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Exaration phenomena at the terminal icesheet parts of the Middle-Polish Glaciation along the northern slopes of the Central Polish Uplands

ABSTRACT: The glacial erosion in the maximum extent zone of the Middle-Polish (= Odranian, = Riss *I*) Glaciation in the Central Polish Uplands resulted in the incorporation of local material into end-morainic sediments, formation of polished surcaces, roches moutonnées and exaration moraines with a chaotic arrangement of local debris. The maximum icesheet extent can be recognized not only by the presence of the Scandinavian material and geomorphologic evidence but also by the results of glacial erosion processes.

INTRODUCTION

The glacial erosion is generally considered to occur in the central parts of icesheet and in the upper reaches of valley glaciers (Klebelsberg 1949). In the lower parts of the glaciers these processes are usually considered to be of local importance (Charlesworth 1957, Gravenor 1975), most frequently resulting in the formation of diverse troughs. This opinion is correct in the case of many icesheets but there are also numerous exceptions, among others in the Central Polish Uplands. There, the glacial erosion was very active in the terminal part of the icesheet of the Middle-Polish (= Odranian, = Riss *I*) Glaciation although it has been underestimated up to now whereas the rubbles composed of a local material were ascribed to periglacial processes. Consequently, the recognition of the maximum extent of this glaciation has been difficult as the sediments with the Scandinavian material are rare or even absent.

METHODS OF INVESTIGATIONS

The glacial erosion, *i.e.* the dynamic acting of the ice against its bedrock, can be recognized by the three methods.

The first one, a conventional method, is based on studies over the traces of a dynamic scouring of bedrock ups and downs by the advancing ice (*cf.* Pl. 1, Fig. 1) and so, a formation of polished surfaces, glacial striae as well as of roches moutonnées (*cf.* Pl. 2, Figs 1—2). They are created mainly when the icesheet meets the elevations inclined opposite to its advance direction. Therefore, a relief of such features enables to define a direction of the icesheet movement.

The second method is based on findings of the local material, derived from the bedrock during glacial erosion and spread over a certain, usually vast area. Observations of this spreading enable to define the direction of icesheet movement and even, if there are lithologically varying bedrock ridges perpendicular to this direction, to describe the successive phase when the debris was transported and deposited (Różycki & Lamparski 1967, Lamparski 1970).

The third method can be only seldom applied. It is based on effects of ice loading noted in the bedrock and resulting horizontal displacements under the influence of the overlying moving icesheet. In some cases a movement and an ice stress result in a formation of breccias between the beds and of pseudojoints (*cf.* Pl. 1, Fig. 2), independent of real joint but concordant with directions of icesheet movement. These structures are thought to be the initial features that develop afterwards into glacitectonic structures.

A typical glacial erosion occurs only if the moving ice enters the slopes inclined opposite the direction of its movement, composed of quite compact or massive rocks. But a similar process acts also if the advancing icesheet collects the loose surface rubble prepared previously by weathering. Although the sediment collection occurs differently, it finally results in similar effects (shearing and scattering of the incorporated material).

EXAMPLES OF GLACIAL EROSION

Since the end of the thirties an attention was paid to the occurrence of a local material in end moraines, tills and proglacial sediments of the Middle-Polish Glaciation at the northern slopes of the Central Polish Uplands. Systematic calculations of the pebble (diameter 1—5 cm) composition carried through in the areas from the Warta to the Vistula for a definite local material (Lamparski 1961, 1968, 1971), enabled to fix a percentage content of the latter at each site. All together, 190 000 specimens from 242 sites were counted, with over 500 pebbles from each site as a statistic basis. These investigations proved that the local material (Cretaceous marls, Jurassic limestones and flints) forms stripes, and its content increases if closer to the maximum icesheet extent (up to 50—90%). The unweathered rocks are more and more abundant in the same direction; for instance at Grabówka near Częstochowa the Jurassic limestones predominate (45%) over flints and silicified rocks (25%), and Scandinavian (22%) rocks.

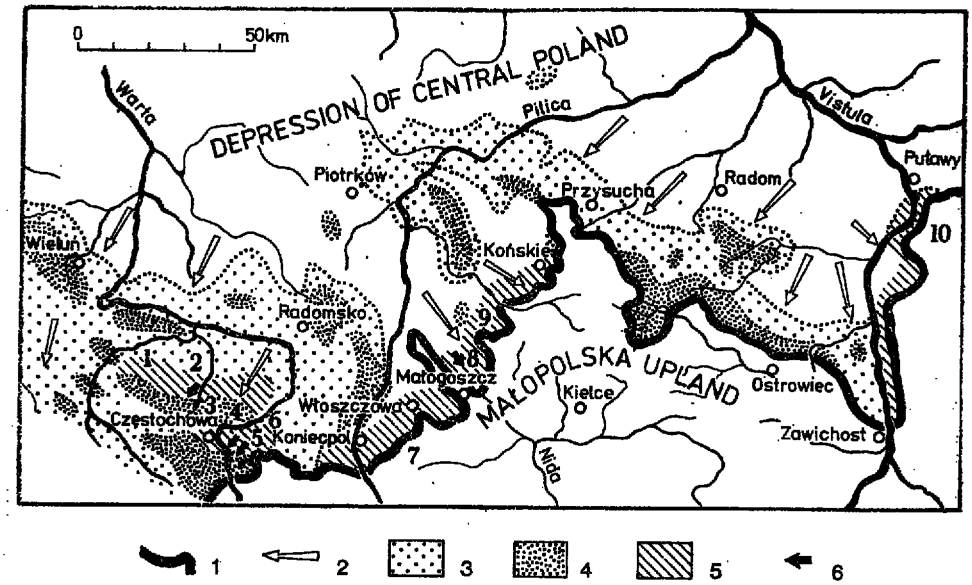

Fig. 1. Zones with local pebbles in end-morainic sediments of the Middle-Polish (Odranian) Glaciation (after Z. Lamparski's investigations)

1 maximum extent of the Middle-Polish Glaciation, *2* directions of icesheet movement, *3* 0—50% of local material in moraines, *4* 50—95% of local material in moraines, *5* bottom exaration moraines, *6* roches moutonnées

Localities with structures attributable to glacial erosion: **1** — Rembielice Królewskie, **2** — Kamyk, **3** — Grabówka, **4** — Kościelec, **5** — Olsztyn, **6** — Przymiłowice, **7** — Secemin, **8** — Mieczyn, **9** — Gnieździska, **10** — Kazimierz-on-Vistula

A width of a morainic stripe with a local material is changeable (20—40 km) and depends on the width of a zone with diversified relief (*see* Text-fig. 1). Along such very zone in the Holy Cross Mts there also appear some other structures that prove vertical and horizontal stress, caused by the overlying ice.

In the quarry at Mieczyn (12 km north-west from Małogoszcz), running along a roche moutonnée, the vertically dipping thick-bedded, Upper Jurassic limestones contain a very well expressed dynamic jointing, concordant with the direction of icesheet movement (Pl. 1, Fig. 2).

At Gnieździska near Łopuszno (8 km north from Małogoszcz) two series of bedded Jurassic limestones are separated by a breccia (Text-fig. 2), formed due to glacial displacements. In the same site, the overlying bedded limestones contain the cracks, being the opposite to each other cones that are also typical of the rock samples subjected to a vertical stress (*see* Różycki 1982).

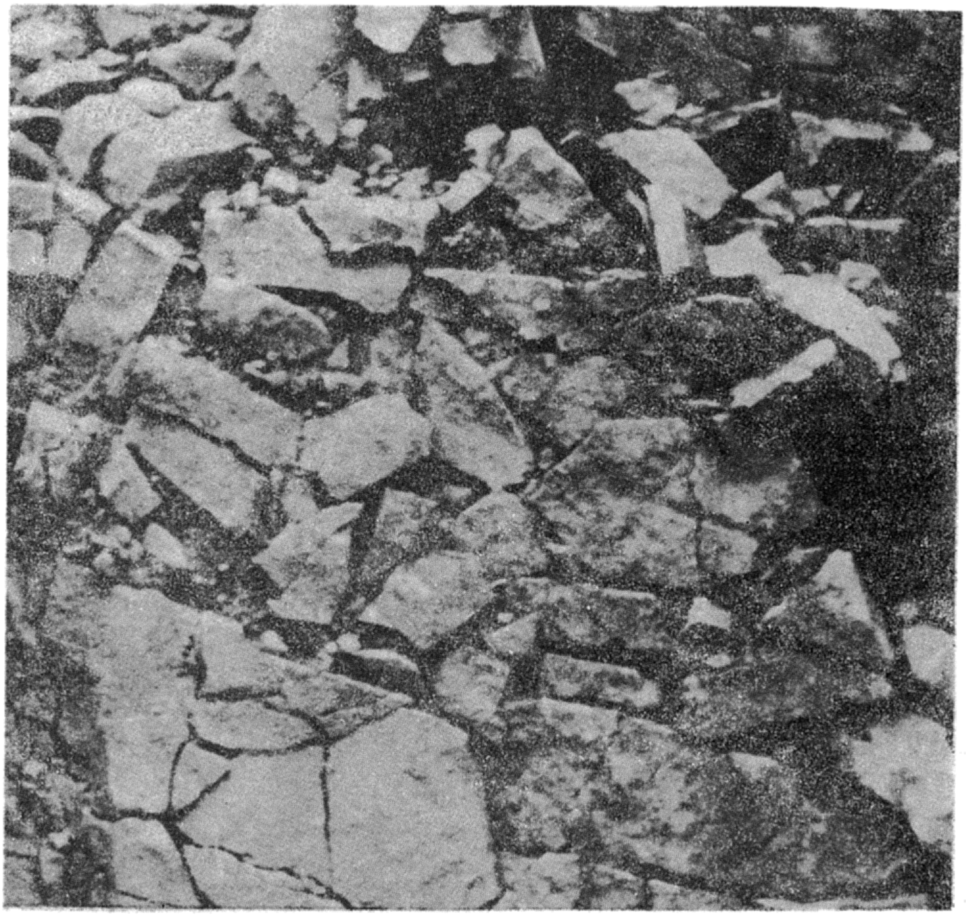

Fig. 2. Arrangement of blocks within an exaration moraine exposed at Gnieździska near Łopuszno

An occurrence of rubbles, with an irregular block arrangement at levelled bedrock surface in the terminal icesheet zone (Pl. 3, Fig. 2) show quite a different profile than ordinary or periglacial weathering wastes (*cf.* Różycki 1982). Such rubbles near Mieczyn entered the surface of roches moutonnées, marking then their connection with a glacial erosion, and also that the rubbles played a part of a ground moraine; they are named here the "exaration moraines".

A common occurrence of such moraines in the whole zone between Częstochowa, Włoszczowa and Przysucha at a distance of about 120 km is interpreted as a result of their connection with a morainal zone of the maximum extent of the Middle-Polish Glaciation and have been formed due to a glacial erosion at a terminal part of the advancing icesheet.

The erosion progressed not only in the massive Jurassic limestones of the Polish Jura but also in the Upper Cretaceous marls of the Nida Trough.

An occurrence of such exaration moraines enabled to fix definitely the icesheet extent, which previously has usually been recorded on the ground of a pattern of outwashes in front of the icesheet

The icesheet extent was similarly defined at 70 km distance in the Vistula valley, between Zawichost and Puławy, where it had been previously suggested along a high edge of the right bank of the Vistula, completely devoid of glacial sediments of the Middle-Polish Glaciation; the latter is well documented by the end moraines at the left river bank.

Close to Kazimierz-on-Vistula (13 km south from Puławy) two series of exaration moraines were found to overlie each other. They are composed of coarse debris, separated by a well mixed material, suggesting a repeated ice pressure (Pl. 3, Fig. 1). These rubbles seldom contain single Scandinavian boulders that undoubtedly enable to find these rubbles as the glacial sediments.

Closer to the Central Polish Uplands as the bedrock successively rises, the content of local material quickly increases up to over 50% or 70%, and in some cases even over 90%. In the same direction the pebbles of fresh, non-weathered rocks are more and more abundant. In utmost cases, the morainic sediments with a very high content of local pebbles are very similar to the deposits, described above as the exaration moraines, noted usually in hummocky areas with roches moutonnées.

It is obvious that these facts enable to demarcate the extent of the Middle-Polish Glaciation at two long reaches where it had been impossible with the use of other sedimentary methods.

REGIONAL INTERPRETATION

An intensive glacial erosion in the terminal icesheet zone has been for long an unnoticeable fact. After finding, it needed explanation that was searched in a morphology of the surface over which the icesheet had advanced.

After leaving the Scandinavia, the icesheet entered the area of the Mid-European Trough (Text-fig. 3), the axis of which is located more or less at the Warsaw parallel, expressed by the Mazowsze Lowland, and further to the west by the Wielkopolska Lowland. The Trough is filled with Miocene sands and Pliocene clays, deposited in large inland reservoirs. After passing across the Trough, the icesheet entered almost a flat area located at 70—80 m a.s.l. From the parallel of the Lower Pilica the area got elevated gently but there were no obstacles for the moving icesheet. The Tertiary sediments spread south off Radom but then, the Cretaceous and Jurassic outcrops are exposed from under the

Late Quaternary sediments; the latter have been denuded and eroded during the Mazovian (Mindel/Riss) Interglacial. Besides, flattened hills appear, with their slopes inclined at an angle of several degrees. Already there, some pebbles of local rocks occur within the morainic sediments and their content increases southwards, reaching up to 50% in a zone 10 km wide. The bedrock is inclined at an angle of about 5° in this area but it is more and more steep southwards as coming nearer to the Central Polish Uplands whereas the content of local material in end-morainic sediments reaches 70%. Still further to the south the bedrock rises to 120—150 m a.s.l., gets hummocky and the tills occur even over 250—300 m a.s.l.

Coming nearer to the dissected Central Polish Uplands, the icesheet formed more or less separate lobes and tongues, that entered the depressions admidst the elevations. The level, at which the glacier tongues enter the area, differs considerably and depends on a width of the gate, parallel to a direction of ice movement and icesheet pressure. The icesheet enters the Central Polish Uplands at a level of about 150 m a.s.l. At a vast open forefield of the Koniecpol lobe (*cf.* Text-fig. 3), the icesheet foot occurs at about 200 m a.s.l., amidst the Cretaceous eleva-

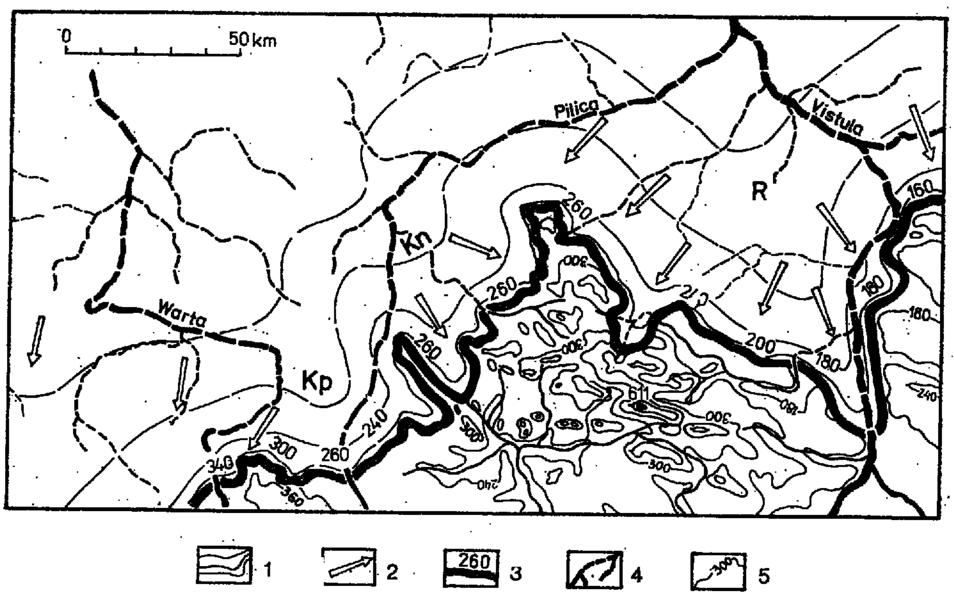

Fig. 3. Relief sketch of the front of the advancing icesheet of the Middle-Polish Glaciation

1 icesheet, *2* directions of icesheet movement, *3* maximum extent of the Middle-Polish Glaciation: numbers at the ice mean the altitude of the icesheet foot in metres a.s.l., *4* courses of present-day rivers, *5* contour lines of the icesheet forefield
Kp — Koniecpol lobe, **Kn** — Końskie lobe, **R** — Radom lobe

tions of the Nida Trough at about 260 m a.s.l. whereas coming closer to the higher elevations of the Polish Jura and the margins of the Holy Cross Mts, it rises to over 300 m a.s.l., reaching its maximum height (340 m a.s.l.) in the Towarne Hills near Olsztyn. In the areas where the icesheet foot rises considerably and the massive rocks occur (massive limestones in the Polish Jura, vertically dipping thick-bedded Upper Jurassic limestones in the Holy Cross Mts), typical roches moutonnées are formed, and at their distal slopes large detached blocks are common (Pl. 2, Figs 1—2).

Summing up, the discussed structures from the Central Polish Uplands evidence that the icesheet, after filling up the vast Mid-European Trough and still growing, started entering the elevations of the Central Polish Uplands. While moving over the area sloping against its movement direction, the icesheet firstly collected a weathering waste of the substratal rocks and incorporated it into its moraine. As the bedrock and the slopes got steeper, the icesheet started to erode its bedrock more intensively, and thus more debris was included into its moraine and a relative content of the Scandinavian material decreased. A content of local bedrock boulders increased up to 50% or even 90%. After the area became steeper and the icesheet stopped at higher elevations, a content of the local debris increased so much that the exaration moraines, with a chaotic debris arrangement have been formed. In this area, the hills composed of rocks *in situ* became transformed into roches moutonnées.

FINAL REMARKS

The literature studies lead to a conclusion that the exaration-like moraines occur not only in Poland but also in other countries, for instance the Valdai Upland (Soviet Union) and in the Harz Mts where they have commonly been considered as the glacial erratic masses.

The presented data from the Central Polish Uplands show that a vast exaration zone is not limited to the central icesheet parts only but occurs also in the zones of their maximum extent where, after filling the depressions, the icesheet enters the slopes of the uplands in its forefield, inclined opposite its movement direction. If its inclination is smaller than 2—3° the icesheet erodes only the rubble at the bedrock surface and incorporates it into its morainic material. If the slopes are more inclined, the admixture of the local material in the moraines considerably increases, reaching 50—80%. If the inclination is equal 5—10°, then there are up to 90% or even more of the local material and the exaration moraines are created, composed entirely of the local material coming from the bedrock and typical by their chaotic arrangement of rock pieces. When the icesheet meets the elevations composed of massive rocks then the roches moutonnées are formed.

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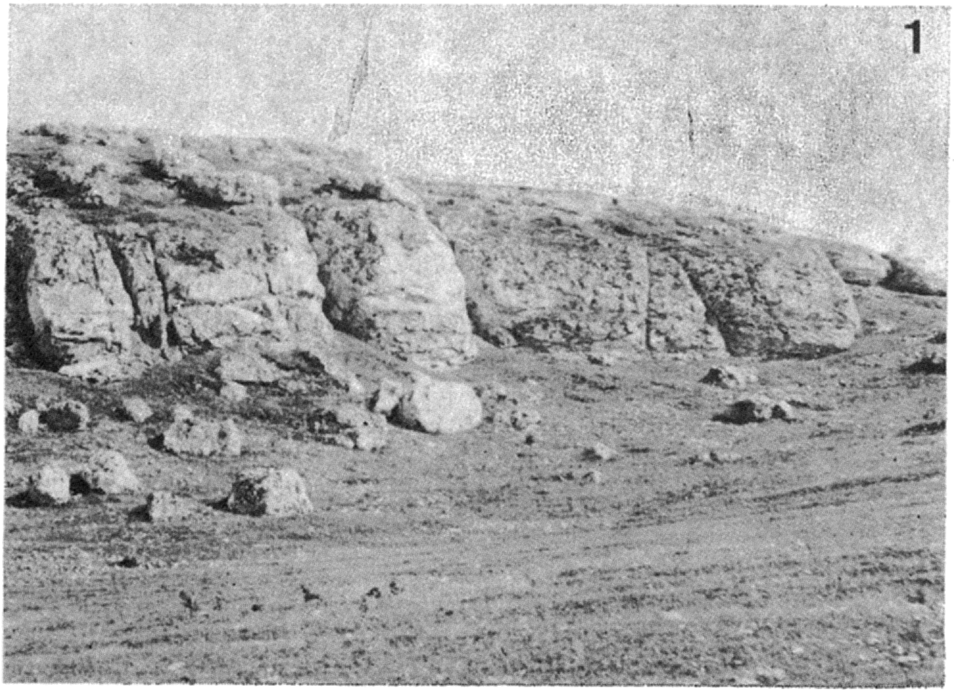
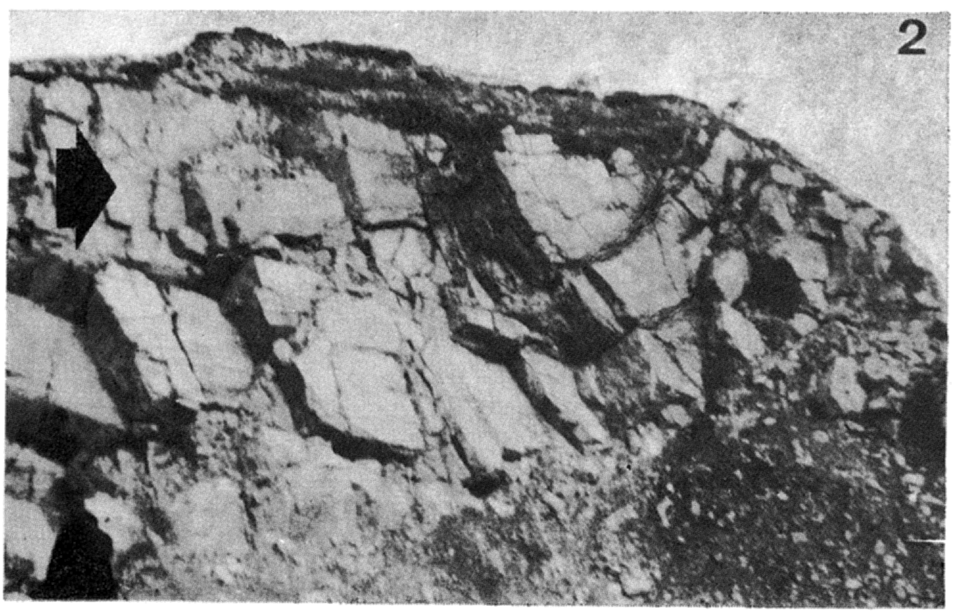
ZJAWISKA EGZARACJI W BRZEŻNEJ CZĘŚCI LĄDOLODU ZLODOWACENIA ŚRODKOWOPOLSKIEGO

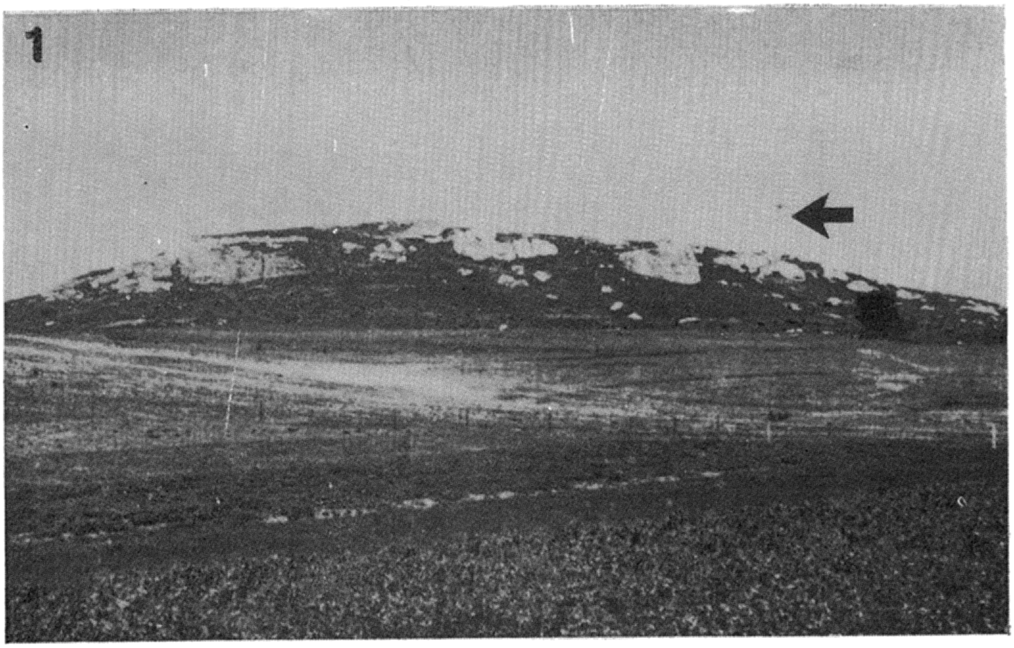
(Streszczenie)

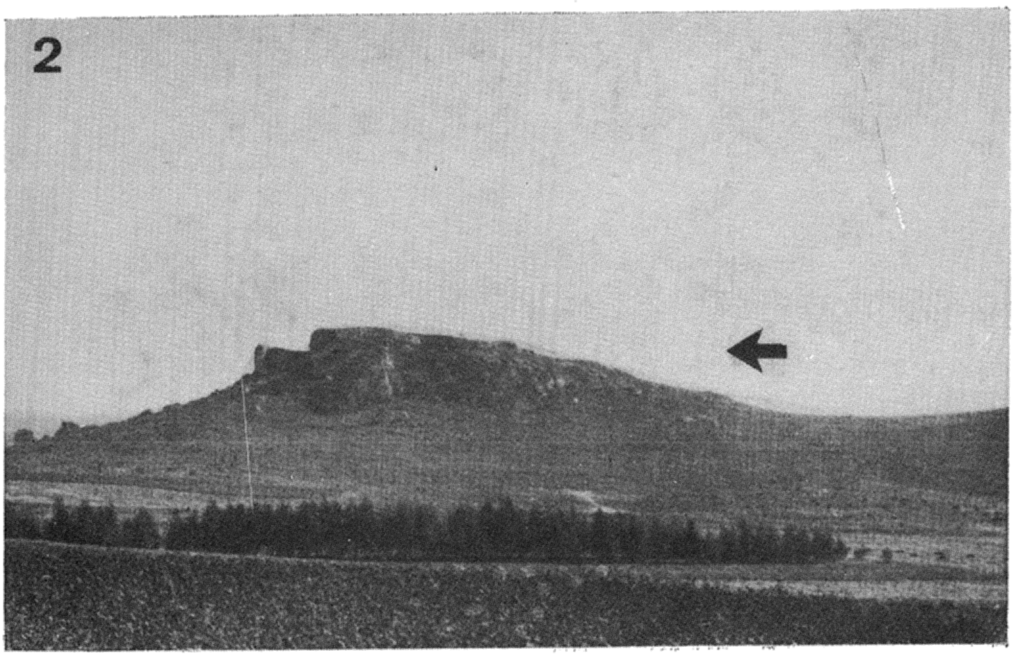
Na przykładzie z obszaru Wyżyn Polski Środkowej pokazany jest układ stosunków, w którym brzeżna część lądolodu skandynawskiego zlodowacenia środkowopolskiego (zlodowacenia Odry), po przekroczeniu wielkiego obniżenia Bruzdy Środkowo-Europejskiej zaczęła się wznosić (ponad 200 m) na obszar Wyżyn Polski Środkowej (*patrz* fig. 1). W miarę zwiększania się kąta nachylenia podłoża w kierunku przeciwnym do kierunku ruchu lodu stwierdzono w strefie od 20 do 40 km szerokości objawy coraz silniejszej egzaracji podłoża (*patrz* fig. 1 oraz 3) i obecność wygładów lodowcowych (pl. 1, fig. 1). Najpierw został zebrany z powierzchni gruz wietrzeniowy skał starszych (górna kreda, jura), a potem przy nachyleniu powierzchni rzędu 3—5° skały lite, w których też pod naciskiem lodu powstał cios zgodny z kierunkiem ruchu lądolodu (pl. 1, fig. 2). Przy dalszym wzroście nachylenia podłoża i oparciu się lądolodu o większe wyniosłości, ilość materiału zdzieranego gwałtownie rosła tak, że w krańcowych przypadkach doszło do powstania złożonej prawie wyłącznie z materiału lokalnego „moreny egzaracyjnej" o chaotycznym ułożeniu gruzu (fig. 2 oraz pl. 3, fig. 2), tworzącego niekiedy nawet dwa poziomy (*a* oraz *b* na pl. 3, fig. 1). Niektóre wzgórza zbudowane ze skał o większej zwięzłości przemodelowane zostały w typowe mutony (pl. 2, fig. 1—2).





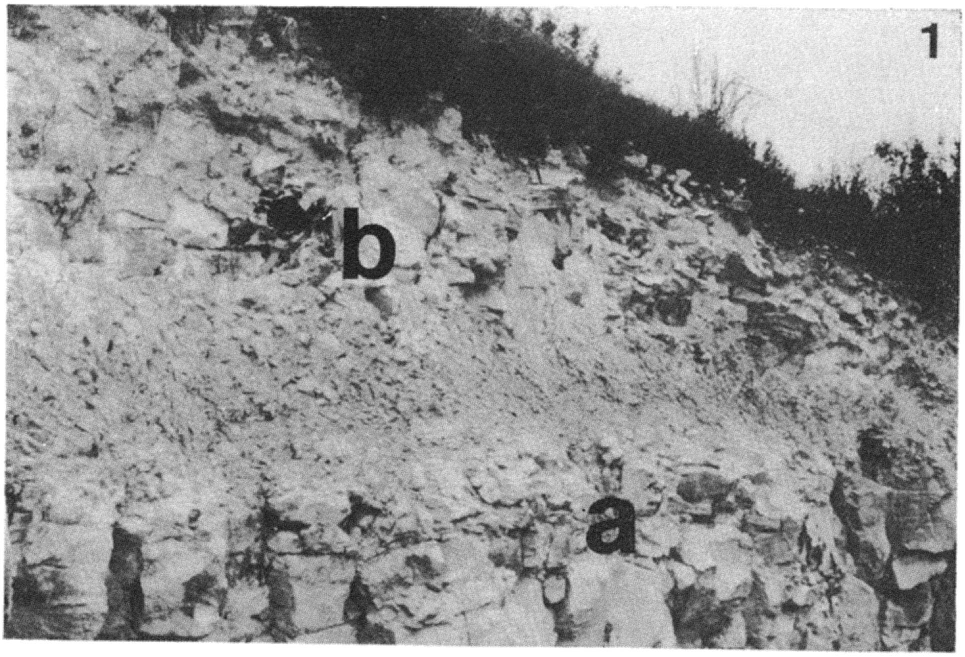
1 — Ice-polished surface; Kusięta near Częstochowa
2 — Glacidynamic joints in vertically dipping thick-bedded limestonens (icesheet direction indicated by an arrow); Mieczyn near Małogoszcz

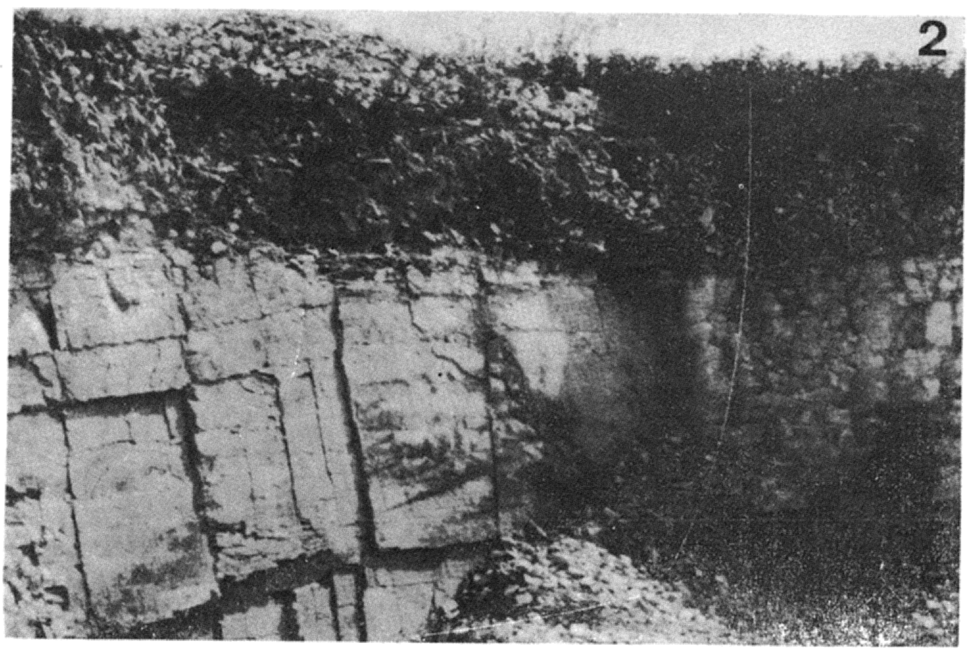




1 — Roche moutonnée (longitudinal view; arrowed is the icesheet direction); Towarne Hills near Olsztyn

2 — Another roche moutonnée (longitudinal view; arrowed is the icesheet direction) with detached rock pieces at the distal side; Towarne Hills near Olsztyn





1 — Two layers (*a* and *b*) of large blocks within an exaration moraine (Upper Cretaceous siliceous marlstones), separated by fine-grained debris; Kazimierz--on-Vistula

2 — Exaration moraines at the surface sheared by glacial erosion; Kościelec near Częstochowa