.	—	<1600	3 syenite boulders	S.13°W.
		The Kallaktjåkko Massif			
Kallaktjåkko		1845	>1825	27 erratic Archaean boulders	
Kallaktjåkko		1845	>1840	11 granites, syenites or porphyritic gneisses	
The NW. peak	W.	1593	~1500	—	S.65°E.
		The Varanger Peninsula, Norway			
Stangenestind	W.	724	~ 715	1 gneiss, 4 amphibolites	SSE.
Kanglefjell	E.	618	~ 610	1 porphyrite	S.30°W.
Lievlamfjell	NE.	374	~ 369	1 amphibolite	
Lievlamfjell		390	~ 386	3 gneisses, 7 amphibolites	
Brandfjell	N.	424	~ 420	1 gneiss, 2 amphibolites	
Tanahorn	N.	265	~ 255	1 quartzite, 1 shale	
Havningberg	N.	143	~ 140	1 shale, striated	S.60°E.
Blodskytten	S.	115	~ 104	1 amphibolite	S.8°E.
		Mageröy			
Nordkap	SSE.	307	~ 290	1 shale, striated 1 phyllite, striated 1 gabbro, striated	
Knivskjellodden	SW.	301	~ 295	1 amphibolite	

more rock material than they gained during the glaciation. There is also some correlation between the petrological composition of the rock and the variation of the quantity of moraine in the northern Caledonides. For instance, quartzitic mountains are mostly poor in moraine, as compared with the surrounding rock areas.

Returning to the problem of moraine on the upper slopes, however, we shall find on these slopes a clear regional variation in the distribution of erratics, that is to say, in moraine materials (see Markgren, 1962–63, pp. 53–59). Poor slopes with 1–5 erratics/2.5 km occur in the central summit areas of large massifs, whereas moderate to rich upper slopes with 5–10 or 10–50 moraine boulders per unit of length are found mainly on the eastern margins of the high central massifs of Norway and Sweden and on slopes facing east or opening in easterly directions. This asymmetry of moraine and boulder deposits is of significance in studying problems of both geomorphology and moraine stratigraphy.

The morainic materials in question were obviously transported to summit regions from lower levels within

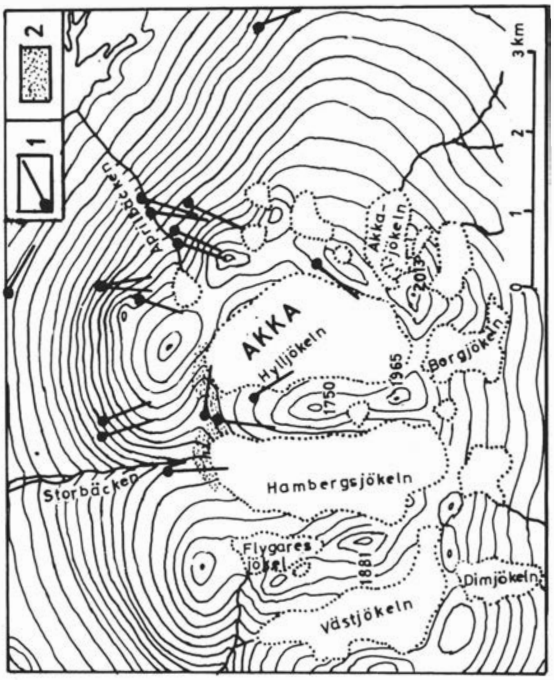

Fig. 4. Central part of the Akka Massif. Centre about 67°35′N. Cf. Fig. 2. Mainly amphibolite resting on syenite. Map by N. H. Pallin 1918–20, revised 1948. Glacial striae according to research by the author. 1, Youngest, anomalous striae. 2, Terminal moraines with erratic boulders dating from the Archaean.

or with the aid of ascending strata of the inland ice. These strata are defined by variation of the velocity and/or the direction of flow. Differential movements within the Pleistocene glaciers are likely to have taken place, according to the distribution of the directions of glacial striae on scarps and steep mountain walls in these areas (see, for example, Markgren, 1964:A). It seems probable that the basal parts of the glaciers on the eastern stoss slopes of the mountain regions were almost stagnant, due to morainic load, and were separated from the upper strata by series of divisional planes (see McCall in Lewis, 1960). As regards the conditions in the central valleys of the massifs, the problems of stagnant or differentially moving glaciers are quite complicated. However, irrespective of the degree and direction of motion of the basal ice in the glacier, it is likely that certain portions of the basal moraine material got trapped in valleys and stoss slopes during several stages of the glaciations.

The author would suggest that a large part of what is called rock debris on mountain slopes is a complicated series of trapped moraines. At present, not much is known about the history, the stratigraphy or even the petrographic composition of these moraines of the Caledonian mountain slopes and summits, except for the information from the fraction of erratic materials analysed.

The subject of this section is exemplified by Table 1 and Figs. 1–5.

2. Anomalous moraine transports

During the late stages of the deglaciation of the northern Caledonides, a number of mountain glaciers were in action for some time. Some of them developed where mountain glaciers are found at present, others occurred in places without recent glaciation but with snow fields or snow patches that persist today. The directions of flow of these glaciers were in many cases anomalous, as compared with the movements of the large glaciers of the preceding glacial stages.

These glaciers occurred in the high western massifs and tectonic ranges of the Caledonides in northern Norway and Sweden. Certain problems of the distribution and/or the glacial and climatic dynamics of the anomalous glaciers were discussed by the author in papers in 1950, 1951, 1952, 1956, 1960 and 1964 (cf., for example, Markgren, 1960, 1964:A, p. 49, and 1964:B, References).

Where the anomalous transports were limited to the upper mountain slopes just below the glaciers in question (Fig. 4), the stratigraphic problems are similar to those presented in section 1. However, in certain areas, for example, in the Stekenjåkk-Jetnam-Sipmege region (cf. J. Lundqvist, 1969) and the Artfjället and the Norra Storfjället regions in southern Lapland, where the anomalous glaciers seem to have been quite large (Fig. 6), the conditions are different. Here the reversed transports took place partly over rather level ground or into depressions. Schematically, the subglacial surface can be regarded as a plain, slightly dipping towards the E. or SE., and the mountain slope behind the glacier as a vertical wall, striking N. or NE. Then the maximal anomalous glacier can be estimated as a prismatic body, limited in the W. by the mountain wall, facing E. and limited in the E. by a possible terminal moraine or a shear-plane moraine.

It is possible to construct a still more schematical prism, a reference prism, limited by a right-angled triangle. In this, the subglacial surface represents the horizontal plane and the mountain wall the vertical plane. The plane of the hypotenuse is the one that falls from the mountain edge behind the glacier to the mean of the nearest sites of possible parent rocks of defined erratics.

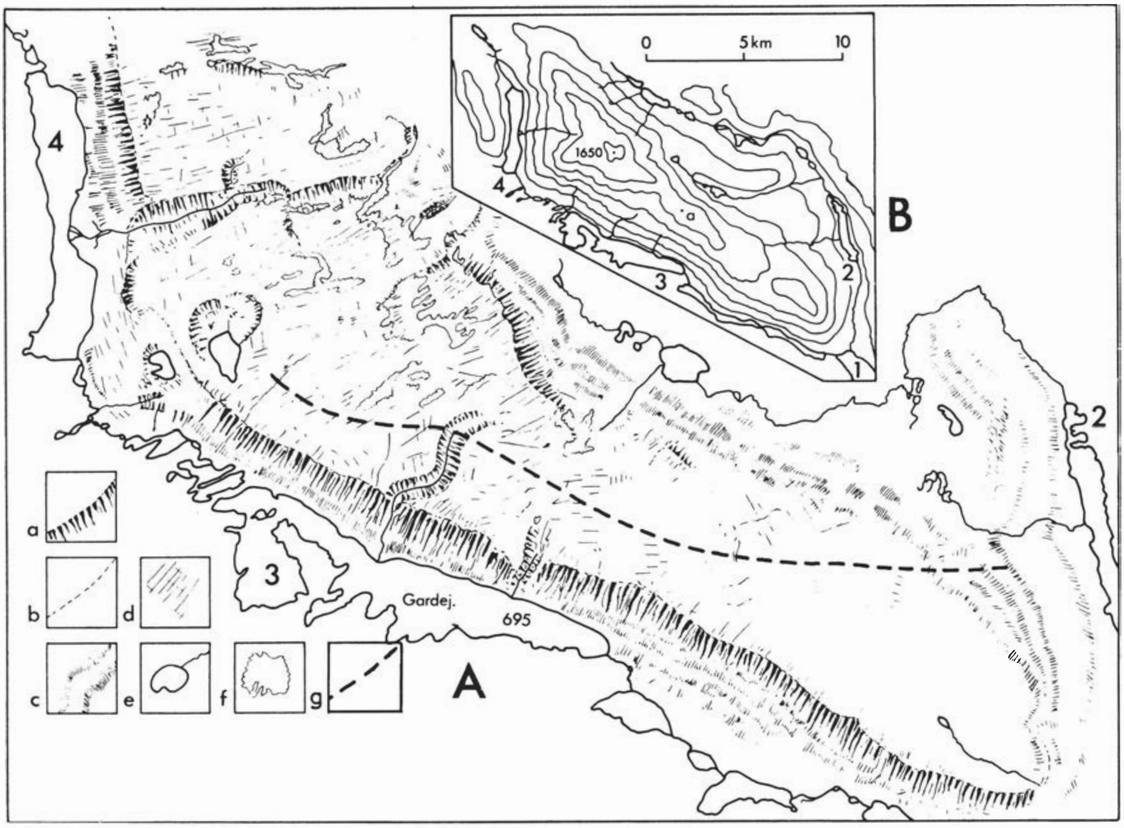

Fig. 5. Kuosteritjåkko = Kustarakaise, A, Sketch map, based on field study and aerial photographs. *a,* Chutes. *b,* Scarps. *c,* Form lines in loose materials. *d,* Furrows and ridges due to structure. *e,* Lakes and rivers. *f,* Glacier remnants and snow fields. *g,* North to northwestern limit of big erratic boulders dating from the Archaean. B, Survey map based on *Sw. Fjällk.,* 5. Contour interval 150 m. *a,* 1494 (1694 m in the official maps). A + B, 1—4, Lakes. 1, Barturtejaure = Partaure. 2, Maranjaure. 3, Gardejaure. 4, Tjålmejaure.

Since the progressional transport of erratics from lower to higher levels must be balanced by the potential energy of glacier masses, it is possible to reconstruct the minimum height and the probable gradient of the upper glacier surface, if the triangel of a reference prism is known. It should be mentioned that erratic moraine materials are found on the summits of mountains reaching over 2000 m (see, for example, Figs. 1, 2 and 4).

Anomalous moraine transports may have taken place more than once in these regions during the Pleistocene. However, the author would suggest that the fresh erratics on preserved glacial surfaces in the summit areas and on the upper slopes of the high Caledonides should be regardes as sediments of the uppermost moraine-loaded strata of the last inland ice in the region. They may be correlated to the moraine available within certain high plains between the large massifs (cf. Figs. 2 and 3).

3. *Combinations of moraines and sediments*

Under this heading, the author wishes to touch upon certain occurrences of submorainic sediments and morainic windows in sediments in the Archaean district of Västerbotten County. In the Vilhelmina area, submorainic sediments occur at different levels (see Markgren, 1951, pp. 450 f.). One of these is to be found at the southeastern end of Lake Malgomaj, along the valley slope, facing NE. There, the entire deposition takes the shape of a terrace, about 5000 m in length, 300 m in breadth and about 30 m in height above the level of Lake Malgomaj. The glacifluvial sediments are covered by a tough and dense till. As regards the petrographic composition, the two constituents of the deposits are quite alike. The terrace is furrowed by some 20 ravines. The genesis of the Malgovik terrace has been discussed by Markgren (1950 and 1951, p. 451). A subglacial deposition of both constituents of the terrace at

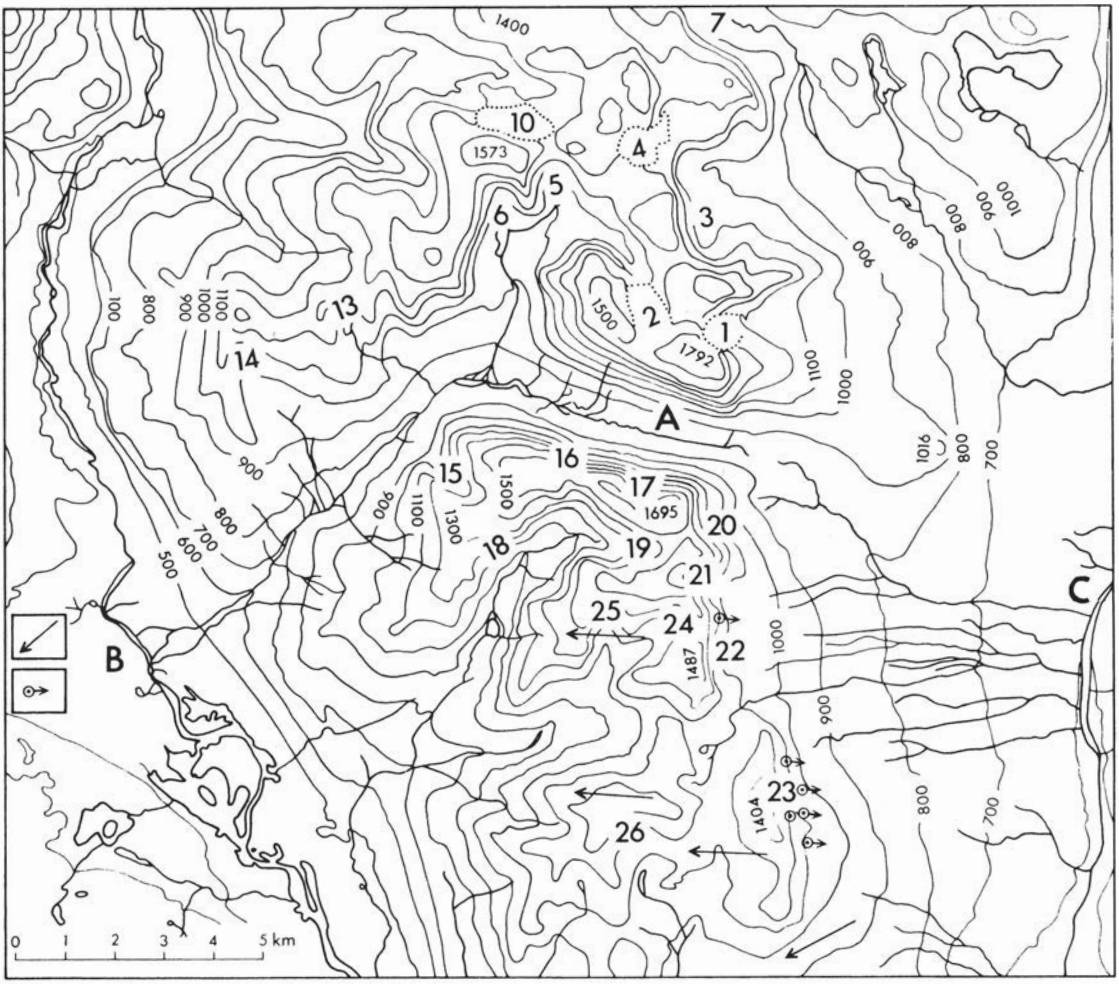

Fig. 6. Cirques, valleys and glacial striae in the Norra Storfjället Massif. Nos. of the cirques (1–7, 13–26) according to RUDBERG (1954), pp. 280–298). A, The Syterskalet Valley. B, The Ume River. C, The Tärna River. Arrow: (Old) glacial striae in the top areas, mainly from the E. Orbit with short arrow: Locality with preserved older striae from the E or NE, and younger anomalous striae, roughly from the W or NW.

Malgovik or a sedimentation of the till during an ice oscillation are two possible explanations. Deeper strata of submorainic sediments, locally varved clays within the Vilhelmina region, were considered (by Granlund, 1943, p. 58) to be of Interglacial age (cf. G. Lundqvist, 1943, pp. 123–130; J. Lundqvist, 1967, 1971).

Sedimentary inclusions, moraines grading into real sediments and vice versa seem to be common features of the Pleistocene deposits of northern Sweden (see Hoppe, 1948; Fromm, 1965; J. Lundqvist, 1969*b*; also Markgren, duplicated MS. in 1969).

Another combination of sediments and moraines occurs in the river valleys of Västerbotten, mainly at levels below the highest shore level. Here mostly transversal moraine ridges occur as local protrusions or windows in the fjord sediments (Markgren and Lassila, 1972, MS. report to the Nature Conservancy Board about an area of the Vindel River valley). Those discontinuities are of a certain interest in ground-water prospecting.

4. *Moraines of the coastal drumlin district*

The drumlin area along the southern coast of Västerbotten was first described in a special study by Högbom (1905). Granlund dealt with the morphology and composition of these moraines (1943, pp. 26–44). Further studies in this field have recently been made by Bergström (1968) and Johansson (1968). Moreover, certain studies of drumlins and transversal moraines in

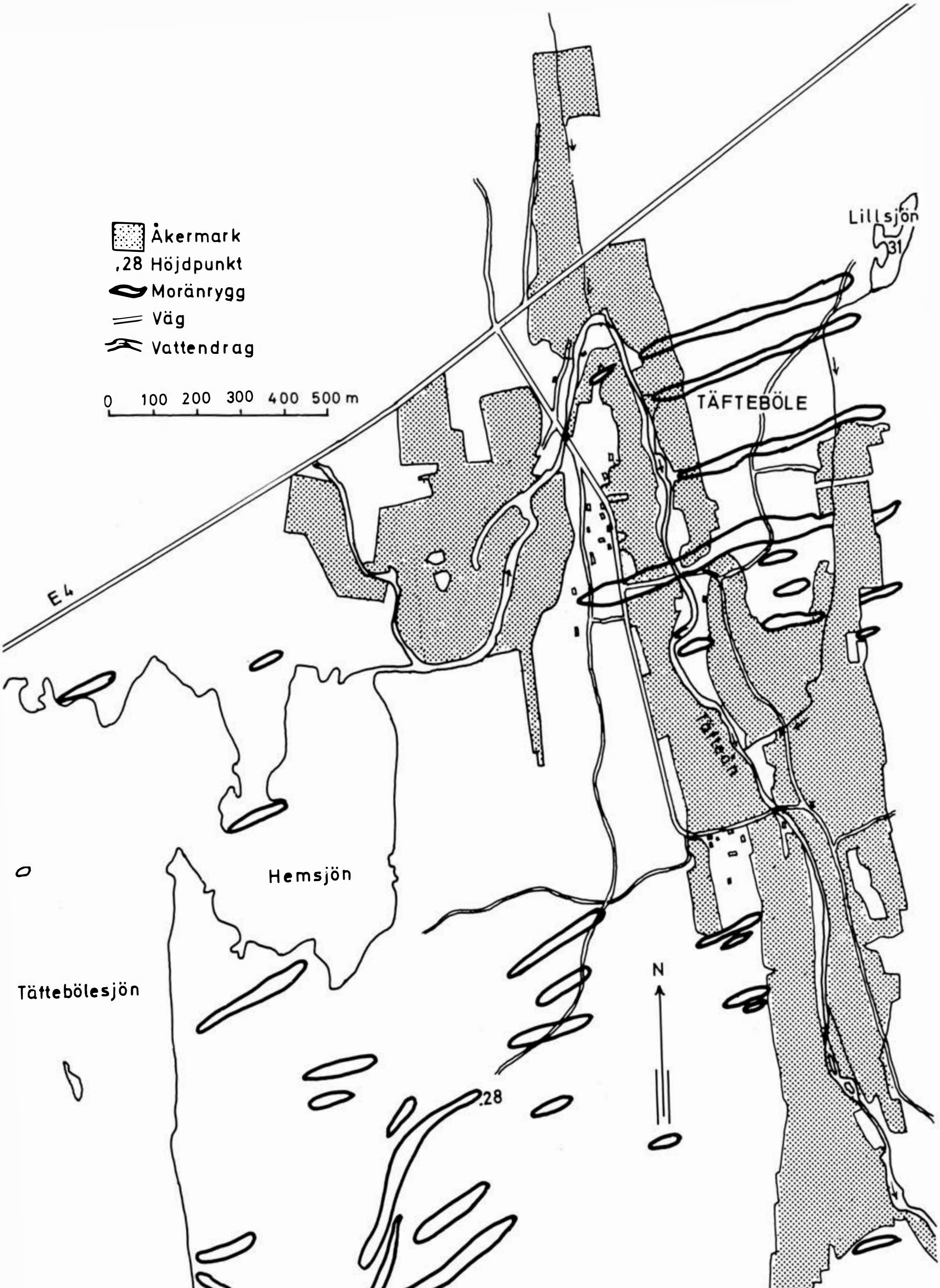

Fig. 7. Drumlins and transversal moraines at Täfteböle.

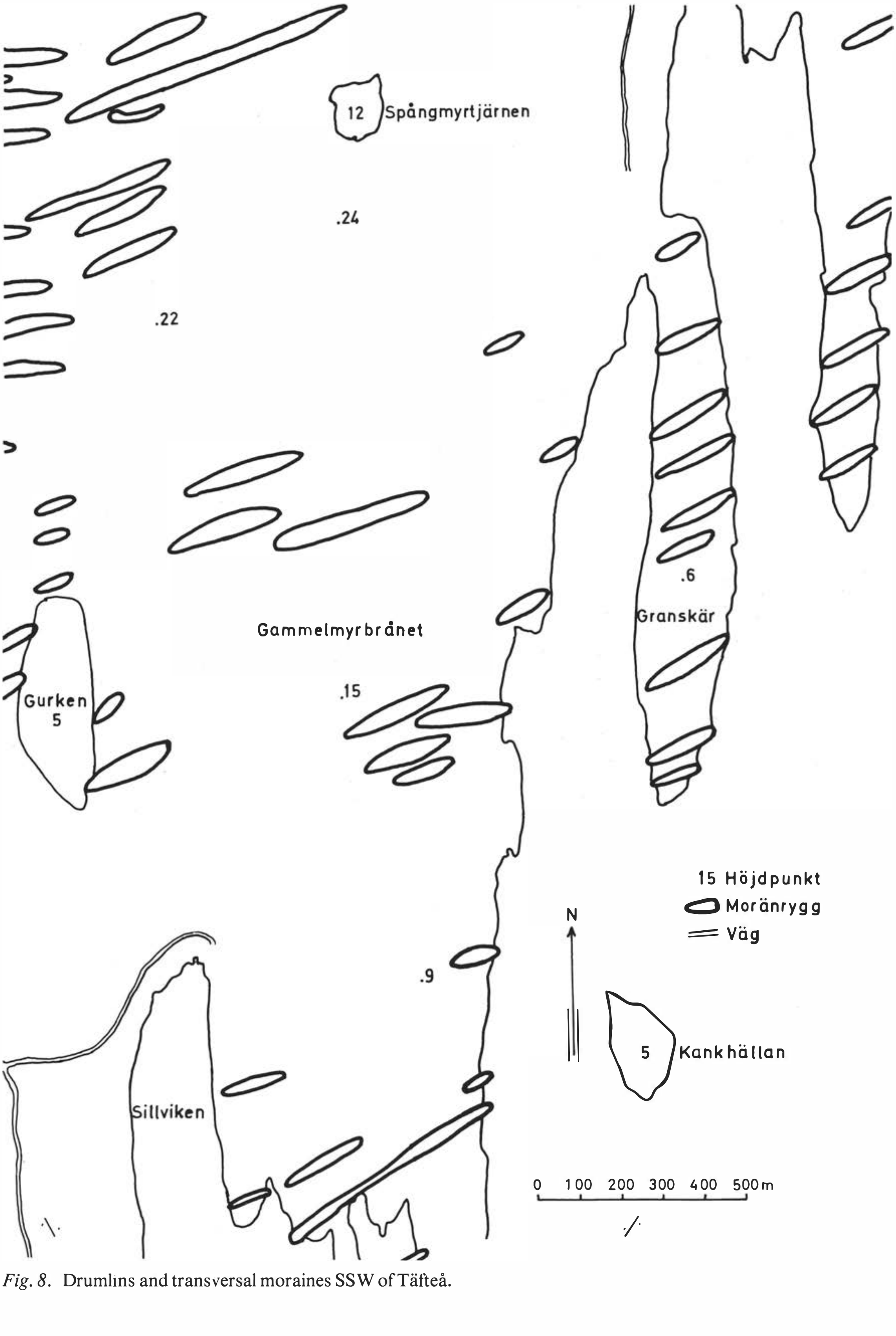

Fig. 8. Drumlıns and transversal moraines SSW of Täfteå.

this district have been carried on by students from the University of Umeå since 1966 (cf. Markgren, 1968). The author made investigations of glacial striae, orientations of defined drumlins and possible occurrences of terminal moraines in the period 1951–55 (cf. Markgren, 1956).

Granlund suggested (1943, pp. 44 f.) that transversal moraines (end moraines, l.c.) do not occur within the same areas as the longitudinal drumlins. Also Bergström (1968, pp. 12, 48 and 62) found quite few transversal moraines, some of which were represented as true end moraines (p. 48). However, in the area between Österfjärden, which is the mouth of the Ume River, and Nyhamnsfjärden, some 5 km to the S. of Ratu, transversal moraines occur in swarms and single ridges frequently as a characteristic feature of that region. This sort of ridge is also seen in the Holmöarna group of islands. Three areas between Yttre Täftefjärden, near Holmsund, and Täfteböljesjön in the N. are shown in Figs. 7–9. (As regards the mechanical compositions of the drumlins and transversal moraines, see Markgren, 1970, Appendix 2.) In the Täfte region, the transversal moraines range from about 100 m to 900 m in length, 10 to 35 m in breadth, and between 2 m and 10 m in height. The moraines in question appear between and on the lower slopes of crag-and-tails, defined drumlins and elongated rocks. As regards stratigraphy, the author considers the transversal moraines to be younger, perhaps slightly younger than the drumlin strata of the coastal district.

Oreintation analyses and analyses of the mechanical and petrologic composition of drumlins from different areas below and above the highest shore level have been made. As regards composition, the results are rather similar to those of Granlund (1943).

In certain cases, it has been possible to analyse the lower strata of crag-and-tail moraines and moraine materials at the contact surface of underlying rock and deep moraine sheets. Some instances will be mentioned here. The sites are (1) the Mariehem hill in the northern part of Umeå, (2) Buberget to the S. of Umeå, and (3) Bergskärsudden on the northern shore of Skeppsviksfjärd, NE. of Umeå.

In 1966–67 the morainic cover on the eastern and western slopes of the gneiss hill of Mariehem, near the site of the new water-tower, was removed locally for the purpose of making house foundations there. The surfaces of the exposed rock proved to be quite different at different places. Some surfaces were polished and striated by glacial stria from about N. 28–33°W., N. 6–11°W. and N. 5°E. There were also some striae from about NNE. Other surfaces were interrupted by pockets of deeply weathered materials–sandy, silty or even clayey.

It could be seen on the eastern slope that sheets of the rock had been transported from the N. and had been deposited some 2 m up-slope. The basal till of the slopes was obviously rich in silt and clay. The locality of Buberget, near Stöcke, about 10 km S. of Umeå, was investigated in 1966 (see Fig. 10). It has also been investigated by Johansson (1968). The locality has been exposed for the exploitation of littoral sand and local boulders for crushing into gravel. S. of the hill of Buberget (46 m), there is a crag-and-tail ridge. Near the top and on most of the slopes there is a thick moraine. This is about 10 m at its maximum anc consists mainly of local boulders. The fine fractions have mostly been washed away. Johansson (1968, p. 24) considers the boulder masses to be a moraine *in statu nascendi.* The present author agrees, for many reasons. The large flat boulders of this deposit show strikes and dips which correspond to the surfaces of rock schistosity and sheeting at the top and to the slope surfaces at lower levels. This moraine may have been moved slightly up-slope, probably in a rather late glacial stage. The bare rock surfaces in the northern part of Buberget are striated from about the N.

Bergskärsudden is the site of a crag-and-tail about the low sea-level. The exposed stratum of this moraine consists mainly of large boulders. These show a preferred orientation in the northern direction. Moreover, many boulders with long axes dip slightly to the N. Many of the boulders have their upper surfaces striated with striae from N. 13°W. to N. 8°E., which is about the mean strike of the local drumlin ridges.

In 1953–55 the author investigated 98 striated, imbricated boulders with long axes in the area between Skellefteå and Kågnäsudden. The following results were obtained:

Orientation of long axes in N. 15°–30°W.: ~ 60 %
Axial plunge (imbrication) towards the N. or NW.: ~ 72 %
Striation between NNW. and NW.: . . . . ~ 57 %

This study of imbricated boulders is not finished. However, it seems likely that this phenomenon is due to the shear-plane movements of basal, moraine-loaded ice, not very far from its margin.

5. Glacial tectonics, disturbed sediments and ice wedges

The author investigated occurrences of the phenomena mentioned above during certain periods from 1953 and 1964, mainly along Öresund, in the sediment cliffs of

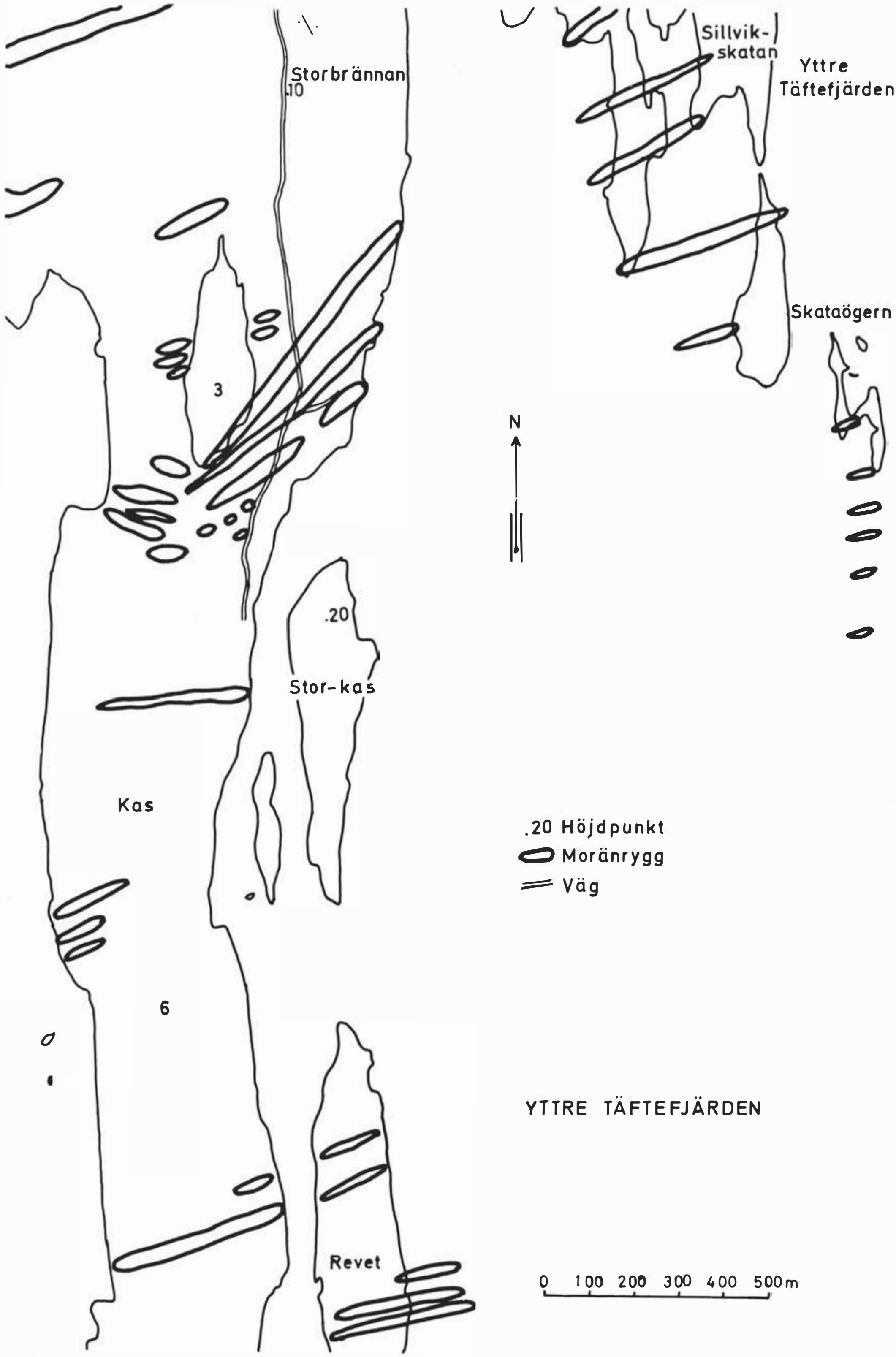

Fig. 9. Drumlins and transversal moraines in the outer Täftefjärd, near Holmsund.

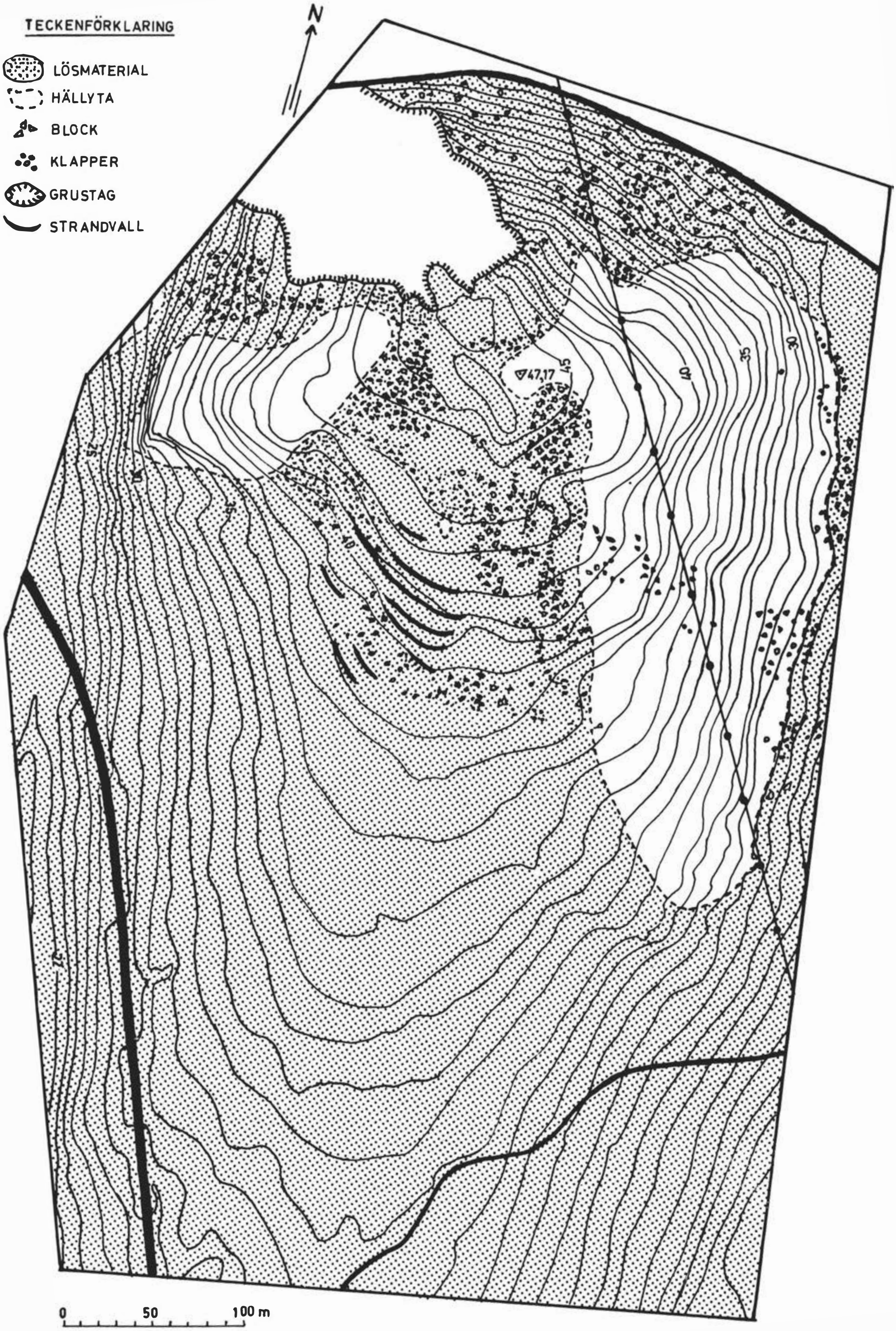

Fig. 10. Buberget, Stöcke, S. of Umeå. Locality of preserved, washed moraine *in statu nascendi* on sheeted gneissic rock. *Lösmaterial* in fig. = moraine and littoral sediments. *Block* = boulders. *Grustag* = striated rock surface, exposed by exploiting sand, gravel, moraine boulders and rock.

Ven and at scattered localities in southwestern Skåne. A preliminary paper about the glacial tectonics of the island of Ven was published (Markgren, 1961). Further research on these subjects was undertaken from 1965 in northern Sweden and from 1969 again in Skåne.

Here the author wishes to touch upon the results of this investigation hitherto in the counties of Västerbotten and Norrbotten. However, the problems of the so-called Kalix *pinnmo* (Kalix ground moraine) will not be treated here (see Hoppe, 1940; Fromm, 1965; cf. J. Lundqvist, 1969 *a*).

Ice wedges seem to be very rare in the Pleistocene sediments within the Archaean region of Västerbotten. The same is true of glacial tectonics. However, in a silty portion of the Malå esker, on the southeastern side of Lake Malåträsk, some 100 m outside Malåträsk, the author and Dr M. Lassila found six ice wedges and four folds, which are probably due to glacier push from about the N. or NNW. The sediments of this locality are being exploited at present. The glacifluvial sediments in the Malåträsk region have in many places been disturbed by other causes, probably mostly by differential movements within the strata.

In the exploited parts of the Vindelälvsåsen esker, disturbances of different kinds are rather common features of the incompetent strata.

Large folds are rare, except for two sites. These are the localities of the Umåker trotting course and the Röbäck sawmill to the S. of Umeå. The Röbäck site has been almost completely exploited. Here 13 large folds were found in strata rich in silt and clay, above coarse sediments and below an unsorted thin layer with boulders. Although compaction of the sediments may have taken place, it seems probable that there was also some post-sedimentary pressure or tangential drag from above in the sites in question (cf., for example, Ross Mackay, 1959, pp. 15 ff.).

In the county of Västerbotten, disturbances of layers of silt and clay in coarse littoral sediments are not unusual, whereas ice wedges are rare in all fractions of littoral sediments below the highest shore level. For that reason, two sites of this kind have to be mentioned. These are the now exploited littoral terrace to the SW. of the mountain ridge of Rävahusberget, Skellefteå. The wedges were found at about 60 m a.s.l. and were about 1 m in depth.

The other locality is a washed stoss-side moraine on the northern slope of the Fäbodberget mountain, near Lake Kroksjön, some 30 km N. of Umeå. Here one well-developed ice wedge is found at about 150 m a.s.l.

It would be rather difficult to investigate the sort of phenomena mentioned in the heading in northern Sweden, without having experience from the areas in southern Sweden with well-developed features of this kind.

The research into the glacial tectonics at Ven is being carried on mainly with the purpose of studying the variety of well-defined, glacier, ice-thrust phenomena and of evaluating their significance for the morphology, the stability of slopes and the ground-water drainage.

Finally, it seems probable that the problem fields of the stratigraphy of the anomalous deposits of the Caledonian glaciers and the problems of the quantity of transported moraine materials may be elucidated by certain results of the research that is being carried on in this part of southernmost Sweden by investigators from different Scandinavian universities.

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