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NATURE DU MILIEU GÉOGRAPHIQUE DES RÉGIONS PÉRIGLACIAIRES À LA LUMIÈRE DES DONNÉES PALÉOBOTANIQUES

Sommaire

La zone périglaciaire pléistocène possédait une flore spécifique qui n'a d'équivalent dans aucun des ensembles végétaux actuels. Les analyses des profils pulvérulents des dépôts périglaciares existant dans la partie européenne de l'URRS ont permis de nous renseigner sur la nature de cette végétation. Ce sont les steppes boisées et les toundras boisées avec prépondérance des plantes herbacées sur les plantes arborescentes. Les recherches ont montré la ressemblance entre les flores des périodes périglaciaires de la dernière et de l'avant-dernière glaciation. La particularité du climat de la zone périglaciaire a été confirmée par les données paléobotaniques.

Les savants polonais sont arrivés à d'importants résultats dans l'étude des conditions géographiques des régions périglaciaires. Dans les travaux des prof. J. Dylik, A. Jahn et de leurs élèves se trouvent présentés les résultats des recherches concernant la désintégration des roches, les formes des cailloux sculptés par le vent, les fentes en coin, les traces de l'écoulement des terres dans les conditions du pergélisol ainsi que toute une série d'autres problèmes du même domaine.

Dans la présente notice je tiens à attirer l'attention sur une autre façon de reconstruire les traits caractéristiques des régions périglaciaires. J'ai ici en vue l'étude des traces de la vie dans la zone périglaciaire. En Pologne le professeur Szafer et son école ont beaucoup fait dans ce domaine. Je désire attirer l'attention sur les résultats obtenus pendant les recherches effectuées dans les dépôts périglaciaires de la partie européenne de l'Union Soviétique et concernant les restes fossiles des plantes. Je me base sur les recherches faites en terrain par les collaborateurs du laboratoire des recherches sur l'histoire du milieu naturel de la Chaire de Géographie Générale de l'Université de Moscou: W. P. Gritchouk, M. P. Gritchouk, A. I. Danilova, G. N. Lisicyna, N. S. Sokolova et l'auteur. Les cinq personnes citées plus haut ont opéré la distinction des restes végétaux qui ont été trouvés.

Toutes les formations périglaciaires dont nous parlons ici se sont formées à une certaine distance du front du glacier à diverses périodes du pléistocène. La genèse de ces dépôts est diverse: ce sont des formations lacustres, fluviales, de solifluction (de congélifluction). On donne ci-dessous une brève caractéristique paléobotanique de ces dépôts, à partir des plus jeunes.

1.

Dépôts de l'époque glaciaire tardive aux environs de Leningrad. Les dépôts varvés apparaissent aux environs de Leningrad. Les recherches que l'auteur y a faites dans les trente dernières années ont démontré que ces dépôts se sont formés à la distance de quelques dizaines de kilomètres seulement du front de la calotte glaciaire pendant une période de 100 à 200 ans après le retrait du front du glacier de cette région. Les dépôts varvés des environs de Leningrad contiennent une riche flore fossile. On y distingue en premier lieu des restes macroscopiques: tels que les feuilles du saule polaire (*Salix*), du bouleau nain polaire (*Betula nana*) et de la dryas (*Dryas octopetala*), ainsi que des aiguilles de sapins, de l'écorce de bouleaux, des lambeaux de feuilles et de petites tiges des mousses. Secondement on a distingué dans ces formations beaucoup de pollens et de spores de plantes aussi bien ligneuses qu'herbacées.

Les résultats des examens du profil faits par M. P. et W. P. Gritchouk près de la ville de Kolpino située à 25 km SE de Leningrad sont présentés sur le diagramme (fig. 1). Le diagramme se compose de 4 parties. La partie gauche du dessin présente les rapports existant entre les pollens des plantes ligneuses et herbacées ainsi que les spores. On y voit les microrestes de tous les genres cités: ce qui frappe, c'est un boisement probablement très faible du terrain. La deuxième partie du diagramme démontre que la couverture ligneuse et buissonneuse de la région est représentée par le bouleau (*Betula*), le pin (*Pinus*), l'aune (*Alnus*) et, à un moindre degré, le sapin (*Picea*). Le grand pourcentage des pollens de l'aune s'explique probablement par le caractère de la région qui est celui d'une plaine basse. C'est pour la première fois qu'on est arrivé à constater les traits caractéristiques des plantes herbacées et des buissons. Dans la troisième partie du diagramme, on remarque qu'à côté des pollens de diverses herbes apparaissant en abondance il y a beaucoup de pollens des chénopodiacées (*Chenopodiaceae*) — jusqu'à 37%; des pollens de l'*Artemisia* — jusqu'à 25% et ceux de l'éphèdre (*Ephedra*). On a constaté dans toutes les épreuves les pollens des plantes de la famille des bruyères (*Ericaceae*). Dans la quatrième partie du diagramme (celle de droite) on a démontré que ce sont les spores de l'hypne (*Hypnum*) qui y prédominent, après eux viennent les spores des sphagnacées (*Sphagnum*), enfin les spores des filicinées (*Filicales*) et des lycopodes (*Lycopodiales*).

C'est ainsi que se présentent les données essentielles. On a constaté actuellement dans ces formations 40 catégories de plantes, la plupart d'entre elles ont été reconnues d'après des restes macroscopiques. Ce qui est nouveau, ce sont les données concernant l'existence de la flore périglaciaire herbacée — ce qui nous a fait défaut jusqu' à présent.

Bien qu'en comparant tous ces matériaux très diversifiés, on y ait constaté le présence d'éléments se rapportant au type de la toundra, au type forestier et steppique, il est impossible de rallier la flore périglaciaire des formations des environs de Leningrad appartenant à l'époque glaciaire tardive à aucun des types énumérés plus haut. On y voyait pousser les plantes des toundras muscinées et lichénées, des lacs et des marais, des forêts conifères et à feuilles, des steppes couvertes d'herbes diverses et de stipas ainsi que les plantes des eaux salées et des versants à grèves. Il est impossible de trouver actuellement un paysage complètement analogue. Une certaine analogie présentent les paysages actuels des plaines basses des bassins de la rivière Jana, Indigirka et Kolyma ainsi que les paysages des plateaux asiatiques. Nous donnions parfois à ce paysage périglaciaire le nom du paysage de la steppe boisée froide.

Je vais citer la description caractéristique de ce paysage d'après M. P. et W. P. Gritchouk (*1*, p. 140): „La région était faiblement boisée. Il y existait seulement quelques petits ilôts de forêts de bouleaux et de pins (*Pinus*) situés là où le sol a été mieux lavé et où le terrain était quelque peu protégé contre les vents froids de l'hiver. Lorsque les conditions du terrain étaient des plus favorables — au sens de la valeur du sol et autre — on trouvait de petites sections couvertes de sapins (*Picea*). Sur les sommets des collines morainiques où le fond argileux a été enrichi par du gravier apparaissaient des groupes herbacés avec un nombre important de xérophiles montagneux et steppiques ou des cenoses rappelant celles qui poussent dans les toundras ou dans les toundras des montagnes. Aux dépressions minimes du relief et aux sols salés des ensembles d'arbres comprenant les *Chenopodiaceae* ou *Artemisia maritima salina* ou *Artemisia incana*.

Ce genre de paysage s'est établi presque immédiatement après le retrait du glacier dans la région de Leningrad, à 100 km. à peine de son front. On se demande depuis combien de temps existait ce genre de paysage?

Il se trouve près de Leningrad toute une série de profils des formations qui expliquent l'histoire de l'époque glaciaire tardive et postglaciaire de la région. Un des profils qui attire l'attention est celui du marais de Lachtynsk. Ce profil a été étudié maintes fois et dernièrement très en détail par Mme G.N. Lisicina. Nous distinguons dans cette coupe une série continue de formations allant des dépôts lacustres glaciaires décrits ci-dessus pour la région de Kolpino jusqu'aux formations actuelles. L'ensemble de spores et de pollens dans la partie inférieure du profil présente le même aspect que celui de Kolpino. Cependant antérieurement, vers la fin de la période de yoldia, quand le front du glacier se retirait des moraines de Salpauselkä, la quantité de pollens des plantes steppiques — chénopodiacées (*Chenopodiaceae*) et artémisies (*Artemisia*) — décroissait rapidement dans la couverture herbacée.

Il en résulte que la limite supérieure des conditions périglaciaires dans la période postglaciaire échoit à la fin de la période de yoldia (plus précisément à la 2-me Yoldia ou autrement dit de la mer Echeneis). A ce moment le front du glacier s'est éloigné de la région que nous étudions de 200 km. environ — ainsi à cette distance il n'a plus eu aucune influence. G. N. Lisicina a obtenu les mêmes données pour les environs de Moscou.

Dans le bassin de la rivière Narova, entre le lac Tchoudsk et le golfe de Finlande, s'étend une plaine sablonneuse. C'est le fond asséché du lac proglaciaire. On y constate, comme dans les environs de Leningrad des formations varvées couvertes de sables lacustres glaciaires. Ces sables ont été dans la suite remodelés par le vent. Toute la surface de la plaine basse est couverte d'une quantité innombrable de dunes. Celles-ci présentent le caractère de vieilles dunes continentales de l'Europe du nord. Les dunes paraboliques aux bouts dirigés vers NW, aux versants raides tournés vers SE et aux versants doux-vers NW (fig. 2) y prédominent. Les espaces qui se trouvent entre les dunes sont remplis par de grandes tourbières qui, certainement, ne s'étaient pas formeés avant la période boréale. L'abaissement du niveau du lac s'est produit, comme le prouvent nos recherches, à une époque un peu plus tardive, après la déposition des argiles varvées de Kolpino — il y a quelques 12 000 ans environ. Ainsi, les vieilles dunes dont nous venons de parler, se sont formées, selon toute probabilité, à l'époque glaciaire tardive et dans des conditions périglaciaires en même temps que baissait le niveau des lacs périglaciaires barrés antérieurement par le front du glacier en retrait.

Pour le moment je me bornerai aux données présentées ci-dessus et se rapportant aux conditions périglaciaires existant à l'époque glaciaire tardive.

2.

Cependant les données concernant la flore périglaciaire ne se rapportent pas uniquement à l'époque glaciaire tardive. Nous disposons également de données pour la zone périglaciaire de la période englobant la dernière extension glaciaire — du Valdaï (de la Vistule), ainsi que pour la période du Dniéper (glaciation Varsovien I).

Au-delà des limites de la dernière glaciation, p. ex. aux environs de Moscou et à l'amont de la Volga, la question de la stratigraphie des dépôts se présente comme suit: sur la moraine de l'avant dernière glaciation (celle du Dniéper) s'étendent les dépôts provenant de son retrait, ensuite les dépôts de la dernière période interglaciaire, enfin les dépôts périglaciaires qui correspondent à la dernière glaciation (du Valdaï). Ces dépôts comblent souvent les enfoncements situés entre les restes de collines moraini-ques provenant de la glaciation du Dniéper. L'épaisseur de ces dépôts croît ordinairement vers le centre des abaissements. Ce sont le plus souvent les dépôts d'origine de solifluction (de congélifluction). Ces produits sont représentés par des limons, quelquefois des limons avec galets et débris végétaux. Ces formations sont souvent de provenance lacustre ou fluviale. Le plus souvent elles renferment des débris végétaux sous forme de pollens et de spores.

Nous connaissons bien des affleurements qui dévoilent les formations périglaciaires provenant du maximum de la période de la glaciation du Valdaï. Le profil le mieux étudié est celui qui se trouve près de la ville de Plosa sur la Volga, entre les villes Kostroma et Iaroslav. C'est un affleurement classique qu'on étudie depuis vingt ans déjà. Les données que nous présentons ici ont été publiées en 1948 par W. P. Gritchouk et E. D. Zaklinska. Sur la moraine de la glaciation du Dniéper se trouvent les couches interglaciaires et au-dessus d'elles les formations périglaciaires dont l'épaisseur atteint 6—7 m. Ces dernières formations sont représentées par des limons stratifiés ou bien des limons sans traces distinctes de stries et parsemés de petits galets provenant des roches cristallines. On trouve des restes végétaux dans presque toute la zone. A une profondeur de 5,7—6,9 m. de la surface, on observe dans les limons les couches de la tourbe de l'hypne avec galets et débris végétaux: *Scorpidium scorpioides, Sphangum repacium, Betula humilis* et *Betula nana* et au-dessus d'eux le limon sapropélique et sapropelite.

On a établi le caractère périglaciaire de cette série sur les trois bases suivantes: 1) elle est déposée sur les formations interglaciaires, 2) au-delà de la dernière glaciation, 3) elle renferme des débris végétaux caractéristiques.

Dans le limon sapropélique les pollens herbacés dominent sur les pollens des arbres qui sont représentés presque uniquement par le bouleau. On rencontre les spores des mousses vertes (*Bryales*), des lycopodes (*Lycopodiales*) et des filicinées (*Filicales*). Vu que les pollens des végétaux ligneux présentent ici $28^{0}/_{0}$, on doit en conclure que cette région était faiblement boisée. Ensuite il faut souligner que la quantité de pollens de l'artemisia atteint $27^{0}/_{0}$ et les pollens de Chénopodiacées — $6^{0}/_{0}$.

Les données très précises qu'on a obtenues permettent de considérer le paysage de cette période comme un type spécifique présentant les traits caractéristiques de la toundra boisée ainsi que de la steppe boisée de bouleaux. Il est donc possible de reconstituer le changement régulier des paysages depuis l'interglaciaire — jusqu'au maximum de la glaciation du Valdaï et jusqu'à la période postglaciaire:

Forêts à feuilles de la taïga	Holocène	
Steppe boisée de bouleaux Toundra boisée Steppe boisée de bouleaux	Glaciation du Valdaï	conditions périglaciaires
Forêts conifères Forêts à feuilles de la taïga Forêts à feuilles	Interglaciaire	

Il faut signaler qu'au maximum de la dernière glaciation la région en question se trouvait à une distance approximative de 200 km. du front du glacier. Néanmoins, les traits spécifiques du climat périglaciaire, le froid et la sécheresse, y ont nettement apparu — tout comme aux environs de Leningrad.

3.

Finalement nous nous arrêterons sur les traits biologiques des conditions périglaciaires de la glaciation maxima ou de celle du Dniéper.

La glaciation du Dniéper est divisée en deux grands stades: le plus ancien — celui du Dniéper et le plus jeune — de Moscou. Divers grès et formations limoneuses, souvent de provenance lacustre, représentent les formations interglaciaires au point de vue lithologique. Ces formations ont été étudiées sur une grande étendue de territoire: depuis la Russie Blanche jusqu'à Moscou et au-delà — jusqu'à l'amont de la Volga. Elles apparaissent partout entre deux moraines de la glaciation du Dniéper et partout elles sont caractérisées par la présence de spores et de pollens. Ceux-ci diffèrent nettement des spores et des pollens renfermés dans les formations interglaciaires, par le manque des pollens provenant d'arbres à feuilles et par une grande quantité de pollens de plantes herbacées dont le caractère est tout spécifique.

Je vais présenter comme exemple le profil des formations interstadiaires des environs du village Ilinskoïe situé à une distance de 120 km. à l'ouest de Moscou (fig. 3).

Ce qui est caractéristique, c'est que la végétation ligneuse y est principalement représentée par le pin (*Pinus*) et le sapin (*Picea*). Dans les deux cas le contenu en pollen des plantes herbacées et des spores atteint 40%. La végétation herbacée est représentée principalement par des herbes diverses, mais on y trouve aussi des pollens de l'*Artemisia* (armoise) et des chénopodiacées — jusqu'à 25%. Parmi les spores c'est les spores des mousses vertes (*Bryales*) et des filicinées (*Filicales*) qui prédominent.

Il en résulte que les conditions caractéristiques de cette période rappellent celles de la dernière glaciation. Il est probable que la région possédait un manteau végétal bien diversifié. Les ilôts des forêts de sapins (*Picea*), de pins (*Pinus*) et de bouleaux alternaient avec des zones steppiques. Les traits caractéristiques du climat sec et froid y apparaissaient d'une façon assez nette.

4.

Le diagramme général fait par W. P. Gritchouk illustre bien les données qu'on vient de présenter (fig. 4). On y voit le changement général des époques glaciaires et interglaciaires de la partie centrale de la plaine russe. et la remarquable hétérogénéité du manteau végétal dans les époques interglaciaires et glaciaires. Ce qui était caractéristique pour les premières — c'était l'extension des forêts mésophylliennes à feuilles et pour les deuxièmes — le règne des toundras boisées et des steppes boisées de l'époque périglaciaire froide et sèche. Selon toute apparence le phénomène était dû à l'affluence de masses d'air froides et sèches provenant du glacier qui se trouvait à proximité.

Ce sont les données paléobotaniques qui nous ont permis de conclure à l'existence du climat périglaciaire. Cette conclusion témoigne de la prédominance du milieu climatique pouvant contribuer aux processus de gélivation,, de congélifluction et de l'action du vent. Les traces de ces processus sont constatées par les savants polonais.

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THE PERIGLACIAL STRUCTURES AT TARZYMIECHY AND THEIR SIGNIFICANCE FOR THE MORPHOGENY AND STRATIGRAPHY OF THE QUATERNARY

Abstract

Sedimentologic investigations were conducted in the well-known exposure at Tarzymiechy on the Wieprz river, 25 km. above Krasnystaw. The presence of two zones of periglacial structures was established. The base zone displays bound involutions and ice-wedges, the top zone forms a well developed, massive involution layer of 3 m. Between these two zones there is a 6—7 m. series of fluvial deposits that accumulated under dry and cold climatic conditions. Both the periglacial zones as well as the interbedded series of fluvial deposits were recognized as formations produced during one glaciation. Considering the paleobotanic and malacologic deposits of earlier interglacial origin appearing at the base of the formations in question, the entire 20 m. terrace series on the Wieprz river must be correlated with the Middle Polish glaciation (Riss). The bi-partition of the sediments records the bi-partition of the Middle Polish glaciation, the upper involution layer being besides related to the Warta stage. The cut, the formation of a new valley floor and the emergence of terraces occurred toward the decline of the Middle Polish glaciation and during the last interglacial period. During the last glaciation the terrace surface underwent transformations that modified the new periglacial morphogeny. These transformations are recorded by denudational troughs appearing on the surface of the terrace. The corresponding, discontinuous congeliflual deposits are the geologic expression of the youngest periglacial morphogeny.

The results of periglacial research afford a better understanding of Pleistocene events occurring both in time and in space. The relief pattern and the periglacial deposits provide a sound basis for conclusions concerning the existence and sequence of glacial periods in the countries adjacent to the glaciated areas of the Pleistocene. The characteristcs of both relief and deposits bear the distinctive marks of the climate in which they were formed. Hence, the stratigraphic and chronological significance of the periglacial deposits and structures.

The most characteristic and direct evidence regarding climate is afforded by structures due to frost-caused disturbance. That is why such structures, in particular congeliflual levels, have frequently served stratigraphic purposes, as can be seen from the works by Czarnocki (*2, 3*), Halicki (*9*), Halicki and Sawicki (*11*), Jahn (*13*), Klimaszewski (*15, 16*), Pożaryski (*23*), Dylik and Chmielewski (*8*).

The farthest advancement in that line is the quite recent work by Horberg *(12)* who, in his stratigraphy of NE-Illinois has introduced periglacial horizons along with glacial and interglacial ones. His was the fullest attempt hitherto undertaken in order to exploit periglacial facts for stratigraphic purposes. Horberg has achieved his aim on the largest possible scale and in a most consistant manner. His conclusions are derived not only from the disturbances but also from the specific — particularly textural — features of the periglacial deposits.

PROBLEMS CONCERNING PERIGLACIAL VALLEY DEPOSITS

A review of the results of periglacial research in Poland (*6*) shows plainly that we do not as yet know much about the events occurring in valleys in periglacial climatic environment. We can only enumerate a few works dealing with this problem (*4, 5, 15*). But even in these rare contributions, the problem is treated only incidentally. The conclusions reached are not based on thourough investigations, and the general remarks contained in these treatments are mostly derived from conclusions reached elsewhere or from speculative conjectures not from direct, personal observations.

In the West, the problem has been given closer attention, particularly in France and in Germany. The well-known general treatments by Büdel *(1)* and Tricart (*26, 28*), as well as the detailed studies by Tricart (*27, 29*), Poser (*21*) and Mensching (*18, 19, 20*) have thrown much light upon the problem of valley deposits and of the correlated processes that rule the morphogeny of periglacial valleys. Besides informations about facts and events, these papers contain also valuable indications concerning research methods. Nevertheless, even these presentations seem to be of too general a nature. There is a striking scarcity of detailed descriptions of the chief exposures and this scarcity can by no means be sufficiently counterbalanced by generalized diagramms on a very small scale.

Professor A. Jahn suggested to the present writer a visit to the now already famous exposure at Tarzymiechy on the Wieprz river, above Krasnystaw. After its discovery by prof. Jahn, this exposure has been studied by several experts on the Pleistocene and discussed in a number of outstanding contributions (*13, 14, 24, 25*). The importance of the exposure at Tarzymiechy is in the organic, dryas and interglacial horizons that were here discovered.

In order to get acquainted with the character of these valley deposits — the age and climatic environment of their base being already determined

— the writer visited Tarzymiechy in September 1954. The exposure reveals the structure of the Wieprz river terrace that rises up to 205 m. O. D. and about 20 m. above the present valley floor (fig. 1, photo 1). The terrace bank being undercut by a bend of the river current, it is continually outwashed. Hence, the changing appearance of the exposure. This is probably the reason why the writer was able to notice a number of periglacial facts that had escaped recognition by the experts who had previously studied the exposure at Tarzymiechy. These facts, first observed in September 1954 were more closely investigated by the writer and his collaborators in February and June 1955.

The structure of the Wieprz terrace is characterized by an uncommonly complicated distribution of the material, which in itself is but slightly diversified. The fraction of the material found in the exposure averages 0,6 mm to 0,001 mm. Mechanical analysis showed that this material consists of fine grained sand, dusts and clays, the predominant fraction being pulverulent silts and loess-like formations (fig, 2, 3).

The lowest portion exhibits dark gray, almost black dryas silts containing vegetal components that were described by Środoń (*24*). The silts are stratified and show congeliturbations belonging to the type of bound involutions (photo 2). Upward, the dryas silts pass into the next series without any sedimentary interruption.

This series is represented by a formation that Jahn (*14*) defined as varved clays. Its varved character is obvious, however, the material is not clay, but clayey silts, as shown by grain size analysis (fig. 2). These clayey silts are brown in colour with characteristic white lime spots, frequently containing tiny molluscs. In the exposure the varved silt have a rough surface and are loose in contrast to varved clays which are compact and have a smooth surface. Like the former one, this series is also frost disturbed. One of its conspicuous features is a 2 m.-long ice-wedge that intersects the whole series from the top to the base, extending in the shape of a narrow vein deep into the dryas silts (photos 3, 4). In June 1955 another ice-wedge was discovered on the same level, about 10 m. northward from the first.

In the presentations by Jahn (*14*) and Środoń (*24*) the 12 m.-thick deposits overlying the varved silts are too much generalized. According to the profiles presented by these authors the silts are overlain with sands about 4 m. thick, the sands with 4 m. of loess and finally the loess with 5 m. of sand (fig. 4). In fact this profile is much more diversified (fig. 1, 5).

Upward, the varved silts pass into stratified loess that has a thickness of about 1 m. northward from the main axis of the presented main profile (fig. 6, photo 5). In the immediate vicinity of the ice-wedge mentioned above, the loess appears on the varved silts only on the right hand side of the wedge, where its thickness is barely 0,5 m. On the left hand side, the loess appears in frays. It also occurs in the wedge itself, composing the filling of its external part, along the walls. The rest of the wedge filling is composed of gray silt and sand.

Only above, on top of the loess and silts that fill the ice-wedge, there is a discordant layer of fine grained sands not over 0,5 m. in thickness. These sands show a ripple mark structure; in their lower part they correspond to the rolling phase of sedimentation, whereas above, their structure reflects the dune phase (photo 6). On the right hand side of the exposure, this sandy layer protrudes in the shape of a wedge. The same occurs on the opposite side where the wedge-shaped layer of sand is paralleled by an increasing thickness of the loess formation. This shows that the ripple mark-sands fill the erosional depressions in the loess. These sands initiate a series of 6—7 m. composed of alternating layers of fine grained sands and silts (photo 7). These small layers of sand and silt frequently overlap and are rather discontinuous. The silt laminae attract special attention (fig. 1, 5, units 5 c). At first glance they look like frost disturbed layers. But closer examination reveals no trace of any disturbances caused by the deformation of the primary laminar pattern. The impression of a complicated pattern of layers is due to the presence of small erosional cuts filled with material deposited from above. All doubts are removed by the canoe-shaped channels that are grooved into the surface of the compact silts and filled with the lighter and coarser sandy silt from the layers 5 b.

This series consisting of small layers of silts and silty sands with ripple marks is overlain without any perceptible discordance with a peculiar 3 m.-series of sandy and clayey silts. A peculiarity of this series are the obvious congeliturbations belonging to the bound involution type which occur in the whole series from the base to the top. The intensity of the disturbance as recorded by the amplitude of the curves, increases upward. A section of the wall that was laid bare exhibits cracs in the shape of tiny ice-veins running obliquely along the entire involution zone (fig. 1, 5, unit 6).

The top of this curious and important series is sharply truncated and veneered with a thin ferruginous cover of a few cm. The top surface is cut by small fissures, filled with ferruginous sand.

Finally, the uppermost portion of the terrace is composed of fine sands and silts, entirely different in character from those of all the series appearing in the exposure. The whole formation of about 5 m. — 3 m. in thickness in the profile described — exhibits parallel stratification with a distinctly varved rhythm (fig. 1, 5, layers 7).

DYNAMIC INTERPRETATION

The sediments exposed at Tarzymiechy testify to an extreme variety of events, whose nature and importance can be inferred from the analysis of their structural and textural characteristics. The most conspicuous feature of the profile described are two large zones of periglacial structures. This plainly reveals the preponderant, perhaps even decisive role of frost processes in the history of the Wieprz valley, in particular of the 20 m. terrace.

The dryas and varved silts represent deposits of a tundra lake, that may have existed in the glaciated area. Cold, periglacial conditions are evidenced by the pulverulent fraction, the varved rhythm, of the dryas and the frost structures. The accumulation of the deposits was associated with a progressive lowering of temperature, which attained its maximum after the deposition of the varved silts. The lowering of temperature is evidenced by the smaller fraction and the perfectly varved rhythm that characterizes the upper silts in contrast to the dryas silts. The sedimentation of the varved silts occurred probably under increasingly severer climatic conditions, due to the advance of the ice-sheet that approached its maximum. This was the time of the development of perennially frozen ground and of ground ice. The intensive formation of ground ice, that was produced at the time of maximum glaciation is evidenced by the ice-wedges intersect the varved silts and extend down into the dryas silts.

At that time, the perennially frozen ground reached up to the top of the varved silts. The loess-like silts overlaying the varved silts on the northern side of the main profile, as well as those that are preserved in the shape of frays above the ice-wedge and constitute part of its filling, were already then included in the active layer of perennially frozen ground. This is evidenced by the discordant pattern of this formation, by the presence of such alien material as the gray silts and the lumps of varved silts visible on fig. 6 as well as by the lower congeliturbations. It is also noteworthy that the varved silts do not contain any organic remains, while the overlying loess-like formation contains molluscs and plant fragments among which a well preserved *salix reticulata* leaf.

The decay of frozen ground occurred before the accumulation of the silty-sandy series overlying the varved silts and the loess-like formation. The ice-wedge is entirely filled with gray silts and brown loess-like silts.

Only the formations that immediately overlie the ice-wedge are curved in the direction of the wedge, whereas the fine sands of ripple mark structure that initiate the silty-sandy series lie almost horizontally and do not show any disturbances in the vicinity of the ice-wedge. A surface of discordance which seems to have a great paleogeographic significance can be observed here. Important, climatically conditioned events occurred mostly during the subaerial period of this surface.

The thawing of the ground ice mass, the filling of the interstitial voids and the formation of the ice-wedge must be regarded as the first stage of the decay of frozen ground in this area. This process could be only the result of a considerable change in climate. The gradual rise of temperature must be attributed to such climatic changes as those of either interstadial or interglacial periods. However, the choice between these two alternatives is by no means an easy one.

The analysis of the series at the base of the terrace goes to prove that the warmer period during which the thawing of the ice present in the wedges took place was not a period of considerable erosion, since one of the ice-wedges is only slightly truncated in its upper portion. The reduced proportions of the destruction may be infered from the situation and the thickness of the loess-like material overlying the varved silts. The loess-like material itself has undergone severe destruction only in the immediate vicinity of the ice-wedge. Further, on the left hand side of the wedge the original thickness of the loess is most probably preserved, as suggested by its mode of passage into the overlying sediments.

As known, the Pleistocene warm interglacial periods with their moderate, humid climate, created favourable conditions for the development of a powerfull activity of river erosion. This led to the formation of cuts, of new valley floors and of terraces rising above them. The Tarzymiechy profile, reveals instead a further development of accumulative processes. The old valley floor is superbuilt by deposits of several meters in thickness.

After the formation of a terrace in the geomorphologic sense i.e. after the formation of a new, lower valley floor, accumulation on its surface could only result from the activity of slope processes. Many examples in the literature go to prove it. T r i c a r t describes from the Cure valley terrace deposits covered with periglacial slope sediments deposited during the last glaciation (*29*). Similar facts are described by M e n s c h i n g (*20*) and, in our country, by H a l i c k i (*10*) and K l i m a s z e w s k i (*15*). However, the deposits overlying the varved silts and loess at Tarzymiechy, are river formations.

The character of the sediments described above leaves no room for doubt. The inclinations are gentle and their direction parallels that of the valley axis. The analysis of these deposits suggests that their accumulation occurred on a vast valley floor with wandering river streams. This is evidenced by the discontinuity of the layers and the highly characteristic wedge-like protrusion of the tiny ripple mark series appearing in the profile (fig. 5).

The described structure of the deposits and their very tiny, mostly pulverulent fraction suggests further that sedimentation on the floor of the Wieprz valley progressed under rather dry climatic conditions. At the same time, this climate was probably also cold. This supposition is not only confirmed by the fine fraction of the material but also by the high content of $CaCO_3$ at all the levels up to the top of the uppermost involution zone inclusively (see table). This shows that the content of calcium carbonate in the entire series is not much lower than in the varved silts and even higher than in the dryas silts. In the base portion alone the content of $CaCO_3$ is comparatively low.

Material	$CaCO_3$ per centage
Rhythmically stratified upper sand (layer 7)	3,2
Silts from upper involution zone (layer 6)	7,5
Sand from terrace series (layer 5b)	2,7
Silts from terrace series (layer 5b)	6,6
Varved silts (layer 2)	8,9
Dryas silts (layer 1)	6,4

All this suggests, that the main part of the terrace was accumulated toward the decline of this warmer period during which perennially frozen ground was liquidated. Toward the top of the series, the symptoms of an increasingly severer climate become more abundant. The entire top portion of this series (layer 6) is composed of pulverulent and clayey material. The thus indicated cooling of the climate, is definitely and conclusively confirmed by the perfectly distinct interference of frost in the very deep involution zone and in the ice-veins.

The top of the upper involution zone exhibits a distinct hiatus, which is an important indicator of the climatic limit in the history of the development of the terrace. This top supported the surface, which for a long time did not undergo any changes due either to denudation or to sedimentation. This is evidenced by the zone of ferruginous material and the small crevasses that may be interpreted as the effects of drying.

The uppermost series discordantly overlying the involution zone was deposited under more humid conditions. It is characterized by a larger quantity of coarse grained, sandy components, a varved rhythm, and a content of $CaCO_3$ twice lower than that of the underlying series. These sediments are probably correlated with the decline of the previous cold period and must have been formed at the time of the decay of frozen ground. This period of greater humidity was also presumably associated with the erosional phase that led to the formation of the cut and thereby to the formation of the terrace. This, however, does not yet mean the end of the chain of events reflected in the present pattern of this form. Later events shall be discussed below in connection with age problems.

AGE PROBLEMS

The profile at Tarzymiechy is of tremendous stratigraphic interest and of importance for the paleogeography and the chronology of the Quaternary. This is due to the vertical amplitude of the profile that cuts through the Quaternary formations down to the chalk appearing at a depth of 61,1 m. to the wide diversification of the deposits and to their organic contents. The periglacial structures discovered in 1954 and more detailed study of the upper part of the deposits have considerably strengthned the paleogeographic and stratigraphic singificance of the exposure.

The total Pleistocene profile in the Wieprz valley near Tarzymiechy is represented in fig. 4. The chronologic interpretation of this profile given by Jahn (*14*) is as follows. The lowest cretaceous gravels are remnants of the river deposits accumulated during the interglacial period preceding the Cracovien glaciation. The series of sandy-gravel deposits which is the largest in the whole profile corresponds to the Cracovien. Gyttja which overlies this series represents the Interglacial Masovien I. The dryas silts and varved silts are correlated with the Middle Polish glaciation (Varsovien I) which did not reach this area. Finally, the last series overlying the silts and the varved clays corresponds to the Baltic glaciation (Varsovien II).

Środoń (*24*) agrees with Jahn's interpretation of the age of interglacial gyttja and of the dryas silts. However, he thinks that the uppermost series or dryas silts was formed during the Middle Polish glaciation.

This divergence of views results in the first place from the difference between the criteria adopted by each of these eminent experts. Środoń bases his opinion on paleobotanic material supplemented by the analysis of the malacologic inventary, whereas Jahn draws his conclusions on the support of morphogenetic data, in particular of the morphogenetic interpretation of the geologic discordance at the base of the terrace series. The detailed and dynamically interpreted sedimentologic analysis outlined above affords new bases for chronologic conclusions.

As regards the chronology of the stratigraphy and the events relating to the genesis of the 20 m. terrace on the Wieprz river, the most important conclusions are those suggested by sedimentologic analysis. The structure of this terrace shows distinct traces of two frost periods — an older one in the layers 1 and 2 and a younger one in layer 6. The first frost period was followed by a phase of considerable warmth during which the frozen ground disappeared. This was also the time of formation of the discordant surface underlain by the loess spread above the varved silts. In the interval between these two frost periods, river accumulation proceded under dry and cool climatic conditions.

The interpretation of these two periods of intense frost and of the intervening warmer phase depends upon the definition of the morphogenetic importance of the geologic discordance that marks the close of the frost-period and upon the character of the deposits accumulated upon this discordant surface. The previously recognized restricted action of erosional activity which did not lead to the formation of a cut and a terrace as well as the further progress of river accumulation suggest that neither the discordant surface nor the overlying deposits can be regarded as related to the interglacial. Hence, the only possible conclusion is that the warmer period recorded by the deposits between layer 4 and 6 is related to the interstadial, the warmest part of the phase coinciding with the thawing of ground ice, whereas the deposits in the layers of series 5 originated during the colder phase towards the close of that period.

The presence of organic contents in the base portion of the series described, which Środoń (*24*) regards as correlated with the Interglacial Masovien I, leads to the conclusion that these deposits at least up to layer 6 inclusively are correlated with the Middle Polish glaciation, as there are no sufficient reasons to distinguish in the series described the deposits of two glaciations. There is no unquestionable evidence advocating the interglacial character of the deposits in series 5. The surface of discordance does not constitute satisfactory evidence and the continuity of the deposits — which in fact are fluvial in origin — excludes all possibility of regarding the time of their accumulation as interglacial.

The views concerning the bi-partition of the Middle Polish glaciation are well known. In connection with this concept, the younger frost period recorded at Tarzymiechy is likely to be regarded as coresponding to the Warta stage.

There is a strong probability that the sequence of events during the here considered stage of the history of the Wieprz river valley developed according to the chronologic scheme outlined above. It is in keeping with the results of Środoń's (*24*) paleobotanic investigations and is supported by a fairly accurate interpretation of sedimentologic data. It is also in accord with the results obtained in other countries. Terraces of the same height as the Wieprz terrace correspond to the German *Mittelterrasse* and are regarded as forms produced during the glaciation prior to the last. It would be rather astounding and difficult to explain if so powerful an incut as the one required to produce a 20 m. terrace should have arisen toward the close of the last glaciation and in the Holocene. It would also disagree with the conclusions relative to the age of terraces in other areas of Poland,

However, this argument cannot yet be regarded as conclusive. Was the material of the Wieprz terrace accumulated during the Middle Polish glaciation, what has become of the traces of the influence of periglacial climatic environment during the last glaciation?

The extensive terrace surface is diversified by corrasional troughs, whose lower parts frequently underwent younger cutting. These denudational troughs are, obviously, younger than the terrace formation. They could be formed only after the erosional cuting that produced the present--day terrace. Hence, they are unmistakable traces of the periglacial morphogeny that accompanied the last glaciation. In this connection it seems appropriate to remind that in Germany terraces cut by denudational or congeliflual troughs are generally and quite correctly regarded as much older than the last glaciation (*20, 30*).

North of the exposure described, a denudational trough running across the village of Tarzymiechy, cuts the terrace to a considerable depth. Westward, close to the village road, part of the slope structure of this trough is exposed. Typical loess can be recognized at first sight. On careful cleansing of the exposure the pattern illustrated in fig. 7 and photo 8 appeared distinctly. A typical congeliflual structure can be readily recognized. It is composed of pulverulent silts, sands, boulder clay, and small cretaceous crumbs. The base portion of this zone exhibits corrasional surfaces, that are characteristic of denudational troughs.

There can be no doubt as to the fact that the congeliflual formations blanketing the slopes of the denudational troughs are younger than the terrace into which the troughs themselves are cut. Hence, apart from the geomorphic record, we are also in possesion of a geologic and a geomorphogenetic evidence of the influence of the periglacial environment, that prevailed after the formation of the terrace.

Thus in the synthetic profile of the terrace appears a third frost--caused, periglacial element (fig. 5). This element closes the Pleistocene history of the Wieprz valley terrace. The recognition of this new stratigraphic feature of the profile not only closes the Pleistocene history of the terrace, but it also — together with the statement of the presence of denudational troughs on its surface — confirms the conclusion that the age of the lower deposits is Middle Polish (Varsovien I).

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Photographs

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PROCESSES AND STRUCTURES IN THE ACTIVE ZONE OF PERENNIALLY FROZEN GROUND

Part II

Abstract

The article contains a review of the terms most commonly used in Polish, Anglo-Saxon, French, German and Russian literature to describe cryopedology, frost-heaving and needle ice.

Cryopedology; kriopedologia (kryopedologia); cryopédologie; merzlotovedenye, pagologya, kryologya, geokriologya, structurnoye ledovedenye.

The modern wave of interest in the Arctic has given rise to a series of studies in both the lines of pure and applied science. These studies permit to answer a number of questions referring to the Pleistocene, while on the other hand they facilitate the solution of practical problems arising in connection with the construction of roads, aerodromes etc. Under the stress of ever-increasing economic needs, science is faced with practical tasks, whose fulfilment accelerates the progress of research concerned with frost-processes and perennially frozen ground.

In 1946, Bryan (*6*) in his article on nomenclature points to the necessity of introducing a special term for the newly born sub-discipline, that he regards as intimately related to pedology, proposing to call it *cryopedology*. According to Bryan cryopedology means such a science of both intensive frost-processes and perennially frozen ground which not only deals with the problems connected with the action of these processes but also endaveours to outline some engineering principles that would permit to avoid frost-caused destruction.

The term *cryopedology* soon made its way in to the French literature as *cryopédologie*. It was introduced by Cailleux (7) in „Etudes de cryopédologie", and later was adopted by Guilcher (*13*), Tricart (*31*) and others.

Bryan's term, although at the time already adopted in France was strongly criticized by Guillien (*14*). Guillien emphasizes the idea of soil in both the morphologic and the pedologic sense. The differences between these two types of soil are most strongly accentuated in the sub-Arctic zone. The pedologic soil cover is very thin in this region. Therefore soil can be here spoken of only in the morphologic sense. Guillien remarks also that any reference to „soil destruction" produced by mass-movement of denudation processes means exclusively soil in the morphologic but never in the pedologic sense. On the support of these considerations, Guillien declares, that since this line of study is mainly concerned with geomorphologic problems, the new sub-discipline should not be associated with pedology.

In the Polish literature, Bryan's term has been not so much adopted as hesitatingly introduced in quotation marks by Jahn (*17*) as *kriopedologia*. In the „Geological Dictionary" by Dziewański and Kleczkowski (*20*) *kryopedologia* also appears among other terms used to designate frost processes. The authors define the word as meaning „the science of the changes occurring in the external ground cover and induced by Polar climatic conditions". By speaking of „ground" instead of „soil", the authors have avoided all ambiguity and removed the objections raised by Guillien.

In the German literature, the term *cryopedology* has not as yet found acceptance.

In the Russian literature already a long time ago the tremendous importance, theoretical as much as practical, of investigations into perennially frozen ground, has been given due attention. Since in the Soviet Union, perennially frozen ground involved 48% of the entire surface of the country, it constituted a serious obstacle for the exploitation and conquest of extensive waste land. Hence, the natural and comprehensible development of research work in that field which eventually gave rise to a new, quite independant branch of science.

In a general sense, this branch of knowledge is usually referred to in the Russian literature as *merzlotovedenye,* which means frozen ground science.

Parhomenko in *Trudy Komiteta po vechnoy merzlote* in 1938 mentions the *merzlotovedenye* or *pagologya* i.e. the study of frozen ground and of the processes occurring therein, as well as of the processes occurring in the zone of contact between frozen and non-frozen rocks. Later Tolstihin (*30*), giving a more precise definition of Parhomenko's terms, says that *merzlotovedenye* refers to the science of the development of frozen „geozone" (merzla geozona, kryohtonna geozona, kryogeozona), whereas the student of cryopedology should be named as merzlodoved.

Tolstihin (*30*) underlines the relationship between cryopedology and a number of other sciences such as e. g. geophysics, geology, climatology and hydrogeology. Hydrogeology, however, is mainly concerned with water in a fluid state whereas cryopedology studies water in a solid state together with the associated phenomena and the widely diversified influence of frozen ground upon relief pattern, vegetation etc.

Apart from the generally adopted term *merzlotovedenye* one may find in the Russian literature a number of definitions referring to the knowledge of ice and frozen ground.

Kalesnik (*18*) speaks of *kryologya* — which means the study of the totality of ice-problems. He considers that glaciology for example, constitutes but a part of cryology. The proper object of cryologic research is ice in general, while glaciology is solely concerned with glaciers.

In 1946, Markov (*21*) emphasized relationship between cryopedology and glaciology. According to Markov the zone of frozen ground constitutes, together with mountain glaciers and ice-sheets, one of three main areas of refrigeration. There are in nature different modes of ice formation, but according to Markov they all belong to the field of glaciology, in a very broad sense.

Shumsky (*27*) regards ice as the most widely spread hard mineral on the earth's surface; it plays an important role in the life of both nature and human communities. Therefore, ice may be studied from various points of view. Shumsky discusses a new branch of study which he calls *structurnoye ledovedenye.* The object of this science is the analysis of the composition and structure of ice leading to far-reaching conclusions as to the conditions of ice-formation in nature. According to Shumsky, *structurnoye ledovedenye* attempts to solve the problem raised by the formation and the conditions responsible for the persistence of ground ice.

In a paper discussing the terminology relating to perennially frozen ground Meister and Shvecov (*22*) question the usage of the term *merzlotovedenye.* They suggest to replace it by the term *geokryologya,* which gives a more precise definition of the essentials of the phenomenon investigated. These authors expect *geokryologya,* which is derived like geomorphology, hydrogeology or geobotany, from a Greek root to become in the future a generally adopted term.

Frost heaving, frost thrust, upthrust; pęcznienie gleby, pęcznienie mrozowe, wymarzanie kamieni, wyrastanie kamieni; gonflement, soulèvement *des pierres (du sol); Frosthebung, Frostschub, seitliche Frostversetzung; puchenye grunta, vypuchivanye, puchiny, yavlenya puchenya, vymerzanye kamney, vytalkivanye kamney, pulsacya pochvy, sdviganye kamney, moroznoye uchenye, vspuchivanye grunta, vzdutye grunta, moroznoye vypuchivanye, vypyachivanye grunta.*

The phenomenon of the volume increase of moisture saturated particles at the time of freezing Dobrowolski (*8*) refers to as *pęcznienie gleby*. Jahn (*16*) rather uses the term *pęcznienie mrozowe*, thus stressing the role of frost as the agent responsible for the increase in volume.

The upthrust of stones and earth lumps due to soil heaving Dobrowolski and Jahn refer to as *wymarzanie*. Bac (*1*) uses instead the term *wyrastanie kamieni* probably under the influence of the popular saying that stones „grow-up" in the fields under the stress of frost heaving.

To designate the process under consideration the Anglo-Saxon literature uses the term *frost heaving* (Taber, *29*) that has met with general acceptance. This term refers chiefly to the upward movement of particles, induced by the slightest pressure and associated with the existence of a capillary system and of an area of water supply. Eakin (*9*) distinguishes the vertical action of *frost heaving* from the process of *frost thrust* due to side-pressure. Bryan (*6*), however, believes that, after the studies by Beskow and Taber, the physical aspect of the phenomenon does not require the introduction of any other terms than *frost heaving*.

In the French cryopedology the process of frost heaving is referred to as *gonflement* (Cailleux, *7*). This expression gives an adequate definition of the process induced by the volume increase.

The phenomenon of upthrust of stones or earth lumps Cailleux (*7*) and Tricart (*31*) refer to as *soulèvement* (*des pierres, du sol*).

In the German, as well as in the Anglo-Saxon nomenclature one may find two expressions relating to the process of frost heaving: *Frosthebung* and *Frostschub*. Considering the meaning of both these terms, Troll (*32*) agrees with Poser, who strictly distinguishes the meaning of *Frosthebung* from that of *Frostschub*. He applies the former to vertical movements due to frost heaving whereas the second he uses to designate lateral movements, which Troll sometimes refers to as *seitliche Frostversetzung*.

The terms corresponding to frost heaving are in the Russian nomenclature those of *puchenye grunta, vypuchivanye*, or simply *puchiny*. These expressions are used to describe all the processes leading to the displacement of the ground. Kapterev (*19*) mentions for example *yavlenya* *puchenya* (the phenomenon of heaving) produced by the expansion of water freezing in the ground and by the formation of ice-crystals. Kapterev thinks that the phenomenon of heaving is intimately connected with *vymerzanye kamney* (upthrust of stones). Bondarchuk (5) uses the term *vytalkivanye kamney,* while the phenomenon of the heaving of ground surface during freeze and of its subsidence at the time of thaw he refers to as *pulsacya pochvy* (pulsation of the soil). Edelstein (*10*) discusses the development of ice filaments inducing *sdviganye kamney. Puchenye grunta* which means the deformation of the surface, under the action of freeze and thaw which is also discussed in the papers by Sumgin (*25*). Pyavchenko (*23*) calls this phenomenon *moroznoye puchenye.* The greatest variety of terms can be found in the works by Grigorev (*12*). To designate the phenomenon of frost heaving he uses the following expressions: *vspuchivanye grunta, vzdutye grunta, moroznoye vypuchivanye, wypyachivanye grunta.*

Needle ice, ice columns, ice filaments; lód włóknisty; la glace fibreuse, filaments de glace, les pipkrakes; Barfrost, Effloreszenzeis, Eisfilamente, Haareis, Haarfrost, Kammeis, Nadeleis, Pipkrake, Stengeleis; ledyanye stebelki, ledyanaya korka, pochvennye vycvety lda, plastinki lda, ziorna lda, kristaliki lda, druzy lda, shchotki lda.

The formation of tiny ice needles under the soil surface, on the walls of soil cracks or beneath the vegetation cover have been recognized rather early as the result of a peculiar frost action upon the soil. To designate this form of frost action, the Polish nomenclature has adopted the term *lód włóknisty,* which was introduced by Dobrowolski (*8*). In his description of *lód włóknisty* (fibrous ice), Dobrowolski also draws attention to the considerable morphogenetic importance of small, needle--like ice crystals that may up-lift or shove lumps of earth and even stones. In the most recent Polish literature dealing with periglacial problems (Jahn, *17*) as well as with present-day soil processes (Bac, *1*), the term is universally adopted.

The German literature posseses the greatest variety of terms relating to needle ice. Richthofen (*24*) in his description of this ice form calls it *Haarfrost* and recognizes its morphologic importance. The most popular term used to designate needle ice is in the German literature (Troll, *32*) and in the papers by authors who write in German (Furrer, *11*): *Kammeis.* However, a number of other terms are being used with the same meaning as *Kammeis.* Such expressions as *Haareis, Nadeleis, Stengeleis, Eisfilamente, Effloreszenzeis, Barfrost* have mostly a distinctly descriptive meaning, that emphasizes such characteristic features of the phenomenon, as the elongated, needle-like or hair-like shape of the tiny crystals composing the bunches of needle ice.

Furthermore, besides the expression *Kammeis* German authors use also the Swedish term *Pipkrake*. In those of his papers that are written in German Högbom (*15*) refers to needle ice only as *Pipkrake*. In fact, the term has acquired an international significance.

In the Anglo-Saxon literature there is an early reference to fibrous ice as *ice columns*. This term was used as far back as 1850, by Leconte. There exist also other terms which — like the German ones — point to the characteristic features of this form of ice: *needle ice*, or *ice filaments*.

The French literature uses the term *glace fibreuse* which is an equivalent of the Polish *lód włóknisty*. French authors also frequently use the Swedish word *pipkrake*, according to the rules of their language. In the papers by Cailleux (7) and Tricart (*31*) one may find such expressions as *sol à pipkrakes, les pipkrakes* etc.

Soviet experts usually and almost exclusively refer to needle ice as *ledyanye stebelki*. The peculiar role of needle ice which induce the displacement of small ground particles and even of stones has been stressed by Kapterev (*19*), Grigorev (*12*), Edelstein (*10*) and a number of other authors. Grigorev, for example speaks of the formation upon the ground surface of needle ice, that give rise to *ledyanaya korka* (ice crust). Owing to this ice crust, the turf become separated from its mineral sub-soil. According to Bondarchuk (5) the relief pattern produced by the action of solidified water depends on the way in which the ice was formed. As regards genesis one may distinguish in nature several categories of ice. Some attempts to classify solidified water have also been made. According to Bondarchuk the best are those by Vernadski, Tolstihin and Dobrowolski. Vernadski (as cited by Bondarchuk) recognizes a form of ground ice which he refers to as *pochvennye vycvety lda* (efflorescence of ground ice). In his description of the occurrence of ice in nature Tolstihin (*30*) mentions also such terms as *plastinki lda, ziorna lda, kristaliki lda,* as well as *druzy lda* and *shchotki lda,* forming in interstices, concavities etc.

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TUNDRA STRUCTURES AT PATOKI

Summary

Abstract

Periglacial structures occurring on the northern margin of the Szczerców basin (Middle Poland) are described. The author is of opinion that some of these structures can be referred to the Warta stage.

On the northern slope of the Szczerców basin near the village Patoki some interesting structures are exposed. From the morphologic as well as the geologic point of view, two different areas may be distinguished here: the floor of the basin drained by the Widawka river and its small tributaries, and the upland. The floor of the basin lies about 15 do 20 m. lower than the adjacent area and is diversified with dunes encroaching also upon the upland.

The area lies within the reach of the Middle Polish (Varsovien I) glaciation. Boulder clay and fluvioglacial sands are predominant rock types. The basin is floored by varved clay, peat and fluvial or dune sand.

The exposure in the culmination of the hillock shows the following succession of layers: the surface is overlain with gravel that vanishes down--slope. The gravel rests upon dark-gray clay. Somewhat below the culmination begins a zone of violent disturbance, congeliflual in character. The thickness of this zone increases considerably down-slope. Within a distance of 22 m. it grows from 0,5 to 2,7 m. The disturbed zone is composed of fine-grained sands with numerous intercalations of gravels and clayey sands. The sections reveal strongly disturbed material. The coarse sand or even fine gravel occur only in the upper portion of the congeliflual zone.

The congeliflual zone presents two horizons (fig. 1). The upper one is most disturbed and contains highly heterogeneous material. The lower one shows less disturbance and better segregation. The latter, however, must have also partaken in congeliflual processes, as indicated by the discontinuous laminations and the lenses or bands of clay and sand in the silty matrix. The same is indicated by the presence of loose, light, stratified sands appearing in the silty mass of indistinct structure. This is very well visible in the cross-section of the congeliflual horizon.

The congeliflual deposit is underlain with a bed of dark-gray clay. Its base dips according to the sloping of the surface, while its thickness grows down-slope. At the base the clay bears traces of lamination, while the top portion is disturbed. There is an occurrence of small curves, distinct overlapping of the clay with the overlying material and intercalations of sand in the clay or of packets of clay in clayey sand. The clayey material contains tiny agglomerations of organic matter which can be best observed in the wall perpendicular to the slope and at the base of the clay series.

In the north-eastern exposure, transversal to the hill-slope the congeliflual zone is interrupted in its lower part by clay penetrating from below. The surface of the clay is very rough and in one place it forms a structure known in the literature as bugor. The bugor is about 0,6 m. hight and 10 to 15 cm. wide. The surrounding material is interrupted at the base, while in its upper part it encircles the form of the bugor (fig. 2, photo 4).

In addition to the bugor and the congeliflual deposits there are here some other structures characteristic of frost environment. Under the gravel in the culmination of the hillock, and lower down-slope, two ice wedges penetrating into the clay (photo 1).

The analysis of the arrangement of material in the exposure at Patoki reveals the following sequence of events and processes. The lower sands of an uniform fraction and slightly rounded grains, as well as the undisturbed, continuous stratification suggest deposition by peaceful waterflow, while the small degree of roundness points to near-by transportation. The gradual passage from sand to silt, as well as the uneven top surface and stripes or more distinct lamination at the bottom of the congeliflual deposits show that periglacial environment invaded the region as the ice-sheet drew nearer. The existence of frost environment in this area is indicated also by the presence of the ice wedges and the bugor at the base of the exposure.

The character of the basal portion of the congeliflual deposit indicates that, at first, conditions permitter a free and greater out-flow of water, traces of which are left in the form of stripes and stratification. Such a state, however, did not last long — the corresponding deposits being only 0,5 m. thick. The change of climate led to a change in sedimentation. The horizon bearing traces of the predominance of down-wash gives place to deposits of colder environment, where congelifluction is the main form of mass movement (fig. 1).

The arrangement of the material observed and the situation of the frost-structures permit to correlate them, especially those from the lower part of the section, with the Warta stage (the end of the Varsovien I glaciation). The lowest sand and clay with plant detritus may belong to a transitional period between the interval preceding the Warta transgression and the periglacial period corresponding to that stage.

The latest, Varsovien II glaciation has left the relief of the area under consideration notably reshaped. The existence of glacial and fluvioglacial deposits in flakes suggests that strong destruction has been performed in that period by denudational processes. The material has been removed by congeliflual mass movement and the entire relief bears evidence of periglacial morphogeny.

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Translated by J. Rulikowska

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Photographs

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THE ICE-WEDGES AT SŁAWĘCIN

Summary

Abstract

An abundant occurrence of ice-wedges was observed in the Kutno terminal moraine near Sławęcin (Middle Polish glaciation). The wedges were studied in the vertical sections as well as in the plane. The fissures in which the wedges are formed display a network pattern. The wedges themselves and the adjacent portions show such traces of the expansive action of ice as shoved boulders and effects of frost weathering.

The exposure studied is situated in the rampart of the terminal moraine extending from Dąbie on the Ner river in the direction of Kutno. Hence, the azimuth of the morphologic axis of this form is N 55°. The culminating point of the rampart 163,5 m., lies 3 km. farther NE. At the place of exposure it is 151 m. in altitude. The southern slopes of the moraine are inclined toward the Warsaw—Berlin *pradolina* (abandoned glacial stream channel). Their gradient is about 5°. The gradient of the northern slopes does not exceed 2° and passes imperceptibly into the gently undulating plain of the ground moraine.

The Kutno moraine is one of the forms that correspond to the Middle Polish glaciation (Varsovien I). The gentle outline of the rampart and the gradual passage from convex to concave and flat forms plainly shows that in this area the initial shape of the glacial forms is obliterated. The morphologic boundary between the Middle Polish and the Baltic (Varsovien II) glaciation extends 20—25 km. from the terrain described. Outside this boundary appear elevations of distinct outlines and deep lake basins. Gradually, the relief pattern becomes more intensive.

The gravel pit at Sławęcin which in several points is 8 m. in depth exhibits an exposed wall, about 90 m. in length, that arcuates northward. This wall was studied in the course of the progressive exploitation of the exposure in the years 1950—1955. During that time the wall receded about 5—10 m.

The geologic structure of the wall studied was laid bare to a depth of 8 m. The base shows reddish boulder clay whose surface slopes abruptly northward. The boulder clay is overlain with a series of fine, distinctly stratified fluvioglacial gravels and sands. On top lies a massive boulder-wall about 5 m. in depth composed of material of widely varying in size. Some of the boulders are over 1,5 m. in diameter. The bouldery is overlain with boulder clay, brown or light pink in colour, containing scattered boulders. Uncommonly well-developed ice-wedges occur in the upper boulder clay overlying the boulder-wall. The profiles (fig. 1) illustrate the changes in outline and occurrence of the ice-wedges that were progressively observed as the wall receded. Since now the exploitation proceeds very rapidly, the wedge zone will be soon entirely destroyed.

The ice-wedges that are poorly developed assume a somewhat festoon-like shape and do not as a rule extend below the base of the boulder clay. The wedges that are particularly well developed intersect the bouldery and frequently extend down into the underlying sands and gravels. The ice-wedges range 2—4 m. in length.

Profiles I, III and IV are of particular interest on account of the number and the size of the ice-wedges involved. The description will refer to five selected wedges that were observed in different parts of the exposure and at different stages.

Wedge *a* (profile I; 3.X.1950) appears in the zone that is relatively nearest to the culmination of the rampart. It is also the largest of all. Wedge *b* was registered several times as: b_1 (profile III; 20.IX.1954), b_2 (profile IV; 4.XII.1954) and b_3 (photo 5). From stage b_2 and after the removal of a 0,5 m. thick layer, wedge *b* was also investigated in the horizontal cast. Wedges *c* and *d* were registerd simultaneously (profile IV). Soon after, they disappeared completely. Wedge *e* was the last discovered (23. VI. 1955) and is not represented by any profile (photo 8).

The boulder clay intersected by the upper portion of the ice-wedges is, round their margins, rosty in colour and here and there strongly sandified. The grain size curve reveals comparatively well sorted material. This is probably due to frost caused comminution which gradually liquidated the coarser material. The grains of gravel and coarse sand contained in this boulder clay are mostly sharp-edged.

The inside fissures of the ice-wedges are filled with yellow sand. The grain size curve reveals material which, on the whole, is rather well sorted, though it shows a fall of the 0,3 mm line. This fall corresponds to a certain differentiation in grain shape. Grains larger than 0,3 mm are, as a rule, rounded, whereas the smaller ones are edged, though they have sometimes retained some fragments of rounded surfaces. This sand contained two facetted stones (wedges *a* and *b*).

In the boulder-wall, the ice-wedges are remarkable for their dark rosty colour. They are mostly filled with material derived from the surrounding bouldery. This material is sometimes strongly comminuted (wedges *a, c, d*). It bears such traces of displacement of individual constituents with respect to one another as: hard, resistant rocks pressed into weathered, crumbled boulders, upthrust boulder clay, fragments of split boulders drawn apart, etc.

Ice-wedges of another type are filled with boulder clay (wedges *b* and *e*). A sample of this boulder clay derived from wedge *b* shows a predominance of coarse, crumbly material, that presumably weathered on the spot. The material is here exclusively sharp-edged. The grain size curve is similar to that of the marginal boulder clay (fig. 5). Both these curves show falls, characteristic of frost weathered material. The increased number of falls in the grain size curve of the boulder clay derived from the inner portion of the ice-wedge suggests that congelifraction was less intensive in the lower part of the wedge than round the margins of its upper part.

The boulder-wall is underlain with a zone of fine, stratified gravels and sands. Some of the ice-wedges intersecting the bouldery terminate only in this series (wedges *a* and *e*).

The horizontal cast illustrates the course of the central fissure of the wedge that is filled with loose, yellow sand (fig. 6). The fissure exhibits a continuous line of varying width, whose side branches form a whole network of fissures, bordered by the rosty boulder clay described above.

Among the stones composing the bouldery, appear scandinavian crystalline rocks, crystallized limestones as well as local material such as Cretaceous stones and sandstones. At the place of occurrence of the ice-wedges $^2/_3$ of the total amount of these boulders is severely weathered [1].

The sedimentary rocks, Silurian limestones and Cretaceous rocks show a similar behavior. The network of fissures is here completely irregular, quite different in each particular case. The texture of the rock does not reveal any features capable to determine any direction in the development of the fissures. Sandstones are split into boulders according to the plane of stratification. During the next stage, the individual sand grains freed themselves from the matrix (photo 9).

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[1] I regret that at the time when these observations on frost weathering were collected I did not yet know the extremely interesting paper by Prof. J. Tricart: Etude expérimentale du problème de la gélivation, *Biuletyn Peryglacjalny*, nr 4.

In the crystalline rocks, the predominant role is that of the grain size and of the textural distribution of minerals (photos 10, 11). In the boulder-wall, some crystalline stones are completely crumbled into sand, some are split into lumps while others show only a few cracks. Boulders are split into large fragments that retained the sharpness of their edges. This seems to suggest several different stages of frost weathering from mere cracking to complete disintegration of the individual, mineral components. The grain size curves of three disintegrated crystalline rocks show characteristic falls (fig. 7).

In the area described, the presence of bouldery created particularly favourable conditions for the development of ice-wedges. The accumulation of material different in shape and size gave all this zone a character of porosity that both facilitated the circulation of water and favoured the formation of ground ice.

The exposed small fragment of the plane seems to suggest that shape of the ice-wedges form a network pattern that may be regarded as a tundra polygon. In the furrows and fissures produced by contraction, ice-wedges were formed which eventually grew larger not in result of the deepening of fissures but rather through the increase of the ice-mass that invaded all the less resistant parts of the adjacent boulder-wall. On thawing of the ice, the wedge fissures were filled either with the boulder clay overlying the boulder-wall or with fluvioglacial sand transformed by frost weathering. The presence inside the ice-wedges of the two faceted stones mentioned above shows that the sand was a surficial material.

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Photographs

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ICE-WEDGES AS GROUND-WATER CONDUCTORS

Abstract

On the support of observations collected in the environs of Warsaw, the author presumes that ice-wedges may afford good passages for rain-water into the aquifers underlying ill-pervious beds. This explains the ready reaction to rainfall of the water-table overlain with impermeable layers. Observations collected in the area of the middle Vistula seem also to confirm the author's supposition that phenomenon may assume an important role in vast areas.

The question of infiltration of rain-water into glacial deposits overlain with comparatively impervious strata belongs to the more difficult problems in hydrogeology. Such conditions occur, for example, in those places where a compact layer of boulder-clay overlies fluvioglacial deposits. The assumption of the infiltration of rain-water into aquifers at their outcrops is in disagreement with the rapid response of the water-table to even short-lasting precipitations. In normal conditions water-bearing strata crop out usually at intervals of several km. Therefore, even if the maximum coefficient of perviousness for the given hydraulic gradient be assumed, the rate of migration of underground water cannot explain the ready reaction of the water-table.

Field observations frequently reveal such rapid fluctuations of the water-table, that coefficients of perviousness calculated from the rate of water-flow attain values that are practically never encountered in glacial deposits. Much shorter ways of infiltration into water-bearing strata than generally assumed in similar conditions should therefore be searched.

Some light may be shed on this phenomenon by the facts observed at Młociny, north of Warsaw. The exposure is situated on the slope of the Warsaw—Berlin *pradolina* (fig. 1). Under a layer of sandy clay, about 1 m thick, passing frequently into poorly assorted sands there is a grayish-brown boulder-clay of varying thickness (averaging 3 m.), partly bearing small fissures, but forming on the whole a uniform layer. The boulder--clay is underlain with fluvioglacial, cross-bedded, poorly assorted sand (photo 4), passing downward into layers of pulverulent sand.

The exposure exhibits four ice-wedges developed in boulder-clay (photo 1, 2). They unite the surface of the slope bench with the fluvioglacial sands underlying the boulder-clay which is also partly cryoturbated. The ice-wedges are situated about 3 m. from one another and form a relatively regular network pattern.

The ice-wedges are filled with quartz sand with a rather low content of dust particles (fig. 3). The grain-size curve shows a wery uniform fraction. Its index of sorting is $U = \sim \frac{d_{60}}{d_{10}} = \sim \frac{0{,}105}{0{,}055} = \sim 1{,}9$. The mean grain d_{50} is 0,095 in diameter.

It is as yet difficult to estimate the percentage of the infiltration area occupied by the ice-wedges. In any case, considering the divergence of the wedge-sides with respect to the surface, this percentage may reach 25. It should be added that beside straight wedges there are at Młociny also such that branch off or cross in the horizontal cast (photo 3) thus obviously enlarging the extent of the infiltration surface.

Hydrogeologic investigations have established a down-ward increase of water content in the ice-wedges, so that at its junction with fluvioglacial sands the wall of the exposure showed (Oct. 1954 and April 1955) distinct seepage. The fluvioglacial deposits display a distinct water-table as exposed by the wells of the adjacent farms and at the junction of the slope with the hight terrace of the Vistula in the form of swamps, oozes and seepage.

The established coefficients of permeability based upon grain-size curves and other laboratory investigations are:

a) according to Seelheim — $k_{10} = 0{,}0376 \cdot d_{50}^2 = 0{,}00376 \cdot 0{,}095^2 = 0{,}000034$ m/sec, which gives $\sim$ 2,9 m. a day,

b) according to Allen Hazen assuming c = 1000 m: $k_{10} = 0{,}0116 \cdot d_{10}^2 = 0{,}0116 \cdot 0{,}055^2 = 0{,}000035$ m/sec, which gives $\sim$3 m. a day,

assuming $c = 700$ m: $k_{10} = 0{,}008 \cdot d_{10}^2 = 0{,}008 \cdot 0{,}055^2 = 0{,}000024$ m/sec, which gives $\sim$2 m. a day.

As the descent of the water-table between the nearest seepage and the ice-wedges is about 2,5 m. — which is the minimum descent assumed — the rate of water-flow ($v = ki$) is respectively:

a) if the index $k_{10} = \sim 3$ m. a day, then $v = 2{,}5 \cdot 3$ m. a day = 7,5 m a day.

b) if the index $k_{10} = \sim 2$ m. a day, respectively: 5 m. a day.

These rough calculations indicate that the assumption of direct infiltration of rainfall through ice-wedges into deeper layers can easily explain the ready response of the water-table to short-lasting precipitations. It should also be noted that the frequency of the occurrence of ice-wedges is on the whole considerable, thus increasing the percentage of the infiltrating water. This connected with the known fact that fossil ice-wedges occur on level ground, one may regard them as a sort of run-off collectors, conducting water into deeper beds.

The phenomenon described above is by no means isolated. Hydrogeologic investigations i.a. in the environs of the middle Vistula and of the river Kamienna reveal the common occurrence of the phenomena discussed, which have not yet been described from this point of view.

Not only ice-wedges can provide passage-ways for underground water. Other periglacial structures, such as involutions or congelifluction may also afford conditions favorable for the loosening of impermeable layers, which in turn become pervious.

Although in this short note the author does not intend to enter upon a detailed discussion of the problem, he wishes to draw attention to the fact that, for instance, congeliflual breccia of varved clay at Dąbrówka--Strumiany, north of Łódź furnishes an example of the possibility of turning impervious beds into pervious ones by periglacial structures of a type different from those described. The author is also aware that the fissures produced by processes acting in periglacial environment, especially in older, more calcareous and compact boulder-clay, considerably facilitate the infiltration of rainfall and the migration of underground water.

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Translated by J. Rulikowska

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LES FILONS DE GLACE DU PLÉISTOCÈNE AU MONT SKAŁA

Résumé

Sommaire

Au sommet en dôme du Mont Skała composé de quartzite du Dévonien inférieur apparaissent, nettement formées, des structures périglaciaires du Pléistocène du genre de filons de glace. On peut y distinguer deux générations qui diffèrent l'une de l'autre par le degré de désintégration du matériel dont elles sont remplies. La plus ancienne des générations de filons a été le plus probablement formée dans le climat périglaciaire de glaciation Varsovien I, alors que la plus récente tire son origine de la zone périglaciaire de glaciation Varsovien II.

Le Mont Skała (359,9 m. au-dessus du niveau de la mer) est situé à l'extrémité ouest de la chaîne dévonienne qui, au sud, avoisine les Monts Łysogóry. Il est composé à sa base de schistes, de grès et de conglomérats et au sommet de quartzite clair et résistant. En 1954, au cours du lever géomorphologique, d'intéressantes structures périglaciaires du genre de filons de glace ont été constatées dans de nombreuses petites carrières se trouvant à proximité du sommet.

Les filons de glace les plus visibles et les mieux formés sont ceux d'une petite carrière au sommet même du Skała. La forme rectangulaire de cet affleurement permet d'examiner ces structures dans trois différentes intersections.

1. Paroi ouest, orientation N 335°. Un quartzite blanc, compact, d'un grain homogène de taille moyenne forme un banc d'une épaisseur de 10 cm. à 30 cm; inclinaison N 15°. Toute la série se trouvant à découvert, jusqu'à une profondeur de 6 m., est coupée par un dense réseau de clivages pour la plupart perpendiculaires, à la surface des couches.

Le long de certains de ces clivages ainsi que le long des couches, sur toute la longueur de la paroi, jusqu'à environ 5 m. de profondeur, se suivent des zones de fragmentation fortement accentuées. Dans cette intersection, les zones en question ont une largeur soit de quelques centimètres soit dépassant une trentaine de centimètres. Dans quelques-uns des secteurs elles adoptent la direction des clivages, dans d'autres, celle des surfaces des couches. A bien des endroits, les différentes fissures se rejoignent, formant un réseau qui encercle les blocs de roches non fragmentées (fig. 1b, photo 1). La forme et la largeur des mailles de ce réseau indiquent clairement leur dépendance génétique des surfaces le moins résistantes de la roche. Les débris remplissant ces zones sont exclusivement angulaires. Leurs diamètres vont de quelques millimètres à une quinzaine de centimètres. Un certain pourcent du dit matériel est également composé de grains sablonneux ou pulvérulent. La composition pétrographique prouve que ce matériel est identique à la roche massive et, par conséquent, provient de sa désintégration.

Du parcours de ces structures, de la forme des débris rocheux dont elle se compose, ainsi que du fait de leur disparution à une profondeur relativement faible (4—5 m.) il est permis de conclure que pour la structure des filons c'est le climat qui a joué le rôle prépondérant. En l'occurrence, il ne s'agit uniquement que de la puissance destructrice du gel constituant l'unique force capable de fendre mécaniquement une roche aussi résistante que le quartzite.

2. Paroi sud, orientation N 85°. Sur cette paroi, apparaît une structure cunéiforme, large en haut de 3 m. et de 0,5 m. en bas, allant environ 3,75 m. en profondeur. Elle est remplie d'un sable jaune, dont émergent ça et là, quelques débris anguleux de quartzite (fig. la). Sur toute sa longueur de nombreux raccordements la relient au réseau de filons de glace de la paroi ouest. Dans le sable qui la remplit on a trouvé 5 cailloux à facettes dont le dernier à une profondeur de 2,20 m. Ces cailloux ont leurs arêtes et leurs vernis bien conservés et l'un d'entre eux possède des cupules allongées. Les arêtes de trois de ces spécimens ont pourtant des brisures d'origine plus récente. La courbe granulométrique du sable formant la structure atteste son haut degré de calibrage. Parmi les plus gros de grains on distingue principalement des grains de quartz, quelquefois dépolis-indice de l'action éolienne subie. On y rencontre aussi, à l'état sporadique, des grains de roches scandinaves, de granit surtout. Le sable est fortement lié par des alliages ferrugineux et, de façon générale, il est dépourvu de structure, bien qu'à certains endroits sa composition met en évidence des stries lenticulaires. La présence des cailloux à facettes et de grains de sable mats dénote une pénétration d'un matériel de surface. Vue d'en haut, la structure a l'aspect d'une mince lentille qui communique avec les filons des parois voisines. C'est donc également un filon de glace, mis à decouvert le long du clivage et rempli d'un matériel plus fragmenté avec un certain apport de grains étrangers.

3. Paroi est, orientation N 335°. Ici le filon est à découvert dans sa coupe transversale. Il est constituté d'un matériel semblable à celui for-

mant la structure de la paroi précédente (fig. 3, photo 2). Ce sable est uniquement composé de grains de quartz et, ce qui est curieux, il est nettement disposé en forme de blocs. Ceux-ci remplissent la partie horizontale du filon et, par conséquent, ne sauraient provenir de la surface. Il est le plus probable qu'ils ont été formés sur place, à la suite d'une désintégration granulaire des blocs de quartzite. L'absence de grains dépolis de quartz, de roches d'origine étrangère et de cailloux à facettes qu'on avait pu constater dans le filon vertical précédant semblent également prouver le processus de cette désintégration.

INTERPRÉTATION DYNAMIQUE ET CHRONOLOGIQUE

La genèse des filons ci-dessus décrits est liée au développement des formations de glace dans le sol faisant partie du tjäle de la zone périglaciaire du Pléistocène. Les fissures des clivages et les surfaces des couches s'élargissaient aussi bien par la contraction de la roche pendant les hivers rigoureux, que par l'expansion, à la suite de la congélation de l'eau qui y avait pénétré, de même enfin, que par l'accroissement des cristaux de glace. Ces processus se répétant d'année en année, aboutirent à la formation d'un dense réseau de filons de glace et à une puissante action de gélivation. Il s'en suivit une fragmentation en blocs de la roche et, dans les parties s'y prêtant davantage, une désintégration granulaire. Dans les zones le dur quartzite se transforma en un sable meuble. A mesure où le climat s'adoucissait, la glace dans le sol fendait en laissant des cavités qui furent remplies par un matériel rocheux. Une grande partie de ce matériel provient d'un quartzite gélivé et ce n'est que dans une proportion insignifiante qu'il y pénétra de la surface. Le transport du matériel venant de la surface, notamment des cailloux à facettes, de grains dépolis de quartz et de particules du matériel scandinave s'opérait avant tout par le ruissellement. La congélifluxion ne peut, en l'occurrence, entrer en ligne de compte, étant donné la situation topographique de l'endroit (sommet plat).

La détermination de l'époque de la formation des filons du Mont Skała constitue un problème important. Cependant, la question de savoir s'ils s'étaient formés uniquement dans la zone périglaciaire de la dernière glaciation, ou s'ils représentent pour le moins deux générations se complique du fait du manque de couvertures. Théoriquement, étant donné la situation de l'endroit en dehors des deux dernières glaciations, il conviendrait de se prononcer pour la deuxième éventualité.

Une série de faits déjà cités dans la partie descriptive de l'article permet, en effet, de conclure à l'existence au Mont Skała de deux générations de filons. Cela résulte de ce que le filon de la paroi ouest a atteint un degré d'avancement différent de celui des filons des deux autres parois qui se trouvent remplies d'un matériel complètement émietté mécaniquement jusqu'au grain primitif. Les filons des deux dernières parois contiennent, en outre, des cailloux à facettes, des grains de quartz dépolis et des particules de roches scandinaves, alors que ceux de la première paroi sont remplis d'un matériel moins morcelé et dépourvu de roches étrangères, de même que de grains marqués par l'action éolienne. L'usure des cailloux à facettes a dû déjà avoir lieu à l'intérieur des filons, peut-être pendant la période périglaciaire postérieure. L'afflux dans les filons du matériel postglaciaire de la glaciation Cracovien n'avait été uniquement possible qu'à une époque périglaciaire synchronique de la glaciation Varsovien I, car, étant donné l'altitude de Skała, ces dépôts n'auraient pas eu la moindre chance de résister aux différents processus d'érosion de la dite période périglaciaire et de l'interglaciaire qui lui succéda. Au temps du climat périglaciaire de la glaciation Baltique les dépôts glaciaires ne pouvaient plus recouvrir le Mont Skała et fournir ainsi le matériel nécessaire pour remplir les filons.

A la lumière des faits cités il semble certain que les filons périglaciaires du Mont Skała représentent deux générations, dont la plus ancienne s'était formée dans la zone du climat périglaciaire de glaciation Varsovien I, et la plus récente est synchronique à la glaciation Varsovien II.

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