

# Glacigenic landform features in marginal zone of Russell and Leverett glaciers, West Greenland

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During glacial ice melting, the sedimentation of transported material creates a variety of landforms depending on bedrock surface, glaciodynamic processes and features of sedimentation in glacial and periglacial environments in the ice marginal zone. The landforms created during sedimentation in glacial and periglacial environments are greatly dependent on the location or subenvironment of the sedimentation process, i. e. on whether it is taking place in subglacial, englacial, supraglacial, terminoglacial or proglacial subenvironments. The landform study at the marginal zone of the Russell and the Leverett glaciers in Western Greenland near Kangerlussuaq was carried out in glacial and periglacial environments. Besides morphological observations, the architecture of glacially accumulated forms was studied in outcrops. All these studies enabled to analyse the landforms in relation to glacial and periglacial facies. Marginal and proglacial forms in front of the Leverett Glacier were mapped in detail. Sedimentation of lodgement, basal, ablation and flow till deposits was observed in different subenvironments of the glacial environment in the marginal part of the glacier. These deposits in the form of till complexes in the periglacial environment were studied as landforms – lateral and end moraines formed in a terminoglacial subenvironment and basal till plains in a proglacial subenvironment left after ice retreat. Ice-cored moraines with a washboard moraine type surface of kettled topography with water ponds in kettle holes were studied in the ice divide area between the Russell and the Isunnguata glaciers. The whole complex of landforms of different origin was studied in the ice marginal zone of the Leverett Glacier, the south-western branch of the Russell Glacier. The data collected during this study indicate the importance of the climatological factors lying behind the exceptional geodiversity of the area and the glaciodynamic contribution to the richness of landforms in the marginal zone of the Russell and the Leverett glaciers.

**Key words:** glacigenic deposits, proglacial landforms, moraines, West Greenland

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## INTRODUCTION

The relationships between the lithofacies in glacigenic sequences allow the delineation of glacial events in areas of continental glaciations. However, the reflection of sedimentary environment in the structure and composition of glacigenic deposits is very complex. For this reason, it is not always easy

to identify the processes of sedimentation during research dealing with glacigenic sediment sequences. Thus, to study the features of sedimentation in present glacial environments in order to find a key to identify them in sediment sequences of old continental glaciations is very important, along with the implication of the analysis method when the knowledge on the present day processes is the key for understanding

the past ones. Therefore, the knowledge on contemporary glacier–landform interactions is the key for Quaternary palaeoglaciological reconstructions.

Eroded bedrock material transported by glaciers is derived either supraglacially from nunataks and valley sides or from erosion of the subglacial bed (Boulton, 1978). Debris eroded from bedrock is initially transported in the basal zone of traction, where particles undergo crushing and plucking. During ice melting, the sedimentation of transported material creates a variety of landforms reflecting the sedimentation environments in the ice marginal zone. The landforms created during sedimentation in glacial and periglacial environments greatly depend on the location or subenvironment of the sedimentation process – whether it is taking place in subglacial, englacial, supraglacial, terminoglacial or proglacial subenvironments (Brodzikowski, Van Loon, 1991). The terminoglacial subenvironment is considered as a space for the creation of a more spectacular landscape in most cases. Quite different landforms are created in a proglacial environment by meltwater streams transporting the glacial

material and accumulating it along the stream passway and in places of its entrance into proglacial lakes. Therefore, the variety of places and conditions of sedimentation in glacial and periglacial depositional environments creates a high diversity of landforms.

## FIELD SITES AND METHODS

The study area (Fig. 1) at the marginal zone of the Russell and the Leverett glaciers in Western Greenland lies near the Kangerlussuaq International Science Support (KISS) centre and can be easily reached from there. The general view of the Russell Glacier is presented in one of the publications of this issue, devoted to the characteristics of basal ice (Baltrūnas et al., 2009). The Leverett Glacier is the south-western branch of the Russell Glacier.

The observation of glacial landforms in the marginal area of the Russell and the Leverett glaciers was carried out in glacial and periglacial environments. Besides the morphological observations, the architecture of glacially accumulat-

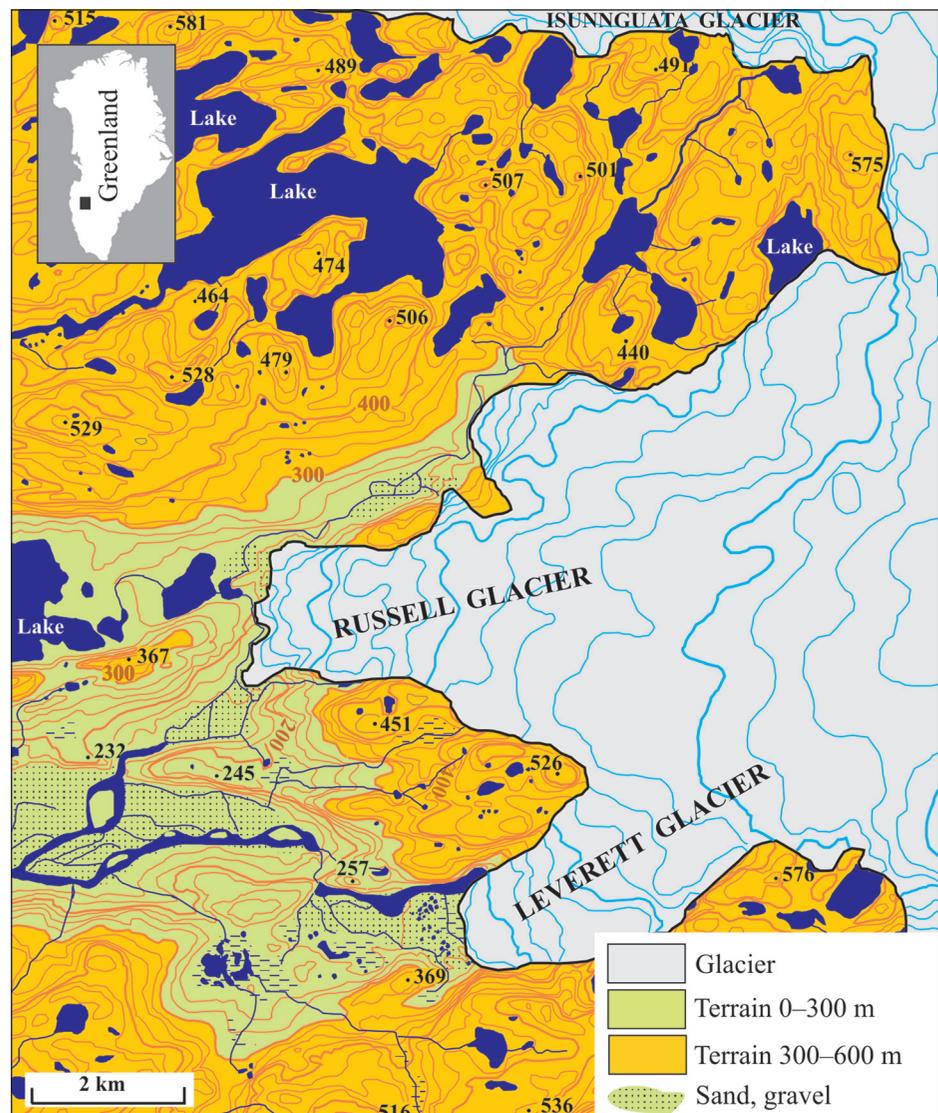


Fig. 1. Topography of Russell and Leverett glaciers area, West Greenland

1 pav. Russell ir Leverett ledynų bei apylinkių Vakarų Grenlandijoje topografija

ed forms was studied in outcrops along with the description of bedforms, lamination, presence of buried ice, etc. carried out in excavations 0.8–1.0 m deep as well. Samples for grain-size measuring were taken from basal and end moraines. Ice-bearing till was analysed as well after the ice had melted and samples were dried in laboratory. All these studies enabled to analyse the landforms in relation to glacial and periglacial facies (Table; Figs. 2, 3).

The morphological features of landforms were measured using a tape-measure and a GPS navigation device. The GPS navigation device was used for the contouring of landforms and altitude measuring. Slope inclinations were measured with an optical hand clinometer. The aerial distribution of glacial and periglacial landforms was studied using simple satellite images found in the Internet and aerial photos, what enabled to delineate the areas of different glacial and periglacial landform types. The marginal and proglacial landforms in front of the Leverett Glacier were mapped in detail.

**THE LANDFORMS STUDIED**

Examination of the depositional setting of ice marginal deposits at the margin of the Russell and the Leverett glaciers by means of observation of exposures and landforms in West Greenland provided a possibility to evaluate an interrelation between glacial facies and landforms. Greenland was completely or almost completely covered with ice

during most of the Quaternary, therefore, glacial deposits are widespread on ice-free land areas and on the adjacent shelf (Bonow et al., 2006). After the latest deglaciation had begun 14,000–10,000 years ago, the minimum position was reached approximately 5000 years ago when the ice margin was at least 15 km inland of its present position in West Greenland (Weidick et al., 1990). So, the margin of the Russell and the Leverett glaciers is situated at the present location after some re-advance. This re-advance could influence the character of landforms; however, it is quite complicated to recognize these features.

Sedimentation of lodgement, basal, ablation, flow and ice-raft till deposits can be recognized in different subenvironments of the glacial environment (Fig. 2) near the margin of the glacier. In the periglacial environment, these deposits are usually observed as till complexes composing lateral and end moraines as landforms formed in the terminoglacial subenvironment or basal till plains in proglacial subenvironment left after ice retreat (Fig. 3).

Sedimentation of **lodgement till** is restricted to a subglacial subenvironment where it is deposited in a contact zone between the ice and substratum during ice movement. Its observation in the marginal part of the Russell and the Leverett glaciers is limited to ice outcrops. Lodgement till deposits can be easier found there in contact between the basal ice and the substratum; however, such outcrops are unstable, appearing and disappearing year after year as the ice moves forward, melts and its edge is eroded by meltwater streams.

Table. Presence of deposits of glacigenic facies in glacial and periglacial subenvironments (after Brodzikowski, Van Loon, 1991; Šinkūnas, Jurgaitis, 1998)  
Lentelė. Glacigeninių facijų nuogulų paplitimas glacialinėje ir periglacialinėje subaplinkose (pagal Brodzikowski ir Van Loon, 1991; Šinkūnas, Jurgaitis, 1998)

Glacigenic facies	Deposits	Glacial environment			Periglacial environment		
		Subenvironments					
		Englacial	Subglacial	Supraglacial	Terminoglacial	Proglacial	Extraglacial
Melting ice	Lodgement till						
	Basal till						
	Ablation till						
	Ice-raft						
	Till complex						
Fluvial	Tunnel						
	Stream						
	Sheet- and streamflood						
	Fluvial complex						
Deltaic	Topset						
	Foreset						
	Bottomset						
	Deltaic complex						
Lacustrine	Lake margin						
	Bottomsets						
	Lake complex						
Aeolian	Dune						
	Coversand						
	Loess						
	Aeolian complex						
Mass transport	Flow till						

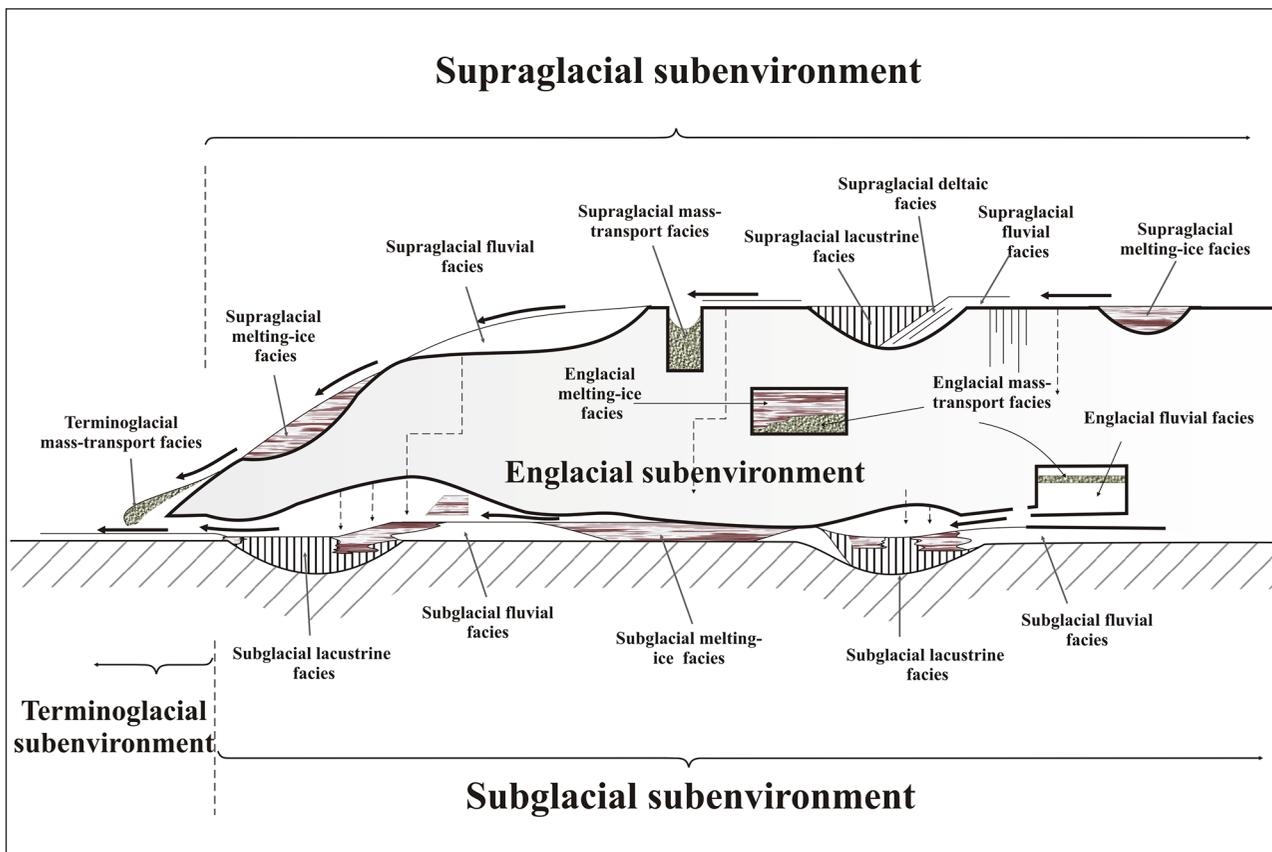


Fig. 2. Glacial environment of sedimentation under continental conditions (modified after Brodzikowski, Van Loon, 1991)

2 pav. Ledyninė sedimentacijos aplinka žemyno sąlygomis (pagal Brodzikowski, Van Loon, 1991)

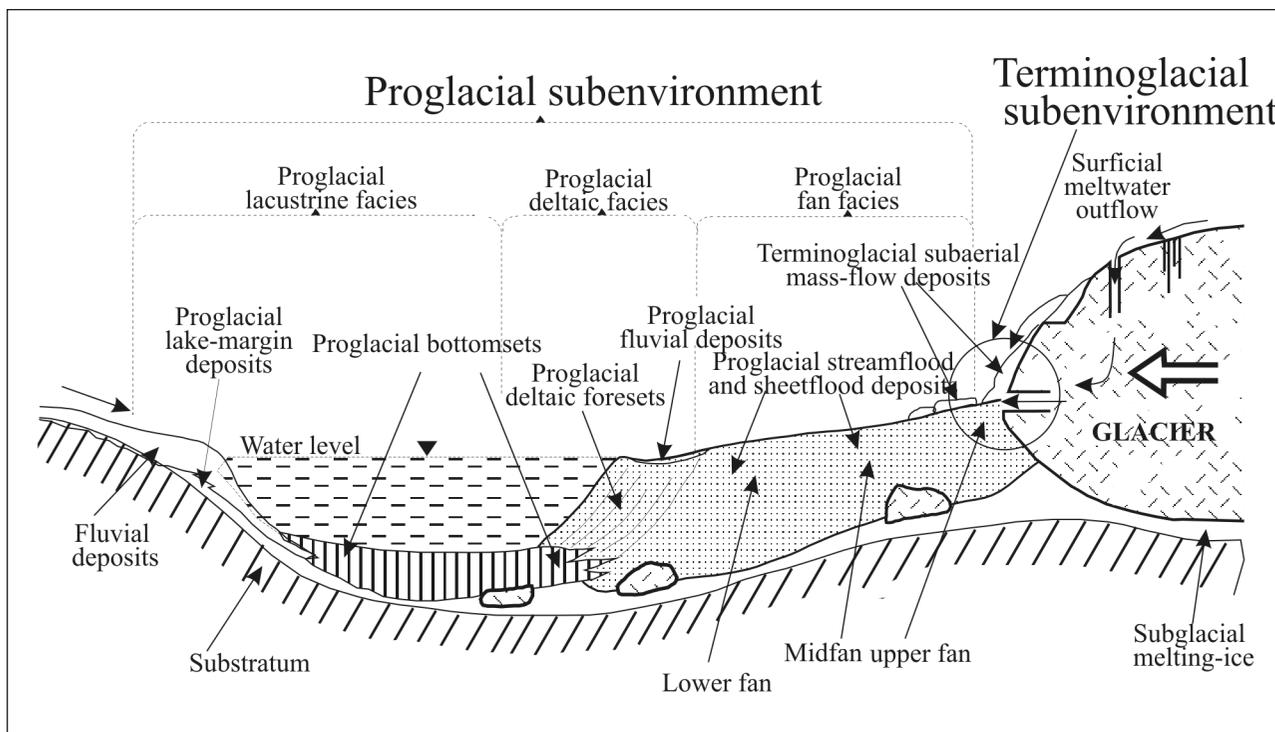


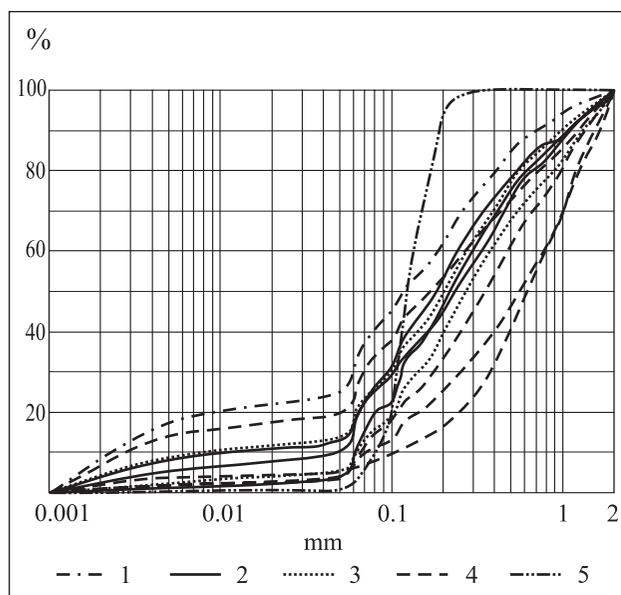
Fig. 3. Terminoglacial and proglacial subenvironments (modified after Brodzikowski, Van Loon, 1991)

3 pav. Terminoglacialinė ir proglacialinė subaplėnkos (pagal Brodzikowski and Van Loon, 1991)

The observation of **basal tills** as *in situ* formed subglacial diamicts is in a similar situation. However, in river or melt-water stream eroded glacial sediment sequences, basal tills in front of the Russell and the Leverett glaciers are more frequently observed in the present proglacial subenvironment in areas of the former passive ice melting.

Conditions of ice melting (or sublimation) due to temperature rise during the warm season are favourable for **ablation till** accumulation more or less *in situ* on glacier surface in supraglacial and terminoglacial subenvironments. In some places, the middle moraine material exarated from nunataks and transported within the glacier feeds the accumulation of till on its surface due to subaerial ice melting. The existence of slopes on the undulated or irregular surface of glaciers favours the mass transport process. Due to plastic flowage, especially on slopes of ice at the glacier margin, the water-saturated material of ablation till is easily involved into mass transport and becomes a **flow till**.

As very little is known about the relationship between grain-size distribution and glacigenic meltout or subaerial mass movement and because the grain-size analysis may reveal possible sedimentation mechanisms, samples for grain-size comparison were taken from basal ice, ablation (flow?) till on the glacier surface, lateral and end moraines. It is obvious from grain-size data (Fig. 4) that silt size and finer particles are the first ones to leave the diamicton under the glacial sediment rewashing with water and further resedimentation.



**Fig. 4.** Cumulative curves of grain-size distribution of clastic material from: 1 – basal ice, 2 – ablation (flow?) till, 3 – lateral moraines, 4 – end moraines and 5 – aeolian deposits

**4 pav.** Nuotrupinės medžiagos pasiskirstymo pagal dydį kumuliacinės kreivės: 1 – pamatinio ledo, 2 – abliacinės (tekėjimo?) moreninės medžiagos, 3 – šoninės morenos, 4 – galinės morenos ir 5 – eolinių nuogulų granulometrinės sudėties

The melt-out material is falling and creeping from subaerial slopes of ice at the glacier edges along the Russell and the Leverett glaciers margins forming end and lateral moraine ridges, especially in places free of steep rock barriers in front of the ice. The terminal moraine ridges as landforms resulting from till accumulation at the glacier margin are well expressed on the surface. The **lateral moraines** are prominent along the northern fringe of the Russell Glacier tongue between the Upper and the Lower Russell lakes. The lateral moraine ridge 180–200 m long and 15–20 m high is separated from the glacier by an ice meltwater stream which is giving source from beneath the glacier at the outlet site of the drainage system of Lake Upper Russell described in a publication of this issue (Česnulevičius et al., 2009). There are two small glaciokarst depressions with lakes in them on the ridge surface. Samples for grain-size measurements were taken at the higher surface sites on the ridge from the depth of 0.3 m. Well expressed lateral moraine ridges can be traced along the southern fringe of the Russell Glacier as well.

The western end of the Russell Glacier tongue is moraine-rimmed (Fig. 5). The **end moraine** ridges accumulated on eroded Proterozoic gneisses are intersected by an ice meltwater stream. At the south-westernmost glacier end corner, the meltwater stream separates the end moraine ridge from the glacier, eroding the glacial ice wall, and keeps it steep. From higher parts of this end moraine ridge 250 m in length, 10–50 m in width and 15–20 m in height, glacial sediment samples for grain-size measurements were taken.

Quite an intricate **moraine complex** is formed on the north-eastern edge of the Russell Glacier in ice divide area between the Russell and the Isunnguata glaciers tongues. The ice divide there is formed by nunatak of crystalline rocks, their surface reaching 500 m a. s. l. The moraine complex in the ice stream divide is expressed by a variety of landforms.

At the proximal side of the end moraine ridge, the glacial ice and ice-cored thrust moraines are covered with subglacial material delivered by meltout and thrusts to the supraglacial position (Roberts et al., 2008). The surface of debris-covered glacial ice and ice-cored thrust moraine is expressed as sub-parallel stripes 1–2 m in height, stretching parallel to the ice margin (Fig. 6). Like washboard moraines, they possibly mark the annual dynamics of ice by small end moraine ramparts formed during winter advance phases (Ehlers, 1996) or covering ice by melt-out material at the edge of a glacier in summer and thus protecting it from melting. The kettled topography with water ponds in kettle holes at the surface of the ice-cored thrust moraine is formed due to buried ice melting.

The entire complex of landforms of different origin was studied in the ice marginal zone of the Leverett Glacier – the south-western branch of the Russell Glacier. The surface of the Leverett Glacier, due to its bedrock topography, lowers gradually to the front of the glacier and equals to the bordering terminal moraines up to 10 m in height (Fig. 7).



**Fig. 5.** End moraine ridge at the western end of Russell Glacier tongue  
**5 pav.** Galinės morenos gūbrys vakariniame Russell ledyninio liežuvio gale



**Fig. 6.** Kettled topography with water ponds in kettle holes and washboard surface of ice cored thrust moraine in ice divide area between Russell and Isunnguata glaciers  
**6 pav.** Glaciokarstinis reljefas su ežerėliais įgriuvose ir skalbimo lentą primenantys gūbriukai morenos su ledo branduoliu paviršiuje

The proglacial area in front of the Leverett Glacier is presented by an end moraine complex stretching about 800 m along the glacial margin and separated from it by a small proximal sandur plain formed by braided glaciofluvial streams. The surface of the end moraine complex, about 450 m wide and 15–20 m high, is expressed by smaller glacial ridges up to 3 m in height and glaciokarst ponds (Fig. 8). The pronounced conical mound

10 m high on the surface of the end moraine complex was interpreted by H. Scholz and M. Baumann (1997) as an open-system **pingo**, as a most conspicuous structure generated in the permafrost region – a conical hill containing ice lens.

The distal part of the sandur surrounds the second-end moraine complex at its distal part. The meltwater streams originated in the glacial environment in the terminoglacial



Fig. 7. Terminoglacial and proglacial subenvironments of Leverett Glacier

7 pav. Leverett ledyno terminoglacialinė ir proglacialinė subaplinkos

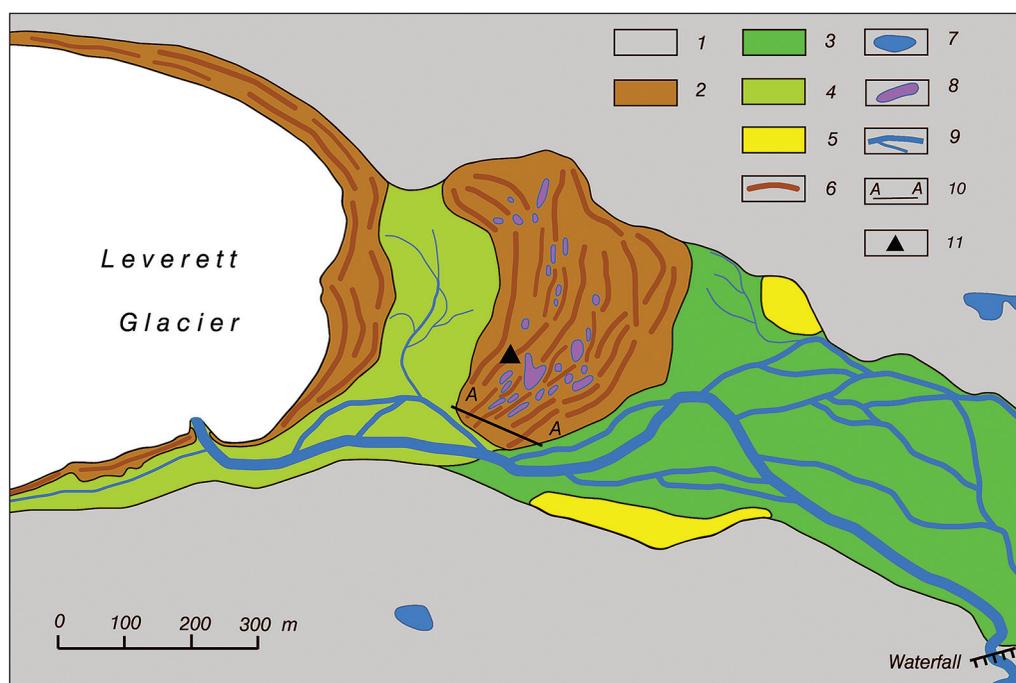


Fig. 8. Terminoglacial and proglacial landform complexes of Leverett Glacier: 1 – bedrock, 2 – end moraine complex, 3 – distal sandur, 4 – proximal sandur, 5 – aeolian complex, 6 – moraine ridges, 7 – lakes, 8 – glaciokarst ponds, 9 – meltwater streams, 10 – outcrop, 11 – pingo

8 pav. Leverett ledyno terminoglacialinio ir proglacialinio reljefo kompleksas: 1 – pagrindo uolienos, 2 – galinių morenų kompleksas, 3 – distalinis zandras, 4 – proksimalinis zandras, 5 – eolinis kompleksas, 6 – moreniniai gūbriai, 7 – ežerai, 8 – glaciokarstiniai ežerėliai, 9 – ledyno tirpimo vandens srantai, 10 – atodanga, 11 – degraduojantis hidrolakolitas



Fig. 9. Section of end moraine complex in marginal zone of Leverett Glacier

9 pav. Galinės morenos pjūvis Leverett ledyno marginalinėje zonoje

subenvironment form the **ice-marginal streamways (prodolinas)** that run parallel to the ice front. Such meltwater streams passing the terminoglacial subenvironment form rivers fed by ice meltwater. The relief, the amount of meltwater and the debris determine the depositional pattern in these streamways. **Aeolian** sedimentation takes place over the entire streamway area, whereas glaciofluvial sedimentation, however, prevail over the deposition of wind-blown material. Drift sands, small dunes and coversands are found along the Watson River formed by a concentration of ice meltwater channels. The grain-size data of aeolian sand (Fig. 4) are the sieving results of an aeolian sand sample taken in the Watson River valley near Kangerlussuaq. The aeolian coversands exist also in the proglacial area of the Leverett Glacier.

The key characteristics of the end moraine complex in the proglacial zone of the Leverett Glacier are presented in a special publication of R. I. Waller and G. W. Tuckwell (2005). The presence of a large stream-cut exposure (Fig. 9) allows examination of its internal structure and surface morphology. It is built up of layers composed of different proportions of ice and sediment, including debris-poor ice, ice-rich diamicton and ice-rich gravel. Ice and sediment units are glaciotectionized and show features of a major fault and an associated drag fold, a planar, erosional unconformity, and a variety of small-scale folds. The structural characteristics are explained by a two-phase model involving ice advance and proglacial or ice-marginal compression, followed by overriding and subglacial deformation and erosion tentatively related to ice advance. This interpretation opposes the explanation that the sequence simply represents a buried basal ice layer. The polygenetic origin of this ice-marginal, glaciotectionic landform can be considered as a contrast to the majority of Arctic push-moraines. They are largely considered to be a result of proglacial deformation and a stacking of imbricate thrust sheets of frozen sediment. This contrast probably reflects differences in the thickness and

spatial continuity of permafrost within the glacier foreland, and adds to the range of ice-marginal landforms associated with glacier-permafrost interactions (Waller, Tuckwell, 2005).

## CONCLUSIONS

The variety of sedimentation places and conditions in glacial and periglacial depositional environments in the marginal zone of the Russell and the Leverett glaciers resulted in a high diversity of landforms.

The initial material creating landforms in different subenvironments of a glacial environment is lodgement, basal, ablation and flow till deposits in a periglacial environment, observed as till complexes composing lateral and end moraines formed as landforms in a terminoglacial subenvironment or basal till plains after ice retreat left in a proglacial subenvironment.

Debris-covered glacial ice and ice-cored thrust moraines, marking the annual dynamics of ice, are widespread in the very margin of the glaciers with a common kettled topography.

The complex of landforms of different origin, studied in the ice marginal zone of the Leverett Glacier, is very representative of ice marginal zones. There it is expressed by bordering terminal moraines, an end moraine complex with smaller glacial ridges and an open-system pingo on it, proximal and distal sandur plains and ice-marginal streamways with aeolian landforms taking place. The presence of an open-system pingo within a system of moraine ridges is quite unexpected.

The structural characteristics of the internal structure of the end moraine complex in the proglacial zone of the Leverett Glacier, well exposed and studied in a large stream-cut exposure, are best explained by a two-phase model involving ice advance and proglacial or ice-marginal compression, followed by overriding and subglacial deformation and erosion, tentatively related to ice advance.

Data assembled during this study indicate that primarily climatological factors lie behind the exceptional glacial geodiversity of the area, and glaciodynamics contributes to the wealth of landforms under particularly favourable conditions in the marginal zone of the Russell and the Leverett glaciers.

## ACKNOWLEDGEMENT

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## GLACIGENINIO RELJEFO YPATYBĖS RUSSELL IR LAVERETT LEDYNŲ PAKRAŠTYJE VAKARŲ GRENLANDIJOJE

### Santrauka

Vakarų Grenlandijoje Russell ir Leverett ledynų marginalinės zonos pradinėje stadijoje kaupiasi dugninė, pagrindinė ir abliacinė moreninė medžiaga. Abliacinė moreninė medžiaga kaupiasi ledyno paviršiuje. Vandeninga moreninė medžiaga dėl gravitacijos ir supraglacialinių bei intraglacialinių ledyno tirpsmo vandens tėkmių poveikio pažemėjimuose ir jų šlaituose virsta tekėjimo (*flow till*) morenine medžiaga. Moreninė medžiaga ledyno pakraštyje kaupiasi formuodama poligenetinės medžiagos kompleksus – galinių ir šoninių morenų reljefo formas. Šoninės ir galinės morenos išsiskiria raiškiais gūbriais, kurių paviršių paįvairina glaciokarstas, įdubose sukurdamas nedidelius, dažnai laikinus ežerėlius.

Ties Russell ir Isunnguata ledynų kristalinių uolienu ledoskyra iškilęs stambus moreninis masyvas pasižymi glaciomorfologinių reljefo formų įvairove. Čia paplitusios glaciokarstinės dubės, vidurinės morenos gūbriai, kurių paviršių dengia įstriži lygiagretūs neaukšti gūbriukai, primenantys skalbimo lentą. Jų formavimasis susijęs su ledyno tirpimu ir kasmetine jo pakraščio kaita.

Leverett ledyno gale susidaręs „klasikinis“ ledyno pakraščio darinių kompleksas apima kelis moreninės ir fluvio-glacialinės kilmės reljefo ruožus. Pačiame ledyno gale formuojasi kelias osciliacinių gūbrių grandines turintis galinės morenos ruožas. Už jo prasideda tipiškas nuolaidus proksimalinis zandras, suformuotas laikinų, nuo ledyno tekančių, klaidžiojančių tirpsmo vandens tėkmių. Proksimalinis zandras siekia senesnį moreninių darinių ruožą, turintį 6–8 osciliacinių gūbrių grandines. Šiame komplekse vyksta glaciokarstiniai ir eoliniai procesai, kurių veiklos rezultatas – glaciokarstiniai ežerėliai, eolinės dangos ir degraduojantis hidrolakolitas (pingas). Nuo Laverett ledyno tekantis koncentruotas fluvio-glacialinis srautas, jungdamasis su kitais panašiais srautais, sudaro ledyno tirpsmo vandenimis maitinamą upę. Nešmenimis užpildžiusi buvusį platų egzaracinį duburį ji už moreninių darinių ruožo suformavo distalinę zandro dalį. Zandrą sudarančios ir prieledyninės upės suneštos nuogulos vietomis perpustomos į eolinio smėlio dangas ir kopas.

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## ОСОБЕННОСТИ ГЛЯЦИГЕННОГО РЕЛЬЕФА МАРГИНАЛЬНОЙ ЗОНЫ ЛЕДНИКОВ РУССЕЛЛ И ЛЕВЕРЕТТ В ЗАПАДНОЙ ГРЕНЛАНДИИ

### Резюме

На исследованном в Западной Гренландии участке в маргинальной зоне ледников Русселл и Лаверетт в начальной стадии накапливается материал донного, основного (базального) и абляционного тиллов. Абляционные отложения накапливаются на поверхности ледника, в понижениях и их склонах; вследствие гравитации, а также потоков супрагляциальных и интрагляциальных талых вод они становятся тиллом (мореными отложениями) течения (*flow till*). Моренный материал в краевой части ледника накапливается в виде полигенетических комплексов, среди которых наиболее распространены такие формы рельефа, как конечные

и боковые морены. Эти морены выделяются четкими гребнями, поверхность которых деформируется под воздействием гляциокарстовых процессов, в результате чего образуются небольшие временные озерки. На ледораздельном участке ледников Русселл и Исуннгуата возвышается крупный моренный массив, характеризующийся обилием гляциоморфологических форм рельефа. Здесь распространены гляциокарстовые просадки и впадины, гребни срединных морен. На склонах последних наблюдаются косонаправленные невысокие параллельные гребешки, в совокупности напоминающие стиральную доску. Их образование связано с таянием ледника и с ежегодной динамикой его краев.

У конечной части ледника Леверетт наблюдается „классический“ комплекс краевых ледниковых образований, охватывающий две полосы ледникового и водно-ледникового генезиса.

В краевой части ледника формируется участок краевых морен в виде нескольких осцилляционных гребней. Вслед за ними начинается сформированный временными талыми ледниковыми водами типичный наклоненный проксимальный зандр. Он отделяет упомянутый краевой моренный комплекс от более древнего, представленного 6–8 вереницами осцилляционных гребней. В этом моренном комплексе протекают гляциокарстовые и эоловые процессы, результатом которых являются гляциокарстовые озерки, эоловые покровы и деградирующий пинго. Основной концентрированный флювиогляциальный поток, берущий начало от ледника Леверетт, сливаясь с другими подобными потоками, образует флювиогляциальную реку, отложениями заполняющую широкую экзарационную долину.