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Łódź

THE MAIN ELEMENTS OF UPPER PLEISTOCENE PALEOGEOGRAPHY IN CENTRAL POLAND

Sommaire

La base des processus agissant pendant la dernière période froide est constituée par le relief élaboré au cours du stade de la Warta et de l'interglaciaire Eemien. Ce qui caractérise les dépôts et les formes de relief développés dans la région étudiée au cours du stade de la Warta ce sont les structures de la tectonique glaciaire, parmi lesquelles on distingue deux types: monoclinal et plissé. Les structures plastiques, plissées, se sont formées dans le matériel meuble; les structures „rigides", monoclinales, ont été déchirées du pergélisol.

Les formes de relief et les dépôts du type d'ablation glaciaire et du type de „contact avec la glace" (ice-contact) indiquent que la déglaciation du glacier de la Warta ne se faisait pas de la façon frontale mais agissait, au même temps, sur un terrain vaste, étant accompagnée de l'éclatement de la couverture glaciaire en des blocs.

L'interglaciaire Eemien a été reconnu à la base des dépôts organiques, principalement tourbeux et carbonatés et aussi à l'aide d'une analyse des sols fossiles, avant tout des podzols.

Les principales unités lithologiques des dépôts minéraux „froids" distungués sont: pavages de pierres, dépôts de congélifluxion et dépôts de versant à litage rythmique.

Parmi les structures fossiles l'attention particulière a été consacrée aux polygones des fentes de gel, aux structures d'injection — avant tout structures à cryolaccolithes, aux structures du karst thermique, au transport des pierres vers le haut dû au gel et aux blocs de pergélisol.

La position stratigraphique des unités lithologiques déterminées d'après leur dynamique et le milieu de formation caractéristique pour les dépôts et les structures particulières a consistué la base pour les reconstructions du climat et de l'évolution morphoclimatique. Au cours de la période froide du Würm on a distingué trois phases différentes: phase de croissance, phase de climax et phase de décroissance. On doit souligner le fait que la notion de la phase de climax ne possède pas le même sens que celle du maximum de l'extension de la dernière glaciation.

The paleogeographical materials discussed in this paper were obtained through numerous and exhaustive studies conducted in the region of Łódź. Most of these studies were extensive and detailed, and included even minute and seemingly unimportant or difficult to explain textural and structural features of the deposits.

The studies mainly concerned with the deposits of the last cold stage. The most important results although still incomplete, pertain to this stage. It was also necessary to include the data and events which had taken place during the Eemian Interglacial and the Middle Polish Glaciation.

That time span is referred to in this paper as Upper Pleistocene. However, this definition does not pretend to be of special importance in general Pleistocene nomenclature, and is only of conventional significance for the problems considered here.

The problem of the Middle Polish Glaciation is not discussed here thoroughly, but only as it pertains the glacial tectonics and to disappearance of the Warta glacier. The conclusions concerning this subject are preliminary and of minor importance, mainly because of the small-scale research conducted in this domain.

Works concerning the Eemian Interglacial are few and incomplete. The Eemian Interglacial is mentioned in this paper mainly for the purpose of definition and as an aid in determining the boundaries of individual events and deposits belonging to the last cold stage.

Several years ago the Łódź scientific center set out to study the taxonomic-lithological units of the last cold stage deposits and establish their stratigraphy. So far this objective has not been completed and numerous problems still remain unexplained. However, there are fairly concrete reasons for drawing conclusions about the various events and their consequences that took place during the last cold stage. Firstly, these are climatically conditioned events. Their interpretation makes it possible to recognize the climatic changes and their history during the last cold stage.

Now we have found more organic deposits and fossil soils that afford valuable paleoclimatic evidence, and thus, particular attention was paid to the lithological features of the mineral deposits. Unlike organic and fossil-soil deposits, the mineral deposits are very common and widespread, however this is not the only reason for their special value to paleogeography. In addition, mineral deposits are a distinct reflection of the morphogenetic phenomena which occurred under specific geographical conditions, and were dependent on climate and are highly sensitive to all its changes.

Detailed studies of both texture and structure of the deposits permit to determine the character of sedimentary environment, thereby allowing to define the character of the process that was responsible for the formation of the deposits. This process leads to the deduction of the type of morphogenetic and geographic environments which in turn are a basis for determining the climatic conditions. It should be emphasized that the study of structure deals with primary structures which are synchronous with the deposits as well as with secondary structures which deform the original stratification of the mineral deposits. From our research conclusions can be drawn pertaining not only to the climatic conditions under which the deposit originates, but also with regard to later conditions.

The detailed analysis of deposits as well as the determination of lithological taxonomic units which is based on this analysis, are the principal points brought out by the paleogeographical results. The stratigraphical construction of the distinguished lithological units, that are interpreted as the determinants of the phenomena occurring under specific climatic conditions, allows to reconstruct climatic changes. Organic deposits and fossil soils strengthen the stratigraphical and chronological bases which depend on the accuracy of determination of the deposits.

STRUCTURES OF GLACIAL TECTONICS AND REMARKS ON THE DISAPPEARANCE OF THE PENULTIMATE ICE-SHEET

The last time that Central Poland was covered by a glacier was during the Warta stage of the Middle-Polish (Riss) Glaciation. Thus this stage is of great importance, especially since the Warta glacial land-forms constituted a form of relief that was later shapped during both the last Interglacial and the Würm cold stage. The glacial deposits of the Riss Glaciation, mainly the Warta stage, were also the source material for the secondary formations during the Interglacial and Würm.

The deformations of primary structure of the Pleistocene and even of the Tertiary deposits, which originated as a result of glacial tectonics, are the most characteristic features of the Warta stage. Glacial tectonic structures in Poland are also found within the areas of other glaciations. However, nowhere are they so common and so well developed as in the area of the Warta stage extent.

In the Łódź region two basic types of glacial tectonic structures can be distinguished: fold and monoclinal structures. The fold structures, which usually contain in their saddle core a very fine grained material such as Miocene clays (Dąbrówka Strumiany), boulder clay (Sikawa, Wiskitno), or silts (Starowa Góra), represent the deformations which occurred in plastic material. This type corresponds to Bülow's (1955) *Stauchenmoränen*, to Keller's (1954) *Drucktexturen*, to Hoppe's (1952, 1957, 1960) *Veiki-moraines* and other forms of *hummocky moraines*, as well as to MacStalker's (1960) *rim* and *terrace ridges* and other *ice-pressed forms*.

The structures were formed as a result of compensatory movements caused by the vertical pressure of the glacier. These were pressure structures of plastic, unfrozen material which were formed subglacially (Pl. 1). In the Łódź region, glacial tectonic structures of fold type are not everywhere identical and may be further differentiated according to structural, second-order features, and position.

Monoclinal structures are distinguished by the fact that they consist of beds or series piled up and often sharply inclined more that 80° in one direction. The direction is opposite to that of the ice-sheet movement.

Folds-saddles, synclines and brachi-synclines are absent. Such structures are called *Schuppenstrukturen* (Gripp 1929), *glacial-pseudomorph structures* (Flint 1948), *dynamische Drucktexturen* (Keller 1954), or *Stapelmoränen* according to Bülow (1955). Monoclinal forms originated as a result of lateral pressure of advancing glacier and were formed in hard and frozen material.

This type of glacial tectonic structures is of great interest mainly because of its association with the glacial and periglacial problems, for the piled up beds occur in blocks detached by the glaciers from permafrost. Thus the monoclinal structures commonly found in the Łódź region (Doły, Niesułków, Wilanów) show the presence of permafrost during the advance or during the oscillation of the Warta glacier.

In the zone of the northern scarp of the Łódź Upland there are some spatial connections of both main types of glacial tectonic structures. They agree with the previous observations of Slater (Flint 1948) and Bülow (1955), who maintain that, in relation to the glacier, the monoclinal structures are in a proximal position and the fold structures in a distal position (Wilanów, Doły-Sikawa, Niesułków).

Also there occur separate fold structures that do not reveal any associations with the monoclinal structures. To this category belong the fold structures situated inside the Upland, generally in the margin zone of depressions and inner valleys, which are characterized by a W—E direction (Jędrowizna, Gałkówek, Dwór-Koluszki).

In addition to the marked differentiation of fold structures in space, some differences in the development of the structures are also observed, as compared with the monoclinal ones. Close to the northern and western scarps of the Upland, complex anticlinoria are found which are formed of numerous anticlines and synclines (Sikawa, Wiskitno). At the center of the Upland, simpler structures also occur which are of smaller spatial extent. They are based on the „massifs" formed of material retaining its original and undisturbed stratification (Jędrowizna, Gałkówek, Dwór-Koluszki). The most simple folds are found in the foreland of the western scarp of the Upland, where some individual saddles rise above the plain formed of boulder clay (Starowa Góra, Konstantyna, Rzgów?).

The presence of the upper boulder clay in the fold structures (Wiskitno) shows that such deformations were formed subglacially due to squeezing of plastic material into the free spaces or voids. One can conclude that the upper boulder clay vanished at the period of strongly advanced disintegration of a dying or already dead glacier, as suggested by Hoppe (1952) and MacStalker (1960). However, a later Warta formation of permafrost should be taken into consideration, since monoclinal struc-

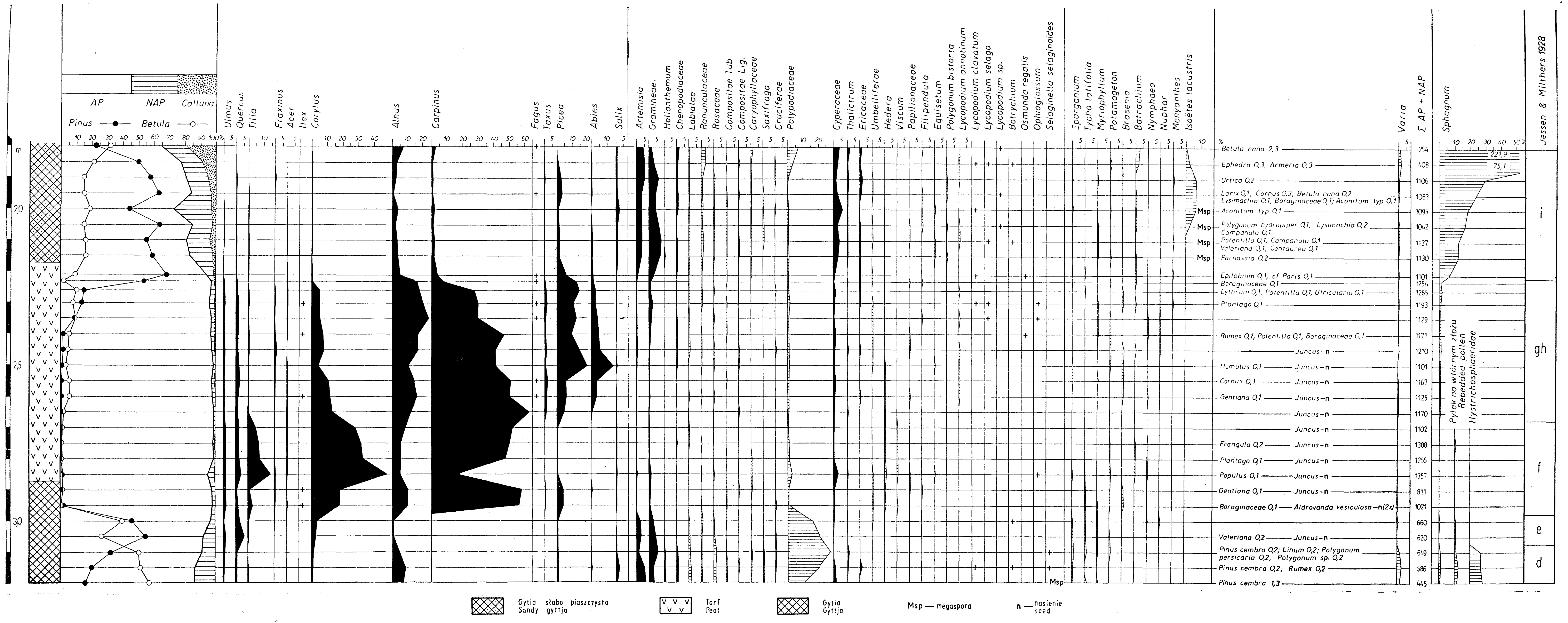

Fig. 1. Józefów. Pollen diagram of the Eemian deposits (after M. Sobolewska 1966)

tures are dynamically connected with permafrost and with glacier movement, and are based on the older fold structures. Therefore, conclusions may be drawn as to the new oscillation of glacier and the formation of permafrost preceding this oscillation, but formed later than the fold structures. However, this problem has not been adequately investigated, thus the conclusions are debatable. Finally, the problem of possible intermediary relations (Bubnoff 1954) between the glacial tectonic phenomena and the young deep tectonics remains completelly open.

Final disappearance of the Warta glacier did not occur frontally, but in its entirety. This did not happen uniformly within the wide areas due to the lack of distinct, well developed end moraines of accumulation type, and the presence of haphazard, drainless basins. The latter ones are numerous, but often only slightly marked and obliterated by the succeeding denudation processes. This is also shown by the found traces of persistent ice-masses in numerous valleys, as in the axial part of the Warsaw—Berlin pradolina, in the area between Dąbie and Łowicz.

The above mentioned drainless basins and some ramparts indistinctly marked in the present-day relief show either a fragmentation of the glacier into completely isolated blocks, or a disintegration of the upper part of the ice cap. These ramparts which were formed of the glacifluvial material were no doubt ice-fissure forms. The interstices dividing them, which are filled with boulder clay, mark the sites of the dead-ice blocks.

The studies on a drainless basin situated at Józefów, near Rogów, and the work of Chmielewski (1961) at Skaratki and of Klajnert (1966) in Bobrówka river drainage system have shown the presence of the ablation material which rests on boulder clay. In the vicinity of Skaratki and Domaniewice stratified gravels are found frequently. Strike and dips of the gravels show that their accumulation may be explained only by the origin from ice-blocks.

Recently, Z. Klajnert (1966) has found boulder clay in the Dąbkowice area, near Łowicz, which is characterized by fluidal structure, overlying various deposits, as e. g. common boulder clay. Thus he arrived at the possible explanation for the differentiated shrinking of glacier. From the isolated ice-blocks or from certain upper patches of uneven surface of the disappearing glacier, the accumulation advanced towards still higher places. These were places left by either completely or partially melted ice blocks, and buried by the deposits of later accumulation. Numerous structural features such as fractures and uniformly oriented bends of the overlying deposits, as e. g. fluidal boulder clay, point to the subsidence of deposits. Probably the subsidence took place as a result of the retarded melting of buried ice masses.

THE EEMIAN INTERGLACIAL

The Eemian Interglacial in the Łódź region is best characterized mostly by organic deposits, weathering zones, discordant surfaces, and probably some river deposits. Recently, generally reliable traces of this interglacial have been discovered. However, its deposits are more rarely found than those of the previous interglacial stage. Maybe this shows a more intense denudation in the last cold stage.

According to B. Halicki (1951) the Eemian deposits are most frequently found in closed- and old lake basins, where they are formed most completely. In some cases, the organic formations pass into the deposits produced subaerally, i.e. into old and mostly buried soils.

B. Manikowska (1966) has examined the Eemian organic deposits that occur in small closed basins at Jeziorko, near Koluszki and at Jabłonów. She has also found calcareous muds at Żabieniec and below the bottom of a large lake basin near Kochanów, between Jeżów and Głuchów. Near Kochanów and at Jabłonów she has also discovered lacustrine chalk. However, Manikowska was mainly interested in old Eemian soils at Jeziorko, Słowik, in the Pilica River—Łódź aqueduct near Zielona Góra. These are podsolic soils.

In 1963, Z. Klajnert found by means of numerous drillings made across the Bobrówka valley, near the so-called Jezioro Okręt, a rich series of calcareous muds containing molluscs and a series of peats reaching up to 7 m in thickness. It is beyond doubt that either the whole series, or at least the greater part, was accumulated during the Eemian Interglacial.

The above mentioned sites were not examined palynologically. It was assigned to the Eemian Interglacial on the basis of stratigraphical and geomorphological analyses, and mainly by detailed paleopedological examinations.

However, complete paleobotanical analyses or sufficient partial analyses have been made from the organic deposits at Skaratki, near Domaniewice, and at Józefów, near Rogów.

In 1959, W. Chmielewski discovered near Skaratki that the organic deposits were resting on the bottom of an only slightly visible drainless basin. A peat bed, 2—3 m thick, overlies plastic mud which is underlain by sand with gravel, covering the boulder clay. Pollen analysis of the samples taken from this peat has been made by J. de Ploey in the laboratory of Prof. Gullentops, Louvain. A diagram made on the basis of that analysis was published in the Guide-book of the VI INQUA Congress (Chmielewski 1961).

The lower peat occurring in the Józefów depression rests on the glacial deposits which consist of clays and lake muds. They are underlain by sandy till and boulder clay. The peat is covered by: gyttja, rhythmically stratified deposits of an older generation, upper peat, congelifluxion deposits, younger series of rhythmically stratified deposits, and loess-like formations.

In the past, statements were made that the older peat at Józefów has been formed during the Eemian period (Dylik 1961a, b). This was proved by Oszast, who found *Dulichium* occurring in the peat. However, a more complete, although still inadequate floristic study of the upper peat from Józefów was made in the 1963 spring.

M. Sobolewska, co-worker in the Institute of Botany, Polish Academy of Sciences, Cracow, has collected a set of 33 samples and studied 13 of them. The simplified diagram was based on her study (Fig. 1). In the examined part of the profile M. Sobolewska (1966) has distinguished the successive phases of plant development, from (f) to (k), according to Jessens's scheme.

The profile shown in the diagram begins with the climatic Optimum of the last Interglacial characterized by thermophilic deciduous forests. Later, hornbeam appears which together with spruce and fir predominate over the mixed oak and hazel forest. Then, during the spruce and fir predominance the percentage of pine increases. During the phase (i), dense forest disappears giving way to park-like forest with pine, birch, and spruce, whereas in open areas grasses, *Carex*, and *Artemisia* develop. In the park-like landscape, birch dominate and heaths develop, thus showing a transition to the last cold stage.

In the sandy gyttja, transition takes place from the Eemian moderate climate to the last cold stage, to which both the upper peat and overlying series of mineral deposits completely belong.

PERIGLACIAL DEPOSITS AND STRUCTURES

Stone pavements represent the most common characteristic of periglacial deposits in Central Poland. They occur in various types, and their origin has not been definitely cleared up.

The primary accumulation of stones was due to vertical up and down movement. The upward movement was caused by upfreezing of the stones, a well known fact in the polar and subpolar regions (Hamberg 1915; Taber 1929, 1943). This phenomenon can be also observed presently in our country but to a much lesser degree. The downward movement was due to destruction of overlying deposits containing stones such as boulder clay or congelifluxion deposits.

Autochthonous pavements are found on flat and horizontal surfaces. Immediately below occurs a stoneless formation which usually forms the top part of a deposit containing numerous stones.

In many sites, especially on sloping surfaces and at the bottom of small valleys or of other concave forms, the upfreezing and the primary accumulation of stones took place in other, higher lying sites. In the places where the stone mantle rests on the deposits that do not contain and did not contain any stones, the presence of allochthonous stone covers can be expected.

Allochthonous stone mantles originated mainly from material transported by congelifluxion, and were transformed by the activity of running water and wind. This change consisted of removing the fine and minute particles from heterogenous, congelifluxion material.

Downwash, particularly on slopes, played an important part in the last stage of the formation of stone covers. However, some evidence shows that the finer material was removed by water. In Góra Św. Małgorzaty stone series are found which have at least three stone layers interbedded by gravels and fluviatile sands. Undoubtedly the stones come from slope transportation and are of congelifluxion type. The stone beds also lack finer particles (Pl. 2).

The occurrence of numerous eologlyptoliths in various stone mantles is very characteristic. The presence of many, two-sided, faceted stones, and a lack of a uniform orientation of the direction of edges, grooves, and flutes show that the process of eolisation was not the last one during the formation of stone mantles. Eolian erosion took place both in the original and in the secondary accumulation of stones. This may show that a great role was played by deflation in the final formation of stone mantles.

Congelifluxion deposits belonging to the most common periglacial formations are of great stratigraphical importance and serve as valuable paleogeographical determinants. The deposits have been described from the entire Poland, but due to their importance and on account of the latest results obtained from the Łódź area, this problem should be again discussed.

When the congelifluxion operates on a great scale in vast, sloping areas, and when only mineral material is usually transported in the vegetation-free areas, congelifluxion deposits do not show distinct structural features. Such deposits can be distinguished only on the basis of their textural properties: great diversity in grain size and the frequently high percentage of angular rock fragments. The congelifluxion deposits from Góra Św. Małgorzaty are an excellent example of this (Pl. 3).

On the other hand, if the movement of congelifluxion mass is more concentrated, i.e. in the case of a greater slope gradient, characteristic lobes or tongues with a distinctly marked front appear. The most interesting structures of such lobes have been observed at Dąbkowice, Smardzew, and in Góra Św. Małgorzaty. The observations of structures found at Dąbkowice (Klajnert 1966) and at Smardzew (Klatkowa 1965) show that movement was determined not by the size of material particles, but by the slope gradient. In both cases the lobes were formed of coarse, glacifluvial gravels and pebbles. Of course, this material must have been oversaturated with water, for permafrost occurs at the bottom of the transported material The structure of the lobe occurring in Góra Św. Małgorzaty (Pl. 3) has a particularly marked and distinct outline, because soil and vegetation were incorporated in mass movement. This example is particularly interesting since it shows the interrelations between both kinds of congelifluxion. It should be noted that the lobe front rest on and even is buried by the deposits of amorphous congelifluxion.

Morainic clay displaced on the slope represents a particular variety of congelifluxion deposits. As it can be seen on the old fossil slope at Walewice, near Łowicz, this formation is characterized by a structure showing pseudostratification. Besides the dominating boulder clay beds, sand laminae, which in a normal stratigraphical position rest under the clay, also occur. The upper surface of the slope clay is not flat but diversified, as in some places in the form of lobes. In the photograph (Pl. 4) a lobe was most probably displaced from its original position. Uplifting of this lobe took place during the later periglacial processes.

Rhythmically bedded deposits represent a group of periglacial formations which are very important for stratigraphy and paleogeography of the last cold stage.

Firstly, they are deposits of sand and silt. The rhythm of stratification is characteristic here. It was formed by alternating laminae containing finer material: such as fine sand or silt, and coarser material, such as fine or medium-grained sand. The individual layers can be called laminae mainly because of the low values of their extent and thickness. The lenght of the individual lenses, generally not too big, ranges from some decimetres up to some scores of meters. As a result the layers are strongly restricted in space and in the general pattern of stratification give an impression of discontinuity. Thickness of the laminae is frequently measured in millimetres and, as a rule, does not reach 1 dcm.

The dip values of the rhythmically stratified deposits, just as those of extent and thickness, change depending upon the grain-size of the deposits. In the immediate vicinity of slopes, mainly fossil slopes buried by these deposits, the inclination of laminae reaches approximately 30° and even more. However, at a distance of some scores of meters from the slope, as e.g. at Walewice, the value of inclination decreases to about 10°. Farther off, towards the valley axis or at the bottom of closed depressions, this value decreases still more and approaches to zero.

According to the changes in the dip values and to the distance from buried slope, a general change in grain-size can be observed, whereas the rhythmical differences in the alternating layers remain unchanged. In the proximal parts, and respectively also in the lower lying portions, fine material of silt, or even of clay size is dominant. On the other hand, the distal parts of the deposits and those situated close to the top are very poor in finer particles, and rich in coarser particles, mainly sand grains (Fig. 2, Pl. 5).

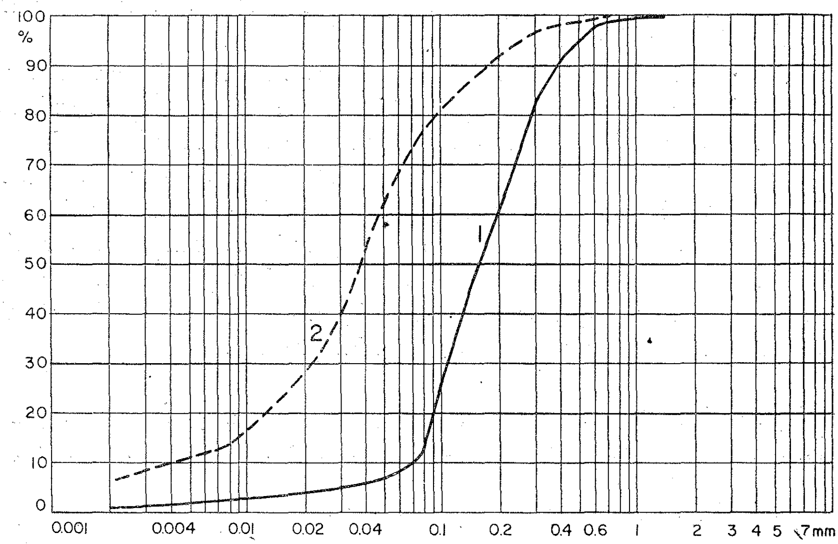

Fig. 2. Walewice. Grain-size curves of distal (1) and proximal (2) part of rhythmically stratified deposits

The direction is also similar, as well as the thickness of layers, the value of which increases from proximal towards the distal side, and from the bottom to the top. This variability, just as the general variability in grain size, are results of qualitative and quantitative differentiation of the processes responsible for the formation of the rhythmically stratified deposits.

Congelifluxion and downwash played the most important part in the formation of rhythmically stratified deposits. Accumulation of the deposits took place as a result of interaction of above mentioned processes. Their part varied here depending upon numerous circumstances, first of all, upon topographical situation and upon the distance from the initial slope.

Congelifluxion dominated during the formation of proximal parts of the deposits, as shown by the characteristic features of texture and structure. The mineral material occurring in the neighbourhood of the slope buried by the rhythmically stratified deposits is highly heterogenous. Proximal deposits at Walewice contain certain elements of all the deposits occurring in the area where the fossil slope is cut. Here, particles of morainic clay are found as well as those of clays and sands. The variety can be observed on small segments of section walls.

In this part of the deposits, laminae are very scarse, thin, and short. They dip approximately according to fossil slope line, at a considerably great angle. Close to the slope the dip is as big as that of the slope surface, i. e. 45°. Farther away from the slope the angle decreases, but it remains unchanged for a great distance, ranging from 20° to 30°. Where the slope is steep and almost vertical, the angles of the laminae also correspond to those vertically oriented. It is possible that in the past thin laminae of thawed mud flowed down and froze to the frozen slope (Pl. 6).

Farther away from the original slope, distinct differences can be observed in the main features of the deposit. The material becomes less fine, and the variability of material is much better arranged. Sand-size particles dominate, the layers are longer and thicker, and their inclination decreases down to 10°, and below. This is a result of runing water activity increasing towards the distal direction. In these remote parts of the deposits a distinct dominance of downwash over congelifluxion can easily be observed.

In the Mroga valley, near Walewice, the rhythmically stratified slope deposits constitute a wide glacis. Its complex history is not presented in this paper. However, one fact cannot be disregarded because it is very important for the origin of slope deposits which are discussed here. Successive surfaces of the glacis were not always uniformly flat which could have resulted from an accumulation developing equally over the whole surface. The analysis of the sections shows that the surface of the increasing glacis has been cut many times due to the better organisation of local surface waters. However, on account of an ephemeral water outflow, which is characteristic of periglacial environment, small erosional land-forms, such as furrows and short small valleys, were filled up.

The investigation of the important part played by the congelifluxion in the formation of rhythmically stratified deposits indicates that they originated under frost conditions. Accumulation and existence of considerably thick congelifluxion and downwash deposits, which under conditions of moderate climate are of ephemeral character, support the previously made statement. It is probable that the formation of the deposits took place in the presence of aggrading and increasing permafrost. The successive annual series or the series of many years became top portions of the aggrading permafrost.

In addition, various periglacial structures are also important which occur in many places in the rhythmically stratified slope deposits. Such structures as epigenic and synchronous, i. e. synchronous structures of frost-fissure polygons, have been found in the deposits.

The rhythmically stratified slope deposits are of great importance for paleogeographical reconstructions of climate and morphogenesis. The deposits helped to fill up the closed depressions, small denudation valleys, and river valleys where they underwent further displacement. In all probability, these deposits comprised the greatest part of the matter which filled up the concave forms during the last cold stage.

A part of the rhythmically stratified deposits comes from the altered, exclusively congelifluxion deposits, as e.g. the sands, yellow in colour, occurring in Góra Św. Małgorzaty. Recently, Z. Klajnert (1966) has found a similar phenomenon occurring on the so-called Dąbkowice rampart. Perhaps the stratified sands which are found in the Warsaw—Berlin pradolina and are classified as deposits of alluvial fans, are a variety of rhythmically stratified deposits. However, this problem so far has not been completely explained.

Formation of the deposits required particular conditions, first of all climatic conditions, although it was not restricted only to one time span even during the last cold stage. Presently at least two generations of rhythmically stratified deposits are known. The first originated in the waxing phase, the second one, at the time of the climax of the last cold stage.

Periglacial structures are particularly valuable remains of the phenomena formed in the Pleistocene. The structures of the last cold stage yield valuable materials which permit to draw conclusions pertaining to the events that took place at various time spans of that stage and the climatic conditions that accompanied these events. They were responsible for respective processes, and facilitated their generally intense course. The different phenomena took place in various periods of the last cold stage, parallel with the climatic changes and the differences in geographical environment caused by these changes resulted in the formation of definite structures, typical of each phenomena.

This is why the periglacial structures are not only direct determinants of the past climate, but also may be considered as important features of

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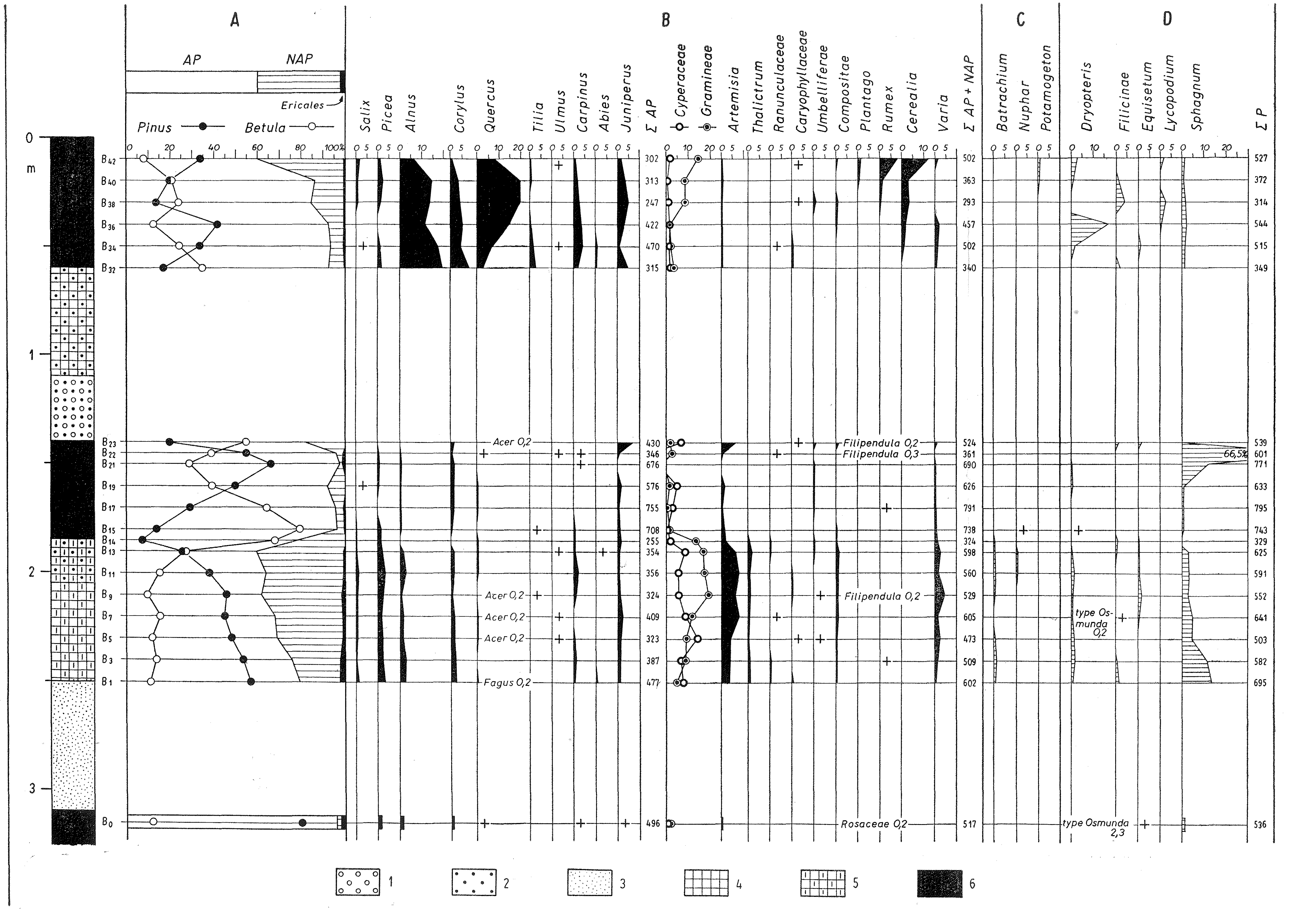

Fig. 3. Józefów. Pollen diagram of upper organic deposits (after J. de Ploey)

1. gravel; 2. sand; 3. clay; 4. silt; 5. peaty silt; 6. peat

the deposits in which they occur. They make it possible to define the stratigraphical position of individual deposits, and particularly, the mineral deposits which do not contain organic remains. They also help to approximate chronology which would be more difficult to determine with rarely occurring organic deposits. Stratigraphical scheme of the periglacial structures gives a basis for paleogeographical conclusions, particularly with reference to the course of climatic changes.

However, it can be concluded that periglacial structures may show the above mentioned values only if their origin is defined accurately. Because of insufficient detailed investigations and comparative studies this is a very difficult task. On the other hand, the origin of some periglacial structures is not known enough. Nevertheless, there occurs a series of types of these structures with clear origin.

Structures of frost-fissure polygons belong to the best recognized ones, and they are very valuable, mainly because of their paleogeographical significance. They occur almost over the entire Poland. However, for the most part, these were described only as fragments of polygons visible in cross-sections and respectively called frost wedges or ice wedges. Usually they were examined in short sections and only very rarely in horizontal projections.

Large fragments of frost-fissure polygons have been discovered at Skaratki, near Domaniewice (Chmielewski 1961) and at Nowostawy, near Stryków (Pierzchałko-Dutkiewiczowa 1961). Here tetragonal polygons have been observed, their side having 18—20 m in length. The site at Nowostawy, shown to the participants of the VI INQUA Congress, so far was the best in Poland and maybe in the entire world. It gave the widest horizontal picture of the Pleistocene polygonal net.

In 1963, a new site was discovered at Walewice, near Łowicz. Here, a polygonal pattern has been exposed in one plane of an area over 80 m², whereas the section at Nowostawy was only about 30 m². The size of the polygons occurring at Walewice is almost identical to those at Nowostawy (Pl. 7).

J. Goździk (1964) observed cross-sections of frost-fissure polygons along the Łódź—Tomaszów aqueduct. On the basis of computations of distances between over ten frost wedges, he estimated the average size of the polygons to be also about 20 m.

The fissures forming the polygonal nets undoubtedly originated as a result of thermal contraction and developed in thick permafrost. Whether this was permafrost or only deep but seasonally frozen ground, depends upon the alternatives to be accepted: either fissures with secondary infilling after the fissure ice, or cracks with the original mineral infilling.

The problem is relatively new, for only A. V. Pataleyev (1955), N. S. Danilova (1956) and T. L. Péwé (1959) showed the presence of the structures called by the present writer frost-fissure polygons with original infilling (J. Dylik 1963, 1966). So far, all fossil ice-wedges and fissure polygons were thought to be the result of infilling the cracks after melting out of fissure ice.

Since this is a new problem, sufficient evidence is lacking, particularly for the structures of previously examined polygons. J. Goździk (1964) thinks that the structures occurring along the Łódź—Tomaszów aqueduct belong to the category of originally infilled cracks. His opinion is mainly based on topographical situation of the polygons occurring on the well drained surfaces. On the other hand, the analysis of infilling of polygonal fissure systems at Walewice show the presence of secondary infilling after the melting of fissure ice. This points to the presence of fissure material that could not occur at the surface during the formation of cracks. The stones up to 1 cm in diameter, found in fissures support this opinion. Such stones could not have been part of the primary infilling, because rapidly formed elementary fissures did not reach more than few mm in size. A characteristic subsidence of stone pavement above the frost-fissure also lends proof for the secondary infilling. This pavement which was formed at the time of fissure-ice existence has been disturbed by melting of ice. Later the individual stones fell into the empty fissures, and the stone mantle was bent down along the fissures (Pl. 8).

Injection structures, also called structures of cryostatic pressure (A. L. Washburn 1955; J. Olchowik-Kolasińska 1962) or congelistatic pressure (J. Dylik 1961 b, 1963; A. Dylikowa 1961) also point to the previous presence of permafrost. They also indicate a very severe and frost climate.

The structures were formed as a result of rapid freezing of the active zone of permafrost. Depending upon the quantity of water in the frozen zone and the rate at which the temperature decreased, injections of mineral mass oversaturated with water or water injections were formed.

Common structures are traces of mineral injections. They were most exhaustively described by A. Dylikowa (1961) and J. Olchowik-Kolasińska (1962), and occurred in many sites which were shown during the excursions at the VI INQUA Congress, as e.g. at Działki Niesułkowskie and Katarzynów. They occur mainly in the form of twisted anticlines, acutely terminated at the top. Frequently, the topmost part appears in the form of a mace with a greatly narrowed neck. In addition, irregular forms composed of twisted layer fragments are also known.

Water injections were responsible for the formation of other type of structures that are called injection-ice structures. They are called so, because water violently squeezed upwards in a closed system froze immediately, making the injection ice (Shumskiy 1955). In that way ice accumulated in the form of laccoliths which are also called hydrolaccoliths, ice laccoliths, and according to the suggestion of the Subcommission for Terminology of the Commission on Periglacial Geomorphology of IGU, cryolaccoliths. On the surface of the present-day permafrost, cryolaccoliths appear as round hummocks with a diameter ranging from few meters to several hundred meters and up to ca. 50 m high. They are known by the Eskimo name *pingo* or the Yakutian name *bulgunniakh*.

Remains of the Pleistocene pingos have so far been distinguished only on the basis of geomorphological features of degraded original forms which occur as circular and oval drainless depressions (Maarleveld & Van den Toorn 1955; Cailleux 1956, 1961; Pissart 1956, 1958; Picard 1961).

Fossil Pleistocene structures of cryolaccoliths were recognized and described only in 1963 (Dylik 1963b). The most important feature of these structures are deformations of primary stratification in the form of concentrically bent layers. Such deformations were produced by injection ice. The voids previously occupied by ice underwent different development, thus two types of traces left by cryolaccoliths may be observed (Pl. 9).

One of them is small fossil structures of 2—3 m to ca. 10 m in diameter. Haphazardly arranged material occupies the central parts of the structures where concentrically bent layers, deformed by injection ice, break off. After the melting of injection ice the voids were replaced by the haphazardly arranged material which presently occupies the central part of the structure. This type of cryolaccolith structures for the first were described at Józefów, near Rogów (Dylik 1963b). They were also found along the Tomaszów—Łódź aqueduct, and just recently also in the vicinity of Rogoźno, near Łowicz.

The structures at Józefów belong to the younger generation of cryolaccoliths that developed within a depression left by a large pingo (ca. 400 m in diameter). After melting of such a great mass of injection ice the space was only partially filled, therefore distinct depressions are found on the surface. In the marginal parts of the depression, lower portions of the layers are preserved which are deformed by injection ice and concentrically bent upwards (Pl. 10).

To the structural complex of the two types of cryolaccoliths also belong the old channels of injection waters, which at the same time are similar to the frost cracks. Naturally, these channels are not empty but filled like the infilled interstices after ice laccolith.

Thermal karst is a process of the melting of ground ice within permafrost with subsequent formation of relatively empty spaces. Thus, all the primary periglacial structures altered by the melting of ground ice belong to this type of thermal karst forms. Of course, these structures are larger and more distinct the larger have been masses of ground ice. Therefore, the largest structures and even the land-forms resulted from melting of injection ice. This ice was represented in much greater mass than other types of ground ice. To the primary structure only marginal parts of small cryolaccolith structures belong i.e. those layers which are concentrically bent upwards. The whole structure especially the space infilled after the melting of ice, is a result of an alteration and constitues thermal karst structure (Pl. 11).

Many, and perhaps the majority, of fossil periglacial structures belong to the thermokarst category, because they are not primary structures but only their derivations, transformed by the melting of ground ice. Structures of frost-fissure polygons with secondary infilling after the melting of the ice also belong to the thermal karst phenomena.

Fossil structures of thermal karst are of great paleogeographical importance. First of all, they are valuable evidence for the previous presence of permafrost and give direct evidence for the process of ground-ice disappearance. Further research on the thermal karst and the thermokarst structures will make it possible to understand the degradation of permafrost. However, observations pertaining to this problem must have adequate data which will enable the differentiation between structures which originated as a result of local thermal karst and those which developed due to a general melting of any ground ice, a process leading to the general degradation of permafrost (Dylik 1963a, 1966).

Frost heaving structures resulted from deformation caused by the formation of segregation ice. They are gentle, dome-like anticlines. Hummocks of thufur type are considered to be the most common equivalents of these structures in the present-day periglacial areas. Of the same origin also are peat mounds, the formation of which is associated with segregation ice. They are over tens of meters in diameter, and are called *palsa*.

In contrast to the injection ice, the formation of segregation ice is a slow process and takes place under relatively milder climatic conditions. The segregation ice that originates during slow freezing process influences the cementation of mineral particles in the permafrost. However, its formation is not completely connected with permafrost.

Structures of the upfreezing of stones represent a new type of periglacial structures and were described for the first time in 1961 (Dylik 1961b). The example from Działki Niesułkowskie (Pl. 12) illustrates the formation of such a structure in the beginning stage of development. Upfreezing and lifted stone disturbs the primary structure of the material in which it occurred. Into the space left by the ejected stone fine particles detached from the walls of this space seeped in. Thus, a structure develops which is pocket-like at first. During further movement of the stone, it elongates upwards and takes a chimney-like form. However, structures of this type cannot be always recognized, since the presence of stones in the upper part of the structures can be observed only under exceptional conditions. In other instances we have only the analysis of the structure in three-dimensional system.

Permafrost block structures so far have not been differentiated. Only the small packets of loose, probably frozen material were described because such lumps found in the congelifluxion formations had been displaced entirely, similarly as the blocks of solid rocks.

At a buried slope of the Mroga river valley, near Walewice, a large permafrost block was discovered in 1963. It was formed of rhythmically stratified deposits. The layers of the block are mostly vertically oriented, whereas those of the same formation, in their original position, immediately near the buried slope, dip at an angle of 10°. The block rests almost parallel to the slope. Its length is about 8 m, and width ranges from 0.40 m to over 1 m, and maximum height hardly exceeds 1 m. The block is broken along the strikes of layers (Pl. 13, 14).

It should be mentioned that the block in vertical section looks like a structure of glacial tectonics. Only by digging further to the material underlying the block, an exposure of the block allowed to interpret the problem properly.

The above presented possibility for misinterpretation shows that it is necessary to distinguish this new type of periglacial structures. This is also important for many other determinants of permafrost.

CLIMATIC CHANGES AND MORPHOCLIMATIC EVENTS

The basis for chronological differentiation of the last cold stage are included in the stratigraphical sequence of its deposits. The individual lithological units defined by their textural and structural features permit to draw conclusions about the climatic conditions existing during the formation of the deposits and also the epigenetic structures. On the basis of the succesion of well defined lithological units we can also reconstruct the succession of climatic conditions varying in time and define the tendency of these changes. The resulting transposition of the stratigraphical scheme into climatic phases defines the general chronological scheme which is usually accepted for the entire Pleistocene and in particular, for the individual cold stages.

To the second category belong organic deposits and fossil soils which permit more definite and even absolute dating. At the same time the formations of this type, which are characteristic of the warmer stages i.e. interstadials, are more accepted as the basis for stratigraphy than the mineral deposits.

The upper peat overlying the Eemian at Józefów, near Rogów, represents the earliest organic horizon of the last cold stage. It has been dated as the Amersfoort Interstadial.

Presently, the Józefów Interstadial is best dated as the earliest interstadial of the last cold stage. However, it is found not only at Józefów. The knowledge of the individual lithological units of the Würm periglacial deposits and their succession which was obtained from detailed studies on the drainless hollow at Józefów, has led to interpretation in many other sites in Central Poland.

The detailed studies of fossil soils by B. Manikowska yielded much data concerning the interstadials of the last cold stage (fig. 4). This pertains to the earliest interstadials corresponding to the Amersfoort and Brörup. She correlated and made age determinations on the succession of the definite lithological units and the recognized types of fossil soils.

The organic deposits occurring at Jabłonów, Jeziorko, and Zielona Góra have been defined as probable determinants of the oldest interstadial. By the stratigraphical position these deposits are considered of Amersfoort age. They are analogous with the position of the upper peat from Józefów. Just as the upper peat at Józefów, these deposits show a close association with the Eemian deposits and underlie the lower series of rhythmically stratified deposits, and all periglacial structures.

To the same interstadial also belong fossil soils of podsolic type from Józefów which occur in a continuation of the upper peat bed and probably at Walewice, above the older buried slope of the valley.

Fossil soils formed during the second interstadial are more characteristic and more frequent. Well formed fossil soils occur at Bedoń, Kochanów, Jeziorko, Słowik, and Zielona Góra. These are brown soils, frequently of various podsolic character, resting above the deposits or soils of the

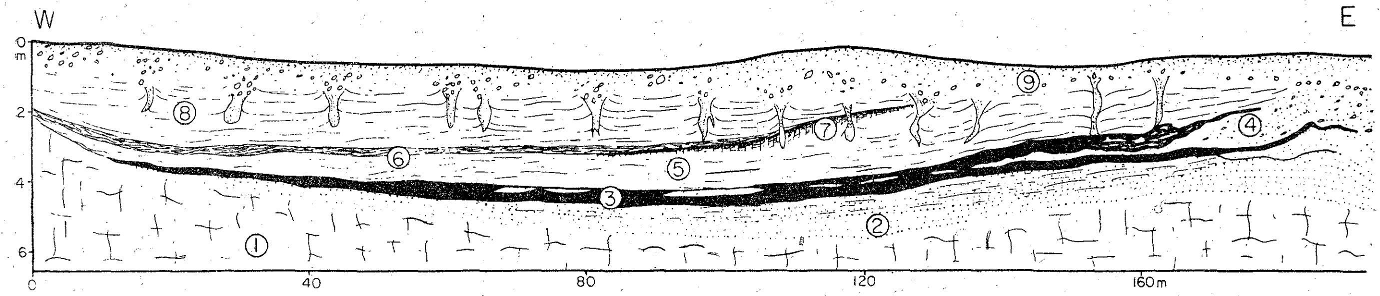

Fig. 4. Z i e l o n a G ó r a, Łódź region. Cross-section through the depression in the terrace of Miazga (after B. M a n i k o w s k a 1966)

1. boulder clay of the Warta stage; 2. sand with silt striae—lacustrine deposits; 3. peat, Eemian and first Würmian interstadial (Amersfoort?) in age; 4. stratified sand—slope deposit; 5. stratified sands and silts — lower series of rhythmically bedded deposits; 6. brown soil of the second Würmian interstadial (Brörup?); 7. silt; 8. stratified sands and silts — upper series of rhythmically bedded deposits, with frost-fissure polygons in the top part; 9. sand with pebbles

oldest interstadial and usually at the top of older rhythmically stratified deposits. Their stratigraphical position and the type of the soil formed in a forest environment leads to the correllation of the second interstadial with the Brörup Interstadial.

At Rogóźno, near Domaniewice, organic deposits occur as a 10 cm thick layer of gyttja which rests in the top part of a fine sand alternated with silt and clay. The sand occurring at Rogóźno within the pradolina terrace is ca. 4 m thick and rests on the Warta morainic clay. In the Bobrówka river valley, under the bottom of a pond called Jezioro Okręt such sands are 10 m in thickness and are separated from the sand and gravel which in turn overlie morainic clay by a 2—5 m thick series of bedded organic deposits: lake marl and peat. The organic deposits occurring in the Okręt basin were reached by deep-boring only in November and December 1963, therefore they have not been studied as yet. However, we can already assume that these are Eemian deposits, but a later age for the top portion should not be excluded. One may also suppose that the stratified sands and silts overlying the Eemian series within the Okręt basin and on the Warta clay at Rogóźno belong to the oldest deposits of the last cold stage. Maybe they are even contemporaneous with the older, rhythmically stratified deposits from Józefów.

K. Wasylikowa of the Institute of Botany, Polish Academy of Science, Cracow, made pollen analyses and diagrams of the Rogóźno deposits. According to this author, at the time of the formation of organic deposits at Rogóźno, the adjacent area was woodless or had a park-steppe character with rare patches of pine and birch. Such treeless or tundra-park formation occurred under the conditions of cool but not cold climate, since the presence of *Filipendula* and *Plantago media* required relatively high temperatures.

A diagram made on the basis of the samples taken vertically at 20 cm intervals is somewhat characteristic and does not show any changes. This limits Wasylikowa's observation for the age of the organic deposits from Rogóźno. Thus her opinion with all the reservations is that the deposit is older than the Oldest Dryas.

The organic deposits from Rogóźno are constituents of fossil cryolaccolith structures, thus they are older than the formations of the crylaccoliths. This supports the hypothesis for the older age of the organic deposits from Rogóźno, since the younger generation of the Józefów cryolaccoliths, which most probably is contemporary with the Rogóźno cryolaccoliths, originated in the climax of the last cold stage.

It is possible that the boggy soils found by B. Manikowska at Bedoń and Słowik correspond to the organic deposits occurring at Rogóźno.

The time of their formation also falls in the climax phase of the last cold stage. From the age and character of these deposits we may suppose that they belong to the cool Paudorf Interstadial.

Fossil soil of gley type occurred at the bottom part of the younger, rhythmically stratified deposits at Józefów (Pl. 15) and was also formed in the climax phase. The Paudorf age is also possible because of the stratigraphical position of this soil and the climatic conditions characteristic of it.

Thanks to the investigations made by M. and W. Chmielewski and by K. Wasylikowa at Witów, near Piątek, new data pertaining to the Bölling and Alleröd Interstadials was obtained. They also made archeological and floristical studies and the deposits were dated by means of C^{14} (Chmielewska 1961; Chmielewska & Chmielewski 1960; Chmielewska & Wasylikowa 1961; Dylikowa 1958).

Because of its climatic features, the last cold stage was rather uniform, except for considerable changes in climate and many events determined by it. In other words, great climatic changes and events corresponding to these changes were continuous. At the end of the Eemian, cool and humid climate became more and more colder and dry, and attained its maximum continental character with the very low temperatures. After that maximum phase the climate became again more humid and cool, and it turned into warmer towards the lower boundary of the Holocene. The form and direction was also similar for the formation of morphoclimatic events. The climatic changes, in the form of interstadials, are secondary changes. They did not influence the general direction of climate development, but caused only a small variation or oscillation. The same maybe applied to the morphoclimatic events. The formation and development of permafrost were made by major climatic changes. During the last cold stage, outside the extent of continental glaciation, probably the permafrost was formed only one time and developed parallel with the increasing continentality. Minor climatic changes caused only degradation or aggradation of permafrost.

Major climatic changes mark three phases in the last cold stage: the waxing phase, the climax, and the waning phase (Dylik 1961b). The terms *waxing* and *waning* have been used due to the increasing or decreasing continentality.

The waxing phase begins at the outset of the last cold stage. However, it must be explained in greater detail. From geological and geomorphological point it appears that the beginning of the cold stage should be best defined on the basis of the first traces of periglacial phenomena. Such traces should be dated and tied with the paleobotanical system, a problem which has not been discussed at all. However, we may make an analogy with the course of the present-day boundary zone of periglacial areas, which according to Troll (1944) and Frenzel (1960) include the Boreal zone.

To the deposits of the waxing phase belong the oldest deposits of the last cold stage, together with the organic deposits and fossil soils of two earliest interstadials. Thus, are included the sands and gravels from Katarzynów (Dylikowa 1961b), Smardzew (Klatkowa 1961), sands from Góra Św. Małgorzaty, and maybe also sands with gravels occurring under the congelifluxion till at Walewice. Congelifluxion tills found at Katarzynów and Walewice, and older rhythmically stratified deposits at Walewice and Józefów have undoubtedly been laid down at the time of the waxing phase. In the same phase were also formed the rhythmically stratified deposits from Dąbkowice, and the previously mentioned sands alternated with silts and clays in the pradolina, near Rogóźno. Probably, the similar formations occurring near Gieczno and Witów also belong to this phase. The older rhythmically stratified deposits at Józefów underlie the upper peat which most probably is from the oldest interstadial.

Sand and gravel deposits, which are the oldest ones in this phase, point to an increased activity of water flowing in the valleys which were usually formed at the decline of the previous cold stage. These processes took place under conditions of cool and humid climate as reflected by taiga type vegetation (fig. 3). Later, the vegetation cover became less dense causing a vigorous activity of deflation processes, which were responsible for the eolian sands in the top part of the gyttja underlying the upper peat at Józefów.

At the time of formation of this type of peat, the open tundra again gave way to a forest formation, which may be considered as an indicator of warmer and more humid oscillation of the oldest interstadial.

The congelifluxion tills from Katarzynów and Walewice show more severe climate. It was still humid but very cold, more so than at the beginning of the waxing phase, before the Józefów Interstadial. The process of congelifluxion did not end after the sedimentation of the above mentioned slope till, but persisted in forming the sedimentation of the older rhythmically stratified deposits, as it may be best observed at Walewice.

It can be concluded from the above mentioned lithological features that during the formation of the rhythmically stratified deposits, the climate became colder and drier and also continental. These conditions were already favourable for permafrost formation. The activity of congelifluxion processes soon after the Józefów Interstadial prove the formation of permafrost. They were responsible for the deposition of the slope till and their activity was continuous and not of short duration, and persisted through the entire formation period of the older series of rhythmically stratified deposits.

Congelistatic structures found in the congelifluxion till and in the older rhythmically stratified deposits are additional proofs for permafrost formation. Furthermore, the large pingo which was formed at Józefów after the time of sedimentation of the upper peat represents the most valuable proof.

The beginning of permafrost formation and its aggradation show the appearance and increase of continentality of the colder climate. This occurred already at the time of the waxing phase. The formation of permafrost mainly due to the accumulation of segregation ice was a slow process. Traces of the beginning of permafrost formation cannot be found at all. On the other hand, the formation of injection ice takes place very fast, and results from strong thermal gradients that are indicators of growing continentality. Therefore, it appears that the beginning of pingo formation should be considered as the determinant of the end of waxing phase.

The climax phase of the last cold stage is not considered here as an analogy to the maximum of the last glaciation. From the above assumption it can be concluded that phases will be distinguished on the basis of lithologic features which reflect climatic conditions. Differentiation of lithologic features is a direct result of morphoclimatic events, among which the development of permafrost and the accompanying processes play the most important part in the periglacial environment.

The advanced formation of permafrost, severe continental climate, and formation of great injection-ice masses represent already certain features of the climax of cold stage. However, data for a better definition for the beginning of the climax is lacking. The pingo at Józefów was formed after the oldest interglacial of the last cold stage, and the upper boundary of the formation of this cryolaccolith can hardly be determined.

It can be concluded that the formation of pingo at Józefów was completed before or rather after the second of the oldest interstadials. Because of this the beginning of the climax phase should be pushed back. In all probability, the beginning is distant in time from the maximum extent of the last ice-sheet.

Congelifluxion deposits containing numerous eologlyptoliths and younger rhythmically bedded deposits represent the most important and the most common deposits of the last cold stage climax. Those occurring in Góra Św. Małgorzaty and at Józefów belong to the best recognized deposits.

The congelifluxion deposits at Józefów rest directly on the gleyed deposits of the older generation of rhythmically bedded ones, and fill up the hollows after pingo degraded. On the other hand, in Góra Św. Małgorzaty they are underlain by organic deposits which are considered to belong to one of the oldest interstadials. Thus, a considerable gap must have existed between the final phase of the sedimentation of the older rhythmically stratified deposits and the formation time of congelifluxion deposits. We should stress that the events occurring at the climax are more numerous and diversified than it would be expected considering the number of the deposit types.

It was already previously mentioned that after sedimentation of the upper peat, large pingo was formed in the Józefów depression. Perhaps before the degradation of that cryolaccolith, an intense eolian erosion took place which resulted in the formation of eologlyptoliths. They were later displaced by congelifluxion.

Melting of the injection ice, and consequently also the degradation of pingo, must have taken place before the formation of soil occurred on the rhythmically stratified deposits of older generation. No evidence exists that the degradation of pingo was due to a general warming of the climate. It is possible that degradation of the cryolaccolith has resulted from the thermal karst under the influence of local conditions. This can occur under very severe climatic conditions and even in the presence of aggrading permafrost (Kachurin 1955; Dylik 1963a).

Only after the second interstadial a long period of congelifluxion activity started. The intensity and duration of this process is shown by the congelifluxion deposits occurring together with alternating downwash sediments in Góra Św. Małgorzaty which are up to 10 m thick. At Józefów they do not exceed 2 m, because they have been accumulated more uniformly on a fairly large bottom of a small *alas* lake.

After the congelifluxion processes ended, a new period of numerous cryolaccoliths started, which can be seen in Góra Św. Małgorzaty, Rogóźno, and Józefów. Those processes recurred several times during the sedimentation period of the younger generation of rhythmically stratified deposits. This means that the beginning of an oscillation was characterized by a greater humidity. At the time of congelifluxion development, the climate became more severe and contrast.

The new series of the rhythmically stratified deposits, just as in the older generation, reflected a rapid aggradation of permafrost. Rhythmic bedding and small thickness of alternately sedimented layers indicate a low temperature and point to the shallow seasonal thawing. The formation of injection ice shows great temperature gradients.

When the cryolaccoliths of second generation were formed or a little later, frost-fissure polygonal systems develop which were filled with fissure ice. This should be interpreted as a sign of an extremely continental cold climate characterized by frequent oscillations of low temperatures, at least $-20\,^{\circ}$C. The period of formation of these polygons may be considered as the apogee of the climax and also of the entire last cold stage.

The formation of the frost-fissure polygons was accompanied by a new period of intense eolian erosion. Open areas of debris tundra with little or no snow cover, presented favourable conditions for effective wind activity. Faceted stones and other eologlyptoliths found in great numbers in stone pavements which covered the surfaces of polygons show this eolian process. Most probably it took place simultaneously with the frost-fissure formation. This can be shown by stone pavements occurring on the surface of the polygons at Nowostawy, Skaratki, and Walewice. Probably also at the same time eolization of the stones occurred; wind-worn stones are frequently found in the so-called stone series in Góra Św. Małgorzaty.

The time of the greatest intensity of the characteristic features of the cold and continental climate was not only the apogee of the last cold stage, but also the end of the climax. The formations covering the polygons, first of all, the stone pavements, already belong to the next and last phase.

The waning phase of the last cold stage has not been adequately explained, mainly because the corresponding deposits are not always easily found. They are distinctly marked above the surface of the frost-fissure polygons. However, they do not exceed 1 m in thickness and are strongly reduced and destroyed by soil processes. The deposits of the late waning phase, which occur in the dune facies, are best recognized. At Katarzynów and Witów, successive deposits of waning phase have been studied beginning with the top layer of the Oldest Dryas.

A series of sections found in Góra Św. Małgorzaty allows to trace the oldest deposits of the waning phase. On the truncated surface of the yellow sands rest the above mentioned stone series. These yellow sands are analogous to the younger generation of rhythmically stratified deposits and constitute the top series of the climax deposits. The stone series begins with a bed of stones 20 cm thick and covered with fine, bedded sands, bedded gravels, and fine sands. These in turn are discordantly overlain by the second stone series and covered in similar fashion. The last of these covering deposits contains bedded coarse sand and gravel. Its truncated surface is overlain by the third stone series.

The stones are from 15 to 20 cm in diameter. Most of the boulders show distinct traces of strong eolization which was responsible for the faceted stones and other eologlyptoliths. Long axes of the stones are oriented like in a fan in W—E direction.

The bedded sands and gravels are most probably down-wash deposits. The stone orientation was also controlled by the river. However, the origin of the stone beds should be related to the slope processes. The eolization of the eologlyptoliths took place before slope transportation, most probably during the climax of the last cold stage.

The stone series occurring in Góra Św. Małgorzaty signifies the beginning of the waning phase. It indicates an increase of water quantity and a general change of the climate, which was more humid and probably warmer. The run-off underwent perturbations which were caused by congelifluxion as shown by the beds of accumulated stones.

Stone pavements, which are common in the top part of Pleistocene formations in Central Poland, especially those resting on the surfaces of the frost-fissure polygons, as e.g. at Nowostawy, Skaratki, and Walewice, can be correlated with the all or a part of the deposits of stone series from Góra Św. Małgorzaty. So far it is not clear whether these pavements are reduced or shortened or whether they correlate to the entire stone series, or only of the lowest stone layer.

The earliest part of the waning phase represented in Góra Św. Małgorzaty by the stone series probably falls in the early period of ice-sheet shrinkage. Considering the fact that Góra Św. Małgorzaty is located in the axis part of the Warsaw—Berlin pradolina and outside the ice-sheet front (ca. 50 km), we may assume that an increased activity of the run-off has been caused by glacial meltwaters.

More probably the increase in the river flow during the waning phase of the last cold stage was a reflection of the climatic change. H. Klatkowa (1965) found river sands of considerable thickness, which filled a dry valley near Rudunki, north of Zgierz. These sands rest discordantly on the deposits of the climax phase, thus they may represent the formation of the early waning phase. Geographical situation of the sands of Rudunki supports the hypothesis for the direct climatic influence upon the increased activity of rivers.

Similar sands also occur in other valleys, as in the Miazga river valley. They make up the most important portion of the infilling material of the valleys cut during the climax phase. In the intervalley plains, slopes, and various hollows stratified covering sands are equivalent to these formations.

The stratigraphy and the deposits overlying the formations of the early waning phase, represented by the stone series, as well as the valley sands and stratified cover sands of approximately the same age are little known. The dune facies are an exception, for in contrast to other deposits of the younger part of the waning phase they are known excellently. It should be stressed that the deposits of the early waning phase of the last cold stage were formed in half the time of the whole waning phase.

In the top part of the Pleistocene deposits outside the dune areas, loess-like deposits and unstratified sands are commonly found. Usually these deposits do not exceed 1 m in thickness and show some changes of soil processes that hinder a closer examination.

The loess-like formations have features that show eolian origin. They are composed of silt and loess particles. They cannot be considered as deposits originating as a result of soil-forming processes, because they do not show any enrichment in colloids. In addition, the distinctness of this deposit is stressed by the presence of silts and not clay particles.

The determination of the age of the loess-like sediments presents some difficulties because they are not thick and occur close to the present-day surface. However, there are certain features in this formation which permit to determine their age and origin.

Loess-like deposits are frequently associated with the stone mantles, as e.g. at Lipiny near Brzeziny (J. Dylik 1952) where the deposits filled the hollows in the stone pavement; they were interpreted as stone circles. Such relationship permits to conclude that the age of the loess-like cover cannot differentiate very far from the pavements, which were put in the beginning of the waning phase.

However, the loess-like formations do not always rest immediately on the stone pavements. For example, in the Józefów depression they overlie the stratified covering sands. Also in the Pilica—Łódź aqueduct, J. Goździk (1964) has found that a loess-like deposit rests on stratified covering sands and is overlain with the upper covering sand showing no stratification.

In can be concluded from the above discussion that the time of sedimentation of the loess-like deposits falls at the end of the early or the beginning of the late waning phase. Stratigraphical position of these deposits is shown by the top of the stone series from Góra Św. Małgorzaty and the top of the stratified covering sands. Most probably the sedimentation of the loess-like deposits precedes the sedimentation of the dune sands.

The stratigraphy of the deposits and the succession of the events in the early waning phase of the last cold stage are well known from the works of M. and W. Chmielewski, A. Dylikowa and K. Wasylikowa,

(W. Chmielewski 1961; M. Chmielewska & K. Wasylikowa 1961; A. Dylikowa 1958).

The sands deposited by wind and downwash comprise the first eolian cover in the waning phase. At Katarzynów these sands have fossil soil which is placed in the Bölling Oscillation. This interstadial or oscillation was thoroughly studied floristically and dated by C^{14} at Witów, where the organic deposits were found.

The development of true parabolic dunes took place immediately after the Bölling. The Alleröd recognized by the organic deposits and by fossil soil of Usselo type represented a period characterized by stagnation of dunes, growth of vegetations on them, and formation of soil cover. At the close of the Alleröd Interstadial man appeared at Witów, and during the Younger Dryas parabolic dunes formed ridge-like land-forms.

The time interval for the descending phase is similar to *Spätglazial*, but it does not coincide with it. The *Late Glacial* begins with the ice-sheet retreat from the end moraine position of the Pomeranian stage (Gross 1958). On the other hand, the waning phase begins with a change of climate which tends to be relatively warmer and more humid. The features of the deposits laid down at that time served as a basis for distinguishing that phase. Most probably climatic conditions also changed as compared with those predominating during the climax. They were responsible for shrinkage of ice-sheet beginning with its maximum extension. Thus, the beginning of the *Late Glacial* thought to be about 17 000 years ago[1] shows that the beginning of the waning phase must have been considerably earlier. K. Wasylikowa (Chmielewska, Wasylikowa 1961) described the characteristic climate and vegetation for the latest subphases of the Pleistocene. She based her conclusions on Witów studies (Fig. 5).

The climate of the Oldest Dryas was subarctic, and the vegetation bore a woodless tundra character with the brushwood of willow and dwarf birch. During the Bölling, which lasted from 12 300 to 11 825 B.P. (Chmielewska, Chmielewski 1960), the climate became moderately cool, and the area was covered by a park-like forest with birch and aspen.

Recurrence of the subarctic climate took place in the Older Dryas. The forest withdrew and only single trees remained in the open vast areas partly covered by seabuckthorn and *Artemisia*.

The forest reappeard in the Alleröd which lasted from 11 600 to 11 065 B.P. (Chmielewska, Chmielewski 1960). At first these were sparce forests of birch and birch-pine. Later, birch was replaced by the pine,

[1] Personal communication by Professor H. Gross (February, 5th, 1962).

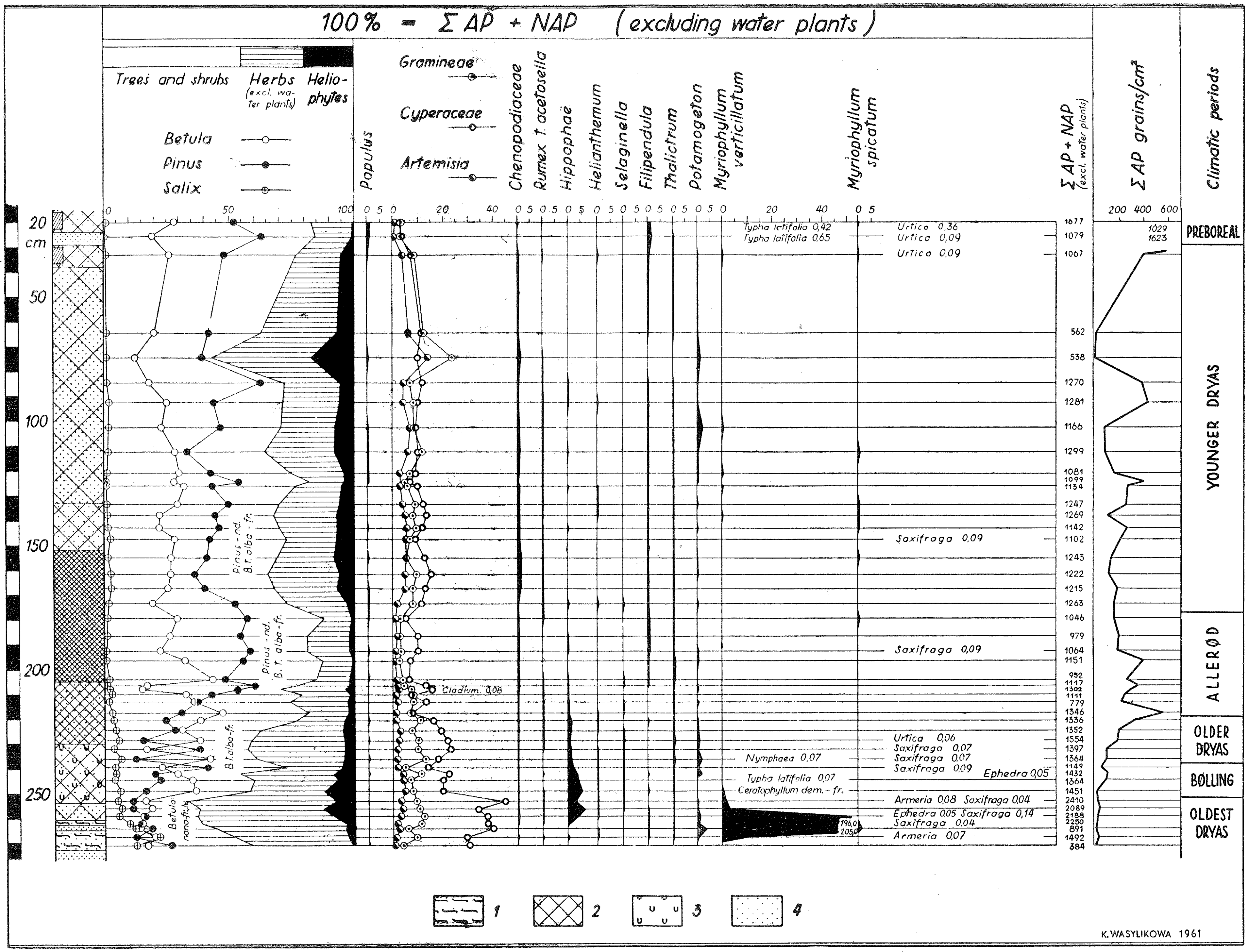

Fig. 5. Witów. Pollen diagram (after Chmielewska and Wasylikowa 1961)

1. *Amblystegiaceae* peat; 2. coarse detritus gyttja; 3. lake marl; 4. sand

and pine forests became dominant. The climate was moderate with warm summers, and fairly continental.

A repeated movement of the polar boundary of the forest to the south took place in the Younger Dryas due to the recurrence of subarctic, dry and continental, climate. The landscape was dominated by a park-like tundra with steppe vegetation and various kinds of *Artemisia.*

Translated by Romuald Żyłka

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Photo. by J. Dylik

Pl. 1. Sikawa. Glacial tectonic structure, type of deformations produced in plastic material

Photo. by J. Dylik

Pl. 2. Góra Św. Małgorzaty. Stone series

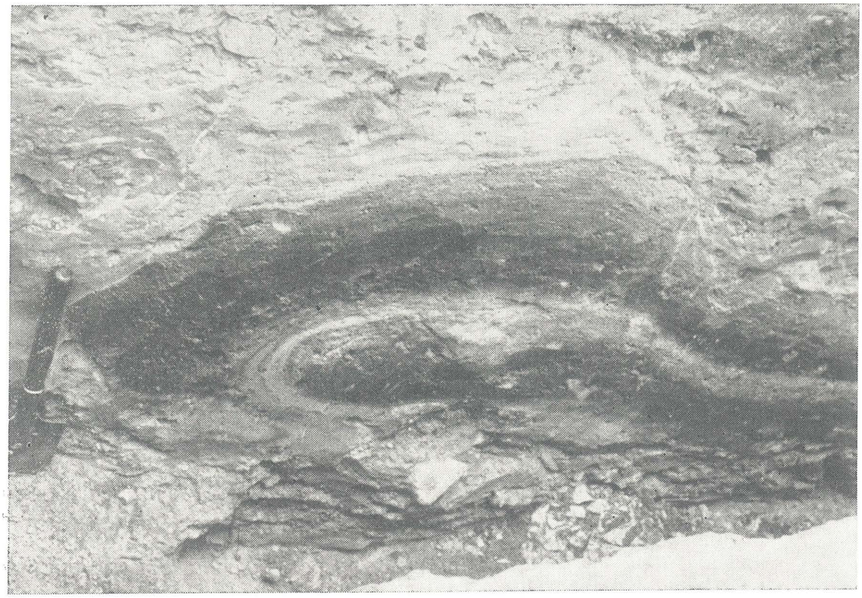

Photo. by J. Dylik

Pl. 3. Góra Św. Małgorzaty. Lobe buried in deposits of amorphous congelifluxion

Photo. by L. Jędrasik

Pl. 4. Walewice. Congelifluxion lobe deformed by posterior injection process

Photo. by J. Dylik

Pl. 5. Walewice. Distal part of rhythmically bedded deposits

Photo. by J. Dylik

Pl. 6. Walewice. Proximal part of rhythmically bedded deposits. Laminae accumulated by congelifluxion are to be seen

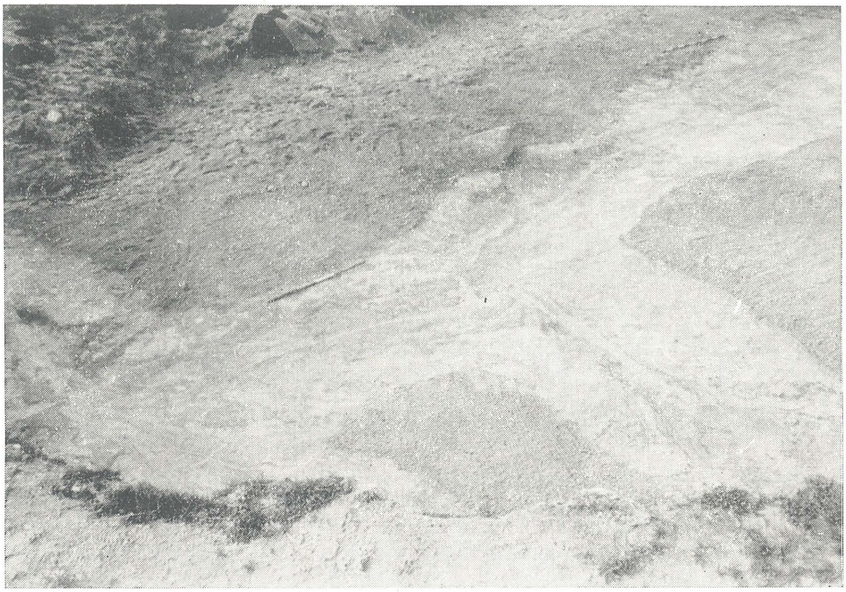

Photo. by L. Jędrasik

Pl. 7. Walewice. Fragment of frost-fissure polygon

Photo. by L. Jędrasik

Pl. 8. Walewice. Frost fissure developed in stone pavement

Photo. by J. Dylik

Pl. 9. Józefów. Structure of small cryolaccolith

Photo. by J. Dylik

Pl. 10. Józefów. Structure of the border part of the pingo

Photo. by L. Jędrasik

Pl. 11. Józefów. Thermokarst structure originated through degradation of a cryolaccolith

Photo. by J. Dylik

Pl. 12. Działki Niesułkowskie. Upfreezing structure of a stone

Photo. by J. Dylik

Pl. 13. Walewice. Fossil slope and vertical section through broken off frozen block of the slope

Photo. by J. Dylik

Pl. 14. Walewice. Exhumed frozen block

Photo. by L. Jędrasik

Pl. 15. Józefów. Fossil soil of a gley type