ANNALES SOCIETATIS GEOLOGORUM POLONIAE
ROCZNIK POLSKIEGO TOWARZYSTWA GEOLOGICZNEGO

v. 55/3-4: 307-332 Kraków 1985

Hanna RUSZCZYŃSKA-SZENAJCH

ORIGIN AND AGE OF THE LARGE-SCALE GLACIOTECTONIC STRUCTURES IN CENTRAL AND EASTERN POLAND

Geneza i wiek wielkoskalowych struktur glacitektonicznych w środkowej i wschodniej Polsce

Hanna Ruszczyńska-Szenajch: Origin and age of the large-scale glaciotectonic structures in central and eastern Poland. Ann. Soc. Geol. Poloniae, 55/3-4: 307-332, 1985 Kraków.

Abstract: The dominating genetic kind of the large-scale glaciotectonic features in central and eastern Poland is represented by squeezed-up end moraines which are mainly composed of local substratum material and are often accompanied in their proximal sides by corresponding depressions being source zones of the squeezed-up sediments. The push-forward end moraines and other features pushed frontally by glacial ice, which do not contain material from beneath, are much scarcer in the area discussed. The glaciotectonic features occur in all the successive glaciogenic horizons. The dimensions of deformations – in areas characterized by the occurrence of thick soft substratum – point to the thickness of corresponding disturbing ice, while their directional features give evidence concerning the direction of the ice flow. However, the latter data show also the dependence on the buried hard bedrock which influenced the geometry of the deformations.

Key words: glacial tectonics, glaciotectonic structures, glaciotectonic processes, glaciotectonic transport, Pleistocene, Poland.

Hanna Ruszczyńska-Szenajch: Department of Geology, Warsaw University, al. Żwirki i Wigury 93, 02-089 Warszawa (Poland).

manuscript received: March, 1984 accepted: September, 1984

INTRODUCTION

During the X INQUA Congress in England (1977) an idea arose – initiated by a group of geologists working in areas reached by Pleistocene Scandinavian ice sheets and from the British Isles – to gather evidence and ideas concerning glaciotectonic features in these countries, which would facilitate some paleo-glaciological reconstructions.

The glaciotectonic features, however – recording the mechanical action of glacial ice upon its substratum (Ruszczyńska-Szenajch, 1983) – are very common in glaciated areas and show very different dimensions. So, the writer selected for the present review the conspicuous structures building separate landforms (e.g. glaciotectonic end moraines), marked in recent surface or buried, which she called large-scale structures because in glaciotectonic scale they belong to the largest features. There also are considered some features (e.g. diapirs) which do not form separate landforms but they penetrate the whole or almost whole horizons of glacial deposition. No exact metric limit was taken to select the stuctures discussed, but their dimensions may be vaguely defined as being usually of hundreds or tens of metres.

The following paper gives a general characteristics of the regional distribution of large-scale glaciotectonic features in eastern and central Poland, and the discussion concerning the origin and age of particular structures – based on published evidence (usually in the Polish language) and the author's own work.

The writer's intention also was to recognize the main genetic kinds of the glaciotectonic deformations in the area studied – with reference to her former views based on detailed studies – and to draw preliminary paleogeographical pictures for some regions, including general suppositions concerning the movement and thickness of the corresponding ice sheets.

The main genetic units (genetic subdivision), to which the author refers in this discussion, are those recently defined by her (Ruszczyńska-Szenajch, 1979, 1983). The Quaternary stratigraphic units and nomenclature are used mainly according to Różycki (1972) (to assist correlation with older publications), and in the last chapter they are correlated with newer stratigraphic subdivision (Różycki, 1978). The oldest link of the Quaternary, representing possibly the youngest Tertiary, is called in a traditional way Preglacial, and the series of the undoubted youngest Tertiary on the territory discussed, represented by variegated clays and associated deposits, is called (as in majority of the publications discussed here) Pliocene, though there is now some discussion suggesting that a part of this series may belong to Miocene.

REGIONAL DISTRIBUTION AND GENETIC CHARACTER OF GLACIOTECTONIC FEATURES

For a long time there has existed in Poland a widely accepted view that the most intense glaciotectonic deformations were concentrated mainly in the western part of the country, whereas in the eastern part such features were rather scarce. However, new exposures and more numerous boring data have considerably changed this opinion. The writer characterizes glaciotectonic features from this "non-glaciotectonic" part of the country, which also shows distinctly marked zones of different-age glacial relief: from a comparatively mature landscape in the south, corresponding to the Cracovian (Mindel) Glaciation, to increasingly younger in northward direction – through zones of the Middle Polish (Riss) units to the Vistulian (Würm) zone (Fig. 1).

From the area reached only by the Cracovian ice sheet (Fig. 1) there are not reported conspicuous glaciotectonic deformations examined in detail, although this ice sheet caused numerous large-scale deformations stated in more northern sites, which are covered by younger series and will be described later.

In the area reached by the Middle Polish ice sheet during the maximal "stadial",

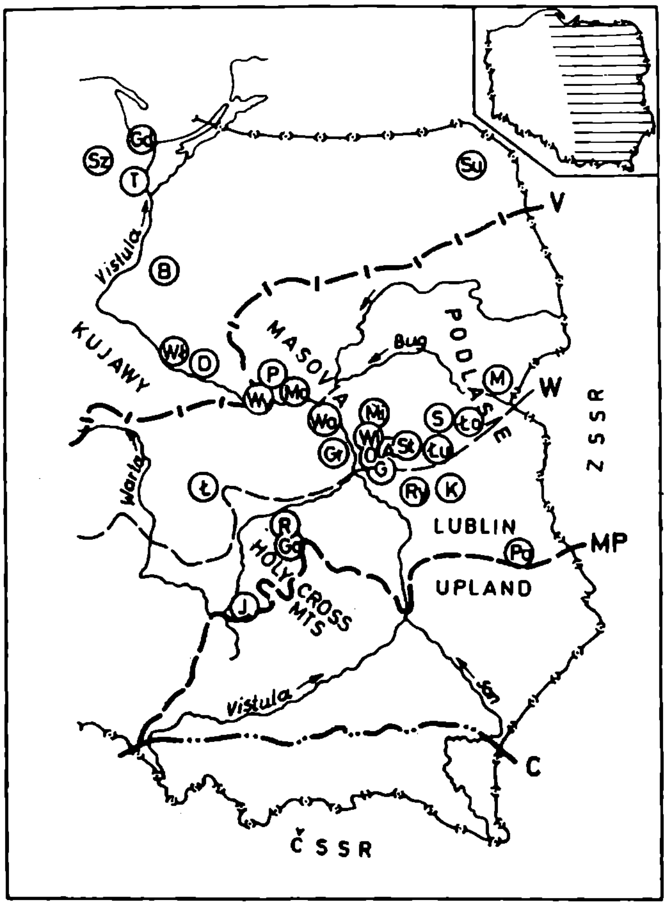


Fig. 1. Maximum extent of successive ice sheets in central and eastern Poland (after Różycki, 1972). C – Cracovian, MP – Middle Polish, W – Wartanian, V – Vistulian. Localities mentioned in the text: A – Anielinek, B – Błędowo, D – Dobrzyń, G – Garwolin, Go – Gowarczów, Gd – Gdańsk – Gdynia, Gr – Góra Kalwaria, J – Julianka, K – Kock, Ł – Łódź, Ło – Łosice, Łu – Łuków, M – Mielnik, Mi – Mińsk Mazowiecki, Mo – Mochty, O – Osieck, P – Piączyn, Pa – Pawłów, R – Rozwady, Ry – Ryki, S – Siedlce, St – Stoczek, Su – Suwałki, Sz – Szymbark, T – Tczew, Wa – Warszawa (Warsaw), Wl – Wólka Mlądzka, Wł – Włocławek, Wy – Wyszogród

Jahn (1956) describes some glaciotectonic deformations in the Lublin Upland which is characterized by the occurrence of Cretaceous bedrock built of limy rocks and covered in places by Tertiary sediments. The most conspicuous deformations described in detail occur in Pawłów Basin (Fig. 2) – in a zone of maximal extent of the mentioned ice sheet. Jahn characterizes these deformations as consisting of two parts. The "external" (distal) part is represented by hills built of disturbed Pleistocene and Tertiary deposits piled up at the top of a buried slope of consolidated Cretaceous rocks and situated in the southern rim of the Pawłów Basin. Down the slope (inclined to the north) the "internal" (proximal) part of the deformations occurs, represented by a belt of disturbed morainic deposits containing squeezed-in Tertiary sediments. At the bottom of the Basin the Tertiary sediments do not occur at all. According to Jahn's interpretation, they were removed from there by glaciotectonic action and displaced to the south – up the Cretaceous slope. Though the mechanism of the displacement is not described in the work discussed, the characteristics of the material and of the geological situation in the area in question is so clear that the present author would not hesitate to call these features the squeezed end moraines, which are accompanied (at their proximal side) by the glaciotectonic source zone, from where the Tertiary material had been squeezed out.

A quite different kind of deformation is described by Jahn in the northern part of the Lublin Upland (Fig. 3). The disturbed series, several metres thick, is represented here only by fluvioglacial deposits (containing some inclusions of till) and covered in places by coarse residual material. Jahn interprets the deformations as having been caused by local oscillation of the ice front during the general retreat period of the ice sheet. The present author would add to this interpretation that the deformations were probably formed by the pushing-forward action of the ice, resulting from its movement only, without any squeezing-out process (they do not contain substratum material). So thay may represent push-forward

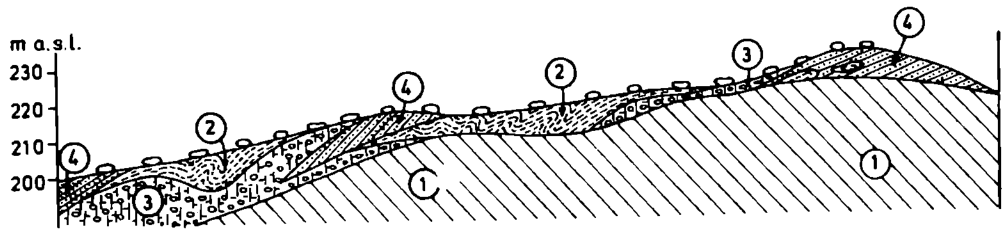


Fig. 2. Glaciotectonic structures of a hill southward of Pawłów (after Jahn, 1956). *1* – Cretaceous, *2* – deformed Tertiary clays, *3* – till, *4* – fluvioglacial sands. The south is to the right

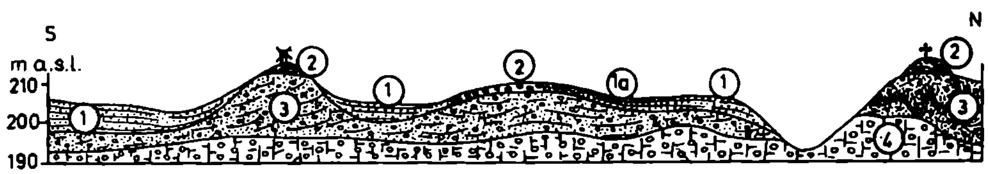


Fig. 3. Profile Majdan Krasienińiski – Krasienin (after Jahn, 1956). *1* – stratified dusty sands, *1a* – dusty deposits corresponding to bed "1", *2* – weathered gravels and boulders (residual material), *3* – folded fluvioglacial gravel and sand with till layers, *4* – till

moraines – according to the genetic terminology mentioned in the introduction. However, the possibility cannot be excluded that they represent deformations originating from the melting of glacial ice underneath the fluvioglacial deposits – during the process of sedimentation or just after the accumulation. If this were the case they would not represent glaciotectonic features at all.

The area of Holy Cross Mountains, stretching to the west of the Lublin Upland, was also reached by the maximum extent of the Middle Polish ice sheet and was closely surrounded by the ice from the NE and NW sides (Lindner, 1971). The widespread occurrence of consolidated rocks showing differentiated relief and covered in some zones by soft sediments a few to some tens of metres thick, created (in these zones) good conditions for glaciotectonic activity affecting the deformable substratum. The conspicuous feature of this kind has been found SE of Gowarczów; it is described by Lindner as "push moraine".

Just recently a paper was published by Różycki (1982), giving a general characteristics of glaciotectonic zones – characterized by disturbed Cretaceous deposits together with Pleistocene sediments – occurring in the region of maximum extent of the Middle Polish ice sheet SW of Holy Cross Mountains. It contains a detailed description of exposure at Julianka (Fig. 1), showing deformed Albian and Cenomanian sands and sandstones overlying Pleistocene sediments (loess), however the mechanism of deformation is not discussed in detail.

In the Łódź region, to the north-west of Holy Cross Mountains, Dylik (1961) and Klatkowa (1972) describe zones of distinctly marked glaciotectonic deformations involving Tertiary and Quaternary sediments, and corresponding to the maximal extent of Warta ice sheet. Dylik (1961) interprets these structures as representing: a) folds formed subglacially (because they contain till of the deforming ice sheet) of unfrozen material, and b) monoclinal structures formed of rigid frozen material by lateral pressure. Since in many cases these two kinds of structures occur together, Dylik suggests an existence of time intervals (connected with ice oscillations) separating the formation of the structures. The interesting descriptions of exposures, showing substratum material much elevated above its primary beds, incline the present writer to interprete most of these deformations as squeezed end moraines. It seems probable that each separate unit of these moraines may involve different geometric elements i.e. scales ("monoclinal structures") and folds, and the mentioned presence of till of the deforming glacier does not necessarily prove a "subglacial" origin of glaciotectonic structures (Ruszczyńska-Szenajch, 1981).

Klatkowa (1972) also distinguishes two kinds of deformations: 1) "fold structures", which she identifies with diapirs, and 2) "monoclinal structures", including scales. The former were exposed in fragments only (e.g. Fig. 4), so their geometry may be a point of discussion, as well as their diapiric origin. The "monoclinal structures" are characterized in the discussed work as the most widespread in the area discussed, striking generally NW–SE. They usually show up in fragments, though one exposure offers a perfect view of the whole scales superposed upon substratum, which is only slightly deformed at the contact with the scales (Pl. I: 1). Klatkowa draws attention to the fact that the strikes of particular scales occurring together within a separate monoclinal assemblage are differently oriented,

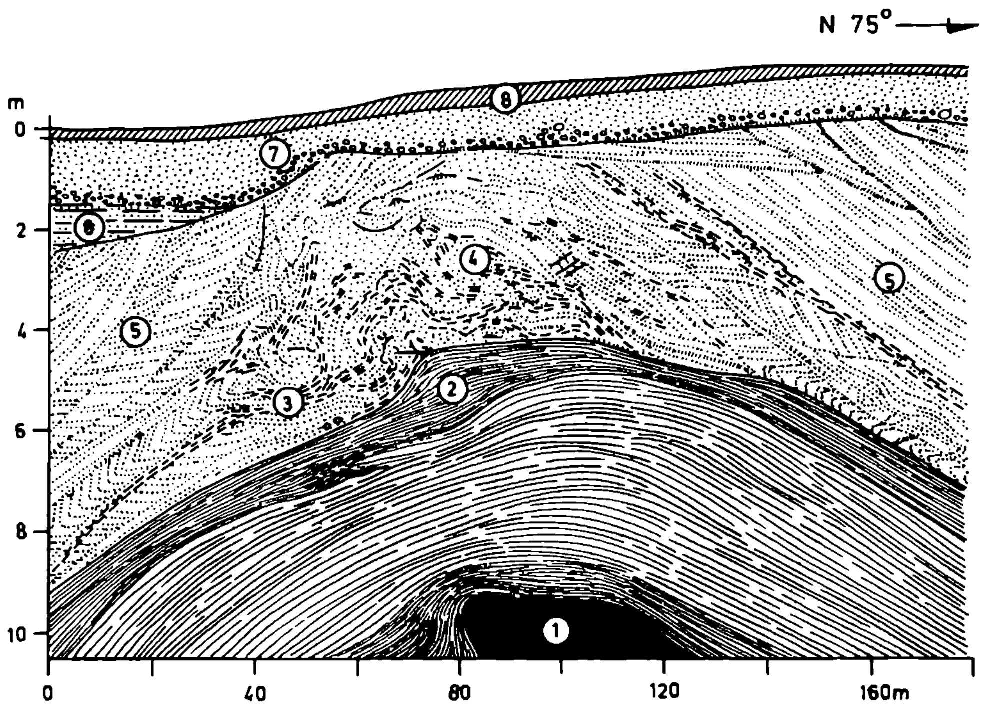


Fig. 4. Exposure at Dąbrówka–Strumiany (after Klatkowa, 1972). *1* – brown coal, *2* – gray silts and clays, *3* – silty-and-clayey series, *4* – silty-and-sandy series, *5* – cross bedded, deformed sands, *6* – horizontal bed of sands interbedded with silts, *7* – unstructural sands with "pavement" at the bottom, *8* – humus layer

and that the direction of ice movement was not the only factor resulting in the orientation of glaciotectonic structures. So, the orientation alone cannot be treated as a proof of particular direction of ice advance. Klatkowa does not characterize the mechanism of formation of "monoclinal structures", but the evidence she gives, and her interesting remarks concerning the arrangement of these structures allow one to suppose that they represent squeezed end moraines (compare the discussion in Ruszczyńska-Szenajch, in print), possibly some of them slightly, remodelled by continued ice advance. Klatkowa also mentions the possibility of superposition of scales onto large diapiric structures, but this statement – analogically to that concerning the existence of large diapiric structures in the area discussed – needs more evidence (exposures) undoubtedly showing the interpreted geological situation.

In mid-eastern Poland, situated to the north of the Lublin Upland, reached by the maximum stadial and (in the northern part) by the Warta stadial of the Middle Polish Glaciation, the average thickness of soft Tertiary sediments – mainly clays, silts and sands – overlying hard Cretaceous bedrock is some tens of metres. The thickness increases to the north to one hundred metres and more. Several glaciotectonic generations have been described from this area by Ruszczyńska-Szenajch (1976a). Comparatively dense boring data combined with surface exposures allowed the author to discover there and characterize a close genetic relation of squeezed-up end moraines, built of disturbed Tertiary and Pleistocene sediments, to glaciotectonic source-depressions occurring behind these moraines and also filled with disturbed (squeezed-down) Tertiary and Pleistocene series (Ruszczyńska-Szenajch, 1976a: Figs. 6, 13, 27).

Older glaciotectonic generations in this area (covered by younger glacial deposits) are mainly represented by glaciotectonic depressions. The largest of them – several tens of metres deep and some tens of kilometres long – occur in a zone Mińsk Mazowiecki – Siedlce – Łosice (they were formed by the ice sheet of the oldest, Podlasian, Günz Glaciation), and in the regions of Garwolin and Kock (formed during the Cracovian, Mindel Glaciation). The squeezed end moraines corresponding to these depressions have usually been largely destroyed by successive ice sheets, but the clearly marked remains of them are represented by large glacial rafts built of Tertiary material and occurring most abundantly in the immediate forelands of the depressions. In the region of Stoczek the younger (?) glaciotectonic generation in the area (of Middle Polish, Riss Glaciation?) has been ascertained. The squeezed end moraines of this age occur at the recent surface (Pl. II).

The squeezed end moraines accompanied by glaciotectonic source-depressions constitute the majority of known glaciotectonic features in mid-eastern Poland. In most cases the disturbed material of the substratum has lost its contact with primary beds, and occurs now as glacial rafts. Hence, the author concludes that some large glacial rafts found in separate borings may suggest (though not prove) the existence of buried glaciotectonic features. This subject will be also discussed later.

Near the eastern periphery of Poland, in the Łosice region, Nowak (1977) described a zone of "pushed" moraines, characterized by clearly marked topographic expression, corresponding to the Warta stadial. She also describes older glaciotectonic deformations in this region – formed during the Cracovian Glaciation and during maximal stadial of the Middle Polish Glaciation – which are now represented by the buried glacial rafts. The mentioned author does not explain the process of formation of the "pushed" moraines, but their geological structure – represented mainly by disturbed Tertiary and soft Cretaceous deposits – strongly suggests their origin as squeezed end moraines. The geological sections enclosed in the paper discussed (e.g. Fig. 5) may also suggest the occurrence of glaciotectonic depression there. Such depression has already been stated previously (Ruszczyńska-Szenajch, 1976a) and confirmed by new investigations (Michalski, 1980). Besides the large ice-marginal features, Nowak also describes in the Łosice region the occurrence of "esker-like" and "kame-like" hills, and she interpretes them as having been formed due to the squeezing of soft substratum into crevasses within the ice.

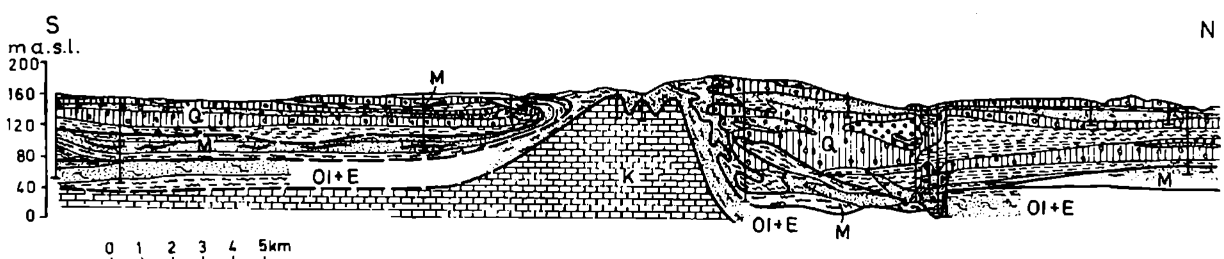


Fig. 5. Geological section in Łosice region (after Nowak, 1977). K – soft Cretaceous deposits, Ol + E – Eocene and Oligocene sands and silts, M – Miocene sands and silts, Q – Quaternary tills, sands and silts

In the region of the lower Bug River, Straszewska (1968) mentions some glaciotectonic deformations, usually buried and corresponding to Middle Polish Glaciation, but she gives no detailed characteristics of them.

Interesting data have been published by Rühle and Zwierz (1961) from the region of Mielnik on the Bug River. The authors analysed boring data, and they find (on a distance of some kilometres) 3–4 "protrusions" built of soft Cretaceous deposits and "piercing" through more than 100 m of Quaternary series. The authors interpreted those features at that time (1961) as originated from fluvial erosion, but this interpretation met considerable discussion and the present author would rather consider the features as representing the results of glaciotectonic squeezing-up processes.

In the north-eastern part of Poland, i.e. in Suwałki Lake District reached by the Vistulian (Würm) Glaciation, Ber (1974) describes numerous hills of glaciotectonic origin formed during the Pomeranian stage of this glaciation. The mentioned author – dealing mainly with stratigraphic questions – calls the hills pushed moraines and squeezed moraines but he gives no criteria of such differentiation and he does not discuss in detail either the structure or the origin of these features.

Probably the best known buried glaciotectonic structures documented by a lot of borings, occur in the area of Warsaw. They are the subject of most controversial views (cited below). The main part of these structures occurs underneath an almost flat-lying till left by the Warta ice sheet, the youngest in this area. It is represented by the "elevation" (piling-up) of Pliocene clays forming a buried ridge several km long, 1 – 2 km wide, and running generally in a NNW – SSE direction. The ridge was already recognized by Lewiński and Różycki (1929), who gave its detailed characteristics and defined it as having been a result of glacial tectonics, i.e. of ice-pressure and ice-movement. The glaciotectonic origin of the ridge was confirmed and documented by increasingly abudant evidence in the next works (Sujkowski & Różycki, 1937; Mojski & Domosławska-Baraniecka, 1965), though the mechanism of formation of the ridge was not discussed in detail in these publications. In 1972 Różycki denied the glaciotectonic origin of the ridge, and interpreted it as a fold-structure having originated from the plastic flow of clayey masses due to upward movement of the Kujawy anticlinorium during the Great Interglacial. However, Brykczyńska and Brykczyński (1974) gave new evidence (Fig. 6) and thorough discussion concerning the ridge in question. They proved its glaciotectonic origin and attributed it to the so-called valley-side glaciotectonics, i.e. to the formation by an "ice tongue filling the river valley and stretching onto the neighbouring upland (and) exerting a strong pressure on the valley escarpment" (Brykczyńska & Brykczyński, 1974: 218). Though the glaciotectonic origin of the ridge is nowadays widely accepted, its valley-side tectonics aspect is a point of intense discussion because there is no satisfactory evidence of a valley having existed here in the time of the formation of the ridge. The time of the glaciotectonic formation of the ridge is attributed by most of the authors mentioned, to the maximum stadial (preceding the Warta stadial) of the Middle Polish Glaciation.

The other glaciotectonic structures in Warsaw occur to the north-east of the described ridge, and are covered by fluvial series of the recent Vistula valley. These forms are represented mainly by elongated and comparatively narrow depressions formed within Pliocene series, stretching generally NNW – SSE, whose average depts are several tens of metres. The deepest and longest (some kilometers) depressional form has been defined formerly as a fluvial valley (Samsonowicz, 1927) and such a view is held more recently by Domosławska-Baraniecka and Gadomska (1965). In other works this form is characterized as a kind of syncline being either of tectonic (Lewiński, 1929; Różycki, 1972) or glaciotectonic origin (Sujkowski & Różycki, 1937; Brykczyńska & Brykczyński, 1974). The geological documentation for the area of Warsaw given by Domosławska-Baraniecka and Gadomska (1965: Pl. 12 – 16) does not show characteristic fluvial infill of any part of this depressional form, and it shows infills mostly of glaciogenic and cold--lacustrine type. It also does not show the characteristic "synkline" structure of the depression because of the very irregular occurrence of deposits of different age and origin forming the infill. However, the documentation mentioned gives (for the discussed depressional form) some perfect examples of infills of glaciotectonic source-depressions. Besides this largest depressional form there exist others which are either shallower or shorter and which are defined by Domosław-

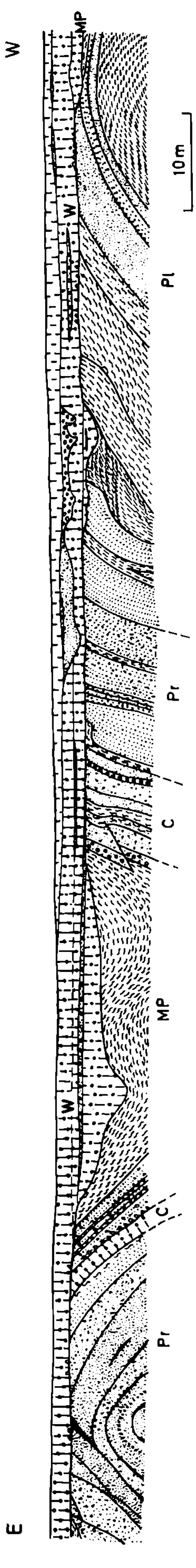


Fig. 6. A part of geological section along Łazienkowska Line (after Brykczyńska & Brykczyński, 1974, modified). *Pl* – Pliocene (clays, silts and sands), *Pr* – "Preglacial" (mainly sands and gravels), *C* – series corresponding to Cracovian Glaciation (till, gravels, sands and silts), *MP* – series corresponding to the maximum "stadial" of Middle Polish Glaciation (till, gravels, sands and silts), *W* – series corresponding to Warta "stadial" (mainly till)

ska-Baraniecka and Gadomska (1965) as having originated from glaciotectonic processes, though the authors do not discuss the mechanism of formation of these features.

Summarizing the above account of data and opinions concerning the Tertiary "elevation" and large depressions in the area of Warsaw, it seems most probable – in the present author's opinion – that the former represents buried squeezed end-morainic ridge, and the latter (at least in some parts) are glaciotectonic source depressions from which the material of this ridge has been squeezed-out. Depressions filled with lacustrine series are of rather different origin.

The age of the glaciotectonic features, apart from their different genetic interpretations, is most often defined by the cited authors as corresponding to the maximum stadial of the Middle Polish Glaciation. However, the documentation by Domosławska-Baraniecka and Gadomska (1965) provides evidence for discussion of this question. These authors define a till horizon occurring at the south-western foreland of the ridge and another one occurring at its north-eastern hinterland (and directly covering the depressions) as one stratigraphic unit left by the mentioned stadial of the Middle Polish Glaciation. The tills are underlain in places by waterlaid deposits defined by the authors as the equivalent of the time interval immediately preceding this stadial. But the difference of altitude of occurrence of those tills, and especially of the top of underlying waterlaid deposits, is about 30 m in a distance not exceeding a few kilometers. So it seems probable that the till occurring much lower and covering the depressions at the hinterland of the ridge belongs to the older, i.e. Cracovian (Mindel) Glaciation. In such a case the main squeezing process would have been connected with an oscillation of ice front during the retreat period of the ice sheet of the Cracovian Glaciation, and the ice did not override its squeezed moraines (no Tertiary rafts within the Cracovian till at the foreland of the ridge). The next ice sheet, of the maximum stadial of Middle Polish Glaciation, overrode the well expressed ridge and produced abudant Tertiary rafts of smaller dimensions occurring within the till of this age at the foreland of the ridge (as illustrated by the documentation mentioned).

In the south-eastern environs of Warsaw, glaciotectonic deformations have also been found, most of them covered by till (or tills) of Middle Polish Glaciation. A known locality is Wólka Mlądzka, where Pliocene clays and "Preglacial" series are considerably elevated and disturbed. They are described by Browkin-Markulis (1967), and interpreted by this author as representing glaciotectonic deformations formed by the ice sheet during the Middle Polish Glaciation. Baraniecka (1975) interprets these same deformations (and the Warsaw Pliocene ridge as well) as having been caused by other tectonic (not glacio-tectonic) processes. Nevertheless, close resemblance of these structures to the nearby buried squeezed moraines in south-eastern Masovia (Ruszczyńska-Szenajch, 1976a) as well as their geological position make the opinion of Browkin-Markulis more probable.

Other glaciotectonic sites in the south-eastern environs of Warsaw, where disturbed series often forming glacial rafts have been exposed, are those at Góra Kalwaria and Osieck, described by Sarnacka (1965). This author gives interesting examples of deformations, whose age she ascribes to the Middle Polish Glaciation (to the maximum stage and the Warta stadial), but she does not pay much attention to the interpretation of the mechanism of formation of these features. In the present writer's opinion, these deformations – especially those at Osieck, characterized by the occurrence of elevated large masses of Tertiary material covered by till – may represent squeezed moraines overridden by ice. When covered by the ice sheet, the flattened and attenuated squeezed moraines may have been subjected to additional deformations and secondary detachment of their material, what have resulted in the formation of frequent glacial rafts of smaller dimensions. Nevertheless the genetic interpretation is difficult here, because of the lack of general geological section showing the relation of disturbed series to their substratum and to the surrounding strata, and – as pointed out already by Sarnacka – because of the lack of exposures cutting the features discussed, in a direction parallel to the previous ice movement.

Perhaps the most conspicuous deformations of Quaternary and Tertiary deposits in central Poland (described in many works) are those exposed along the northern steep escarpment of the Vistula valley. The best known localities are: Mochty, Wyszogród, and the region of Dobrzyń – Włocławek.

The deformations at Mochty are exposed on a segment about 2 km long. They are mainly within the "Mochty till" horizon, several metres thick (truncated by younger series), described in a detailed way by Różycki (1970). Różycki interprets these deformations as having been formed underneath the moving ice sheet during the accumulation of the till correlated by him with Cracovian (Mindel) horizon. He calls the deformations dynamic structures, not glaciotectonic ones. The cited paper was one of the first works in Poland drawing attention to many aspects of structural features of tills, and to processes responsible for the formation of these features. In the period of more than ten years which has elapsed since the publication of this paper, a lot of new evidence and ideas concerning tills and glacial tectonics has been published. According to these new works many details of the Mochty profile may be interpreted in a way different from that of 1970, but the main idea of Różycki – the formation of the discussed horizon underneath moving ice – still remains valid. The present writer would not hesitate today to call the struc-

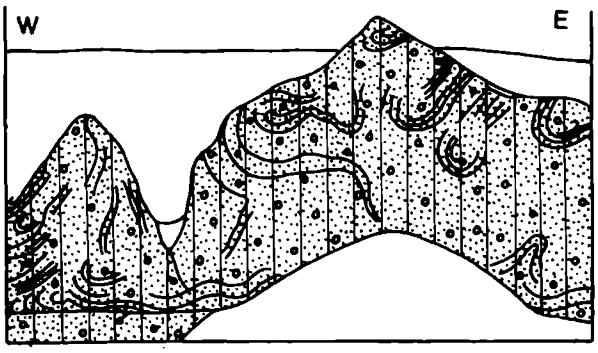


Fig. 7. Deformation of the younger till at Wyszogród. The section, within the Vistula escarpment, is about 20 m high (after Ruszczyńska-Szenajch, 1976b)

tures at Mochty, glaciotectonic deformations – produced, as already explained by Różycki, underneath a moving ice sheet and synchronous with the accumulation of deformed till.

At Wyszogród two till horizons build the escarpment 20–30 m high, and they are well exposed over a distance of about 2 km, showing different kinds of deformations (Fig. 7). According to the latest interpretation given by the writer (Ruszczyńska-Szenajch, 1976b) the escarpment cuts here – unfortunately not in a transverse way – a glaciotectonic source depression filled partly with older till but mainly with lodgement till of the younger horizon (Fig. 8; Pl. III). So, the deformations had most probably been formed beneath the frontal part of advancing ice sheet. They are, in general, of the same age as the younger till, i.e. they correspond to the Warta stadial of the Middle Polish Glaciation.

The exposures of the Vistula escarpment at Dobrzyń and westward of Włocławek – in the area reached already by the youngest glaciation – show deformations of large dimensions (tens of metres) of the Tertiary and old-Pleistocene series, which are covered by younger Pleistocene glacial deposits. The deformations are often called folds, but in some cases they may represent large scales (thrust sheets) often dipping (generally) to the north (e.g. Figs. 9, 10).

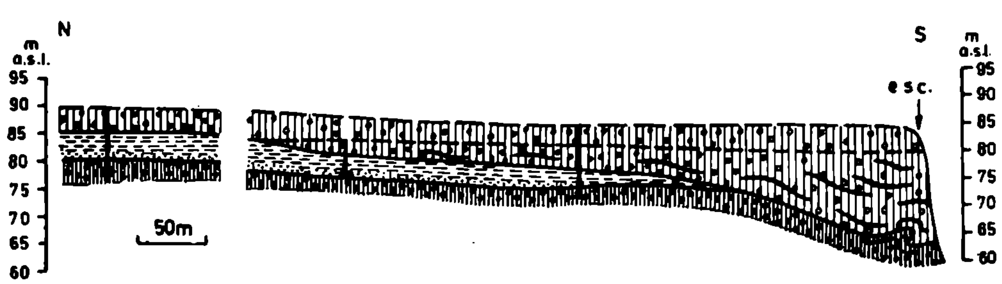


Fig. 8. Geological section transverse to the Vistula river escarpment (esc.) at Wyszogród, showing two tills separeted with waterlain sands and silts. The younger till in the vicinity of escarpment is composed of two genetic horizons, i.e. deformed lodgement till covered by melt-out (and flow) till – shown also on Pl. III (after Ruszczyńska-Szenajch, 1976b)

The origin of these structures was attributed to tectonic processes by some authors (Lewiński, 1924; Ber, 1960; Różycki, 1972) but in works based on examination of the whole neighbouring territory (Skompski, 1969) or upon detailed structural analysis (Jaroszewski, 1963; Brykczyński, 1982) they are interpreted as glaciotectonic structures. Jaroszewski (1963) attributes them to end-morainic zone, formed most probably by the ice sheet of Cracovian Glaciation. In agreement with that view,

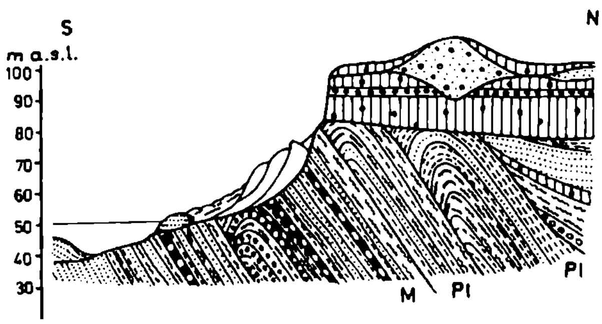


Fig. 9. Glaciotectonic scales ("*luski*") composed of Miocene (*M*) and Pliocene (*Pl*) sediments in Dobrzyń region (after Skompski, 1969)

and in accordance with the terminology accepted in this paper, the writer would call the Dobrzyń – Włocławek structures squeezed end moraines (buried), because the disturbed Tertiary masses are situated much higher than the parent Tertiary series occurring *in situ*. A different interpretation of these structures was recently given by Brykczyński (1982), who considers them to be a result of valley-side glacial tectonics (referring to Banham, 1975), i.e. caused by a glacial "tongue" advancing to the east along a paleo-valley of large river, regarded by Brykczyński as paleo--Vistula. Main objections against such view, discussed during the meetings of the Polish Geological Society in 1980 and 1981, are: 1) the Tertiary masses derive from horizons deeper than those cut by the buried valley escarpments in that part of the country (Ruszczyńska-Szenajch), 2) a lack of corresponding (in age) sediments of large river in the area in question (Skompski), 3) the orientation of the glaciotectonic structures in some parts of the exposures may point to the glaciotectonic impact from NE, i.e. from the direction opposite to that interpreted by Brykczyński (Skompski). By now, the problem remains open, though the majority of Quaternary geologists, cannot accept the idea of a comparatively narrow glacial tongue in lowland area, where known paleogeographic data deny such possibility.

In the area stretching north of the parallel segment of the Vistula valley, the push-forward end moraines have been stated at Piączyn (Ruszczyńska-Szenajch, 1979, 1981). They are mainly built of ice-marginal fluvioglacial series, and do

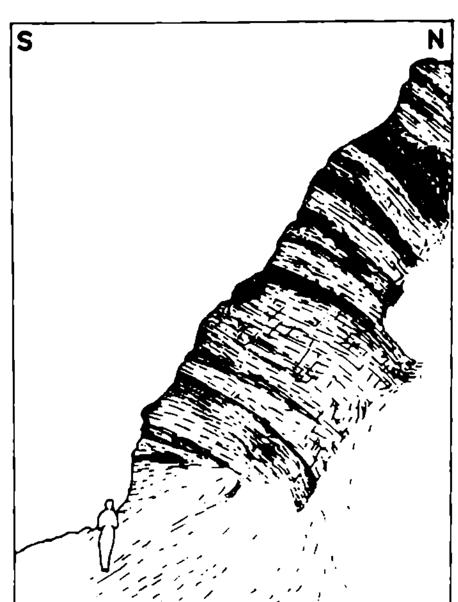


Fig. 10. Disturbed Miocene sediments, exposed in the Vistula river escarpement at Dobrzyń. A drawing from photograph

not show any trace of material squeezed out from beneath. They correspond to the Wkra stadial – the one following the Warta stadial of Middle Polish Glaciation.

Much older, usually buried, glaciotectonic structures have been described in the region of Northern Masovia by Michalska (1967). The author mentioned does not characterize the features in detail nor does she analyse the mechanism of their formation, but she mentions squeezing as a process responsible for the existence of some "elevations" of Tertiary series. Michalska attributes the age of these deformations to the Podlasian (Günz) and the Cracovian Glaciation.

Interesting evidence concerning glaciotectonic features is reported from the central part of northern Poland, i.e. from the region adjacent to the lower Vistula valley, which was reached by the youngest glaciation. Much of this evidence is published by Galon (1961) and co-authors, who describe glaciotectonic "push" (or "thrust") moraines corresponding to the mentioned glaciation, e.g. at Błędowo, Szymbark and Tczew (Pl. I: 2). The cited book includes also numerous

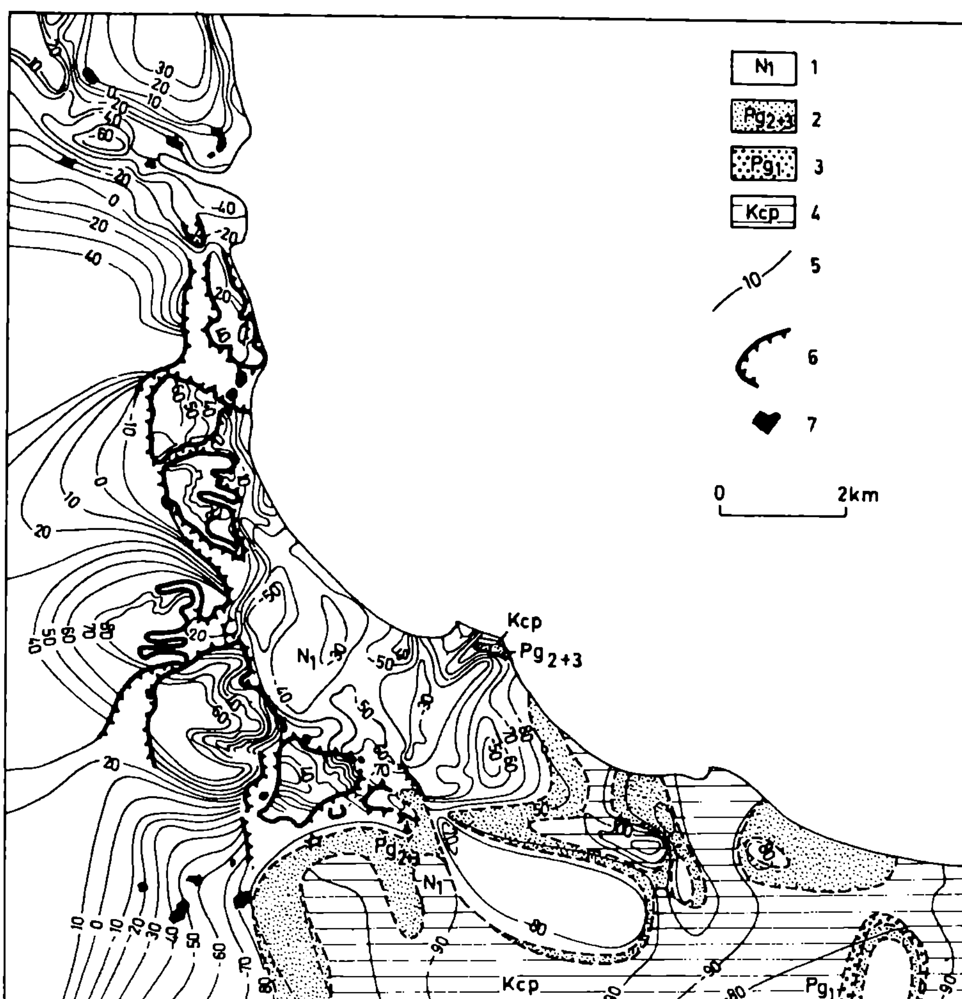


Fig. 11. Geology of Gdańsk region, without the Quaternary formations (after Mojski, 1979). *1* – Miocene, *2* – Eocene (?) and Oligocene, *3* – Paleocene, *4* – Campanian, *5* – contour lines of the sub-Quaternary surface, *6* – escarpments of different origin, *7* – glacial rafts of the substratum sediments, within the Pleistocene deposits

descriptions of large glacial rafts composed of the Pliocene, Miocene, Oligocene and even Cretaceous deposits. Some of these rafts are connected with glaciotectonic end moraines (e.g. Oligocene raft at Bytów), indicating their squeezed-up origin, and others are usually vaguely referred to glaciotectonic action, though the mechanism itself is not discussed in this publication.

Very interesting features were described by Mojski (1979) from the Gdańsk region. This author found there a buried escarpment, about 100 m high, built mainly of soft Miocene deposits and in places "dissected" by "valleys" filled with till containing numerous Tertiary rafts. The escarpment (situated in a zone of the Holocene Baltic Sea cliff) represents a very steep eastern and north-eastern slope of a narrow chain of buried Miocene elevations with their top-surface situated about 40 m higher than the adjacent (to S and W) top-surface of Miocene series in the surrounding area (Fig. 11). All these features are documented by hundreds of borings and also by some exposures. However, the reader is in a somewhat difficult situation, because Mojski uses different expressions for the same features (of buried escarpment) in different parts of the work, interpreting them as "glaciotectonic" or "glacio-erosional" (Mojski, 1979: pp. 17–21), and he does not differentiate clearly between these two groups of processes. So, the subject provokes a discussion.

In the writer's opinion the narrow chain of the highest Miocene elevations in Gdańsk region (Fig. 11) represents buried squeezed moraines. The Miocene sediments were squeezed out from NE and superposed on the undisturbed Miocene series at the front of the ice sheet. As the squeezed sediments are almost identical from a lithological point of view with those occurring *in situ*, they seem now to form a continuous series, and their differentiation on the basis of boring data is really a very difficult task. Nevertheless, the comparison of this elevated chain with detailed characteristics given by Mojski for successive Miocene horizons, concerning their thickness and height, strongly suggests a secondary superposition of the "elevations". Of course, paleobotanic or another detailed stratigraphic analysis is urgently needed in such a case. However, other published examples in the area discussed show large masses of Miocene deposits thrust also over Quaternary series or "interbedded" with them (Pazdro, 1960), and thus representing large glacial rafts produced most probably by squeezing processes. The abundance of Tertiary (mainly Miocene) rafts in the zone discussed has also been stressed by Mojski.

The writer's brief excursion to the cliff exposure in Gdynia-Orłowo adds also new data to the above discussion. The exposure (Pl. IV) reflects, in the writer's opinion, the squeezing-up process of the Miocene and Pleistocene sands ("layer" 1), and partly of the (most probably) subglacial lodgement till ("layer" 2a), from under the frontal part of the ice. These processes are recorded here in form of melt-out till with well preserved basal debris bands up-turned during the squeezing process ("layer" 2b). The interpretation of the process is based on a very close analogy of the exposure in question to the exposure at Kazimierz, north of Gdynia, examined in more detail (Ruszczyńska-Szenajch, 1981). The stratigraphic position of the till exposed in the part of Orłowo cliff illustrated by Pl. IV is most probably of Middle Polish (Riss) age – according to Mojski (1979; Fig. 4). So, this was the time of the (most?) intense glaciotectonic action here.

The quoted evidence supports the above opinion concerning the squeezing-up of the redeposited Miocene masses in the discussed area, and the adjacent Gulf of Gdańsk represents the main possible source zone from which the Tertiary sediments have been squeezed-out by dynamic pressure of the advancing ice front. So, the Gulf is primarily a glaciotectonic depression – of probably younger Pleistocene age – which then underwent changes caused by other processes.

In some geological publications concerning Polish Lowlands glaciotectonic questions are discussed in an interesting but very general way, e.g. Liszkowski (1975), Michalski (1979). There are also very numerous works dealing mainly with other Quaternary subjects, and discussing only some glaciotectonic examples e.g. Baraniecka (1975, 1979), Różycki (1972) and many, many others. In other words – there hardly exists any publication on regional or stratigraphic Pleistocene problems in the Polish Lowlands which does not present some glaciotectonic examples. The conclusion is that glaciotectonic deformations are very widespread in Poland – both in surface features and in older, buried glaciogenic series. Those buried features are most commonly described as glacial rafts, some of them tens of meters thick. Many authors do not attribute the origin of such rafts to glaciotectonic processes, usually not discussing their origin at all, but some of the authors – as already mentioned before – point this relation in a general way. A more thorough study of both glacial rafts and glaciotectonic structures (Ruszczyńska-Szenajch, 1976a) reveals close genetic connection between some of these features, and this undoubtedly adds considerable number of sites characterized by (or at least suspected of) the occurrence of glaciotectonic structures.

SUCCESSIVE STRATIGRAPHIC GENERATIONS OF GLACIOTECTONIC DEFORMATIONS, AND SOME PROBABLE DYNAMIC FEATURES OF THE CORRESPONDING ICE SHEETS

Glaciotectonic features occurring at the surface in the area discussed usually correspond to the latest ice sheets in particular zones. Hence, in general, the age of these surface features may be read from the map showing the maximum extent of successive ice sheets. However, new geological evidence shows an increasingly common occurrence of buried glaciotectonic deformations. Quite numerous regions exist (e.g. Masovia and Podlasie) where two or more glaciotectonic horizons occur within geological profiles, and they are separated from one another by undisturbed series. The buried glaciotectonic features are often shown in exposures but a lot of them are found only in borings. The latter present most difficult problems, when determining their age as well as their genetic character, because the structural and glacio-sedimentological studies are very restricted in such cases, and the stratigraphy itself may be also examined only in a general frame.

Besides the difficulties mentioned above in defining the age of some glaciotectonic deformations, there also exists a serious difficulty in the stratigraphic correlation of particular surface and subsurface features which have been studied by different authors and at different times. The writer has tried to group the deformations – basing on the existing literature and her own works – into main stratigraphic horizons corresponding to the main glacial periods in central and eastern Poland, but the resultant sequence must be treated as a very approximate picture. It must also be stressed that one cannot yet be sure that particular glacial units described from southern, middle and northern Poland correspond to one another without any doubt. The names of the main glacial units (glaciations and stadials) are mainly used after Różycki (1972) and they are supplemented with the terms according to Różycki (1978).

The oldest generation of glaciotectonic deformations is connected with the oldest series of lowland glaciations corresponding to the Podlasian i.e. Narevian Glaciation (Günz), whose ice sheet in mid-eastern Poland extented roughly to the parallel of Warsaw. The deformations (and the whole glacial series of this age) occur at a considerable depth of several tens of metres; they are covered everywhere by younger deposits and are documented by borings. The largest deformed zones of this age are represented by depressions elongated in a general E – W direction in the region of Mińsk Mazowiecki – Siedlce – Łosice (Fig. 1). They are interpreted by the writer as glaciotectonic source depressions of the squeezed end moraines, formed in the frontal zone of the oldest advancing ice sheet (Ruszczyńska-Szenajch, 1976a). The depressions and their fillings are preserved very well, while the corresponding squeezed moraines are largely destroyed and are represented only by scarce Tertiary rafts occurring within the glacial series discussed. The subsurface deformations attributed to the glaciation in question were also reported from Northern Masovia by Michalska (1967).

The dimensions of the deformations of Podlasian Glaciation, especially glaciotectonic source depressions several tens of metres deep, point to a comparatively "strong" – thick and fast moving – ice sheet, even in the zone very close to its maximum extent i.e. in the zone Mińsk Mazowiecki – Łosice. The direction of E – W elongated source depressions may suggest the ice advance (almost) straight from the north in this region (compare Ruszczyńska-Szenajch in print).

The next (younger) glacial horizon in Poland has usually been attributed to the Cracovian Glaciation (Mindel) also called the South Polish Glaciation. This horizon shows clear bipartition, especially in southern Poland, which is interpreted as having resulted from glacial accumulations corresponding to the two stadials, or even two separate glaciations, within the period mentioned (Różycki, 1972, 1978). These two units have recently been called Nidian (the older unit) and Sanian (the younger unit).

Glacial series of the older unit (Nidian) contains in Masovia and Podlasie fillings of depressional source zones, occurring behind glaciotectonic end moraines, which (moraines) are represented by large Tertiary rafts in the regions of Garwolin, Łuków, and south-west of Kock (Ruszczyńska-Szenajch, 1976a, 1978).

Both glaciotectonic features are known from borings only. The largest depression, near Garwolin, is more than 100 m deep and stretches in a NE – SW and NNE – SSW direction (Ruszczyńska-Szenajch, 1976a: Fig. 26). The depth points to comparatively thick and active ice, and the direction (together with the location of the glacial rafts) may suggest an ice flow directed to SE and ESE. However, the direction of the Garwolin depression may have been strongly controlled by the configuration of Cretaceous marls underlying soft Tertiary sediments subjected to squeezing processes. This control may be deduced from the very close proximity of the whole depression to the buried Cretaceous slope facing NW and WNW (Ruszczyńska-Szenajch, 1976a: Fig. 25). In this situation the ice advancing in an almost straight line to the south may have formed the feature of very similar shape.

A southward, and even south-westward, direction of the ice flow is also suggested by the stretching of a source depression at Łuków and its relation to the squeezed-up Tertiary rafts (Ruszczyńska-Szenajch, 1973).

The depressions situated south-west of Kock (documented by a few borings only) are shallower (20 – 40 m) and much smaller than that at Garwolin. They stretch approximately E – W (Fig. 12), and show a close relationship to the squeezed Tertiary rafts occurring immediately south of them (Ruszczyńska-Szenajch, 1978). So the ice movement was directed here most probably from the north to the south, and the ice sheet was probably much weaker than in the more northern Garwolin region.

Small and shallow (several metres) glaciotectonic depressions, connected most probably with the older series of the Cracovian Glaciation, have also been found at Ryki (Ruszczyńska-Szenajch, 1978; Fig. 12). The NW – SE direction of their axes, and the occurrence of squeezed-up Tertiary material immediately to SW of them, may point to a south-western movement of the ice in this place. It is probable that glaciotectonic features occurring south-west of Kock and at Ryki have been formed by a large ice lobe moving south-ward; and the Ryki region was situated in the south-western flank of the lobe. Both regions occur quite near to the line of maximum extent of the ice sheet in question. It seems most probable that this ice sheet has been rather weak in its frontal part during the time of maximum reach in the area discussed.

The "older stadial" age of the Cracovian Glaciation is also attributed to the Dobrzyń – Włocławek deformations (Skompski, 1969). The movement of the disturbing ice has been defined by this author as directed there from NE to SW (Fig. 9). Both questions (the age, and the direction of ice flow) have recently been strongly argued by Brykczyński (1982), who attributes the deformations – as already discussed above – to valley-side glacial tectonics caused by a younger "ice tongue" moving down the former Vistula valley. The Dobrzyń – Włocławek structures represent large (tens of metres) glaciotectonic features, and they are comparatively well exposed (Fig. 10) along the northern escarpment of the recent Vistula valley, which is roughly parallel to the strike of the structures. In spite of thorough stratigraphic works and geological mapping of the surrounding territory (Skompski) and a detailed structural examination of the deformations (Brykczyński) opinions differ as to the direction and age of this really strong ice responsible for the deformation.

The younger glacial unit (Sanian) of the Cracovian Glaciation most probably corresponds to the maximum ice extent in Poland. It involves also, in mid-eastern Poland, clearly marked zones of glaciotectonic deformations. They are known from borings, and are represented mainly by the fillings of glaciotectonic source depressions, which are well preserved and comparatively well documented (Ruszczyńska-Szenajch, 1976a, 1978). The deepest (60 – 80 m) depressions occur in the region of Garwolin, immediately north-west of the older depression described above (Ruszczyńska-Szenajch, 1976a: Fig. 26), and in the north-western part of the Kock region (Fig. 12, except the small and older depressions at Ryki). All of them show a general NE – SW stretch and point to the most probable north-westerly flow of the strong ice sheet, though the dependence of the stretch on the configuration of buried bedrock cannot be excluded (compare e.g. Figs. 12 and 13). Much shallower (not exceeding 20 m) depressions, showing E – W orientation of their axes and also corresponding to the glacial horizon in question, have been found north-east of Kock. However, their small depth and their directions must have strongly depended in this area on the shallow occurrence of top surface of the consolidated Cretaceous rocks underlying thin Tertiary sediments – as is shown on the maps of top surfaces of the Cretaceous and Tertiary series (Figs. 12 and 13).

In the previous section the writer suggests that the age of the main glaciotectonic deformation in Warsaw area corresponds also to the Cracovian Glaciation (younger unit) – in spite of a generally accepted view that it is already connected with younger glaciation. If the writer's interpretation of this deformation is correct, the fillings of source depressions several tens of metres deep and the conspicuous ridge of the squeezed-up Tertiary sediments at the foreland of the depressions – both features stretching NNW – SSE – point to SW or even WSW as being the most probably direction of movement of very strong ice. The ice probably corresponded to an oscillation during the general retreat of the Cracovian (younger unit) ice sheet.

Besides the sites described, corresponding to the younger and older unit of the discussed glaciation, there are also reported deformations attributed in a general way to the Cracovian Glaciation, e.g. in eastern Podlasie (Nowak, 1977) or northern Masovia (Michalska, 1967), and they are not discussed in this chapter. It must also be stressed – once again – that one cannot be sure that the older and younger units in southern, middle, and northern Poland correspond to each other without any doubt. The same is true of the units of the younger glaciations.

The next glacial series in the territories discussed is connected with the Middle Polish (Riss) Glaciation. It also shows two major units – formerly regarded by many researchers as stadials, and called the maximum (or Radomka) stadial and the Warta stadial (Różycki, 1972) – and now believed by some researchers (Ró-

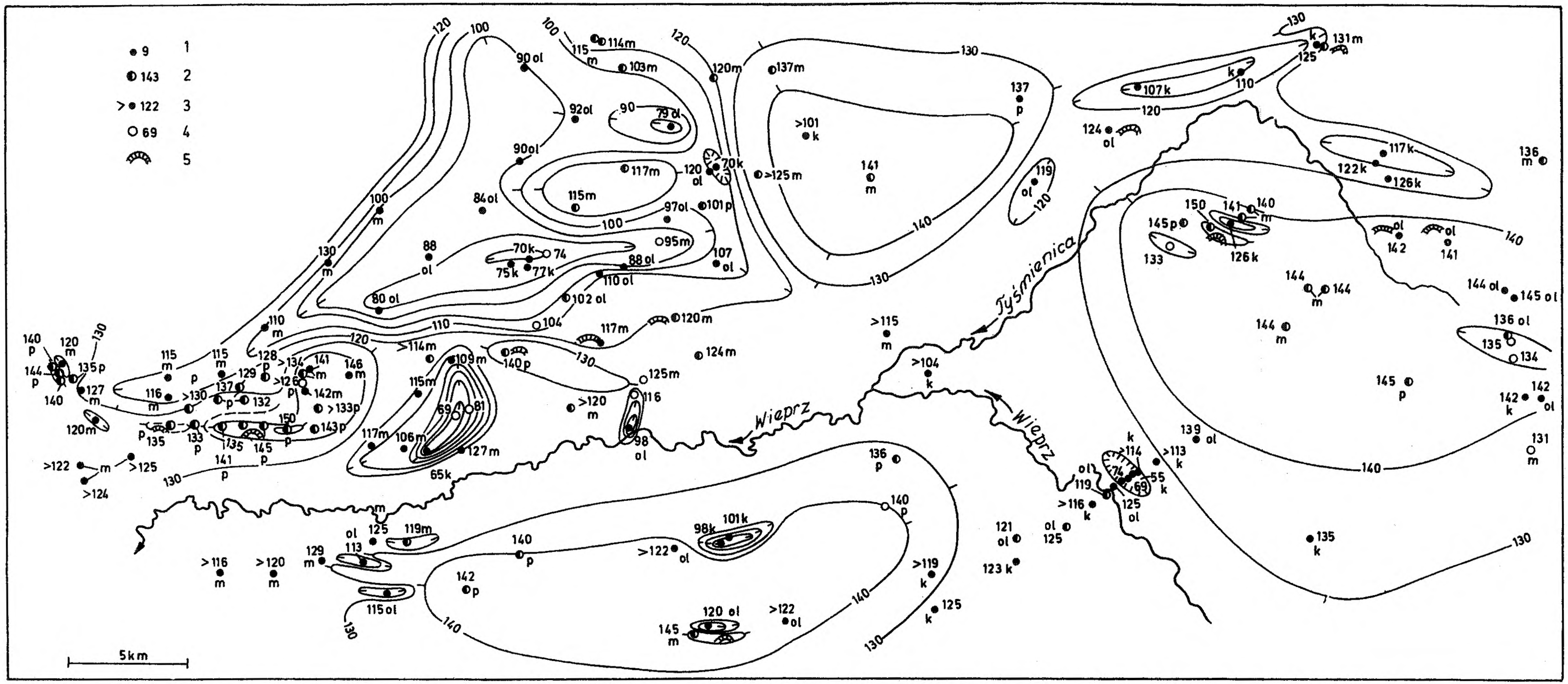


Fig. 12. Top surface of Tertiary deposits in Kock region (after Ruszczyńska-Szenajch, 1978). *1* – documentation of the top of Tertiary (and older) deposits, *2* – documentation of the top of Tertiary deposits, whose age is defined with considerable probability, *3* – documentation of the top surface of Tertiary deposits lowered by posterior processes, *4* – not reached top of Tertiary deposits by comparatively deep boring, *5* – zones of occurrence of buried squeezed moraines, *p* – Pliocene, *m* – Miocene, *ol* – Oligocene, *k* – Cretaceous

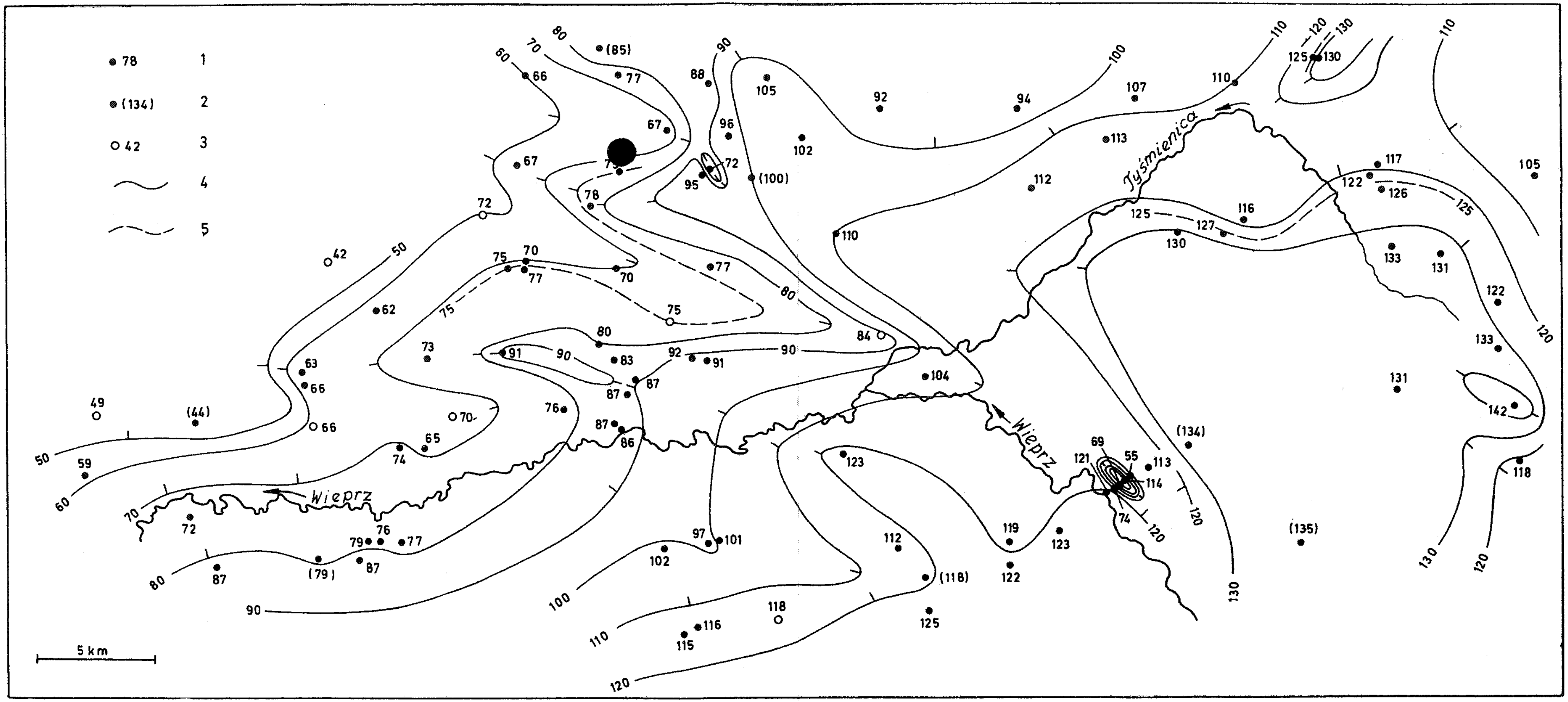


Fig. 13. Top surface of Cretaceous rocks in Kock region (after Ruszczyńska-Szenajch, 1978). *1* – top surface of solid Cretaceous rocks, *2* – top surface of unconsolidated Cretaceous deposits, *3* – not reached top of Cretaceous rocks by comparatively deep boring, *4* – contour lines every 10 m, *5* – contour lines (additional) every 5 m

życki, 1978, and others) to be separate glaciations, called the Odranian and Wartanian Glaciations respectively.

The older unit (Odranian) of the glaciation discussed was connected with the maximum extent of the ice sheet at this period (Fig. 1). The ice reached the Lublin Upland, Holy Cross Mountains, and farther south-western areas. Its action there was also marked by glaciotectonic deformation e.g. in Pawłów Basin (Jahn, 1956; Fig. 2), Gowarczów (Lindner, 1971) and Julianka (Różycki, 1982). In the two former cases the ice movement was generally from the north-west to the south-east, with more northerly component in the Pawłów region (Jahn, 1956), and more westerly one at Gowarczów (Lindner, 1971). In Julianka region the ice flowed almost from the north-east (Różycki, 1982). However, the soft deformable sediments form in these regions only a thin cover upon the hard bedrock whose relief must have strongly controlled the local directions of the ice flow (compare Różycki, 1982: Fig. 1). The amplitude of the deformed (squeezed-out?) features does not exceed here 30 – 40 m. This is rather small in comparison with some of the older deformations described above, but again the shallow occurrence of hard bedrock makes estimation of ice thickness (based on the depth of ice pressure penetration) difficult because even very thick ice could have squeezed the soft sediments only to their (shallow) bedrock.

The retreating ice sheet of the Odranian unit of Middle Polish Glaciation showed clearly marked oscillations which in places caused glaciotectonic deformation, e.g. in the northern part of the Lublin Upland (Jahn, 1956; Fig. 3). The ice-flow here – according to the cited author – was directly from north to south, but a general estimation of the thickness of the ice is rather difficult, because the deformation – as discussed in the previous chapter – most probably results from a pushing-forward process and does not show traces of squeezing from beneath. So it provides evidence of an obvious forward movement of the ice front during the general retreat period, but it tells little about the ice pressure depending on its thickness.

The ice sheet corresponding to the next, Wartanian, unit of the Middle Polish Glaciation has been known for a long time for its vigorous glaciotectonic activity in the zone of maximum extent, especially in western Poland. It is now clear that its behaviour in central and eastern parts of the country has been very similar. However, the largest deformations of this age in those areas are usually situated several kilometers behind the maximum extent of the ice, e.g. the deformations exposed within surface features in Łódź region and near Łosice – discussed in previous chapter. This may point to an oscillation of a comparatively strong ice front, following the maximum reach of the probably weaker ice. On the other hand, one cannot exclude the probability of the different permafrost conditions during the first invasion of the ice and during its retreat period, and their influence upon the effectiveness of glaciotectonic processes.

The deformations in the Łódź region (Fig. 4 and Pl. I: 1) point to an ice movement from north-east to south-west (Klatkowa, 1972), while near Łosice (Nowak, 1977) from north-west to south-east. These directions are closely related to the lobe-

-shape of the maximum extent of the Wartanian ice (Fig. 1). This also draws attention to the fact that some older (buried) structures, which were formed in frontal zones, may show differentiation of directions reflecting former lobes of advancing ice sheets (as previously mentioned – in connection with the older "stadial" of the Cracovian Glaciation).

More realiable indicators of a general direction of movement of larger ice masses seem to be supplied by the subglacial deformation, often represented by syndepositional deformation of lodgement till. This kind of structures has been reported e.g. from Anielinek, SE of Warsaw, where there is evidence of south--eastward movement of Wartanian ice (Ruszczyńska-Szenajch, 1976a, b). However, in the writer's opinion, the deformations formed underneath the main ice body usually are – on the contrary to the features originated in frontal zone – considerably smaller and rarely attain large-scale dimensions, and thus (in spite of their essential importance for the question discussed) they are only mentioned in this paper.

The retreating Wartanian ice had shown in northern Masovia at least two major advances of substage order (Różycki, 1972). The older one caused some glaciotectonic deformation (after reaching its maximum extent), e.g. pushed-forward end moraine at Piączyn (Ruszczyńska-Szenajch, 1979). Sedimentological analysis of the glaciogenic deposits accompanying the pushed sediments at Piączyn revealed the occurrence there of the fossil glaciodynamic features which had been formed within the frontal part of the ice due to compressive flow (Ruszczyńska-Szenajch, 1981). Both glaciotectonic and glaciodynamic structures point to the south-westward direction of ice movement in that place. In the writer's opinion the process of pushing-forward at Piączyn did not need a considerable thickness of ice. This is also confirmed by a comparatively short segment of occurrence, within a longer morainic chain, of glaciotectonic frontal features, pointing to a very local readvance of the ice front.

Apart from the glaciotectonic sites described, corresponding to the Wartanian and Odranian stages, there also are deformations, reported from central Poland, which generally are attributed to the Middle Polish Glaciation, e.g. at Góra Kalwaria (Sarnacka, 1956) or Wólka Mlądzka (Browkin-Markulis, 1967). There also exists a conspicuous glaciotectonic deformation in Gdańsk is northern Poland – discussed in the previous section – which is attributed (Mojski, 1979) to this glaciation, and which points to the south-westward movement of very strong ice. However, correlation between the Middle Polish glacial units in northern and in central Poland is as yet a difficult and risky task (Mojski, 1979).

Glaciotectonic structures in the northern part of central and eastern Poland are mostly known from surface forms corresponding to the last, Vistulian Glaciation, and especially to the Pomeranian stadial of this glaciation, e.g. in Suwałki region (Ber, 1974) or in the area adjacent to the lower Vistula valley (Galon, 1961). Unfortunately, the directional and genetic features of the structures are seldom discussed in a systematic way in the works mentioned. This makes estimation of some dynamic features (based on glaciotectonic evidence) of the Pomeranian ice difficult, until new works, some of them already reported at the Annual Meeting of the Polish Geographical Society in 1983, will be published.

CONCLUDING REMARKS

The above concise review of glaciotectonic structures reveals the fact, that the most common large-scale glaciotectonic deformations in central and eastern Poland are represented by squeezed-up end moraines composed mainly of local substratum material. They often occur at the surface in zones occupied successively by younger and younger glaciations, and – in the writer's opinion – many reported buried deformations, established in borings, represent also the same genetic kind of glaciotectonic structures. The squeezed moraines are often accompanied on their proximal sides by corresponding depressions being source zones of the squeezed-up sediments, and usually completely filled with glaciogenic deposits and with squeezed-in substratum material.

The push-forward end moraines and other features pushed frontally by glacial ice, which do not contain material from beneath, are much scarcer in the area discussed.

The glaciotectonic features occur in all the successive glaciogenic horizons. The evidence existing does not supply, as yet, the basis for systematic palaeoglaciological or palaeogeographical studies concerning the whole territory discussed (like for example in Denmark – Berthelsen, 1978), though in many cases it may allow one to reconstruct local geological history, and in some cases to draw preliminary conclusions on a regional scale.

Acknowledgements. The writer thanks Dr. Krzysztof Brodzikowski for the discussions of glaciotectonic questions and for the critical remarks on the manuscript.

REFERENCES

Banham, P.H., 1975. Glacitectonic structures: a general discussion with particular reference to the contorted drift in Norfolk. *In*: Wright A.E., Moseley F. (Eds.): *Ice Ages, Ancient and Modern*, 69–94. Liverpool.

Baraniecka, M.D., 1975. Zależność wykształcenia osadów czwartorzędowych od struktur i dynamiki podłoża w środkowej części Niżu Polskiego. The dependence of the development of Quaternary deposits upon the structure and dynamics of the basement in the central part of the Polish Lowlands. *Biul. Inst. Geol.* 288, 5–98. Warszawa.

Baraniecka, M.D., 1979. Osady plioceńskie Mazowsza jako podłoże czwartorzędu. Pliocene deposits as the Quaternary substratum of the Mazowsze region. *Biul. Geol. Wydz. Geol. UW.* 23, 23–40. Warszawa.

Ber, A., 1960. The age of the foldings near Dobrzyń. *Biull. Acad. Pol. Sci.* 8, 49–52. Warszawa.

Ber, A., 1974. Czwartorzęd Pojezierza Suwalskiego. The Quaternary of the Suwałki Lake District. *Biul. Inst. Geol.* 269, 23–106. Warszawa.

Berthelsen, A., 1978. The methodology of kineto-stratigraphy as applied to glacial geology. *Bull. Geol. Soc. Denm.* 27, 25–38. Copenhagen.

Browkin-Markulis, H., 1967. Czwartorzęd w rejonie doliny Świdra koło Wólki Mlądzkiej.

La Quaternaire dans le région de la vallée du Świder aux environs de Wólka Mlądzka. *Acta Geol. Pol.* 17, 431—442. Warszawa.

B r y k c z y ń s k a, E. & B r y k c z y ń s k i, M., 1974. Geologia przekopu Trasy Łazienkowskiej na tle problematyki zaburzeń osadów trzeciorzędu i czwartorzędu w Warszawie. The geological section in the Łazienkowska Route and the problems of the deformations of the Tertiary and Quaternary sediments in Warsaw. *Prace Muz. Ziemi* 22, 199—218. Warszawa.

B r y k c z y ń s k i, M., 1982. Glacitektonika krawędziowa w Kotlinie Warszawskiej i Kotlinie Płockiej. Valley-side glacitectonics in the Warsaw Basin and the Płock Basin. *Prace Muz. Ziemi*, 35, 3—68. Warszawa.

D o m o s ł a w s k a - B a r a n i e c k a, M.D. & G a d o m s k a S., 1965. *Atlas Geologiczny Warszawy*, Czwartorzęd. Wyd. Geol. Warszawa.

D y l i k, J., 1961. The Łódź Region. *Guide-book of excursion, VI INQUA Congr.* Łódź.

G a l o n, R., 1961. North Poland, area of the last glaciation. *Guide-book of excursion, VI INQUA Congr.* Łódź.

J a h n, A., 1956. Wyżyna Lubelska, rzeźba i czwartorzęd. Geomorphology and Quaternary history of Lublin Plateau. 453 pp. Państw. Wyd. Nauk. Warszawa.

J a r o s z e w s k i, W., 1963. Młode zaburzenia tektoniczne w Dobrzyniu nad Wisłą. Young tectonic disturbances at Dobrzyń on the Vistula. *Biul. Geol. Wydz. Geol. UW.* 3, 263—273. Warszawa.

K l a t k o w a, H., 1972. Paleogeografia Wyżyny Łódzkiej i obszarów sąsiednich podczas zlodowacenia warciańskiego. Paléogéographie du Plateau de Łódź et de terrain avoisinant pendant la glaciation de Warta. *Acta Geogr. Lodz.* 28, 220 pp. Łódź.

L e w i ń s k i, J., 1924. Zaburzenia czwartorzędowe i „morena dolinowa" w pradolinie Wisły pod Włocławkiem. *Sprawozd. Państw. Inst. Geol.*, 2, 3—4. Warszawa.

L e w i ń s k i, J., 1929. Preglacjał i tzw. preglacjalna dolina Wisły pod Warszawą. Das Präglazial und das sogenannte präglaziale Weichseltal bei Warschau. *Przegl. Geogr.* 9, 141—159. Warszawa.

L e w i ń s k i, J. & R ó ż y c k i, S.Z., 1929. Dwa profile geologiczne przez Warszawę. *Sprawozd. Tow. Nauk. Warsz.* 22, 30—50. Warszawa.

L i n d n e r, L., 1971. Stratygrafia plejstocenu i paleogeomorfologia północno-zachodniego obrzeżenia Gór Świętokrzyskich. Pleistocene stratigraphy and palaeogeomorphology of the north-western margin of the Holy Cross Mountains, Poland. *Studia Geol. Pol.* 35, 113 pp. Warszawa.

L i s z k o w s k i, J., 1975. Wpływ obciążenia lądolodem na plejstoceńską i współczesną dynamikę litosfery na obszarze Polski. The influence of ice sheet loading on Pleistocene — recent dynamics of lithosphere in Poland. *I Krajowe Sympozjum: Współczesne i neotektoniczne ruchy skorupy ziemskiej w Polsce.* 255—278. Warszawa.

M i c h a l s k a, Z., 1967. Stratygrafia plejstocenu północnego Mazowsza w świetle nowych danych. La stratigraphie du pleistocene de la Masovia du nord a la lumiere des donnees recantes. *Acta Geol. Pol.* 17, 393—418. Warszawa.

M i c h a l s k i, T., 1979. Mechanizm powstawania niektórych zaburzeń glacitektonicznych. The mechanism whereby certain glacitectonic disturbances occur. *Biul. Inst. Geol.* 317, 51—94. Warszawa.

M i c h a l s k i, T., 1980. Wpływ pola cieplnego Ziemi na powstanie zaburzeń glacitektonicznych okolic Łosic. *III Symp. Glacitekt.*, 165—174. Zielona Góra.

M o j s k i, J.E., 1979. Zarys stratygrafii plejstocenu i budowy jego podłoża w regionie gdańskim. Outline of the stratigraphy of the Pleistocene and the structure of its basement in the Gdańsk region. *Biul. Inst. Geol.* 317, 50—60. Warszawa.

M o j s k i, J.E. & D o m o s ł a w s k a - B a r a n i e c k a, M.D., 1965. *Atlas Geologiczny Warszawy. Trzeciorzęd.* Wyd. Geol. Warszawa.

N o w a k, J., 1977. Specyficzna budowa geologiczna form polodowcowych zależnych od podłoża. Specific structure of forms of Quaternary age dependent on the substratum. *Studia Geol. Pol.* 52, 347—360. Warszawa.

P a z d r o, Z., 1960. Budowa geologiczna regionu gdańskiego. Geological structure of Gdańsk Region. *Rocz. Pol. Tow. Geol.* 29, 337—346. Kraków.

R ó ż y c k i, S.Z., 1970. Dynamiczne uławicenie glin zwałowych i inne procesy w dennej części moren lądolodów czwartorzędowych. Dynamic stratification of tills, and other processes in the basal part of moraines of the Quaternary ice sheets. *Acta Geol. Pol.* 20, 561 – 586. Warszawa.

R ó ż y c k i, S.Z., 1972. *Plejstocen Polski środkowej.* Państw. Wyd. Nauk., 314 pp. Warszawa.

R ó ż y c k i, S.Z., 1978. Od „Mocht" do syntezy stratygrafii Plejstocenu Polski. From Mochty to a synthesis of the Polish Pleistocene. *Rocz. Pol. Tow. Geol.*, 48, 445 – 478. Kraków.

R ó ż y c k i, S.Z., 1982. Zaburzenia glacitektoniczne w rejonie Julianki. Glacitectonic deformations nearby Julianka. *Biul. Geol. Wydz. Geol. UW*, 26, 161 – 171. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., 1973. Kry lodowcowe wyciśnięte glacitektonicznie na terenie SE Mazowsza i S Podlasia. Glacial floes – bedrock masses – squeezed by ice sheets in mid-eastern Poland; preliminary report. *Kwart. Geol.*, 17, 560 – 576. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., 1976a. Glacitektoniczne depresje i kry lodowcowe na tle budowy geologicznej południowo-wschodniego Mazowsza i południowego Podlasia. Glacitectonic depresions and glacial rafts in mid-eastern Poland. *Studia Geol. Pol.*, 50, 106 pp. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., 1976b. Examples of differentiation of tills due to bedrock conditions prevailing in the place of deposition. *In*: Stankowski W. (Ed.): *Till – its genesis and diagenesis*, 81 – 89. Poznań.

R u s z c z y ń s k i - S z e n a j c h, H., 1978. Serie glacigeniczne i kopalne doliny rzeczne środkowego plejstocenu w rejonie Kocka. Glacigenic series and buried river valleys of middle-Pleistocene age in Kock region. *Kwart. Geol.*, 22, 339 – 359. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., 1979. Zróżnicowanie zaburzeń glacitektonicznych w zależności od przewagi oddziaływania ciężaru lodu lub ruchu lodu. Differentiation of glacitectonic deformations due to prevalance of ice-pressure or ice-movement. *Biul. Geol. Wydz. Geol. UW*, 23, 131 – 142. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., 1981. Fossil remnants of up-turned debris bands in Pleistocene glacial deposits of Poland. *Sedimentology*. 28, 713 – 722. Oxford.

R u s z c z y ń s k a - S z e n a j c h, H., 1983. Glacitektonika. *In*: W. Pożaryski & W. Jaroszewski (Eds): Słownik Tektoniczny. *Prz. Geol.* 8: 502 – 505. Warszawa.

R u s z c z y ń s k a - S z e n a j c h, H., (in print). Relation of the large-scale glacitectonic features to substratum-and-bedrock conditions in central and eastern Poland.

R ü h l e, E. & Z w i e r z, S., 1961. Przekrój geologiczny doliny Bugu na Podlasiu w okolicy Mielnika. Geological section of the Bug River valley in the area of Podlasie. *Biul. Inst. Geol.* 169:213 – 240. Warszawa.

S a m s o n o w i c z, J., 1927. Budowa geologiczna i dzieje okolic Warszawy. *In*: Przewodnik geologiczny po Warszawie i okolicy. 1 – 69. *Polska Akad. Umiejętn.*, Warszawa.

S a r n a c k a, Z., 1965. Struktury glacitektoniczne i marzłociowe w Górze Kalwarii i Osiecku na południe od Warszawy. Glacitektonic and frozen ground structures at Góra Kalwaria and Osieck south of Warsaw, Central Poland. *Biul. Inst. Geol.* 187: 217 – 238, Warszawa.

S k o m p s k i, S., 1969. Stratygrafia osadów czwartorzędowych wschodniej części Kotliny Płockiej. Stratigraphy of Quaternary deposits of the eastern part of the Płock Depression. *Biul. Inst. Geol.* 220, 175 – 258. Warszawa.

S t r a s z e w s k a, K., 1968. Stratygrafia plejstocenu i paleogeomorfologia rejonu dolnego Bugu. Pleistocene stratigraphy and paleogeomorphology in the Lower Bug region, central Poland. *Studia Geol. Pol.* 23, 149 pp. Warszawa.

S u j k o w s k i, Z. & R ó ż y c k i, S.Z., 1937. Mapy geologiczne m. st. Warszawy wraz z tekstem objaśniającym. Zarząd Miejski m. st. Warszawy. Warszawa.

STRESZCZENIE

Problematyka glacitektoniczna budzi obecnie coraz szersze zainteresowanie nie tylko w badaniach geologii glacjalnej, ale również ze względu na jej znaczenie dla paleoglacjologii oraz rekonstrukcji paleogeograficznych i paleoklimatycznych. W czasie międzynarodowego Kongresu INQUA w Anglii (1977) stwierdzono dotkliwy brak ogólnie dostępnych wiadomości z zakresu badań glacitektonicznych dla tych obszarów polodowcowych, dla których prace z tej dziedziny publikowane są tylko lub głównie w mało znanych za granicą językach macierzystych; dotyczy to bezpośrednio badań polskich.

W niniejszym artykule podano zarys regionalnego rozmieszczenia wielkoskalowych struktur glacitektonicznych (budujących przeważnie odrębne formy rzeźby) w środkowej i wschodniej Polsce oraz dyskusję dotyczącą ich genezy i wieku – na podstawie publikacji (głównie w języku polskim) wielu autorów oraz własnych prac autorki. Na tle tego, stosunkowo bogatego, materiału autorka wyróżniła podstawowe grupy genetyczne zaburzeń – w nawiązaniu do swoich poprzednich prac, opartych na szczegółowych analizach geologicznych. Określono także wstępnie kolejne generacje wiekowe zaburzeń oraz postawiono zagadnienie ogólnego szacowania niektórych cech dynamicznych (jak kierunki płynięcia i grubość) odpowiadających im lądolodów.

Wyniki dotychczas publikowanych prac nie pozwalają jeszcze na szersze rekonstrukcje paleogeograficzne (jak np. dla południowej Danii – Berthelsen, 1978), ale w wielu przypadkach dają podstawę do odtwarzania historii geologicznej mniejszych obszarów (jak np. południowe Podlasie czy, bardzo dyskusyjny, teren Warszawy).

Znacznie wyraźniej natomiast, zdaniem autorki, rysują się zagadnienia genezy struktur występujących na omawianym obszarze – rozpatrywanych w makroskali tzn. całych dużych zgrupowań zaburzeń, jak np. ciąg moren czołowych glacitektonicznych. Fakt częstego występowania w obrębie zaburzeń materiału lokalnego podłoża pochodzącego ze stosunkowo dużych głębokości pozwala przypuszczać, że przeważająca większość wielkoskalowych struktur to moreny czołowe wyciśnięte. Dotyczy to zarówno form rzeźby współczesnej, jak i form kopalnych. Przypuszczenie to potwierdzane jest w wielu przypadkach przez występowanie – na zapleczu takich moren – źródłowych stref, z których materiał został wyciśnięty. Natomiast struktury pchnięcia lodowcowego (innymi słowy różne przejawy tzw. glacitektoniki krawędziowej) mogą być udokumentowane tylko w nielicznych przypadkach. Sytuację taką autorka tłumaczy warunkami paleogeograficznymi, jakie napotykały na Polskim Niżu transgredujące lądolody.

Odrębnym ciekawym zagadnieniem, jakie można rozpatrywać na tle opublikowanych dotychczas prac, jest problem zależności procesów i struktur glacitektonicznych od podłoża. Zagadnienie to autorka omawia w oddzielnym artykule (Ruszczyńska-Szenajch in print).

EXPLANATIONS OF PLATES

Plate I

1. Exposure at Dąbrówka – Strumiany. Scales of Pleistocene deposits (*2*) resting on Tertiary clays showing plastic deformations (*1*) – after Klatkowa, 1972. The section is about 3 m high
2. Structure of thrust end moraine near Tczew (after Galon, 1961). The section is about 3 m high

Plate II

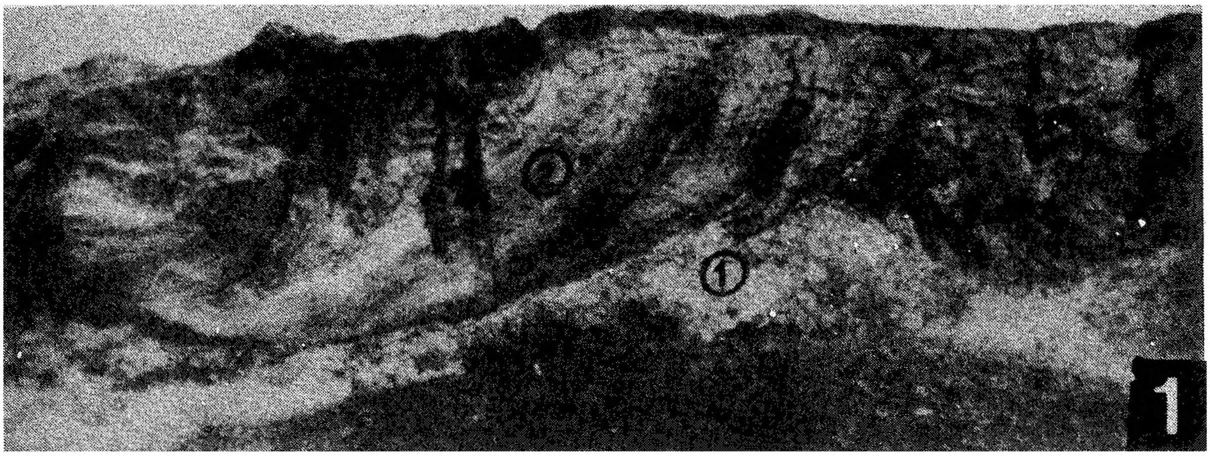
Squeezed-up Pliocene sands and clays. Exposure near Stoczek. Photo from color slide by B. Drozd

Plate III

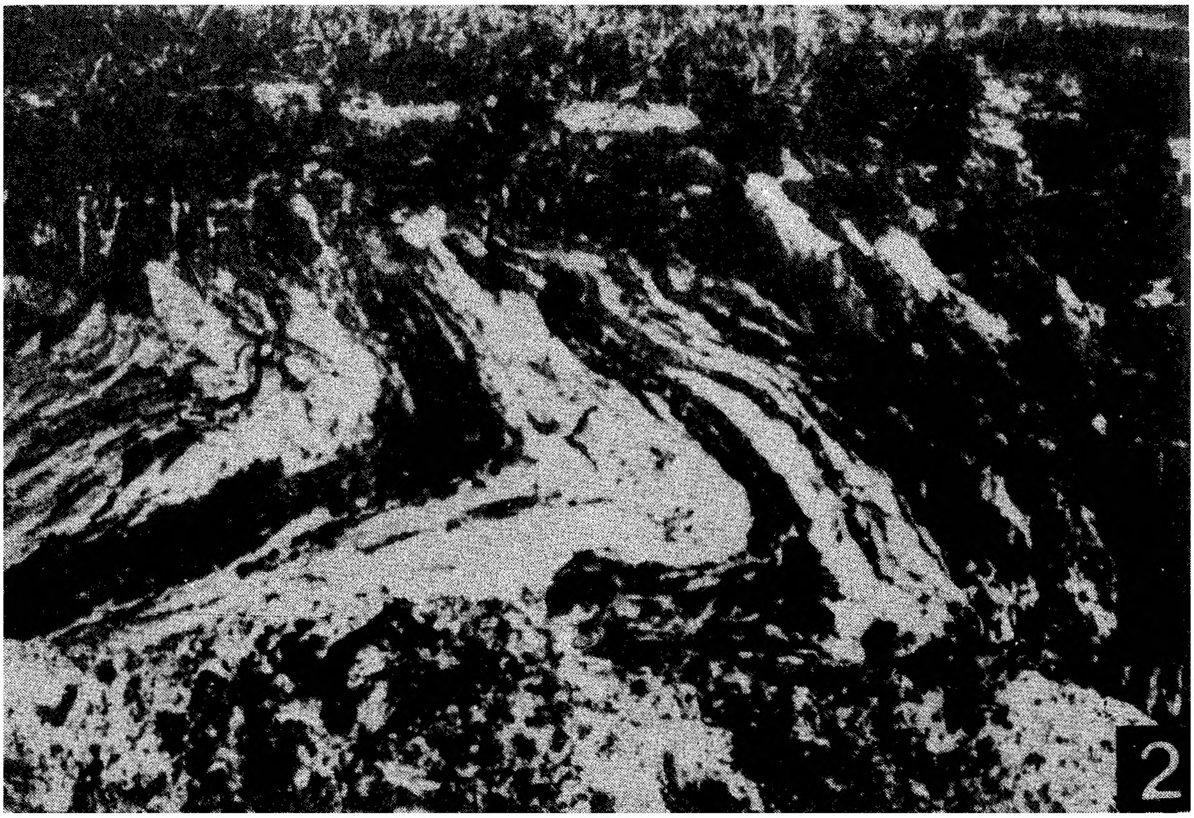
Younger till exposed in the Vistula river escarpment at Wyszogród, composed of deformed lodgement till (g2) covered by melt-out (and flow) till (g2a). The section is about 12 m high

Plate IV

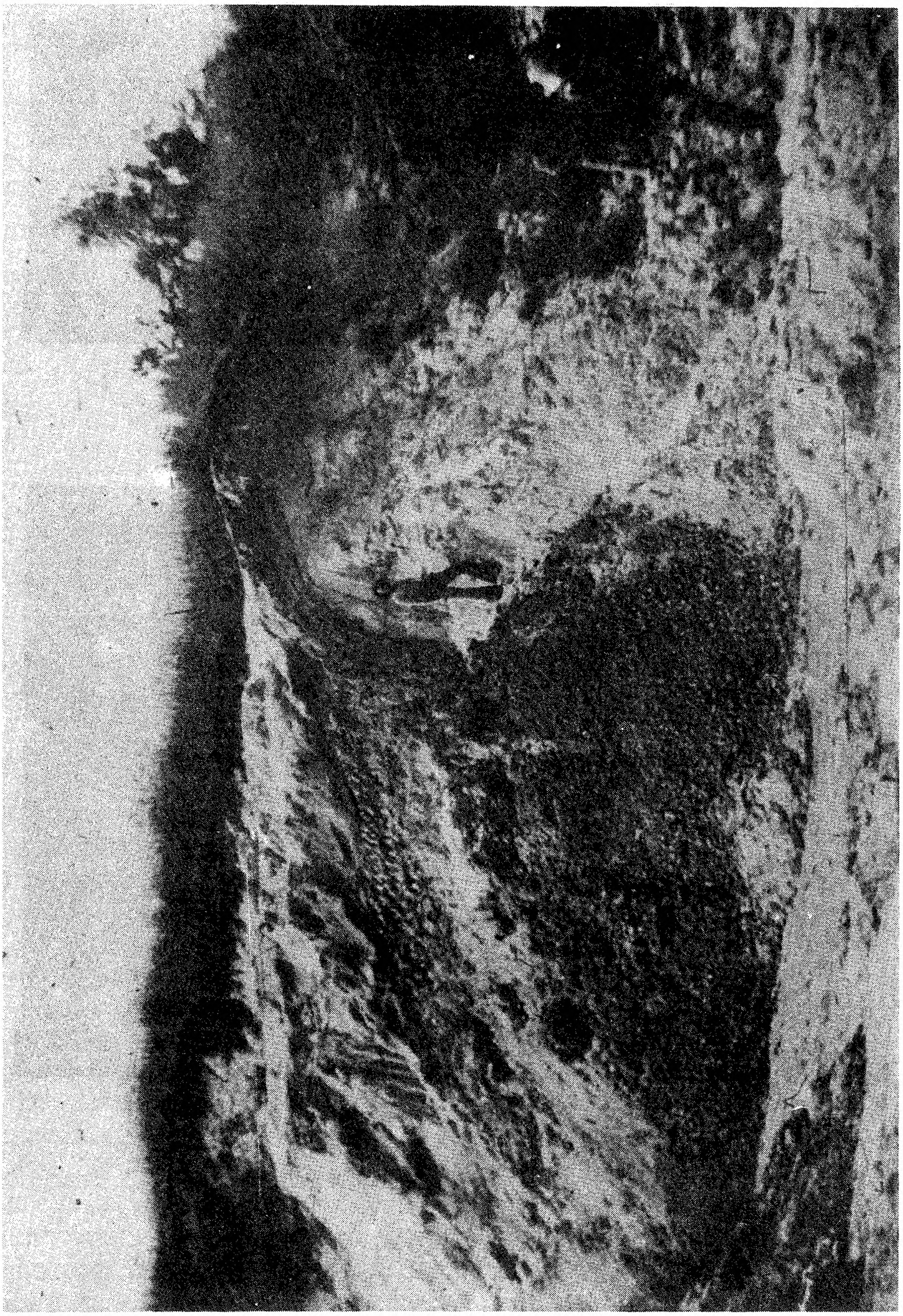
Baltic cliff at Gdynia-Orłowo. *1* – Squeezed-up substratum sands, *2a* – lower part of the till: glaciotectonically deformed lodgement till, *2b* – upper part of the till: mainly melt-out till, with preserved glaciodynamic structures (debris bands) up-turned by the squeezing of sands from beneath. Photo from color slide by S. Kolanowski

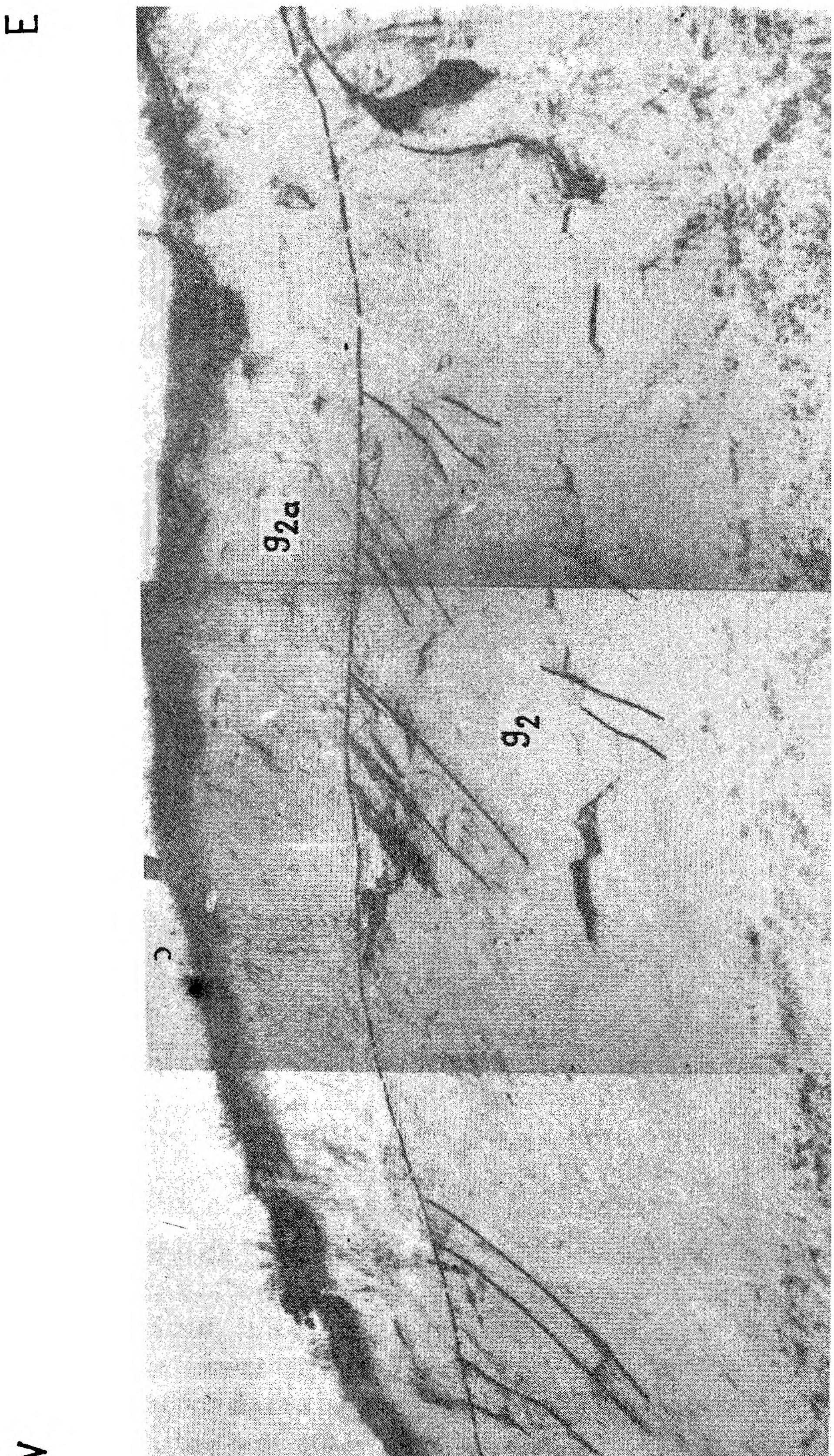


1



2




E
g2a
g2
W


2a
1
2b