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SEDIMENTARY ENVIRONMENTS OF GLACIOFLUVIAL UPLANDS AND GLACIOFLUVIAL CREVASSE FILLINGS AGAINST THE GENERAL BACKGROUND OF OTHER GLACIOAQUEOUS ENVIRONMENTS

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Abstract: Glaciofluvial uplands have been recently characterized by the writer. They are mainly built of glaciofluvial stratified gravels and sands which in many places are interbedded and/or capped by comparatively thin and discontinuous beds of flow till. These uplands most probably represent features accumulated upon dead ice areas with prevailing braided system of glaciofluvial discharge coexisting with the glacial sensu stricto deposition from the protruding debris bands.

Glaciofluvial crevasse fillings – very vaguely defined in the literature – are described here as originated from ice-slope-washing processes within crevasses in glacial ice, which (crevasses) were not steadily occupied either by running or by ponded water. This is revealed by very differentiated kinds of sediments, ranging from (flow) tills and poorly stratified gravels to laminated fine sands with silt. These sediments, however, do not show any regular pattern except that the coarse material was supplied from both sides of crevasse, and that it was suppliedd more abundantly in a final stage of deposition. Attention is drawn to the fact that "undulated" top surface of some eskers may have been a result of (final) changing from typical esker (running water) environment into a crevasse-filling environment described in the paper.

A genetic subdivision of glaciofluvial features is also proposesd, with their sedimentary environments – running water, ice-slope-washing, dammed water – used by the writer as main criteria. Zones of deposition asssociated with the ice body – i.e. englacial, proglacial, ice-marginal – which until now have been used as main criteria, are treated here as subordinate ones. Very conscise remarks on sedimentary environments of glaciofluvial features, subdivided according to the mentioned criteria, are given as a background of the more detailed characteristics of glaciofluvial uplands and crevasse fillings.

Key words: Glaciogenic, glaciofluvial sediments, glaciofluvial uplands, glaciofluvial crevasse fillings, eskers, deglaciation, Polish Lowlands.

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INTRODUCTION – THE PROBLEM OF GENETIC SUBDIVISION OF GLACIOFLUVIAL SEDIMENTS

Glaciofluvial sediments and landforms – composed of material which has undergone glacial transport and which has then been deposited by meltwater of the same glacier – are very common in glaciated areas. The history of investigations of glaciofluvial deposits was outlined by Jurgajtis (1980), who also summarized the works of a group of the international INQUA Commission dealing with these sediments (Jurgajtis, 1980, 1982). Jurgajtis agrees with the "generally accepted" subdivision of glaciofluvial sediments into "englacial" (i.e. ice-contact) and "proglacial" ones, and he distinguishes also a third kind, i.e. "ice-marginal" deposits (Jurgajtis, 1982, p. 39).

The subdivision of glaciofluvial features into two main groups, i.e. ice-contact and proglacial, mainly after Flint's widely known books (1957, 1971), seemed for a long time the most convenient. However, more advanced sedimentological studies have revealed considerable difficulty in linking to- gether, within the ice-contact group, such different features as eskers (deposited in running water), kames (mainly accumulated in ponded water) and also so called crevasse fillings and depositional end moraines (which most frequently originate from ice-slope-wash processes – Ruszczyńska-Szenajch, 1982a). The proglacial group, including only outwash plains and akin features (outwash fans, valley trains etc.), was much less controversial but the occurrence of so called supraglacial sandurs introduces in this case confusion also.

The writer's studies on glaciogenic features in the Polish Lowlands (Ruszczyńska-Szenajch, 1981, 1982a, b) together with the evidence published by other authors (e.g. Flint, 1971; Grzybowski, 1970; Klimek, 1972; Saunderson, 1977) inclined her to consider three main sedimentary environments created by meltwater in terrestial conditions: 1) the environment of running water, in linear and braided patterns, regarded for a long time as pure glaciofluvial, 2) ice-slope-washing environment, rarely defined until now, and 3) the environment of ponded and dammed water, which is merely a glaciolacustrine environment but often change transitionally into a glaciofluvial one.

However, the application of this subdivision alone for more detailed studies is not satisfactory, because each of the quoted main sedimentary environments may be superposed on different zones peculiar to glaciated areas. This produces different subordinate environments according to the zone in which the sedimentation occurs, i.e.: 1) within the ice-covered areas, 2) at the ice margin, or 3) away from the ice. It is worth noticing that these zones have been treated as main criteria in the previous subdivisions quoted above (compare also Francis, 1981; Drewry, 1987), and thus such features as e.g. kames and kame terraces (accumulated in almost identical hydrodynamic conditions) have been placed in quite different groups, and vice versa e.g. kames and eskers (accumulated in quite different hydrodynamic conditions) have been put together, as already mentioned, into one group.

Hence it appears that a more proper way is to reverse the criteria and accept the main sedimentary environments (running water, slope-washing, dammed water) as main criteria, and treat the zones associated with ice body – onto which main environments are superposed – as subordinate ones.

The writer proposes to distinguish three main environmental groups (listed below) in which particular sediments and associated landforms are being formed, and a separate group including different micro-environments producing particular sediments but failing to create landforms.

I. Running water environments:

1. Linear (mostly single channel) meltwater discharge within ice-covered areas, in which eskers are accumulated.

2. Braided system discharge in zones within ice-covered areas (upon dead ice areas), giving origin to glaciofluvial uplands.

3. Braided system discharge outside (near) the ice, producing outwash plains, outwash fans, outwash terraces, and "valley trains".

II. Ice-slope-washing environments:

1. Ice-slope-washing at the ice front, where glaciofluvial end moraines are formed.

2. Ice-slope-washing in crevasses within ice-covered areas, in which glaciofluvial crevasse fillings are deposited.

III. Ponded and dammed water environments (glaciolacustrine and transitional to glaciofluvial):

1. Ponded and dammed water within ice-covered areas, giving origin to kames and kame plateaux.

2. Ice-supported reservoirs outside the ice, in which kame terraces are accumulated.

IV. Glaciofluvial micro-environments.

Two units, quoted within the above subdivision, are not commonly distinguished in publications concerning glaciogenic features. They are: glaciofluvial uplands and glaciofluvial crevasse fillings. These units have been examined by the writer in more detail (first presented in: "Glaciofluvial sedimentary environments: the criteria for genetic subdivision of glaciofluvial sediments and landforms", oral presentation at the Meeting of the Polish Geological Society, Sedimentological Branch, Warsaw, June 1983; an abstract published earlier – 1982b). The recognition of origin of these two units is the main subject of the present paper while the genesis of the other units listed above – discussed in many publications – is considered here in a general way, mainly from the point of view of their belonging to particular sedimentary environments quoted above. Hence, the writer does not discuss in a detailed and systematic way all diagnostic features (compare Eyles *et al.*, 1983) for recognition of these generally treated groups, except some basic features reflecting main paleohydrological conditions prevailing during their sedimentation, and thus reflecting the paleohydrology of (de)glaciated areas.

RUNNING WATER ENVIRONMENTS

LINEAR (MOSTLY SINGLE CHANNEL) MELTWATER DISCHARGE WITHIN ICE-COVERED AREAS. ESKERS

There is a widely recognized fact, discussed already by Flint (1971), that typical eskers are composed of material characterized by structures analogical to those of river channel deposits. A feature which hardly suited this pattern was the occurrence of coarse, (almost) unsorted material in many eskers, usually in their central parts (cores of eskers). This feature is interpreted in the later works (Saunderson, 1977; Aario & Forsström, 1979) as resulting from sedimentation in the conditions of full pipe flow under hydrostatic pressure. This in turn is in agreement with the known fact that some streams and rivers flowing within ice-covered areas very much resemble those of karst regions, where full pipe-flow conditions are common.

Another feature, commonly reported from lowland areas (Skompski, 1963; Michalska, 1971), also does not suit the sedimentation in a channel environment. It is the occurrence in some eskers – usually in their upper parts – of poorly sorted or massive gravels and sands, which often occur together with flow tills. Skompski (1963) and Michalska (1971) interpret such sediments as having been deposited in "crevasses" within the ice. From sedimentological point of view such upper parts of eskers most probably represent a down-ice-slope transported glacial material (flow tills) and ice-slope-wash glaciofluvial sediments (gravels and sands containing finer fractions), which have been deposited immediately down an ice slope onto the already accumulated channel series. This may have taken place in ice-walled valleys, or tunnels, in which the previous linear water discharge had already ceased. So these eskers, deposited in a regular channel regimen, have been then covered by sediments accumulated in conditions characteristic of glaciofluvial crevasse fillings, discussed in the respective section.

Drawing the environmental conclusion from the above remarks one may say that eskers record free linear outflow of meltwater within ice-covered areas, which – in many aspects – may be compared to non-glacial river channel environments. In some cases the sedimentation began in comparatively narrow tunnels, completely filled with water, analogous to some karst conduits. The tunnels then must have become wider and occupied by free-surface flow, either in tunnels or in already open ice-walled valleys. If the linear outflow ceased to exist along an eskers channel, whose ice walls were still high enough and contained glacial debris, the down-ice-slope processes began to work and produced material characteristic of a different, mainly slope-wash environment. This was responsible for a composite origin of the esker-and-crevasse-filling features which will be discussed later in the section concerning crevasse fillings.

BRAIDED SYSTEM DISCHARGE WITHIN ICE-COVERED AREAS. GLACIOFLUVIAL UPLANDS

In 1972-1976 the writer studied an area east of Stoczek, mid-eastern Poland (Fig. 1), which had not suited any distinguished feature of glaciogenic origin though the whole region was undoubtedly formed during deglaciation. The morphology of the area (Pl. I: 1) is much the same as the morphology of till uplands which are very common in the Polish Lowlands. However, the terrain near Stoczek (several tens sq. km large) is mainly built of stratified sands and gravels (Pl. I: 2), and till – a deposit commonly building till uplands – occurs here mostly as interbeddings within stratified sediments or as small patches at the surface. The interbeddings and small covers of till are, however, quite frequent, and their widespread occurrence does not allow the area to be regarded as an outwash plain. The characteristics of the till i.e. its discontinuity, low copmaction, occurrence at differentiated levels and common interbeddings with water-laid gravels, point to its "flow" origin.

Fig. 1 Localities mentioned in the text

The term "flow till" is being constantly used by the writer in spite of the controveversions concerning this term and its meaning, and in spite of replacing it with other terms by some authors (Lawson, 1979; Eyles *et al.*, 1983; Eyles & Kocsis, 1988). The problem concerning the origin of "flow till" – and the question of including this sediment into real tills or considering it rather as a glacioaqueous sediment – was subject of vivid discussion of a Work Group of INQUA Commission on Origin and Lithology of Glacial Deposits during the last several years. The writer agrees with one of the conclusions of this discussion, saying that "flow till" ought to be called so because it is a real glacial (*sensu stricto*, however "secondary") sediment, when: 1 – the material melted out from a glacier has not been disagregated during the following flowage process, and 2 – the sediment does not show the structures characteristic of water-laid sediments. The writer also appreciates the view by Drewry (1987) concerning the "sedimentation continuum" between the "true terrestial till" and "glaci-fluvial" sediments (Drewry, 1987, p. 145).

There also is no necessity to call any kind of till (i.e. the deposit of obvious glacial *sensu stricto* origin) with a descriptive term "diamict" or "diamicton" (compare Eyles *et al.*, 1983). The writer agrees with the opinion that the latter term is to be used – in glacial geology – for those (till-like) sediments which are of unrecognized origin or for those of non-glacial *sensu stricto* origin e.g. glaciomarine or glaciolacustrine diamicts.

The above quoted geological data from the area near Stoczek drove the writer's attention to the evidence from Spitsbergen, concerning recent deglaciation, published by Boulton (1967, 1968). Boulton (1968, p. 400) describes water-laid sediments on dead ice, which are about 15 m thick and interbedded and capped by flow till. This author also publishes the excellent photograph of the recent environment on dead ice (Boulton, 1967, p. 726), showing a debris band ridge protruding some metres above the surrounding supraglacial surface, and producing flow till in the immediate neighbourhood of glaciofluvial sedimentation.

It was quite probable that a similar environment – possibly much larger and characterised by more abundant running meltwater – had been responsible for the formation of the upland east of Stoczek. The student E. Jezierska (1979), who examined a part of this upland for her master thesis, gathered further geological data which confirmed this interpretation, and moreover she pointed out a regularity in the topography of the area, i.e. the existence of elongated rises stretching generally WNW-ESE, separated by lower situated zones often with undrained depressions. Hence the topography controlled by the previously existing debris bands roughly parallel to the former margin of the ice (the problem also discussed theoretically by Boulton, 1967) was strongly suggested in the case of the Stoczek area.

Just recently (1986-1987) a new gravel pit was being excavated at Zabiele near Stoczek within a culmination zone of the upland discussed, which supplied interesting data. The exposure shows a till ridge protruding from under stratified gravels and sands, which is surrounded an truncated by these sediments (Pl. II: 1). The ridge stretches also in WNW-ESE direction i.e. parallel to the culminant zones of the upland. It is built of brown till which is mainly massive but within the proximal, north-eastern, part of the ridge it shows distinct bands (layers) stretching parallel to the ridge and dipping steeply (32°) to northeast (Pl. II: 2). It is also worth adding that beds of stratified gravels and sands, exposed in the immediate neighbourhood of the north-eastern part of the till ridge (much shaded in Pl. II: 1), are inclined about 20° sideways of it, which probably points to a penecontemporaneous subsidence of the beds due to the melting down of remaining ice underneath the sediments. A remarkable feature also is that the sedidments are changing from coarser, immediately by the ridge, to finer, away from it, and in some places they are interbedded with thin (several centimetres) layers of flow till wedging out away from the ridge. So, the source of the material must have been situated very close, in the zone of (recently existing) till ridge.

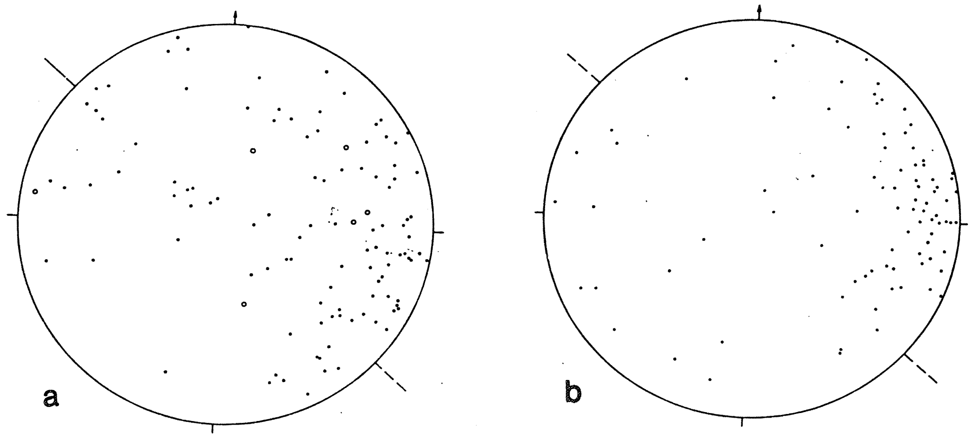

Fig. 2 Orientation of elongated clasts within the till ridge shown in Pl. II: 1 (Wulff, lower hemisphere): *a* – in the central part of the ridge (110 measurements plus 10 almost vertical not shown in the diagram), and in the proximal part (only 6 measurements, marked with circles), *b* – in the distal part of the ridge (92 measurements plus 3 almost vertical not shown in the diagram). Broken line shows the direction of longitudinal axis of the ridge.

The quoted evidence strongly suggests that the till ridge is a remnant of up-turned debris bands (compare Ruszczyńska-Szenajch, 1981). The measurements of orientation of elongated clasts within the till show that most clasts are oriented E and ENE, obliquely to the longitudinal axis of the ridge (Fig. 2a, b). Since the longitudinal axes of up-turned debris bands are usually more or less perpendicular to the ice flow (Boulton, 1967), one may conclude from the data discussed that main ice movement in the area of Zabiele was directed to the south-west, and the strongest impact within the brought up debris bands was directed not quite consistently with it but tended almost straight to the west. Both these directions are not consistent with the general ice advance of the latest ice sheet in Podlasie Region, which was directed to south-east. So the area of Zabiele was probably situated in the south-western flank of the large ice lobe flowing south-east.

The conclusion from the above evidence is that debris bands near Stoczek – like those photographed in Spitsbergen – must have protruded above the lowered surface of decaying ice flooded by glaciofluvial streams during a late stage of deglaciation. The streams were also fed with debris from the decaying bands, and finally they truncated the bands covering them with gravels and sands and thus making them entirely buried features.

Hence, the area east of Stoczek has been most probably formed upon dead ice area during a final stage of degalaciation of that region. This supraglacial surface must have been quite low at that time, i.e. the ablation processes had already reached the lower, debris rich, parts of the ice sheet. Melting of the remaining ice produced water which was abundantly supplied with debris and probably loaded near its transport capacity, so the water must have flowed in braided patterns on a comparatively wide area. Most of the debris must have been carried and deposited by meltwater along lower zones at the surface of the debris-laden dead ice or at the locally ice-free substratum. The lower zones were – at least in some places – separated by the protruding (still frozen) debris ridges roughly parallel to the previous glacial front and producing flow till which interbedded and capped glaciofluvial sands and gravels.

The described new evidence, recording previous close coexistence in Stoczek area of the glaciofluvial and glacial *sensu stricto* sedimentary environments, still does not allow the resulting feature to be regarded as outwash plain (which is purely a glaciofluvial proglacial form). The writer proposes to call such feature a glaciofluvial upland, analogically to till upland which may be formed in similar conditions bur characterized by less abundant meltwater, i.e. in dominating glacial *sensu stricto* environment producing mainly supraglacial flow tills. The dominance of glacial or glaciofluvial environment is very probably controlled by climatic conditions – temperature and humidity. This subject is discussed in a separate paper (Ruszczyńska-Szenajch, 1982a) and will be also considered later on in the present paper.

The term "glaciofluvial upland" undoubtedly is an awkward name, especially for a feature which may constitute a part of Lowlands. However, neither "plain" nor "plateau" suit this feature from geomorphological point of view, and these terms are already used in another meanings, also concerning glaciofluvial (and some glaciolacustrine) features i.e. "outwash plain" and "kame plateau".

It is also worth adding that in the Stoczek region an esker, about 1 km long, is "flooded" by gravels and sands of glaciofluvial upland (Jezierska, 1979). The esker is directed almost perpendicularly to the mentioned elongated rises of the upland, what reflects the primary orientation of the channel(s) parallel to the ice flow. This situation was then followed by the considerable change of meltwater discharge direction and regime. So tha glaciofluvial upland, like till upland, may also comprise another glaciogenic features, e.g. eskers, whose deposition slightly preceded the main process of sedimentation of the upland itself.

The nature of deglaciation inferred from the Stoczek area may have been similar in some aspects to that attributed to some areas in Denmark by Marcussen (1977). On the other hand, it seems probable that a closer examination of some features regarded as outwash plains, but characterised by frequent occurrence of flow till, may possibly reveal their origin similar to that outlined above.

BRAIDED SYSTEM DISCHARGE BEYOND (NEAR) THE ICE. OUTWASH PLAINS

The proglacially accumulated outwash plains and fans in lowlands, and so called valley trains in mountain valleys, are already being observed "*in statu nascendi*". There is no doubt that they are formed proglacially by braided meltwater rivers considerably loaded with debris (e.g. Flint, 1971; Klimek, 1972). The ancient outwash plains built of sands and gravels, which do not contain frequent till inclusions, really are the less controversial as concerns their "pure" glaciofluvial origin and their proglacial position. Hence, they are not discussed here. The more complicated cases are represented by some outwash terraces, formed by running water, which sometimes change into kame terraces accumulated in dammed water. These cases are briefly discussed in the section on kame terraces.

ICE-SLOPE-WASHING ENVIRONMENTS

ICE-SLOPE-WASHING AT THE ICE SHEET FRONT. GLACIOFLUVIAL END MORAINES

The geology of end moraines in lowland areas and corresponding sedimentary environment is discussed in more detail in another paper (Ruszczyńska-Szenajch, 1982a). The evidence presented in that paper shows that most of the examined end moraines are built of glaciofluvial stratified gravels and sands, which are commonly interfingered or capped by unstratified gravels with sands (being a transitional link between glaciofluvial and glacial *sensu stricto* deposits) and/or by flow tills. This type of end moraines is set against the rarely encountered pure "glacial" (or "cold") end moraines, built almost entirely of flow till, and to pure glaciofluvial ones, almost deprived of till.

The conclusion in the cited paper is, that "depositional environment in which end moraines are accumulated is a transitional one between glacial *sensu stricto* and glaciofluvial environments. It may be equally well represented by pure glacial conditions, characterised by an accumulation of flow till at an ice front, as by pure glaciofluvial processes, mainly sedimentation at the foot of an ice front of steep fans built of gravels and sands. However, the most widespread in the lowland areas studied are glaciofluvial-and-glacial end moraines built mainly of stratified gravels and sands, and containing also glacial (flow) deposits". Another concluding remark is that the differentiation of the depositional environments and processes (glacial *versus* glaciofluvial) may probably depend on climatic – mainly thermic – conditions, which influence the amount of meltwater during deglaciation. The relations quoted are illustrated in the present paper in Table 1, and the environment itself is discussed in more detail in the next section.

It is worth adding that the environment of slope-washing at the ice front may be roughly compared to the environment of sedimentation of alluvial fans at the foot of mountains (general characteristics of the latter in: Gradziński *et al.*, 1976). Both these environments produce short-transported deposits, composed usually of sediments deposited in braided channel pattern which are interfingered with debris flows and mudflows. The latter members in end moraines are most commonly represented by different kinds of flow tills.

Table 1

Relation of glaciogenic depositional landforms discussed in the paper
The table illustrates mainly

Melt-water supply	Main sedimentary environments related to meltwater discharge			Subordinate sedimentary environments and corresponding: Ice covered area	
High	Glaciofluvial	Running water and ice-slope washing	Short distance down-ice-slope discharge	Ice-slope-washing sedimentation in crevasses	**Glaciofluvial crevasse fillings**
			Linear (single channel) discharge	Sedimentation in ice-walled channels	**Eskers**
			Braided system discharge	Sedimentation in braided systems upon (vast) dead-ice areas	**Glaciofluvial uplands**
	— Mainly substratum control[4] —				
	Glaciolacustrine[1]		Ponded and/or dammed waters	Sedimentation in ice-walled closed reservoirs and/or dammed outflow systems	**Kames and Kame plateaux**
Mainly climatic control[3] —					
Low	Glacial *sensu stricto*[2]		Meltwater discharge almost absent	Flow till sedimentation down crevasse slopes	**Flow till crevasse fillings**
				Flow till sedimentation upon vast dead ice areas	**Till uplands**

[1] Only kame sedimentation considered here – in order to show the full range from glaciofluvial to glaciolacustrine environments.
[2] Only large-scale (resulting in existence of separate landforms) deposition of flow till considered here – in order to show a full range from glaciofluvial to glacial *sensu stricto* environments.

ICE-SLOPE-WASHING IN CREVASSES WITHIN ICE-COVERED AREAS. GLACIOFLUVIAL CREVASSE FILLINGS

The elongated ridges composed of sediments very similar to those of end moraines discussed above, but showing evidence of deposition from both lateral directions i.e. proving the existence of ice slopes at both sides, also occur in previously glaciated lowlands. They may correspond, in the writer's opinion, to the forms called by Flint (1971) crevasse fillings. Though Flint gave no detailed sedimentological characteristics of such features, he distinguished them from eskers and kames. This is essential then that they do not

Table 1

to the main sedimentary environments and to subordinate environments.
glaciofluvial features.

– related to three main zones associated with ice body – geological-geomorphological features			
Ice front		Beyond (near) the ice	
Ice-marginal slope-washing	**Glaciofluvial end moraines**	–	–
–	–	–	–
–	–	Proglacial sedimentation in braided systems	**Outwash plains** (and akin features)
–	–	Sedimentation in ice-supported reservoirs	**Kame terraces**
Flow till sedimentation down ice margin	**Flow till end moraines**	–	–
–	–	–	–

[3] High versus low meltwater supply are related to climatic conditions during deglaciation (climatically controlled).

[4] Glaciofluvial versus glaciolacustrine meltwater conditions depend on the possibility or impossibility of meltwater discharge which is controlled by substratum conditions.

show evidence of dominating channel deposition by running water (characteristic of eskers) or sedimentation in ponded water (characteristic of (kames).

The crevasse fillings in the meaning quoted above are hardly defined in geological literature. These might be caused by two reasons: 1) All the crevasses within decaying ice have usually been occupiad either by running water (accumulating eskers) or by ponded water (giving origin to kames). Thus morainic debris washed down from the slopes of crevasses merged into aquaeous environments and had no possibility of being deposited in a way analogical to end-morainic accumulation described above; 2) The second reason may be an insufficient use of sedimentological criteria in the differentiation of glaciofluvial features, what has resulted in mistaking some ice- slope-wash crevasse fillings for eskers or kames. The second possibility is also strongly suggested by the common occurrence of the eskers of "double origin", discussed in the section on eskers. Moreover, some features described as eskers are almost entirely composed of sediments showing rather ice-slope-wash (and flow till) deposition (e.g. Michalska, 1971: pl. XV).

Interesting evidence concerning the above question has been supplied by gravel pit exposures at Lubania, southwest of Warsaw. The gravel pit cuts culminat part of an elongated hill, directed NNW-SSE (Fig. 3). The hill is situated on a till upland (of Wartanian age) and its relative height does not exceed 4-8 m. To the north it joins a ridge-like culmination, directed almost perpendicularly, whose internal structure is however not exposed satisfactorily. The gravel pit in question has been observed by the writer over a period of about 20 years whilst the exploitation has proceeded.

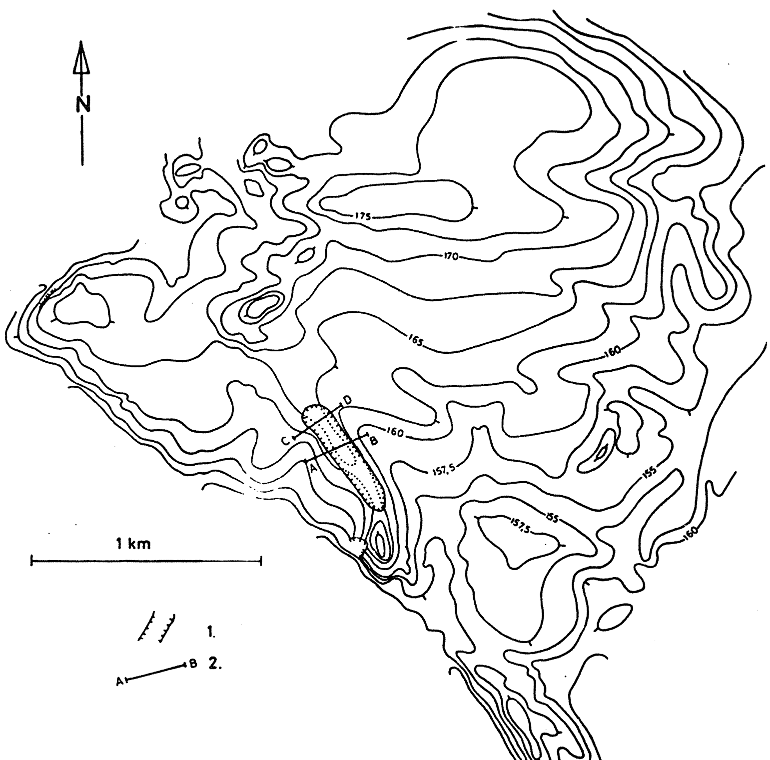

Fig. 3 Geological sections across the gravel pit at Lubania (location in Fig. 3). *1* – well sorted stratified sands, in places with gravelly interbeddings, *2* – poorly sorted stratified gravels with sands, *3* – stratified silty sands, *4* – poorly sorted gravels with cobbles and sand, with poorly marked stratification, *5* – till. Dotted line – hill topography before exploitation. Broken line – exploitation surface poorly exposed.

The lowermost exposed sediments in the central part of the hill are mainly represented by medium and coarse sands, in places changing into gravels, almost devoid of silt. These sediments are of grey colour and show distinct cross-bedding which points to the general southward direction of transport – parallel to the long axis the hill – by a (rapidly) flowing stream. They were shown only fragmentarily in the deepest cuttings of the gravel pit situated below the level of the till upland surrounding the hill (Fig. 4, bed 1).

Sediments overlying the above described sands and gravels have been widely exposed in the walls of the gravel pit. They are characterised by strong differentiation described below.

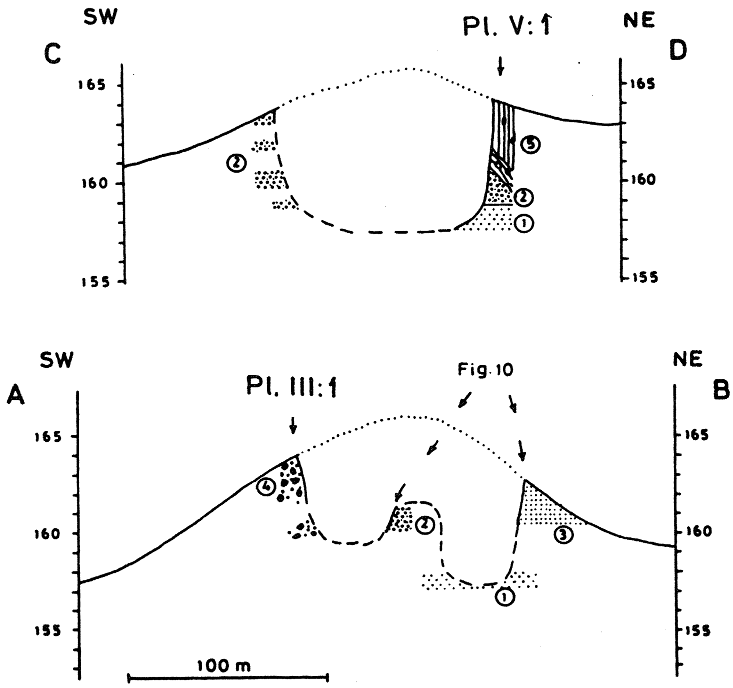

Fig. 4 Topographic setting of the gravel pit at Lubania. *1* – gravel pit, *2* – lines of geological sections. Contour lines every 2.5 m

The exposures in the central segment of the hill show coarse gravels with cobbles and sands, containing silt fraction, roughly bedded, with bedding planes inclined generally to the south (Fig. 4: section A-B, bed 4; Pl. III: 1) These sediments build recently the western part of the discussed segment of the hill and – according to previous observations – they also built its top part here, being now already removed. The coarse roughly bedded gravels change – in the direction of the axial part of the hill – into gravels showing better selection and more distinct bedding (Fig. 4: section A-B, bed 2; Pl. III: 2), and these are replaced in the eastern flank of the hill by fine and silty sands with occasional gravelly interbeddings, usually showing horizontal and almost horizontal stratification (Fig. 4: section A-B, bed 3; Pl. III: 2).The irregular contact – exposed in fragments only – of the two latter sediments indicates that the deposition of the fine-grained sands must have been synchroneous and partly posterior to the accumulation of the gravels. A distinct feature of the three sediment series discussed is their colour being usually grayish-brown and grayish-rusty (gravels) or grayish-yellow (sands), and distictly different from the clear grey colour of the lowermost sands described above.

A segment of the hill which is situated about 250 m to the northwest from the above described one shows an almost reverse arrangement of sediments (Fig. 4, section C-D). The western flank of the hill is here built up of stratified sands and gravels, containing silt, which occur on different levels but are not well exposed as a whole. The opposite, eastern flank of the hill is much better exposed (Pl. IV: 1). Its dominant feature is a large mass of till cutting trough gravels and sands. The latter sediments are well shown in the southeastern part of the exposure discussed. They consist of three beds of coarse gravels, almost unsorted and unstratified, separated by beds of fine and medium sands, containing silty fraction, showing mainly horizontal stratification (Pl. IV: 2). The till mass cuts these sediments along a sharply marked steep line and the gravels and sands near this boundary line are faulted and flexured (Pl. IV: 2).

The lowermost portion of the central part (Pl. V: 1) of the exposure discussed shows medium and coarse sands, devoid of silt, of light-grey colour, mainly cross-bedded, pointing to a transport direction generally southward, i.e. more or less parallel to the morphological axis of the hill. They most probably correspond to the analogical sands exposed in the lowermost cuttings in the more southern segment shown on section A-B (Fig. 4, bed 1). The sands shown on Pl. V: 1 are overlain by gravel with sand, poorly sorted, containing silt, mainly cross-bedded and showing variable directions of transport. The boundary of these two beds is erosional (Pl. V: 1). The gravels in turn are truncated by the distinctly marked oblique base of the till mass (Pl. V: 1). The lowermost parts of the till show in this place interbeddings of gravel and the till itself has a fluidal structure (Pl. V: 2), while higher up it is mainly massive.

The lowermost parts of the till are better exposed in the northwestern part of the expopsure discussed. They are composed of irregular till layers, containing boulders, interbedded with layers of poorly sorted gravel and sand, and changing upward into bedded till of fluidal character (Pl. VI: 1). These sediments truncate discordantly the yellowish stratified sands, and the till layers are dipping about 30° E (the direction of the wall is about 120° and the strike of the till layers is approximately 150°). So the till mantles in a steep way the eastern flank of the discussed segment of the hill. The lowermost layers of the till are cut by faults (Pl. VI: 1), which have probably been formed almost syndepositionally, when the till layers were yet in a semi-fluid state. This is revealed by a till layer partly disrupted by two faults (Pl. VI: 2). The layer must have been bent downward by the deformation, and the unconsolidated till has flowed to the lower position and leant against the fault surface as a bulging mass conected only by a thin "neck" with the undisturbed part of the layer (Pl. VI: 2). The bulged till lump is also connected by another thin "neck" with the yet lower situated (thrown down by the next fault) part of this layer (Pl. VI: 2). The faults have been most probably formed due to differential loading during the mass-movement deposition of the overlying (massive) till. The till reaches the topographic surface and is probably the youngest member of the sediments constituting the hill. It occurs in the highest, culminant part of the hill and also mantles the hill flank, as already mentioned.

The above evidence points to the following environmental changes during the deposition of sediments constituting the hill discussed. A crevasse in the ice was occupied by a stream which deposited well sorted, cross-bedded, grey sands and gravels, occurring in the lowermost parts of the gravel pits, and corresponding (most probably) to the "esker stage" of the deposition (bed 1 on Fig. 4). Then, the previous regular and continuous outflow along the line of the recent hill axis ceased to work, and it was replaced by washing-down processes into the still existing crevasse from its ice-slopes. These processes resulted in sedimentation of poorly sorted, variably stratified gravels and sands, forming discontinuous beds, constituting very probably glaciofluvial fans superposed upon the esker series and upon one another in the crevasse (bed 2). This kind of sedimentation might have locally dammed the outflow of (not abundant) meltwater, which resulted in deposition of the silty sands (bed 3) in a small reservoir within a widened, eastern part of the crevasse. Finally the coarse gravels with cobbles (bed 4) and the large mass of flow till (bed 5) were deposited. The flow-till deposition event was preceded by local erosion of already deposited gravels and sands – probably due to a newly open outflow in the ice caused by melting processes – and by deposition of alternating gravel and flow till beds. These sediments were almost syndepositionally deformed during the deposition of the main body of the till, accumulated in a mass movement process. This points to a very close existence of debris-rich ice (debris bands) situated high enough to produce mass movement of released debris, which truncated water-laid sediments. Since the till mantles steeply the eastern flank of the hill, it was most probably deposited in a widened part of the crevasse, in the final stage of its filling process. The till, as well as the mentioned (earlier deposited) silty sands, point to permanent existence of ice walls of the crevasse during the process of sedimentation, while the supply of coarse material from both sides (Fig. 4) says that both walls contained debris-laden ice.

So, the hill at Lubania represents a composite feature: glaciofluvial (built mainly by ice-slope washing, with occasional linear transport and local damming of meltwater) and flow-till crevasse filling, superposed onto a most probable esker series.

As regards crevasse fillings superposed on typical esker series the writer would then suggest the explanation of the commonly occuring "undulation" of their top surface. The rises of the crest of such features most probably record the previous existence of up-raised debris bands in decaying ice (compare Ruszczyńska-Szenajch, 1981). Since the up-raised debris bands are usually more or less parallel to the ice front (Goldthwait, 1951) and esker channels most commonly run more or less transversally to this front, the rises of the "undulating" top surface of an esker-and-crevasse-filling feature most probably reflect zones of cutting by the esker channel through zones of upraised debris bands. Until the channel was occupied by running water most of the debris supplied was carried and deposited by the stream, but when the linear discharge ceased the washed down and slid down material was accumulated in places of more abundant supply i.e. in places of intersections with debris-laden bands.

The quantitative relation between the glaciofluvial sediments and glacial flow till, of which a crevasse filling is composed, probably also depends (analogically to end moraines discussed in the previous section) on local climatic conditions controlling the intensity of meltwater supply. However, this is only valid for the main stage of deglaciation, untill the proportions of clean ice to debris-laden ice are in favour of the former. In the final stage of (areal) deglaciation only the lower parts of glacier ice remain. They usually contain much more debris, and the proportions change in favour of debris-laden ice. So even the warmest climate cannot produce enough meltwater to transport and accumulate the enlarged quantity of debris in the hydrodynamic conditions which prevailed before. Hence, flow till and/or other coarse and poorly sorted sediments very commonly occur on tops and/or slopes of many glaciofluvial and some glaciolacustrine features, constituting the youngest members of the deposition.

PONDED AND DAMMED WATER ENVIRONMENTS (GLACIOLACUSTRINE AND TRANSITIONAL TO GLACIOFLUVIAL)

PONDED AND DAMMED WATER WITHIN ICE-COVERED AREAS. KAMES

The origin of kames has usually been attributed – in a general way – to glaciofluvial environments (see various papers in Goldthwait, 1975; Jurgajtis, 1980). However, some authors regard them as glaciolacustrine features (Lavrushin, 1977), and others distinguish "limnoglacial kames" and "fluvioglacial kames" (Niewiarowski, 1965). There is also a number of works in which the term kame is attributed to any feature deposited in a crevasse or other "hollow" in (dead) ice, regardless of sediments recording different sedimentary environments. The comparatively frequently reported "limnoglacial kames" show obvious differences in geological composition when compared to eskers or glaciofluvial crevasse fillings described above. Both latter feautures are mainly built of gravel with sand while "limnoglacial kames" are usually composed of fine sand and silt characteristic of cold-lacustrine accumulation. Detailed sedimentological studies of some kames from Polish Lowlands (e.g. Grzybowski, 1970) have revealed that some kames built of fine sands and silts may have been deposited in an environment of (slowly) running water and in many cases the sediments are deltaic. This points to a (common?) existence of conditions transitional between glaciofluvial and glaciolacustrine. So it seems convenient to join the transitional features and the "limnoglacial kames" under the common name kames.

From a geomorphological point of view – known from numerous publications – the "limnoglacial kames" usually represent separate hills (isolated or groupped) and sometimes they reach dimensions of plateaux. As they often occur at the highest elevations of an area, they must have been surrounded by ice walls which enabled their deposition in reservoir(s) of meltwater. Some kame plateaux may represent, in the writer's opinion, the equivalents of glaciofluvial uplands, i.e. they must have been formed on areas occupied by dead ice but without free meltwater discharge (Table 1).

The evidence briefly outlined above inclines the writer to regard kames as glaciolacustrine features including also transitional and composite forms. The latter are accumulated in dominating glaciolacustrine environment with intervening – occassionally or repeatedly – glaciofluvial conditions. The deltaic character of some parts of kames, especially of so called "kame fingers" joining a main hill or plateau, may represent – as already discussed in the literature – the mouths of tributaries joining a reservoir of kame sedimentation.

A commonly reported feature concerning kames (built of fine-grained sediments) is the occurrence of coarse material at their tops and/or flanks. This feature is sometimes the subject of considerable debate. The writer's interpretation is analogical to that outlined in the end of the previous section.

ICE-SUPPORTED RESERVOIRS OUTSIDE THE ICE. KAME TERRACES

The term "kame terraces" was originally used, and is still used, to denote a glaciofluvial terrace built by meltwater running along the side of a valley glacier: between the glacier and the valley wall (Flint, 1971). Hence, the resulting feature is usually composed of coarse gravels and sands with sedimentary structures recording running water environment. However, the terraces composed of very fine sands and silts – pointing to dominating lacus- trine environment – are also reported, especially in lowlands and uplands (Klimek, 1966; Ruszczyńska-Szenajch, 1964). They usually were accumulated in reservoirs dammed by glaciers against the elevations of substratum which prevented a free outflow of meltwater (compare also Baraniecka, 1969).

The marked contrast in geological composition between the two kinds of terraces, quoted above, reflects quite different sedimentary environments, and deserves a differentiation of their names. The writer would propose to restrict the term "kame terraces" to the features deposited in dominating glaciolacustrine conditions, and "outwash terraces" to those accumulated by running water outside the margin of a glacier. She would also propose a term "lateral outwash terraces" for those deposited by running water at the sides of valley glaciers.

GLACIOFLUVIAL MICRO-ENVIRONMENTS

The inclusions of glaciofluvial sedidments within glacial deposits *sensu stricto*, i.e. within tills, are commonly reported. They are most frequent within flow till (Boulton, 1968; Lawson, 1979; Macrussen, 1973; Ruszczyńska-Szenajch, 1981) and sometimes occur in equal proportions with the tills forming so called flow till complex (Boulton, 1980). The glaciofluvial sands and gravels involed within flow tills are often deposited by small rillets running among the tongues of creeping down unconsolidated till. A very interesting study of such environments is published by Lawson (1979). Thus, the glaciofluvial inclusions within a flow till are in the strict sense syndepositional with the till.

Glaciofluvial inclusions occurring within melt-out till are not so frequently reported. They sometimes form sandy fillings of small channels within the till (Pl. V: 3) which show undisturbed sedimentary structures. The erosion and accumulation within some channels have most probably already occurred before the melting of the ice cementing morainic material, i.e. they were connected with the meltwater circulation in dead ice. In these cases the fillings are – in the detailed approach – pre-depositional features in relation to the till in which they occur. In a general sense they may be regarded as syndepositional with the till. The undisturbed sedimentary structures of such fillings prove a considerable stability of the surrounding till mass and have been regarded by some researchers as diagnostic features for recognition of the melt-out till (Shaw, 1979).

Sandy and gravelly inclusions of glaciofluvial origin occurring autochthonously within lodgement till are hardly reported in the literature. However, they sometimes may occur as thin layers deposited in a subglacial environment by local small bodies of running water accompanying the lodgement process (oral discussion among the patricipants of the field meeting of the Sedimentological Branch of the Polish Geological Society, 1972). They are, in such a case, syndepositional with the till in which they occur. Lodgement tills may also be cut subglacially by small channels filled then with glaciofluvial gravels and sands – analogical to those encountered in melt-out tills – but in this case the channels are, of course, post-depositional in relation to the till which is cut by them.

It is worth noticing that the word "inclusion" is used here to denote a sediment body which is considerably smaller than the till bed in which it occurs. These small glaciofluvial inclusions originate in the glacial *sensu stricto* environments dominating over the glaciofluvial ones. This also results in the lack of individual morphological expressions of such small glaciofluvial beds.

CONCLUDING REMARKS

Any of the discussed glaciofluvial sedimentary environments seldom prevails alone for a long time, and thus it may rarely create a pure genetic kind of geological feature. The frequently occurring features are composite or transitional ones, resulting from the abrupt or gradual changes of depositional processes according to variations of sedimentary environments in glaciated areas. Probably the most frequent "chains" of depositional modifications are represented by: a) changing from glaciofluvial environments to glacial *sensu stricto* ones (and *vice versa*), this frequently occurs in zones of ice slopes and upon dead ice areas, and most probably results from meltwater supply, and b) changing from glaciofluvial environments to glaciolacustrine ones (and *vice versa*); this occurs as well within ice-covered areas as beyond (near) the ice, and is mainly caused by the (changing) nature of meltwater discharge. Thus the geological structure and relief of a feature, resulting from the particular course of depositional processes, must strongly depend on the duration of the dominant sedimentary environment. This, in turn, most probably depends on climatic conditions controlling meltwater supply, and on substratum conditions (including dead ice configuration) controlling meltwater discharge (Table 1).

Two of the three groups (quoted in the *Introduction*) of main sedimentary environments created by meltwater in terrestial conditions seem to show considerable analogy to the corresponding environments in non-glacial conditions. These are running water and ponded water environments. The third one, ice-slope-washing environment, seems to be most peculiar to glaciated areas. However, it shows some analogies with the environment of deposition of alluvial fans formed at the foot of mountains.

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Streszczenie

ŚRODOWISKA SEDYMENTACYJNE WYSOCZYZN GLACJOFLUWIALNYCH I GLACJOFLUWIALNYCH FORM SZCZELINOWYCH NA TLE INNYCH ŚRODOWISK LODOWCOWO-WODNYCH

Hanna Ruszczyńska-Szenajch

ZAGADNIENIE GENETYCZNEGO PODZIAŁU OSADÓW I FORM LODOWCOWO-WODNYCH

Osady i formy określane ogólnie jako “wodnolodowcowe” ("fluwioglacjalne") były od dawna dzielone na dwie główne grupy tj.: akumulowane w strefach kontaktu z lodem ("ice-contact") i ekstraglacjalne ("proglacial"). Podział ten był szeroko rozpowszechniony głównie przez prace Flinta (1957, 1971). Jurgajtis (1980, 1982) w podsumowaniu prac Komisji INQUA nad tym zagadnieniem wymienia jeszcze trzecią grupę jako równorzędną z dwoma powyższymi, tj. osady i formy marginalne ("ice-marginal"). A więc jako główne kryteria podziału przyjmowane były dotychczas strefy charakterystyczne dla obszarów zlodowaconych: strefa zajęta przez lód (określana jako “englacial"), strefa marginalna ("ice-marginal") i strefa ekstraglacjalna ("proglacial").

Coraz bardziej zaawansowane badania sedymentologiczne wykazują jednak, że trudno jest zaliczać do jednej (genetycznej) grupy, np. do grupy akumulacji w strefie zajętej przez lód, osady tak różne jak ozy (akumulowane przez wodę płynącą), kemy (akumulowane głównie w zbiornikach) i niektóre formy szczelinowe (akumulowane głównie przez zmywy ze zboczy lodowych). Jak widać, w każdym z trzech wymienionych przypadków mamy do czynienia z całkowicie odmiennym środowiskiem sedymentacyjnym. Z drugiej strony, osady i formy akumulowane w analogicznych warunkach, jak np. kemy i tarasy kemowe, umieszczane są – w tradycyjnym podziale – w odrębnych grupach. Również nieścisłe okazało się nazewnictwo, jak np. powszechne stosowanie określenia "wodnolodowcowe" zamiast lodowcowowodne, gdy głównym czynnikiem transportu i akumulacji jest w tym przypadku woda.

Prace autorki nad osadami glacjogenicznymi Polskiego Niżu oraz materiał opublikowany przez innych autorów skłoniły ją do wyróżniania trzech głównych środowisk sedymentacyjnych tworzonych przez wody topnienia lodowców w warunkach lądowych: 1) środowisko wód płynących, od dawna uważane jako klasyczne "fluwioglacjalne", 2) środowisko zmywów ze zboczy (krawędzi) lodowych, rzadko dotychczas wyróżniane i 3) środowisko zbiorników wód topnienia, które jest w zasadzie środowiskiem glacjolimnicznym, ale bardzo często stwarza warunki przejściowe do glacjofluwialnych.

Jednakże zastosowanie powyższego podziału do badań bardziej szczegółowych nie jest wystarczające, ponieważ każde z trzech wymienionych środowisk może nakładać się na różne strefy właściwe obszarom zlodowaconym i tworzy w ten sposób podrzędne środowiska. Tak więc najbardziej właś-ciwym wydaje się odwrócenie kryteriów i przyjęcie głównych środowisk sedymentacyjnych (wód płynących, zmywów ze zboczy lodowych oraz zbior- ników wód topnienia) jako główne kryteria, a stref charakterystycznych dla obszarów zlodowaconych jako kryteria podrzędne.

Autorka proponuje (dla obszarów lądowych) przyjęcie następującego podziału środowisk sedymentacyjnych wód topnienia, w których akumulowane są określone typy osadów i odpowiadajce im formy rzeźby:

I. Środowiska wód płynących:

1. Linearny odpływ wód topnienia na obszarach zajętych przez lód; akumulacja ozów.

2. Roztokowy odpływ wód na obszarach zajętych przez (martwy) lód; akumulacja wysoczyzn glacjofluwialnych.

3. Roztokowy odpływ wód topnienia na zewnątrz (w sąsiedztwie) lodowców; akumulacja zandrów.

II. Środowiska zmywów ze zboczy (krawędzi) lodowych:

1. Zmywy z krawędzi szczelin lodowych na obszarach zajętych przez martwy lód; akumulacja glacjofluwialnych form szczelinowych.

2. Zmywy z krawędzi czoła lodu; akumulacja glacjofluwialnych moren czołowych.

III. Środowiska zbiorników wód topnienia (glacjolimniczne i przejściowe do glacjofluwialnych);

1. Zbiorniki wód topnienia na obszarach zajętych przez (martwy) lód; akumulacja kemów i plato kemowych.

2. Podparte lodem zbiorniki wód topnienia na zewnątrz lodowca; akumulacja tarasów kemowych.

IV. Jako czwartą grupę autorka wyodrębnia mikro-środowiska sedymentacji wód topnienia w obrębie dominujcej akumulacji lodowcowej sensu stricto. W środowiskach tych akumulowane są zazwyczaj niewielkie wkładki osadów wodnych występujące w obrębie glin lodowcowych ale nie budujące odrębnych form rzeźby.

Dwie spośród wymienionych wyżej jednostek nie były wyróżniane (lub jasno sprecyzowane) w dotychczasowej literaturze; są nimi wysoczyzny glacjofluwialne i glacjofluwialne formy szczelinowe. Tym dwom jednostkom autorka poświęca główną uwagę w niniejszym artykule – pozostałe szkicuje tylko ogólnie jako tło różnych środowisk sedymentacyjnych – i tylko te dwie uwzględnia w obecnym streszczeniu.

WYSOCZYZNY GLACJOFLUWIALNE

Zagadnienie genezy wysoczyzn glacjofluwialnych omawiane jest na przykładzie rejonu Stoczka Łukowskiego (Fig. 1), który to rejon stanowi część większej jednostki o analogicznych cechach, rozciągającej się ku południowo-zachodnim okolicom Siedlec. Morfologia obszaru koło Stoczka (Pl. I: 1) jest taka sama jak morfologia wielu wysoczyzn morenowych na Niżu Polskim. Jednakże obszar ten jest zbudowany głównie z warstwowanych żwirów i piasków (Pl. I: 2). Natomiast glina lodowcowa – osad budujący wysoczyzny morenowe – występuje tu tylko w formie cienkich przewarstwień w obrębie żwirów i piasków lub w formie niewielkich płatów na powierzchni, wykazując w obu położeniach cechy dość typowe dla glin spływowych. Występowanie przewarstwień i niewielkich pokryw glin lodowcowych jest jednakże często spotykane i nie pozwala ono na określenie badanego obszaru jako zandr.

W latach 1986-87 odsłonięto w żwirowni na wschód od Stoczka grzbiet (wał) zbudowany z gliny lodowcowej, który jest otoczony i ścięty oraz przykryty przez glacjofluwialne żwiry i piaski (Pl. II: 1). Zarówno cechy gliny budującej grzbiet (Pl. II: 2 i Fig. 2) jak i otaczających go żwirów i piasków – które w bezpośrednim sąsiedztwie grzbietu zawierają grubszy materiał i wkładki glin spływowych – wskazują, że może on reprezentować kopalny odpowiednik wyniesionych warstw lodowo-morenowych.

Zebrany dotychczas materiał pozwala na ogólne określenie środowiska sedymentacji osadów budujących omawiany teren. Była to najprawdopodobniej strefa zajęta przez martwy lód, w końcowej fazie deglacjacji tego regionu. Powierzchnia supraglacjalna musiała już być w tej strefie znacznie obniżona, tj. procesy ablacyjne dotarły do dolnych partii lodu, bogatych w materiał morenowy. Topnienie pozostałego lodu uwalniało więc wodę, która musiała być przeładowana materiałem skalnym. Tworzyła ona w omawianej strefie szerokie przepływy typu roztokowego, efektywnie akumulujce żwiry i piaski przy najmniejszych nawet spadkach siły transportu. Obszary przepływu wód topnienia były miejscami oddzielone przez sterczące nad powierzchnię martwego lodu grzbiety zbudowane z warstw lodowo-morenowych – analogicznie do sytuacji, obserwowanych w terenach współcześnie zlodowaconych. Wyniesione nad powierzchnię warstwy lodowo-morenowe były źródłem glin spływowych, które obecnie przewarstwiają i (lub) przykrywają w wielu miejscach osady glacjofluwialne.

Autorka proponuje nazwać jednostkę powyższego typu wysoczyzną glacjofluwialną, przez analogię do wysoczyzny morenowej. Ta druga może bowiem powstawać w zbliżonych warunkach, jednakże przy zdecydowanie mniejszym udziale wód topnienia, tzn. w supraglacjalnym środowisku lodowcowym *sensu stricto*, gdzie akumulowane są głównie gliny spływowe (Tabela 1).

GLACJOFLUWIALNE FORMY SZCZELINOWE

Nazwa "formy szczelinowe" jest od dawna używana w geologii i geomorfologii glacjalnej, ale zakres tego pojęcia jest często utożsamiany a jeszcze częściej niejasno odgraniczany od zakresu pojęć "kemów", a nierzadko i "ozów". Autorka określa jako formy szczelinowe formy powstałe w tych szczelinach w martwym lodzie, którymi nie odbywał się ani ciągły przepływ linearny (dający początek ozom), ani nie wypełniały ich długotrwałe zbiorniki wód topnienia (w jakich tworzą się kemy). Głównymi procesami sedymentacyjnymi w omawianych szczelinach – w warunkach dominującej sedymentacji lodowcowo-wodnej – były najprawdopodobniej zmywy zboczowe z krawędzi szczeliny, powodujące akumulację materiału głównie w postaci stożków napływowych na jej dnie, z większym lub mniejszym udziałem lodowcowych glin spływowych. Budowa geologiczna wskazująca na tego typu sedymentację jest omówiona w niniejszym artykule na przykładzie wzgórza w Lubani (Fig. 1).

Wzgórze w Lubani ma wydłużony kształt o kierunku zbliżonym do południkowego (Fig. 3), a jego wysokość względna nie przekracza 4-8 m nad poziom otaczającej je wysoczyzny morenowej. Kulminacyjna część wzgórza rozcięta jest przez dużą żwirownię (Fig. 3), której ściany dostarczyły ciekawych odsłonięć. Odsłonięcia te stały się podstawą niniejszego opracowania i wynikających zeń wniosków, dotyczących środowiska sedymentacyjnego.

W najgłębszych wykopach w dnie żwirowni odsłonięto miejscami piaski i żwiry szare, pozbawione pyłu (Fig. 4: warstwa 1 oraz Pl. V: 1), których warstwowania przekątne wskazują na przepływ wód w kierunku południowym. Osady te reprezentują najprawdopodobniej początkową, "ozową" fazę wypełniania szczeliny. Następnie jednak konsekwentny przepływ linearny uległ zanikowi i został zastąpiony przez procesy spłukiwania lodowych krawędzi szczeliny, zawierających materiał skalny, co spowodowało sedymentację żwirów i piasków o barwach żółtawych i rdzawych, o słabej selekcji, zawierających domieszki pyłowe, o różnorodnym warstwowaniu nie wskazującym na jednolity kierunek transportu. Osady te odsłonięto w różnych częściach ścian żwirowni (Fig. 4: warstwa 2 oraz Pl. III: 2, Pl. IV: 2 i Pl. V: 1). Tworzą one najprawdopodobniej glacjofluwialne stożki, nakładające się na ozową serię, a następnie kolejno jedne na drugie. Ten rodzaj sedymentacji mógł zatamować na pewien czas niezbyt obfity odpływ wody, która utworzyła niewielki zbiornik we wschodniej, poszerzonej na skutek topnienia, części szczeliny. Istnienie takiego zbiornika dokumentowane jest tam przez piaski mulaste, wykazujące przeważnie poziome warstwowanie (Fig. 4: warstwa 3; Pl. III: 2).

W końcowych fazach akumulacji osadów budujcych wzgórze w Lubani zostały osadzone gruboziarniste żwiry z głazami i domieszką pyłu, ze słabo wyrażonym warstwowaniem, występujące w zachodniej części wzgórza (Fig. 4: warstwa 4 oraz Pl. III: 1). Osad ten jest zbliżony do przejściowego między osadami glacjofluwialnymi a glacjalnymi *sensu stricto*. Natomiast z przeciwległej, wschodniej strony wzgórza występuje duża masa gliny spływowej (Fig. 4: warstwa 5 oraz Pl. IV: 1), której spąg ścina warstwowane żwiry i piaski (Pl. IV: 2) oraz stromo otula zbocze wzgórza. Akumulacja tej gliny – na drodze ruchów masowych – była poprzedzona lokalną erozją (przypuszczalnie spowodowaną utworzeniem się nowego odpływu na skutek procesów topnienia) oraz akumulacją przewarstwiających się wzajemnie żwirów i cienkich warstw glin spływowych (Pl. VI: 1). Te ostatnie osady zostały również zdeformowane – zanim jeszcze warstwy gliny uległy konsolidacji (Pl. VI: 2) – przez osunięcie uwolnionej z lodu masy gliny. Obecność gliny w tym położeniu świadczy o ówczesnym bezpośrednim sąsiedztwie lodu przeładowanego materiałem skalnym, który to lód znajdował się na tyle wysoko, że mógł dać w efekcie tak duże osunięcie wytopionego materiału. Były to najprawdopodobniej wyniesione ku górze warstwy lodowo-morenowe ("up-raised debris bands").

Zarówno występowanie gliny spływowej jak i poziomo warstwowanych piasków mulastych świadczy o ciągłej obecności ścian lodowych ograniczających szczelinę. Obustronna dostawa grubego materiału wskazuje, że obie krawędzie utworzone były w lodzie zawierającym materiał morenowy. Reasumując można stwierdzić, że wzgórze w Lubani jest glacjofluwialną (częściowo gliniastą) formą szczelinową, która według wszelkiego prawdopodo- bieństwa została nałożona na zaczątkową formę ozową.

W zakończeniu warto zwrócić uwagę na fakt, iż – sądząc na podstawie materiałów publikowanych – znacznie częściej obserwować można sytuację odwrotną od powyższej tzn. typowa seria ozowa jest nadbudowana cieńszą serią szczelinową. Świadczy to, iż względnie długotrwałe środowisko przepływu linearnego uległo w końcu zanikowi, a jego miejsce zajęło środowisko analogiczne do opisanego wyżej. Omówiony tu typ sedymentacji pozwala również stosunkowo prosto wyjaśnić "falistą linię grzbietów" niektórych ozów. Mianowicie: ponieważ akumulacja zilustrowana przykładem z Lubani następowała bardzo blisko albo wręcz bezpośrednio obok źródła materiału, stąd wyniosłości grzbietu ozu (nadbudowanego serią szczelinową) mogą stanowić nagromadzenia materiału w strefach znajdujących się obok lodu najbardziej przepełnionego materiałem skalnym. Jest bardzo prawdopodobne, że najwyższe wyniosłości zostały zakumulowane w strefach przecięcia dolin ozowych (zazwyczaj mniej więcej prostopadłych do czoła lodu) ze strefami wyniesionych warstw lodowo-morenowych (które najczęściej przebiegają w przybliżeniu równolegle do czoła).

EXPLANATION OF PLATES

Plate I

1 — A general view on the glaciofluvial upland near Stoczek.
2 — Sands and gravels of the glaciofluvial upland near Stoczek.

Plate II

1 — Till ridge protruding from sands and gravels exposed in gravel pit at Zabiele.
2 — Till bands within the proximal part of the till riddge at Zabiele.

Plate III

1 — Gravels with cobbles and sand, exposed in western flank of the hill at Lubania. More exact location of the exposure is shown in Fig. 4, section A-B.
2 — Gravels with sand and occasional cobbles, occurring in axial part of the hill at Lubania. In the background: fine silty sands exposed in the eastern flank of the hill. More exact location is shown in Fig. 4, section A-B.

Plate IV

1 — Exposure in north-western segment of the hill at Lubania, showing a "flow-mass" of till (t) cutting trough gravels and sands. Central part of the exposure is shown also in Fig. 4 (section C-D) and on Pl. V: 1. The framed detail is shown on Pl. VI: 1.
2 — Gravels and sands, almost vertically cut and deformed by the till mass. The south-eastern part of the exposure shown above (Pl. IV: 1).

Plate V

1 — Central part of the exposure shown on Pl. IV: 1. *a* – well sorted, light-grey sands; *b* – poorly sorted gravels with sand; *c* – flow till with fluidal structures, changing upward into massive till.
2 — Fluidal structure of the till. A detail of Pl. V: 1.
3 — A fossil tunnel within till, filled with glaciofluvial sands (removed near entrance). The fault-like structures in the till are not marked within stratified sand filling the tunnel. Exposure in the Vistula valley escarpment at Wyszogród.

Plate VI

1 — Irregular till layers interbedded with poorly sorted gravel and sand (t-s), changing upward into bedded "fluidal" till (t) and truncating yellowish sands (s). Note the faults near the center of the picture, shown also below (Pl. VI: 2). Spatula is about 20 cm long. A detail of the north-western part of the exposure shown on Pl. IV: 1.

2 — Till layer disturbed by two faults. Note a bulged till lump (leaning against the fault line) which is connected by a thin "neck" with the higher occurring non-disturbed part of the till layer and by another "neck" with the lower resting smaller till lump (marked by the spatula). A detail of the upper picture (this plate).


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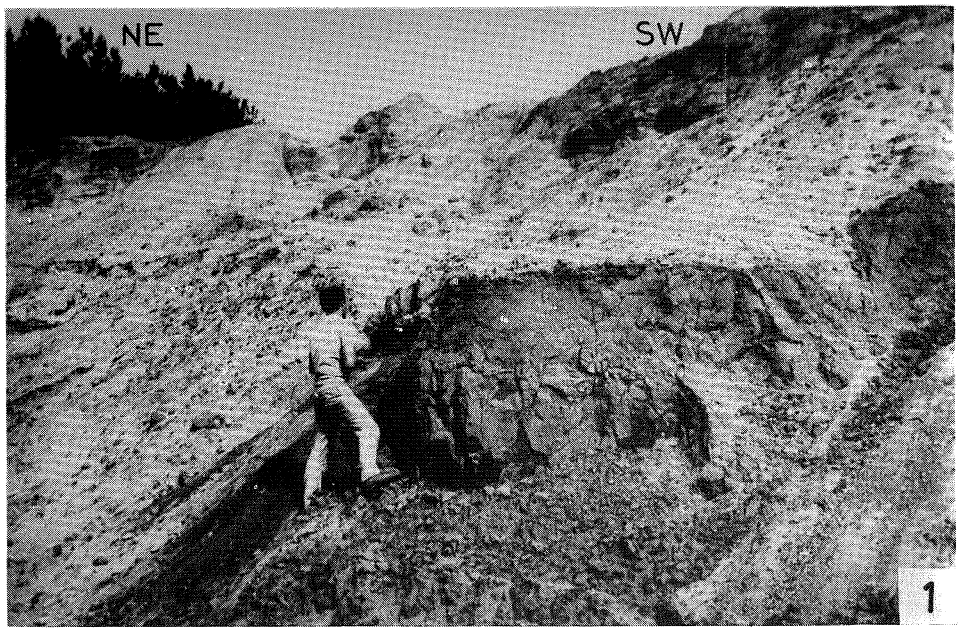
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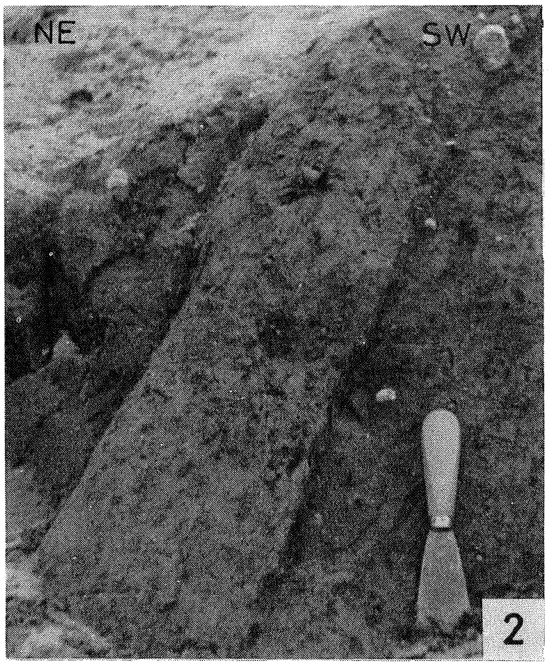
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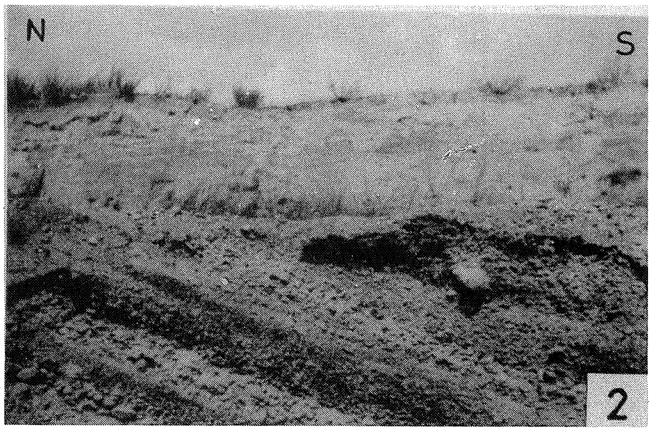
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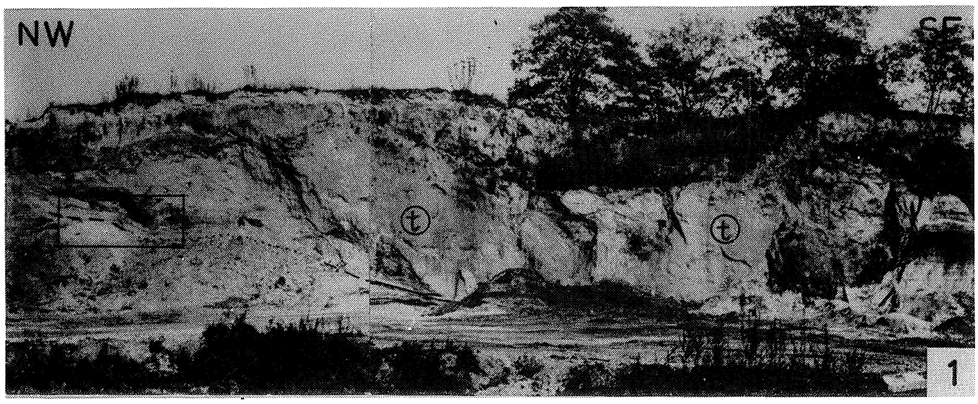
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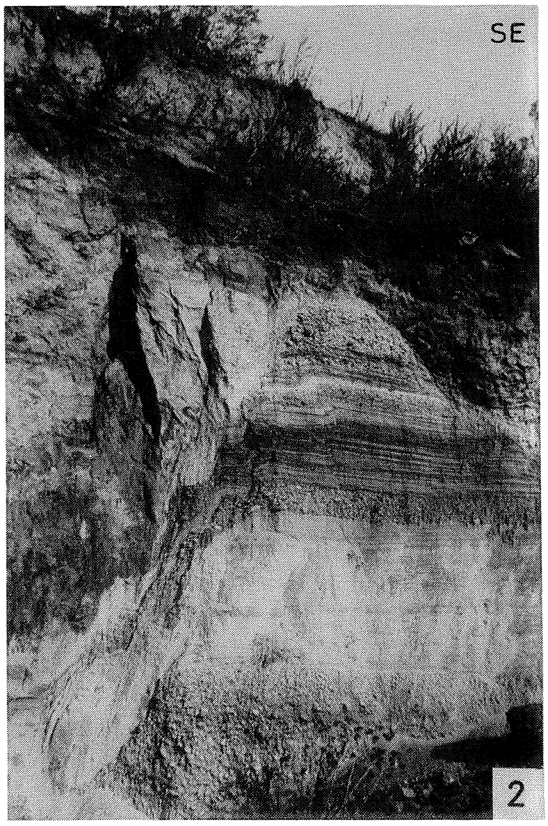
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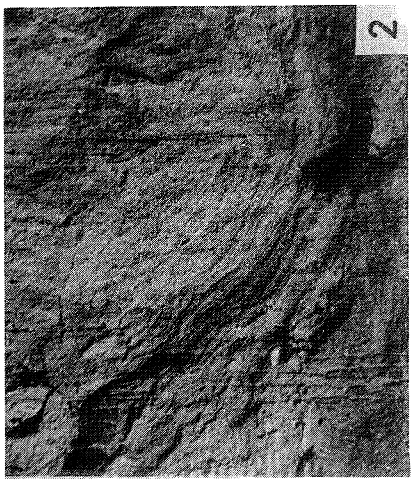
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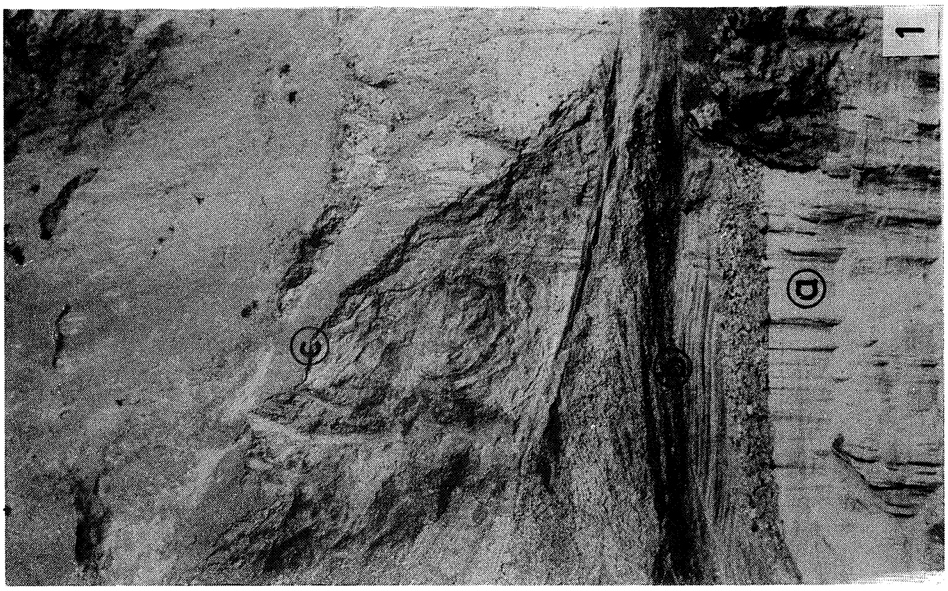
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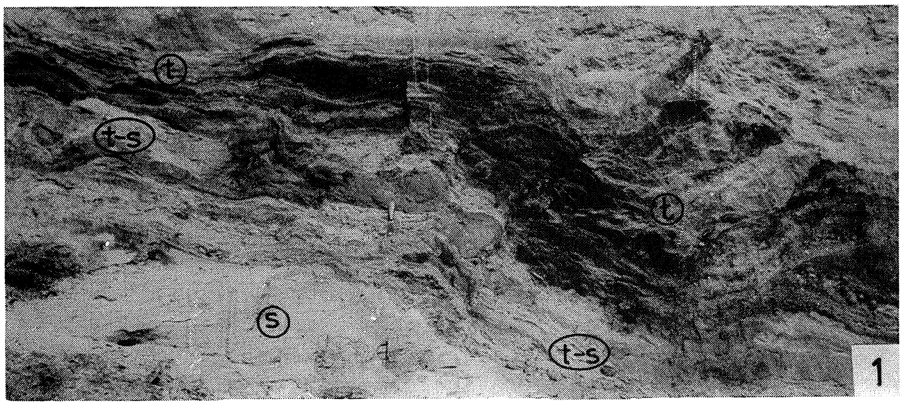
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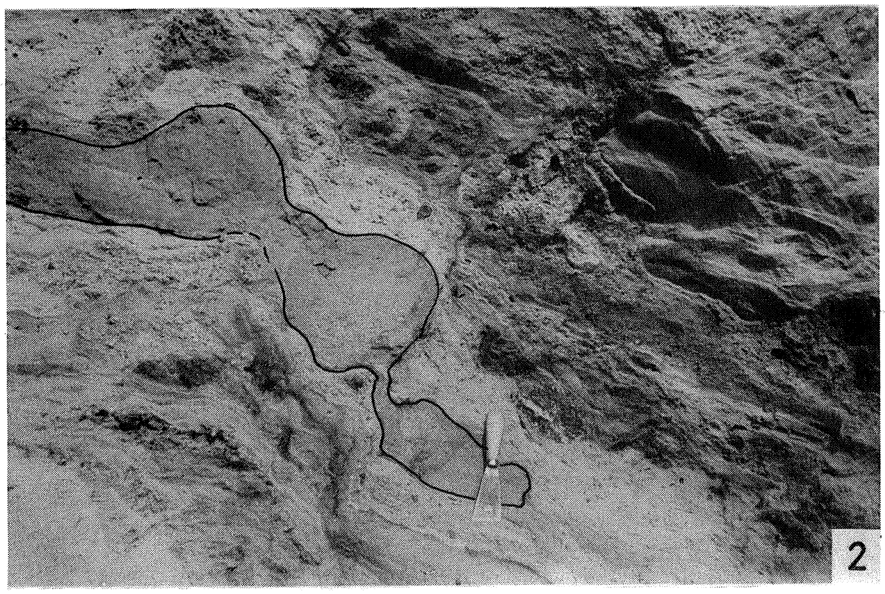
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