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Fluctuations of the snout of Skeidarárjökull in Iceland in the last 100 years and some of their consequences in the central part of its forefield

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Abstract: In the years 1993, 1995 and 1996 the authors carried out geomorphological research in the forefield of Skeidarárjökull in Iceland. During the research, it became obvious that the causes and consequences of the advance of the glacier into its forefield were little understood. Skeidarárjökull is an outlet glacier from the largest ice cap in Iceland, Vatnajökull. It is about 23 km in length and the width at its snout is also about 23 km. On the basis of aerial photographs taken in 1960, 1965, 1986, 1988 and 1992 and data published in the yearly "Jökull" concerning the changes in the position of its western and eastern parts in the last few dozen years, the authors have analysed the frequency and geomorphological effects of the Skeidarárjökull snout fluctuations on its forefield. From 1932 to 1964, the Skeidarárjökull margin retreated. In 1966, a several-decametre advance of the glacier took place. After phases of recession, subsequent sudden advances took place in the years 1972-1975 and 1983-1986, when the glacier advanced by 450 m. During the next four years, until 1990, the glacier margin retreated. The changes in the glacier extent concern only its western part. In the central part of the glacier, where the research area is situated, there is evidence of a double advance of the glacier in 1965 and 1992. It advanced about 430 m as compared to 1960. During this surge, the glacier covered the northern part of an existing proglacial lake. Under the pressure and weight of the glacier, glaciolimnic sediments were pushed to a height of about 12 m above lake level; they were squeezed out and displaced. The reason for the frequent changes in the extent of Skeidarárjökull are probably not climatic conditions but relate to the location of the Vatna ice cap in a neo-volcanic area. Therefore, amongst other factors, the sudden surges in Icelandic glaciers are attributed to changes in the thermal conditions of subglacial waters and the sole of the glacier, subglacial hydrological conditions, tectonic shocks and the raising or lowering of the subglacial surface as a result of the movements of magma.

Key words: Iceland, glacial geomorphology, glaciotectonic

Introduction

Of the many questions which resulted from the authors' geomorphological research on the glacial relief of the Skeidarárjökull forefield in Iceland, one which is undoubtedly of considerable importance is the problem of the causes of the fluctuations of this glacier's snout and their effects on its forefield. Geomorphological research was carried out on Skeidarárjökull in August 1993 during a scientific expedition to Iceland organised on the 25th anniversary of the stay here by the first geographical expedition of the Polish Geographical Society (led by prof. Rajmund Galon) and also in 1995 and 1996.

During this first expedition (in 1968), research on the genesis of the relief of the Skeidarárjökull forefield was conducted by Galon (1973), Bogacki (1976), Jewtuchowicz (1973) and Klimek (1972); hydrographical research by Churski (1974); climatological and glaciological research by Wójcik (1976). Using a terrophotogrametrical method, Konysz (1973) made a topographical map of the west part of the Skeidarárjökull forefield, on which the exact line of its halt in 1968 is marked.

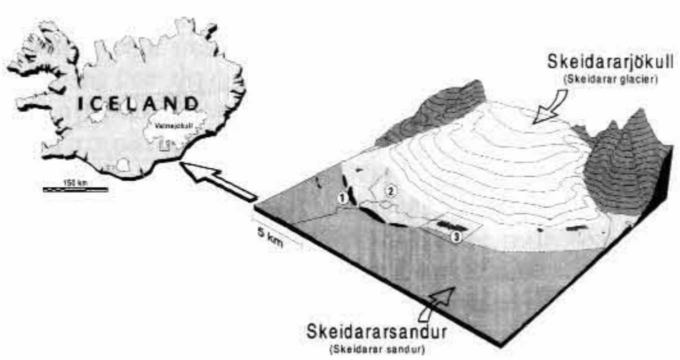

Fig. 1. Location of the study area.
1 - ice-cored moraine ridges of 1890, 2 - inner zone of the forefield of Skeidarárjökull formed after 1890, 3 - area of detailed study.

Fig. 2. Steep glacier snout in the west part of the Skeidarárjökull in 1993.

Changes in the extent of the glacier

Skeidarárjökull projects from the largest ice-cap in Iceland and the third largest in the world - Vatna, which covers a surface area of about 8400 km^2 (Fig. 1). Skeidarárjökull, which flows from the south west part of Vatnajökull, is about 23 km long. Its width is variable; in the upper part, it is 10 - 12 km, in the middle part it narrows to about 7 km, then the glacier widens again to about 23 km at the snout. Comparisons of the progress of the Skeidarárjökull snout in 1968, based on the topographical map made by Konysz (1973) and in 1993, based on aerial photos from 1992, revealed no significant differences in its extent. On the whole, the positions of the glacier's snout from 1968 and 1993 were quite similar. Only in some sections had the glacier either regressed or advanced slightly, but its very steep snout shows that it was in a thrust phase (Fig. 2). This aroused the suspicion that, before 1992, the position of

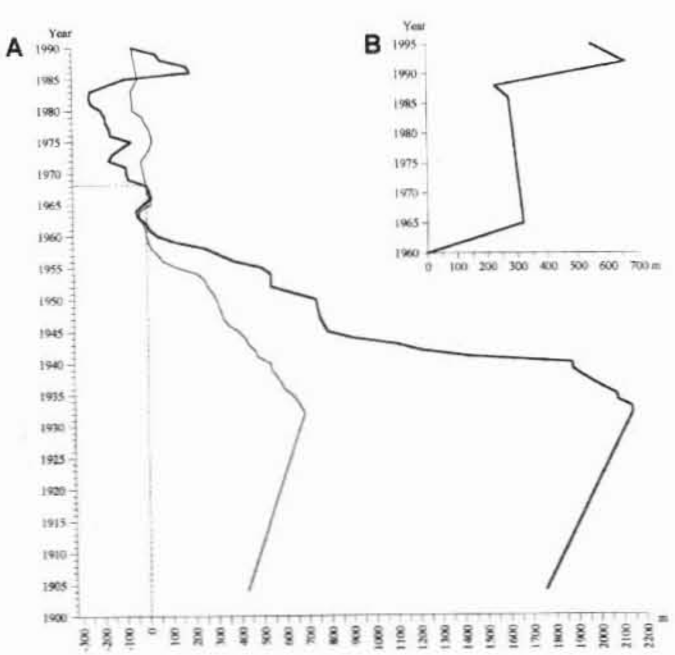

Fig. 3. Position changes of the Skeidarár glacier snout.
A - in 1904 - 1990, based on published data in "Jökull" (thick line the west part of glacier, thin line east part of glacier),
B - in 1960 - 1995, based mainly on air photographs.

the glacier's snout may have been different, i.e. it was in regression, but at an unknown rate.

The aerial photographs obtained in 1960, 1965, 1986, 1988 and 1992, together with those taken by the authors in 1995, were extremely helpful in reconstructing the changes in the extent of the glacier over this 35-year time interval. Moreover, on the basis of data giving measurements of the extent of Skeidarárjökull on its western and eastern margins which were carried out regularly from 1932 and published in the Icelandic yearly publication "Jökulls" (Eythorsson, 1963; Sigurdsson, 1992), it is possible to plot the changes in its position with some precision.

As a point of reference, the extent of the glacier in 1968, which was precisely demarcated by Konysz (1973), was adopted. In that year, the Skeidarárjökull snout had regressed by about 2600 m in relation to the terminal moraines of 1890, as measured along a line from the place where the river Gigjukvisl ravine intersects these moraines (Fig. 1). It must be emphasised that the distances between the course of the terminal moraines from 1890 and the present extent of Skeidarárjökull are not consistent. In the western part they reach 2700 m, whereas, about 3 km to the east of the river Gigjukvisl ravine, terminal moraines occur in the form of isolated elevations for they were badly damaged here as a result of the catastrophic outflows of melt water ("jökullhlaup") from the glacier, which formed vast outwash plains, situated at a high level in this part of its forefield. The residual terminal moraines from 1890 and the 20-25 m high steep slopes of the outwash are about 1000 to 200 m from the glacier. This implies that the eastern part of the glacier is more stable than its western part.

Based on the data published in the yearly "Jökull", the authors estimate that, in 1932, the western side of the glacier advanced by about 2100 m when compared to 1968 - 1993 (Fig. 3A). This indicates that a recession of about 500 m had taken place in the glacier from the line where it halted in 1890; however, this did not take place uniformly. According to the published measurement data, it follows that, in 1904, the Skeidarárjökull snout was separated from the 1890 moraines by a significantly greater distance, amounting to 850 m, than was the case in 1932. Consequently, between 1890 and 1932, Skeidarárjökull receded for about 14 years, followed by an advance. It is difficult to form an opinion whether this was a uniform advance by the glacier over the 28 years, undisturbed by phases of recession, because, between 1904 and 1932, there are no measurement data. It is only the systematic, annual measurements of the position of the glacier in its western and eastern parts taken since 1932 which make it possible to detect its movements precisely. As indicated by Figure 3A, Skeidarárjökull steadily receded between 1932 and 1964 in both its western and eastern parts, though, the recession in the west did not take place uniformly but was interrupted by short yearly or two-yearly halts, e.g. in 1939-40 and 1952-54. After 32 years of recession, an advance of the glacier took place in 1964, but only to the extent of several dozen metres. From 1966 it had approximately the same extent as that which members of the First Polish Geographical Expedition to Iceland had established two years later. From Figure 3A it follows that a regression of the western part of the glacier took place in 1968 - 83, interrupted by an approximately

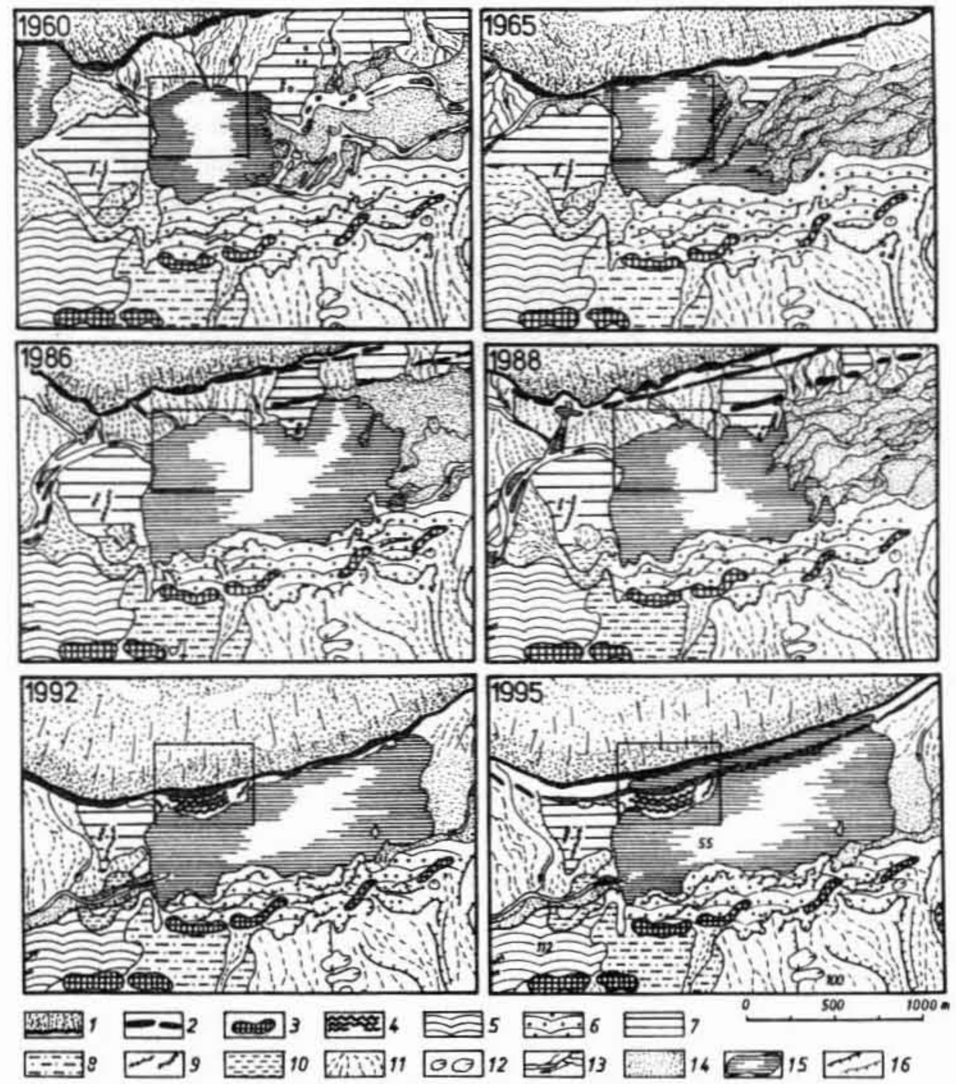

Fig. 4. Changes of the geomorphological and hydrographical situation in the forefield of Skeidarárjökull, 1960 - 1995.
1 - glacier, 2 - ice - cored moraine ridges formed in 1960 - 1995, 3 - older end moraine elevation (hills), 4 - area of the limnoglacial deposits glaciotectonic disturbances, 5 - undulating ground moraine plain, 6 - ice contact forms and sediments, 7 - flat ground moraine plain, 8 - meltwater erosive plains, 9 - eskers, 10 - former valley bottoms of proglacial rivers, 11 - proglacial outwash fans, 12 - kettles, 13 - river system, 14 - alluvial plains, 15 - proglacial lakes, 16 - escarpments and slopes.

100 m long surge in 1972 - 75. A subsequent glacier surge began in 1983. Over 3 years, the glacier advanced by 450 m. Advancing, therefore, at a rate of 150 m/year, it went beyond the line of its 1968 halt by about 200 m. During the next four years, to 1990, the glacier receded.

As distinct from the western part of the glacier, its eastern part is much more stable. Here the glacier has advanced or regressed only to a very small degree since 1959. This is due to the presence the mountainous massif, Skaftafellsfjöll, which is located about 12 km up the glacier on its eastern side, and which directs the flow of most of the ice mass to its western side. Being in the shadow of this massif, the eastern side of the glacier is therefore less mobile.

Analysing the position of Skeidarárjökull on the basis of aerial photos from 1960, 1965, 1986, 1988, 1992, and 1995 and also taking into consideration the available cartographic evidence, attention must be drawn to one more important detail. The scale and reaction time of individual sections of the mobile western part of Skeidarárjökull during its advance and subsequent recession were not at all uniform. Indeed, these differences in the positive and also negative values were as much as several decametres.

The curves of the varying extents of the western and eastern parts of Skeidarárjökull (Fig. 3A), which depict changes during the last several decades along two profiles (which the authors are unable to locate exactly due to the lack of information in publications), cannot be representative for other sections of its snout, but, nevertheless, they display the general tendencies of the glacier's behaviour during the period under analysis.

Attention was drawn to this during research into the effects of the advances of the central part of Skeidarárjökull, where currently, the largest proglacial lake is present. Changes in the spread of the glacier in this section, which has a length of 2-5 km, as revealed by aerial photographs taken in 1960, 1965, 1986, 1988, and 1992 and a photograph taken by the authors in 1995, are depicted in Figures 3B and 4.

In 1960, two proglacial lakes were present in the glacier forefield. That in the west, which is directly juxtaposed to the glacier, had a length of 650 m and a width of 300 m. The second, in the east, was oval and had a maximal diameter of about 650 m; it lay about 300 m away from the snout. Between the glacier and the lake there was an outwash. Moreover, it was replenished from the east by meltwater flowing from the distal part of the glacier. The excess water from the lake discharged into a river flowing from its north - western part into a smaller lake. Five years later, in 1965, the glacier had advanced by about 300 m. The glacier impinged upon the northern shore of the lake, which was progressively enlarging. The westernmost lake disappeared, partly because the glacier had encroached upon it from the north while the remaining part had been filled in by glaciofluvial deposits. However, the outflow from the larger lake continued as before through the river, which washed away the glacier snout along a section of about 300 m. The advance of the glacier in the middle area was also recorded in two profiles (Fig. 3). In 1986, the Skeidarárjökull snout again ran at a considerable distance from the lake shore. Two years later, this distance slightly

Fig. 5. Anticlinal arrangement of strata in the glaciolimnic sediments.

Fig. 6. Glaciotectonic scales of the glaciolimnic sediments.

increased. Its limits in 1965 and 1986 are demarcated by two ice-moraine ridges running parallel to the snout at a distance of about 200m apart. These were damaged by meltwaters which, as they flowed in the direction of the lake, constructed a short outwash cone.

Because of the lack of documentation in the form of aerial photographs, it is difficult to form an opinion on the extent to which the glacier was in the section studied in the years 1989-1991. As can be seen from Figure 3A, the Authors had access to published measurement data on the limits of Skeidarárjökull only up to 1990. It follows from the curve concerning the western part of the glacier that, in the years 1983 - 1986, a fairly significant advance took place, after which it was in a recession phase until 1990. During this time the eastern part of the glacier was stable.

In the section researched by the Authors, the outermost limit of the glacier was in 1992 (Fig. 4), with an advance of about 430 m in relation to its position in 1988, and 660 m as compared to 1960. Skeidarárjökull covered a significant part of the lake from the north, as a result of which it caused substantial changes in the hydrographic system. Under the ice, there was a channel along which the outflow of waters from the northern part of the lake had hitherto taken place. This outflow from the lake, which had accumulated under the ice as a result of the transgression of the glacier, then took place in its south - western part along an existing, but hitherto dry, channel.

Effects of the glacier advance

The glacier surge and its encroachment onto the northern part of the basin of the proglacial lake produced significant disturbances in the glaciolimnic deposits. The pressure and weight of the glacier caused the water - logged deposits to be squeezed out and displaced. Consequently, glaciotectonic disturbances took place on both a large and small scale and they can be observed over an area about 300 by150 m. The surface undulations of this area, which run parallel with the glacier snout, are large-scale forms which resulted from the pressure from the glacier. In the elevations in the distal direction, an anticlinal structure of the layers is visible (Fig. 5) whereas, near the moraine ridge of 1992, the scales of glaciolimnic deposits are inclined in the direction of the glacier

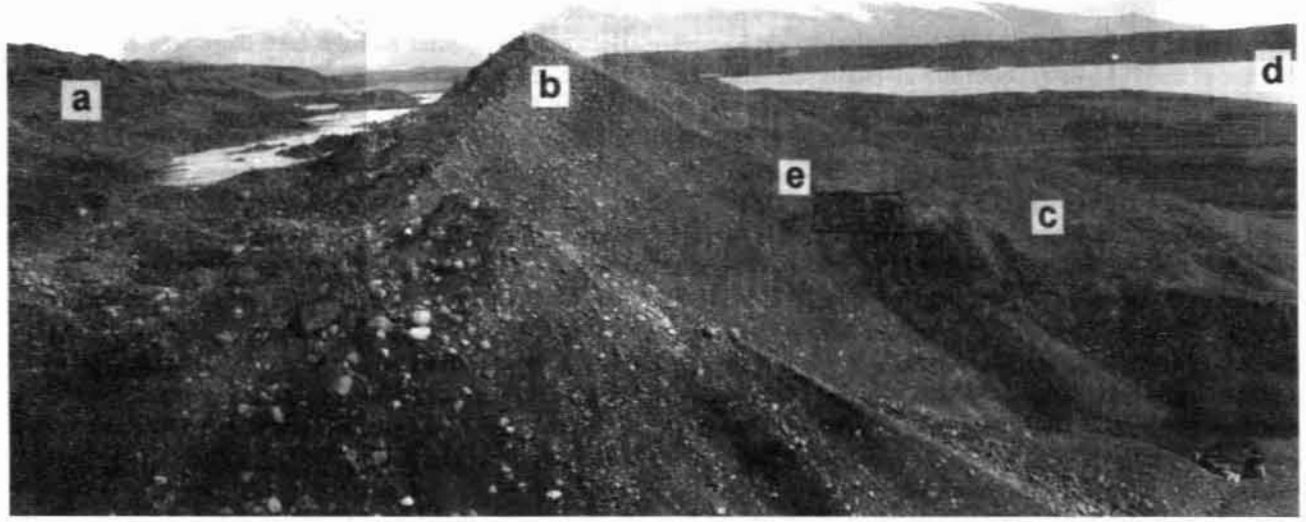

Fig. 7. The geomorphological situation of the disturbed glaciolimnic sediments; a - Skeidarárjökull snout, b - ice-cored moraine ridge of 1992, c - zone of disturbed glaciolimnic sediments, d - proglacial lake, e - Figure 8.

snout (Fig. 6). Additionally, the disturbed glaciolimnic deposits were uplifted to a height of 12 m relative to the level of the lake.

Excavations carried out at the base of the distal slope of the moraine ridge made it possible to characterise in detail the glaciotectonic disturbances of the ceiling layers of the glaciolimnic deposits (Figs. 7, 8, 9). In the lower part of these exposures, a series of fine-grained sands and silts more than 1 m thick is present which shows characteristic deformations of the convoluted type. These disturbances were revealed by laminae of silts, sandy silts and very fine sand, separated by layers of fine-grained sands, macroscopically massive sands and sands with horizontal lamination. In the lower right part of the exposure, these deposits are deformed synclinally; they are built of massive medium-grained sands, which are layered horizontally. Above these deposits there is a series of disturbed variously-grained pebbly sands with horizontal lamination which are nearly 1 m thick.

In the lower part of the exposure, there is a group of reverse faults with an inclination of about 60° and with a northwards backwards vergence, i.e. in the proximal direction. These probably formed in the initial phase of the disturbance of the glaciolimnic deposits taking place under the predominant static pressure during the greatest main stress δ_1 with an approximately vertical axis (Dadlez & Jaroszewski, 1994).

In the upper and middle part of the exposure, it is possible to distinguish a part of a fold and a group of reverse faults (with an inclination of 30° - 40°) with a southern vergence. But, owing to the textural character of the deposits and the size of the exposure, it is possible to establish the axis of the fold only approximately. It is fundamentally convergent with the course of the fault surfaces which intersect it. This structure has the character of a flexure fold which resulted from horizontal pressure during the greatest main stress δ_1, perpendicular to the axial surface of the fold (Jaroszewski, 1980). In such conditions, where the pressure of the burden assumes the role of the main stress (δ_1), and after exceeding the critical value of stresses, different elongated reverse faults appear which intersected the flexure (Jaroszewski, 1980). The courses of these faults, as measured at the exposure, also appear on the slope of the surface of the glaciotectonically disturbed glaciolimnic deposits.

Those glaciotectonic disturbances of glaciofluvial deposits which developed as a result of the advance of Skeidarárjökull in 1992, were observed at its snout at about 2.5 km to the west of the position described above.

Krüger (1985) described the occurrence of glaciotectonic disturbances in several places in front of the snout of Hofdabrekkujökull where they project from the Myrdals ice-cap. Under the influence of its pressure an accumulation moraine was formed which is composed of glaciofluvial deposits or moraine clay.

Causes of recent fluctuations in Icelandic glaciers

The frequent changes of the limit of Skeidarárjökull require us to consider the causes of this phenomenon. It is difficult to accept that they are conditioned by climate (mainly as a result of heavier snowfalls) because, in such a case, the reactions of the glacier would be neither so sudden or frequent. It seems, then, that the main cause of the fluctuations of the Skeidarárjökull snout, and also the other glaciers flowing from the Vatna and Myrdals ice-caps is their location in a neo-volcanic area. Under Vatnajökull there are three currently-active volcanoes, and one under the Myrdals (Katla). In the western part of Vatnajökull and to the north of the projecting

Fig. 8. The upper part of the glaciotectonically disturbed glaciolimnic sediments.

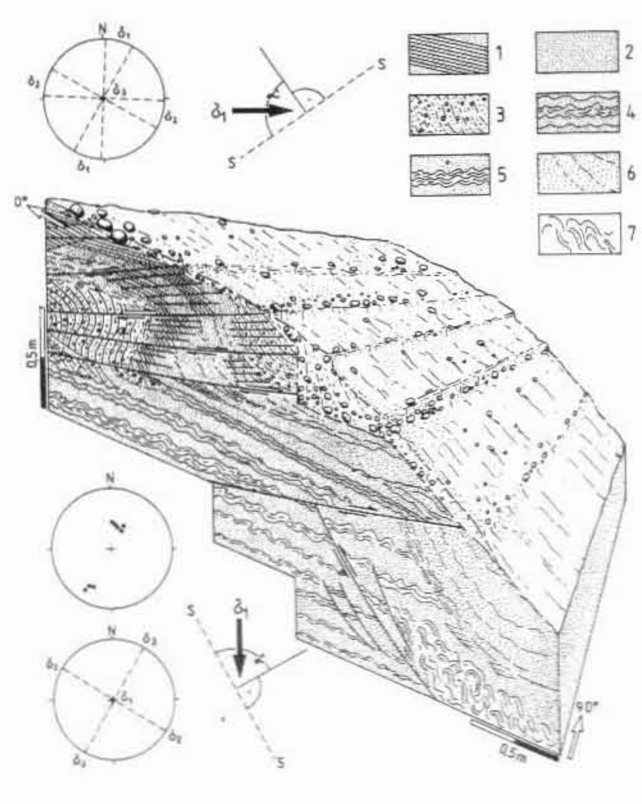

Fig. 9. Glaciotectonic disturbances of the glaciolimnic sediments.
1 - fine sand, silty, grey, horizontally laminated, 2 - dark-grey silt, massive, 3 - variablly-grained sand with gravels, horizontally laminated, 4 - very fine sand, grey, laminated with convolution disturbances, 5 - clayey silt, light-grey, laminated, with convolution disturbances, 6 - medium-grained sand, grey, massive, 7 - fine sand, silty, grey and light grey, deformed. Point diagram (north hemisphere) - poles of both groups of reverse faults and the approximate arrangement of principal stresses based on measurements of reverse faults.

Skeidarárjökull, there is a calderan lake, Grimsvötn, from which water flows, as a result of overfilling, under this glacier, over several-year intervals. This causes huge floods, called jökullhaup, on its eastern side. Consequently, the subglacial changes in the hydrological regime, the thermal conditions of the waters and the base of the glacier, tectonic shocks and the raising or lowering of the subglacial surface as a result of movements of the magma, all give impetus to the sudden surges of Icelandic glaciers (Thorarinsson, 1964). The most recent example was the sudden severance of the projecting Sidujökull in March 1994 on the south-western side of Vatnajökull and its north neighbour Tungnaárjökull, in November 1994 and March 1995.

Acknowledgements

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Obituary

Professor Stefan Kozarski
1930 - 1996

Professor Stefan Kozarski died suddenly in his office on 19th January 1996. For the whole of his industrious working life, he was associated with the Adam Mickiewicz University in Poznań. Here, he gained wide prominence as a scientist, teacher and administrator. Professor Kozarski commenced his geographical studies in 1950. With the submission of a thesis entitled „Recession of the last ice-sheet from the northern part of the Gniezno Pleistocene Plateau and the formation of the ice-marginal valley of the rivers Noteć and Warta", Professor Kozarski was awarded the degree of Doctor of Natural Sciences. He obtained his post-doctoral degree on the basis of a dissertation on „The problem of the outflow way of waters from the western part of the Noteć-Warta Pradolina" (1965). In 1967, Professor Kozarski founded the Department of Geomorphology as part of the Institute of Geography and has been its Head right up to his death. This became the Quaternary Research Institute in 1981. In 1972, Professor Kozarski became assistant professor and in 1978, he became full professor of geographical sciences.

Most of his research concerned the geomorphology of NW Poland and the adjacent area of the former East Germany but, as a participant in various scientific expeditions, he also explored the forelands and marginal zones of the Sidujökull glacier in Iceland and the Hans, Gås and Werenskiold glaciers in Spitsbergen. He investigated the subtropical karst areas of south-east China, where his interests also included glacial and periglacial problems.

A review of Professor Kozarski's scientific work readily shows how diverse his interests were. His greatest achievements were undoubtedly in the analysis of Pleistocene and modern glacial landforms and processes. Among the problems he studied were those of subglacial channels, pradolinas and drainage systems of ice-sheets, kames, the development of ice-cored moraines, deglaciation mechanisms, depositional models of the melting Vistulian ice-sheet and the marginal forms associated with it. He frequently returned to the theme of the genesis of end moraines and, in this work, repeatedly emphasised the role of the ice sheet in the formation of glaciotectonic disturbances.

In respect that glacial problems are closely related to those of the periglacial environment, he was particularly attracted to fossil dunes, periglacial deposits and the geomorphological traces of periglacial processes in young glacial areas. He also investigated the oriented permafrost depressions which are present in the proximal parts of an outwash plain, where syngenetic permafrost depressions had already melted. His explanation of these features was based upon comparative studies of contemporary landforms in Spitsbergen. These ideas were later extended to related phenomena in Great Britain, Denmark and Germany. Professor Kozarski considered that the presence of frost structures and the geomorphological traces of periglacial processes proved the existence of long-term permafrost in the Germano-Polish Lowland as recently as the Late Vistulian.