Kwartalnik Geologiczny, t. 33, nr 3/4, str. 479—494

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Morphology of Quaternary substrate in the Warsaw area and its surroundings*

The paper presents several morphologic features of the sub-Quaternary surface in the Warsaw area and its surroundings. They comprise a primary sedimentary surface, glaciotectonic anticlines and synclines, glaciotectonic rafts and intrusions, subglacial troughs, erosive cuts of the pre-Vistula. Problems concerning progress and age of genetic processes are discussed.

INTRODUCTION

The Warsaw area and its closest surroundings are a peculiar region for studies over Quaternary deposits and its substrate. Many thousand boreholes have been done for various purposes in municipal-industrial zones whereas adjacent non-built areas are locally completely devoid of geologic data. A geology of the Warsaw site have been already of interest of many authors since the end of the previous century. A broad discussion of this literature is presented in the explanatory text to the Geologic Atlas of Warsaw (M. D. Domosławska-Baraniecka et al., 1965) and in explanations to the sheets: Warsaw East (Z. Sarnacka, 1980b) and Warsaw West (W. Morawski, 1980b) of the Detailed Geologic Map of Poland in a scale of 1 : 50,000. The mentioned atlas comprises all the geologic data from Warsaw (central part of the described area) with such a detail that boreholes of the last 20 years have not resulted in significant changes, in a morphology of the Quaternary substrate as well. A stratigraphy of Quaternary deposits as well as morphology of its substrate have a peculiar place in a monography on the Pleistocene of Central Poland (S. Z. Różycki, 1967, 1972). Numerous new data on a morphology of the substrate in Warsaw have been provided by works connected with a construction of the Łazienkowska Tract, housing estates of Służew and Ursynów and underground (W. Z. Należyty, 1972; L. Watycha, 1973; E. Brykczyńska, M. Brykczyński, 1974; W. Morawski, 1984).

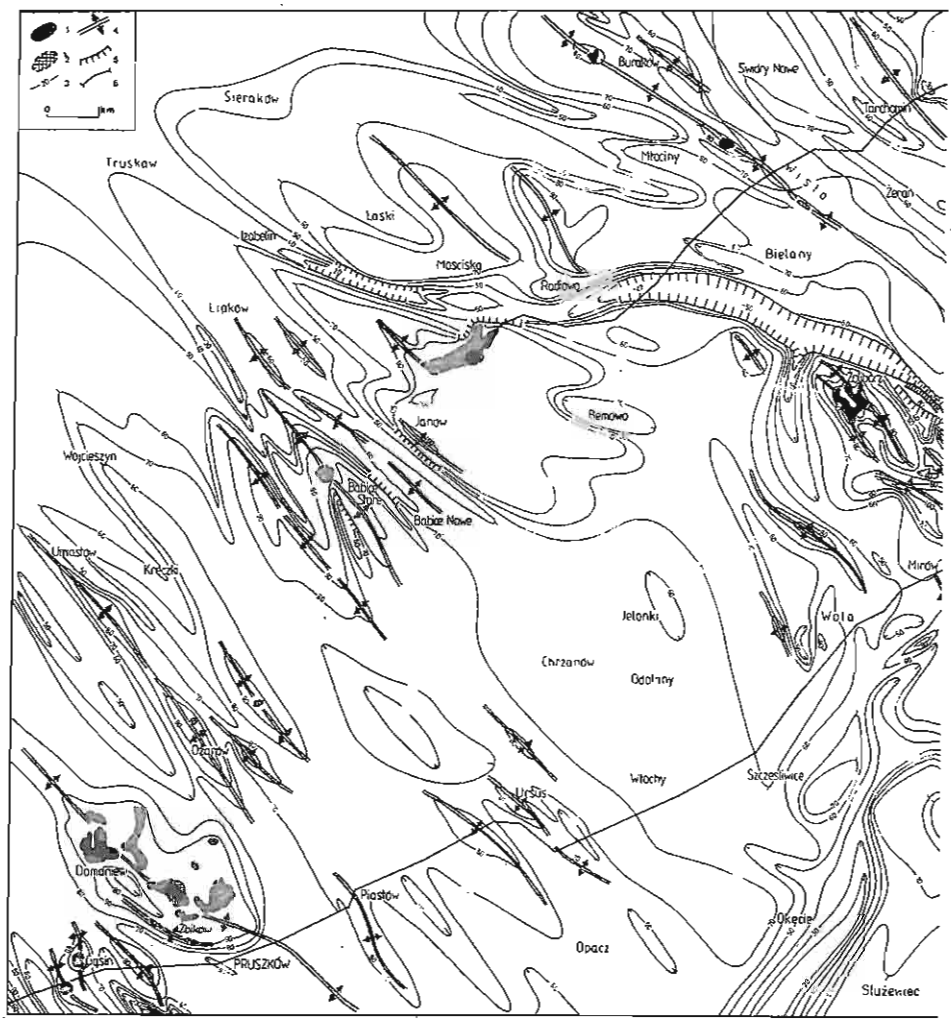
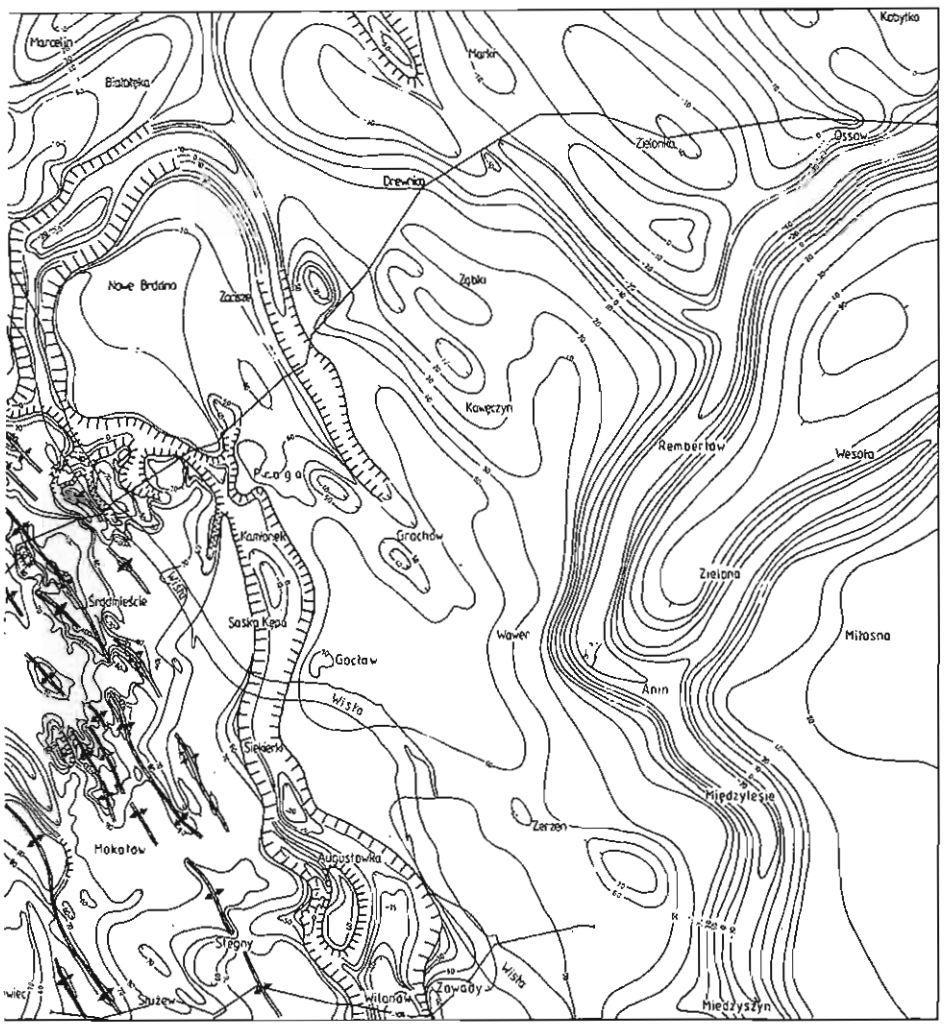


Fig. 1. Morphology of Quaternary substrate

1 — outcrops of Pliocene deposits; 2 — Pliocene deposits at depths to 2 m; 3 — contour lines of the top of Pliocene deposits in metres a.s.l.; 4 — anticline axes; 5 — steep escarps of the top surface of Pliocene deposits; 6 — geologic sections

New ideas on genesis of deformations, being a principal feature of a morphology of the Quaternary substrate in the Warsaw area, are presented in papers of M. D. Baraniecka (1975b) and M. Brykczyński (1982).

A task of preparation of two adjacent sheets of the Detailed Geologic Map of Poland in a scale of 1 : 50,000: Warsaw West (W. Morawski, 1979, 1980 *a*, *b*) and Warsaw East (Z. Sarnacka, 1980 *a*, *b*), undertaken by the Department of Geological Mapping, Geological Institute of Warsaw, was the next important phase in a recognition of a geologic structure (morphology of the Quaternary substrate also inclusive) in the Warsaw



Ukształtowanie powierzchni podłoża czwartorzędu

1 — wychodnie osadów plioceńskich; 2 — osady plioceńskie na głębokości nie większej niż 2 m; 3 — poziomice stropu osadów plioceńskich w m n.p.m.; 4 — osie wypiętrzeń (antyklin); 5 — strome skarpy powierzchni stropu osadów plioceńskich; 6 — linie przekrojów geologicznych

area and its surroundings. Independently on cartographic-geologic works within this task, an electric logging was done at a total distance of over 65 km (W. Morawski, 1977) and 23 research boreholes were drilled, with a full core collection and a total length of 2372 m, that reached the Quaternary substrate. This paper comprises an analysis of about 9400 archival boreholes, including about 2400 ones that passed through the Quaternary deposits and provided with data on a location of the substrate top surface. All these data enabled to prepare a sketch of the Quaternary substrate morphology (Fig. 1) and the sections (Figs 2—4).

PROBLEM OF THE PREGLACIAL

It seems necessary to formulate several comments on deposits of the so-called "Preglacial" before a description of the morphology of the sub-Quaternary surface. A stratigraphic location of fluvial-lacustrine sediments that overlie variegated clays and underlie glacigenic deposits of the Pleistocene, constitutes the problem discussed by many scientists. This series of sediments was described and named the "Preglacial" for the first time by J. Lewiński (1929). The so-called "Ochota Series", described by S. Z. Różycki (1961, 1967), was considered for the younger than the Pliocene and formed the key stratigraphic horizon in the Polish Lowland. But S. Z. Różycki in 1972, due to the Tertiary flora of this series, found it and so the whole Preglacial of Mazowsze to be of the Middle Pliocene age.

But the following years brought the results that induce to a new outlook on this problem. Investigations in the Otwock area — southeast of Warsaw (M. D. Baraniecka, 1975*a*, 1976; L. Stuchlik, 1975) supplied with sections of the Preglacial deposits, particularly the one from Ponurzyca that presents an occurrence of numerous fluvial-lacustrine cycles. The analyzed flora indicates cyclic climatic variation: cold intervals of glacial type and warm ones of interglacial type, and was correlated with the stratigraphic scheme of W. H. Zagwijn (1960).

During the preparation of the sheet Warsaw West several research boreholes, particularly at Mirów and Opacz, provided with new sections of the Preglacial deposits, composed of cyclicly varying fluvial-lacustrine sediments with inserts of organic material. These sections were correlated with the Ponurzyca section (W. Morawski, L. Stuchlik, 1987).

Summing up the earlier conclusions of A. Środoń (1962), M. D. Baraniecka (1975 *a*), L. Stuchlik (1975, 1977), W. Morawski (1979, 1980 *a*, *b*), W. Morawski, L. Stuchlik (1987), B. Kosmowska-Ceranowicz (1987), deposits of the so-called "Preglacial" are to be included into the Quaternary. A location of these deposits in the Mirów-Opacz area seems to be the closest to a primary sedimentary one. Their bottom occurs there on the Pliocene deposits at about 60—65 m a.s.l. and the top at 80—85 m a.s.l. On the other hand the so-called "Ochota Series" is most probably the raft of the Miocene deposits or a series of them, redeposited in a secondary deposit.

Therefore, the sub-Quaternary surface described in this paper, corresponds with the top of the Pliocene deposits and the bottom of the Quaternary deposits, into which the so-called "Preglacial" sediments were included, that is similarly as accepted by E. Rühle (1955).

MORPHOLOGIC ELEMENTS OF THE SUB-QUATERNARY SURFACE (OF THE QUATERNARY SUBSTRATE)

A morphology of the sub-Quaternary surface in the described area of the Warsaw surroundings is considerably varying (Fig. 1). A location of its highest elevations in the Śródmieście area (about 113 m a.s.l.) and of the maximum depressions at Wilanów (108 m b.s.l.) indicates the altitude difference reaching about 220 m. Such variations of the sub-Quaternary surface morphology results from different processes that occurred there

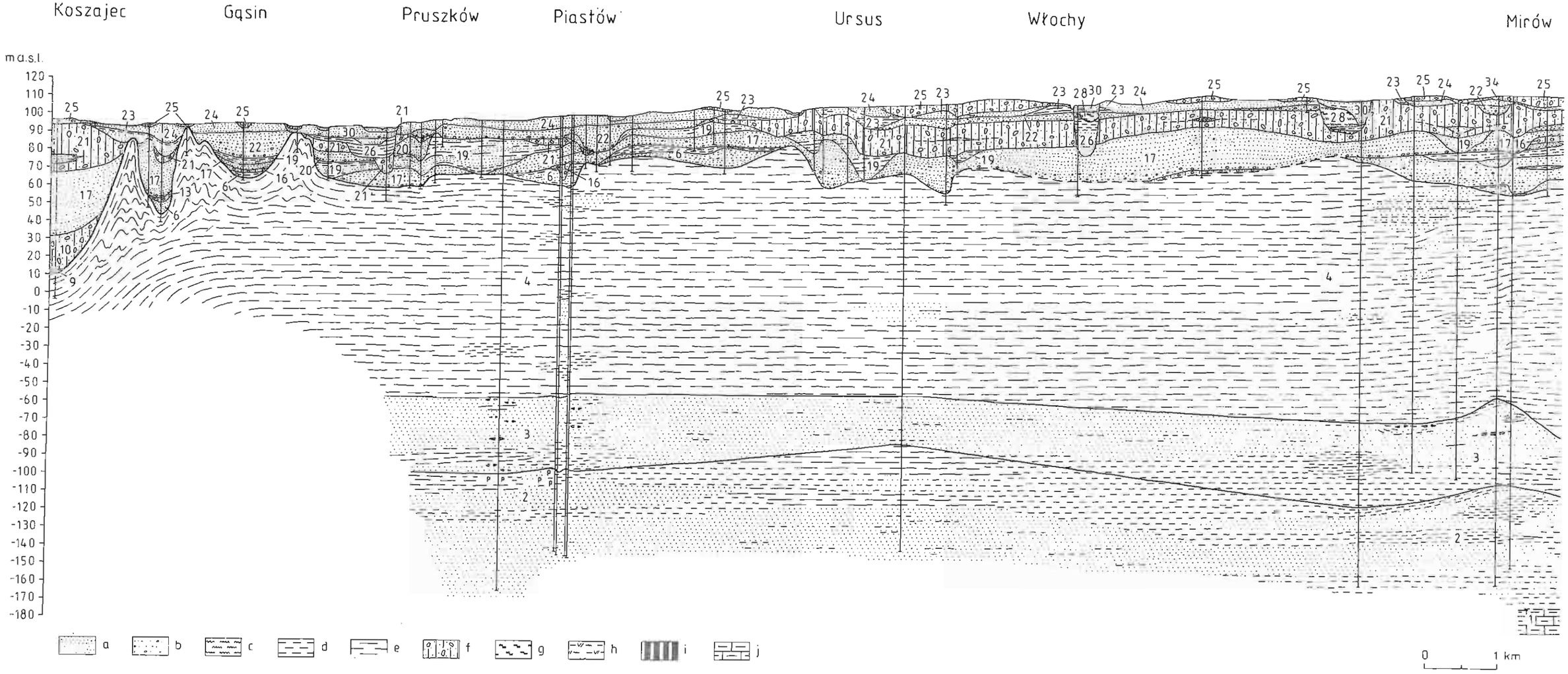
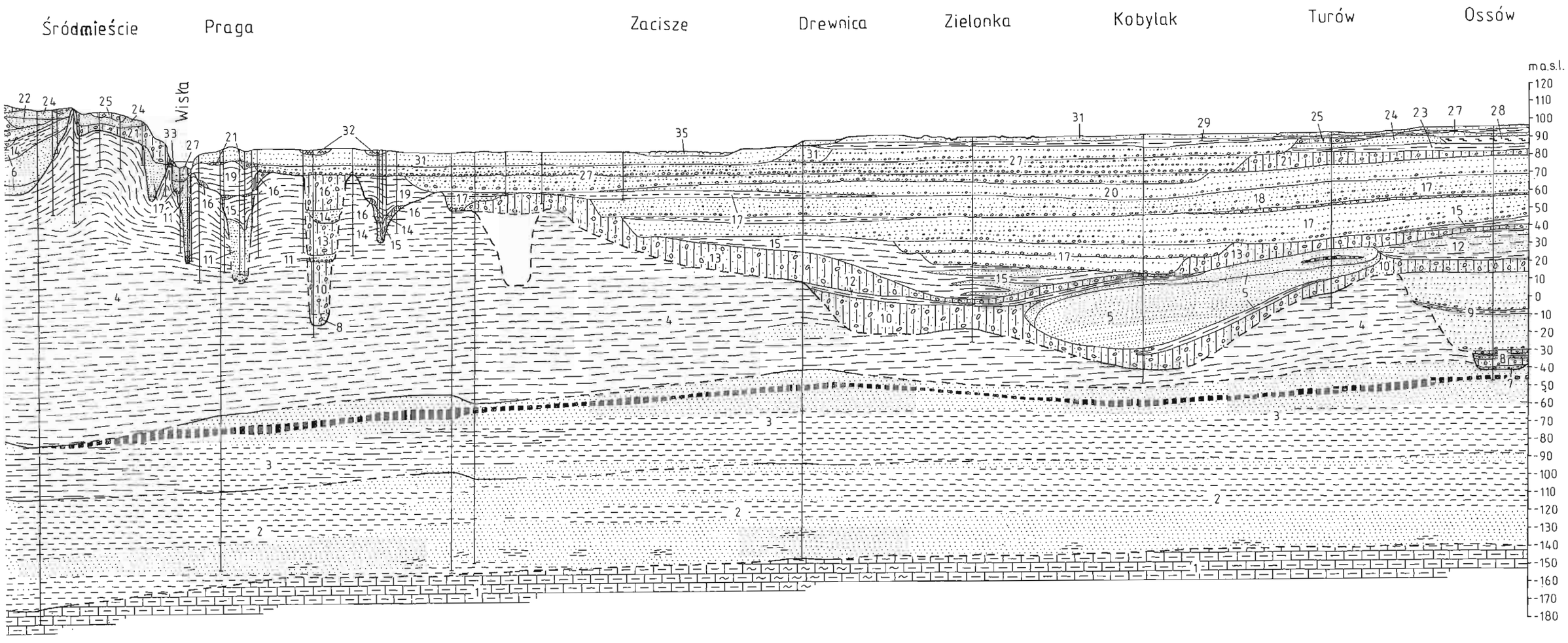


Fig. 2. Geologic section Pruszków-Warsaw-Ossów

Przekrój geologiczny Pruszków-Warszawa-Ossów

Upper Cretaceous: 1 — maris and limestones; Tertiary: Palaeogene: Oligocene: 2 — sands, sands with gravels, clays and silts; Pliocene: 3 — sands, clays, silts and brown coal; Pliocene: 4 — clays, silts, sands; 5 — Pliocene, Miocene and Oligocene deposits as rafts within Pleistocene deposits; Pleistocene: Preglacial: 6 — gravels, sands with gravels and silts; Oldest (Podlasie) Glaciation: 7 — glacifluvial sands with gravels, 8 — tills, glacifluvial sands and ice-dam clays; Cromer Interglacial: 9 — fluvial gravels, sands with gravels, sands and silts as well as residual gravels and boulders; South-Polish Glaciation: Lower Stadial: 10 — tills, 11 — interstadial, partly glacifluvial sands with gravels, 12 — ice-dam clays; Upper Stadial: 13 — lower tills, 14 — glacifluvial sands with gravels, 15 — ice-dam clays, silts and sands, 16 — upper tills; Mazovian (Great) Interglacial: 17 — fluvial sands with gravels and silts; Middle-Polish Glaciation: Pre-maximum Stadial: 18 — tills; Maximum Stadial: 19 — ice-dam clays, silts and sands, 20 — glacifluvial sands with gravels, 20b — tills; Pilica Interstadial: 22 — fluvial locally residual sands with gravels; Mazovian-Podlasie Stadial: 23 — ice-dam clays, silts and sands, 24 — glacifluvial sands, 25 — tills; North-Mazovian Stalial: 26 — ice-dam clays, silts and sands; Eemian Interglacial: 27 — fluvial gravels, sands with gravels and silts, 28 — bituminous shales, gyttjas, lake marl, peats and lake silts; North-Polish (Baltic) Glaciation: 29 — ice-dam clays and sands, 30 — lake silts and sands, 31 — fluvial sands with gravels of suprainundation terraces of the Vistula; Holocene: 32 — light sandy-clayey muds of the lower suprainundation terrace of the Vistula, 33 — fluvial sands of the flood terrace of the Vistula, 34 — heavy clayey-sandy muds (silts) of the flood terrace of the Vistula, 35 — humus sands and sandy muds of valley bottoms and oxbows, 36 — aeolian sands; lithologic symbols: a — sands, b — sands with gravels, c — muds, d — silts, e — clays, f — tills, g — peats, h — gyttjas, i — brown coal, j — marls and limestones

Kreda górna: 1 — margle i wapienie; trzeciorzęd: paleogen: oligocen: 2 — piaski, piaski ze żwirami, iły i mułki; neogen: miocen: 3 — piaski, iły, mułki i węgiel brunatny; pliocen: 4 — iły, mułki, piaski; 5 — utwory plioceńskit, mioceńskie i oligoceńskie jako kry w osadach plejstoceńskich; plejstocen: preglacjał: 6 — żwiry, piaski ze żwirami i mułki; zlodowacenie najstarsze (podlaskie): 7 — piaski ze żwirami wodnolodowcowe, 8 — gliny zwałowe, piaski wodnolodowcowe i iły zastoiskowe; interglacjał kromerski: 9 — żwiry, piaski ze żwirami, piaski i mułki rzeczne oraz żwiry i głazy residualne; zlodowacenie południowopolskie: stadiał dolny: 10 — gliny zwałowe, 11 — piaski ze żwirami interstadialne, częściowo wodnolodowcowe. 12 — iły zastoiskowe; stadiał górny: 13 — gliny zwałowe dolne, 14 — piaski ze żwirami wodnolodowcowe, 15 — iły, mułki i piaski zastoiskowe, 16 — gliny zwałowe górne; interglacjał mazowiecki (wielki): 17 — piaski ze żwirami i mułki rzeczne; zlodowacenie środkowopolskie: stadiał przedmaksymalny: 18 — gliny zwałowe; stadiał maksymalny: 19 — iły, mułki i piaski zastoiskowe, 20 — piaski ze żwirami wodnolodowcowe, 21 — gliny zwałowe; interstadiał Pilicy: 22 — piaski ze żwirami rzeczne, miejscami residualne; stadiał mazowiecko-podlaski: 23 — iły, mułki i piaski -zastoiskowe, 24 — piaski wodnolodowcowe. 25 — gliny zwałowe; stadiał północnomazowiecki: 26 — iły, mułki i piaski zastoiskowe; interglacjał eemski: 27 — żwiry, piaski ze żwirami i mułki rzeczne, 28 — łupki bitumiczne, gytie, kreda jeziorne, torfy i mułki jeziorne; zlodowacenie północnopolskie (bałtyckie): 29 — iły i piaski zastoiskowe, 30 — mułki i piaski jeziorne, 31 — piaski ze żwirami rzeczne tarasów nadzalewowych Wisły; holocen: 32 — mady lekkie piaszczysto-ilaste tarasu niższego nadzalewowego Wisły, 33 — piaski rzeczne tarasu zalewowego Wisły, 34 — mady ciężkie (mułki) ilasto-piaszczyste tarasu zalewowego Wisły, 35 — piaski humusowe i namuły piaszczyste den dolinnych i starorzeczy, 36 — piaski eoliczne; a — piaski, b — piaski ze żwirami, c — mady, d — mułki, e — iły, f — gliny zwałowe, g — torfy, h — gytie, i — węgiel brunatny, j — margle i wapienie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Zacisze
Drewnica
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during various intervals of the Quaternary. Due to these processes separate morphologic elements of this surface were formed. They are to be described below as well as a discussion on their origin and age is to be presented.

PRIMARY SEDIMENTARY SURFACE

Basing on observations of the bottom of the Preglacial series, located in a primary sedimentary position on the Pliocene deposits, an accumulation of the Preglacial sediments transported by rivers from the south is supposed to have been preceded by local erosive processes. The top surface of the Pliocene variegated deposits have been in scarce places incised even to a depth of about 20 m a.s.l. as e.g. in the case of the valley running southwest-northeast through Okęcie towards Mokotów. On the other hand, recent invistigations do not support the fact on occurrence of the Preglacial deposits at greater depths in the right-bank Warsaw area. A bottom sand series filling deep depressions, described by J. Lewiński (1929) from single boreholes in Praga as the Preglacial deposits, initiated the theory on existence of the Preglacial Vistula incised in a narrow channel beneath the present sea level. Then these presumed Preglacial deposits became a main argument for neotectonic or glaciotectonic theories of synclinal features runnig south-north along the present channel of the Vistula.

In a predominant part of the area where the Preglacial deposits occur (Wola-Mirów, Włochy-Opacz, Mokotów-Służew-Wilanów), they cover a relatively smooth surface of the Pliocene deposits located at about 60—80 m a.s.l. To simplify, this surface can be considered for the primary sedimentary bottom surface of the Quaternary deposits. The Preglacial deposits that cover this surface, lie horizontally and do not indicate deformations whereas their sedimentary cycles can be correlated at considerable fragments of the sections. In these areas, the Preglacial deposits are overlain by the Pleistocene ones that represent the South-Polish Glaciation, Mazovian Interglacial, Middle-Polish Glaciation and Eemian Interglacial; the sequence in relatively complete and undisturbed (Figs 2—4).

ANTICLINES AND SYNCLINES

The so-called "Warsaw folds" are the predominant feature in a morphology of the substrate of the left-bank, morainic plateau part of Warsaw. These structures have been described by many authors and are precisely located at structural maps and numerous sections in the Geologic Atlas of Warsaw (M. D. Domosławska-Baraniecka et al., 1965). These structures are of brachyanticline and brachysyncline types, runnnig northwest-southeast and arranged in elevations and depressions of the same direction (Fig. 1). The main elevation of the Pliocene deposits in the Warsaw area runs from Służew through Mokotów, Śródmieście to Żoliborz and further, through Młociny and Buraków. The Pliocene outcrops occur in Żoliborz, Młociny and Buraków. The top of the Pliocene deposits reaches in anticlinal zones 90—110 m a.s.l., maximum to 113 m

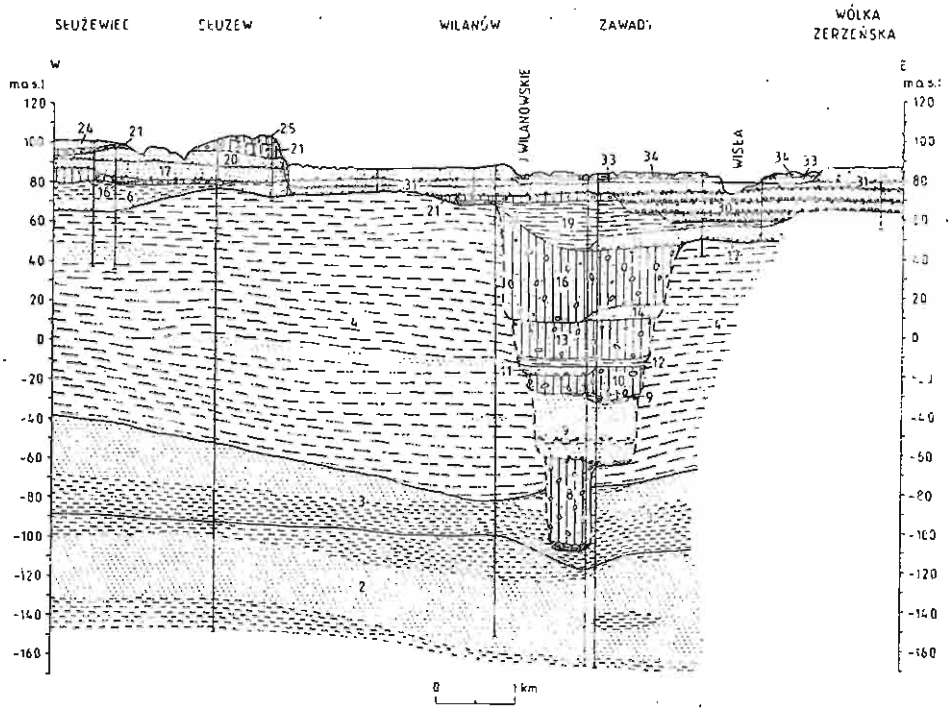

Fig. 3. Geologic section Służewiec — Wólka Zerzeńska
Przekrój geologiczny Służewiec — Wólka Zerzeńska
Explanations as given in Fig. 2
Objaśnienia jak na fig. 2

a.s.l. whereas gets lower to about 50 m a.s.l. in synclinal zones. A strip with these structures is delimited in the east by the Vistula edge whereas die out rapidly at a line running along the borders of Śródmieście and Wola as well as Mokotów and Ochota. Successive series of similarly oriented folds appear already in the Ursus area and then at Pruszków and Gąsin. The elevations there are formed by numerous outcrops of the Pliocene clays, reaching up to 100 m a.s.l.

Due to electric loggings and boreholes, a similar arrangement of anticlines and synclines was noted in the Ożarów-Babice-Klaudyń area. At elevations outcrops or a shallow occurrence of the Pliocene deposits were noted also to the altitude of about 100 m a.s.l. Within synclines a top of the Pliocene deposits gets lower to about 50—60 or even 30 m a.s.l.

In the described western part of the investigated region, the anticlines and synclines in the top of variegated clays of the Pliocene have a significant economic importance. The Pliocene clays within the elevations are exploited by brick fields. In the same time the elevation zones are devoid of water what is highly important for these areas of a horticultural use. On the other hand the synclines, filled with Quaternary deposits, are productive water-bearing areas.

Discussion on evaluation of described Warsaw folds, with a northwest-southeast arrangement and altitude variation of about 50—60 m, comprises several genetic ideas. They explain the origin of these folds as: result of tectonic folding movements (J. Samsonowicz, 1927), sliding of plastic Pliocene clays on an inclined surface of older bedrock and connected with an uplift of the Kujawy-Pomorze Anticlinorium (J. Lewiński, 1929; J. Łyczewska, 1964; S. Z. Różycki, 1972), result of glaciotectonic processes (S. Lencewicz, 1926) and valley-side glaciotectonic — expansion of glacial lobes that moved along the Vistula valley (M. Brykczyński, 1982); a shift of plastic sediments caused by seismic tremors (M. D. Baraniecka, 1975b). This discussion touches also the age of deformations, defined by S. Z. Różycki (1972) for the turn of the South-Polish Glaciation and the Mazovian Interglacial. The same period is ascribed to foldings of the Mazovian Phase by M. D. Baraniecka (1975b). According to M. Brykczyński (1982) folds were formed during the maxmum stadial of the Middle-Polish Glaciation.

Such a short presentation of the discussion over the origin of Warsaw folds is to be now supplemented with the following remarks. The same orientation of folds, not only near the edge of the Vistula valley but also several kilometres away (Pruszków — Ożarów), seems to oppose the idea of a valley-side glaciotectonics. The mentioned folds die out downwards and completely disappear within the Pliocene sediments. It denies a tectonic idea that assumes a reflection of hard bedrock dislocations within the Pleistocene sediments. Just the opposite, the foldings get more intensive towards the surface what suggest the stimulative agent for foldings acted from the surface and so, it was most probably the ice sheet.

Processes of deformation development are slightly elucidated by observations in exposures: cut walls of the Łazienkowska Tract and pits done at Służew and Ursynów during construction works for new housing estates and underground (W. Morawski, 1984). The investigated fold structures many a time show an asymmetry with a southward or southwestward vergence, passing into scales. Similar azimuths of compressive faults and of fold carpets with considerable shifts are also noted. In the same time large fold structures are accompanied by sets of fine folds of a tangenial stress from north southwards or from northeast southwestwards. All these structures prove the action of tangenial forces that seem to have been connected with an ice sheet. A series of clayey-silty Pliocene deposits interbedded with sands as well as a series of Pleistocene deposits, both highly saturated with meltwaters coming from ice sheets, have been undoubtedly a specific physical body that was particularly open to plastic deformations. Series of sediments occurring within the inner strain field are subjected to strains caused by stress or retreats of ice sheets. A pattern of these inner strains must have been connected with a run or also with an uplift of the Kujawy-Pomorze Anticlinorium, location and possibly fissure of the Teisseyre's line, location of axes and limbs of the Warsaw Basin. Therefore, the stimuli of stresses or glaciotectonic relaxations could result in deformations concordant with a strain pattern, existing in the massif.

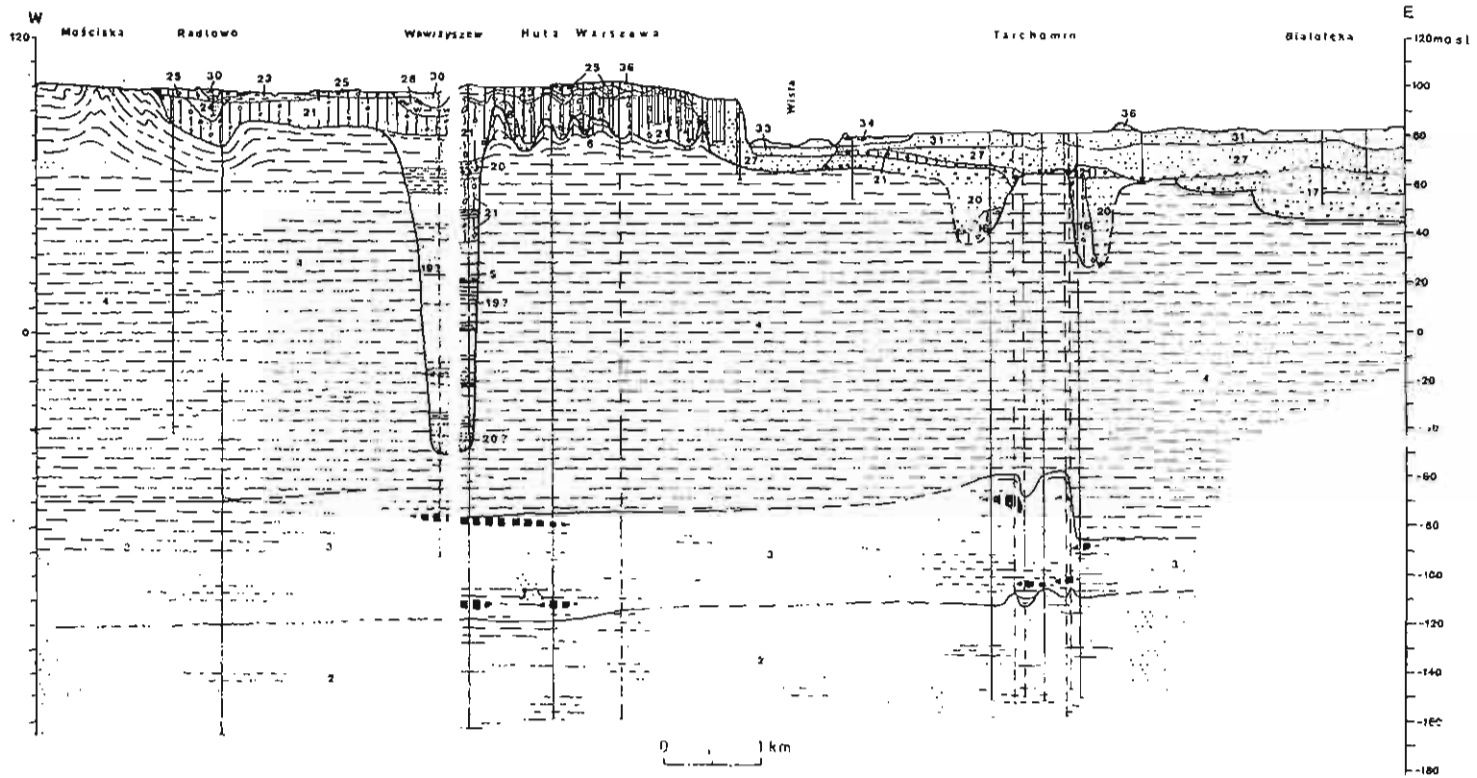

Fig. 4. Geologic section Mościska — Tarchomin — Białołęka
Przekrój geologiczny Mościska — Tarchomin — Białołęka
Explanations as given in Fig. 2
Objaśnienia jak na fig. 2

It seems also possible that the azimuth of bedrock structures could influence the directions of main ice streams flow and thus, resulted in such orientation of glaciotectonic deformations.

An age of described deformations (Warsaw folds) is defined by numerous new data received from exposures in the Warsaw area: cuts of the Łazienkowska Tract, excavations in new housing estates of Wawrzyszew, Bemowo as well as Służew and Ursynów. Observations in all these vast and deep exposures proved that Pliocene, Preglacial and Pleistocene (to maximum stadial of the Middle-Polish Glaciation inclusive) deposits were folded together during a single episode (E. Brykczyńska, M. Brykczyński, 1974; W. Morawski, 1984). The fold structures are smoothed and covered by a thin layer (to several metres thick) of deposits of the Masovian — Podlasie (Warta) Stadial age, mainly by a till. Therefore, the fold structures seem to have been formed in the Warsaw area during the deglaciation after the maximum stadial (relaxation) or during the advance of the ice sheet of the Mazovian-Podlasie (Warta) Stadial. This opinion does not exclude the existence of glaciotectonic deformations during the Early Quaternary but they were probably different from the descibed structures and then, got destructed or remodelled.

GLACIOTECTONIC RAFTS AND INTRUSIONS

Independently of the folds (described above) with a regular orientation, the deformations are locally noted in borehole sections that many a time have a deep extent and seem to be accepted for glaciotectonic ones. Pleistocene deposits contain inserts of Tertiary, mainly Pliocene, sediments whereas in other places a series of deformed Pliocene sediments contains inserts of Pleistocene deposits, mainly tills.

In the area of Marki-Zielonka-Turów (Fig. 2) an occurrence of Pliocene, Miocene and Oligocene deposits (40 m thick) was noted within tills, most probably of the South-Polish Glaciation age. A top of these sediments occurs at 28—53 m a.s.l. whereas a bottom at 11—29 m b.s.l. A bottom of the Quaternary sequence in this area is noted at 20—40 m b.s.l. These structures seem to be a large plate-like detachment of Tertiary deposits, connected with a glacial erosion during the South-Polish Glaciation and dynamic action of the ice sheet exerted on its substrate. Similar structures reaching several dozen metres b.s.l. were described by H. Ruszczyńska-Szenajch (1976) from southeastern Mazowsze.

Slightly different structures are noted locally in single or closely arranged boreholes. Tills are mixed and squeezed with Tertiary deposits to considerable depths. For example, the borehole at Lipków contains numerous till inserts to a depth of 170 m i.e. to 86 m b.s.l. while the top of Tertiary deposits in this area occurs at about 40—50 m a.s.l. The way of development of such structures is not clear. A local "columnar" pressure of an ice sheet could be responsible for such a deep intrusion of younger sediments into older ones. M. D. Baraniecka (1975b) explains such structures as "tectonic depressions", formed due to compensation of lacking sediments squeezed out in the neighbourhood. The mechanism of this process is not quite clear.

SUBGLACIAL CHANNELS

Deep and narrow incisions of linear north-south or northwest-southeast arrangement are the outstanding features of a morphology of the sub-Quaternary surface. They caused a particular interest of many authors. The channel Kamionek — Żoliborz is the best known from a geologic literature of Warsaw. It cuts the described area of Warsaw from north southwards. Its depth is as the following (starting from the north): Białołęka 8 m b.s.l., Żerań 35 m b.s.l., Cytadela 0 m a.s.l., Wileński Station 12 m b.s.l., Kamionek 3 m b.s.l., Saska Kępa 0 m a.s.l., Siekierki 10 m b.s.l., north of Wilanów 26 m b.s.l., Zawady (near Wilanów) 108 m. b.s.l. Further to the south this feature can be still noted at a distance of about 18 km through Jeziorna, Konstancin as far as Bantocha. To the north a continuation of this deep incision is observed towards Jabłonna-Chotomów as far as the Narew Valley (J. Nowak, 1978).

From the Wileński Station this channel branches northwest-northwards to Wawrzyszew (50 m b.s.l.) and Radiowo (47 m b.s.l.). Its further continuation may run across Dziekanów Leśny at 43 m b.s.l. (J. Nowak, 1978).

Another similar channel, arranged north-south, runs in the eastern part of the described area: at Międzylesie 18 m b.s.l., Glinki 34 m b.s.l., with a branch to Miłosna 12 m b.s.l., Rembertów 30 m b.s.l., Ossów 40 m b.s.l. Its further course is to be noted northwards and southwards at a distance Michalin — Karczew — Kępa Nadbrzeska.

The realized investigations pointed out the following characteristic features of the channels:

— north-south or northwest-southeast continuation, apparently similar but in fact inconsistent with axes of anticlines and synclines of the Warsaw folds, locally even crossing them;

— they are narrow: their width reaches several hundred metres usually about 200 m;

— their depth is usually over 100 m; local deepenings (even to 200 m) and shallowings are typical: differences are to over 100 m.

A filling of a described feature is very varying and locally changeable. At the bottom there are usually sandy-gravel series. They were locally e.g. at Kamionek, described as the Preglacial series (J. Samsonowicz, 1927) what has not been confirmed by later investigations. In the borehole at Wawrzyszew, a location of which was especially fixed by detailed electric logging (W. Morawski, 1977) in the axis of the channel, the bottom sandy-gravel layer is of glacifluvial origin (Fig. 4). The overlying infilling deposits, noted in numerous boreholes of the right-bank Warsaw as well as in the Warsaw Steelworks (Fig. 4), are composed of several tills with sandy-gravel interbeddings and Tertiary rafts. In the mentioned borehole at Wawrzyszew, Wolumen Street, the infilling is composed of monotonous series of horizontally stratified and non-deformed fine-grained sands and silts (120 m thick) of ice-dam — glacifluvial origin.

The listed data prove that deep cuts are to be considered for subglacial channels. The age of their formation cannot be easily defined as they have developed most probably in numerous stages. A stratigraphic interpretation of tills within the channels, accepted in previous papers (Z. Sarnacka, 1980 *a*, *b*), suggests their development already during the oldest

glaciation. At the same time they seem to have been repeatedly eroded during successive interglacials as well as could be several times renewed as subglacial channels during successive glacial periods. A more precise definition of the time when the described channels were formed, could be possible after detailed investigations and dating of the infilling deposits.

The cited data seem to reject the previously accepted ideas of: the Preglacial valley of the Vistula, erosive valley (M. D. Domosławska-Baraniecka et al., 1965), deep syncline at an eastern slope of the Tertiary upheaval (S. Z. Różycki, 1972), river valley in connection with structural depressions (M. D. Baraniecka, 1975 b), glaciotectonic syncline (M. Brykczyński, 1982).

EROSIVE VALLEY OF THE PRE-VISTULA

An eastern part of the area — the Vistula Valley — shows a completely different morphologic style of the sub-Quaternary substrate than the folded morainic plateau of the left-bank Warsaw area. Vast zones of this substrate in the valley have been formed due to erosion of the Vistula. Buried terraces of the Vistula (Fig. 2) cut the above described deep detachments of Tertiary deposits (forming rafts) as well as cut the subglacial channels filled with glacial sediments of the Early Quaternary (Figs 2—4). These features are separated by areas with flatly eroded Pliocene deposits, then covered by terraces of fluvial deposits of the Vistula of the Mazovian Interglacial age. This erosive incision reaches maximum to about 10 m a.s.l. Fluvial sediments of the Mazovian Interglacial (about 50 m thick) form 4 sedimentary cycles, noted from Magnuszew to Warsaw (Z. Sarnacka, 1976, 1978, 1982). The axis of this valley runs about 5—10 km to the east from the present channel of the Vistula but its terraces reach as far as the present morainic plateau of the left-bank Warsaw area.

The Eemian Interglacial was the successive phase of erosion in the Vistula Valley. The channel migrated westwards and erosion of this time modelled the zone within the present channel of the Vistula. The valley of the Eemian Vistula was not so narrow as during the Mazovian Integlacial and was close to the present one. In southern part of Warsaw the erosive cuts of the Vistula during the Eemian Interglacial reached a depth of 58—70 m a.s.l. (Zerzeń-Międzylesie) and 56—65 m a.s.l. in the northern part (Zielonka).

The Eemian fluvial sediments are mainly composed of gravel with pebbles that locally overlie directly the eroded Pliocene deposits (Żerań, Marcelin). The Eemian erosion reached further westwards, already within the present plateau e.g. in Bielany a burried terrace of the Eemian Interglacial age was found incised in Pliocene deposits to a depth of about 65—68 m a.s.l. (W. Morawski, 1979, 1980 b). Depths of erosive cuts of the pre-Vistula during the Mazovian and Eemian interglacials prove lower (than now) locations of the base of erosion (E. Rühle, 1955).

The Vistula channel from the North-Polish Glaciation and the Holocene is also worth mentioning. It locally cuts just the Pliocene deposits and thus, formes already the Holocene relief of the mentioned sub-Qua-

ternary surface. And so, in the Vistula Tract (Wisłostrada) running at the foot of the Bielany escarp, the Pliocene clays were noted in pits under a thin layer of sands of the present flood terrace of the Vistula. The boreholes as well, done in the bottom of the Vistula, prove an occurrence of Pliocene deposits under a several metres thick bed of channel deposits of the present river.

CONCLUSIONS

A relatively small area of the nearest surroundings of the Warsaw is, due to extremely rich geologic documentation, the exceptionally well recognizable one for studies of morphology of the Quaternary substrate. This surface is morphologicly highly differentiated, with altitude changes to 200 m, but also varied in its genesis and stratigraphy.

This surface was modelled by glaciotectonic processes as well as glacial, subglacial, and fluvial erosion.

Glaciotectonic processes formed belts of northwest-southeast oriented anticlines and synclines as well as deep detachments and intrusions of glacial deposits into Tertiary ones.

Processes of subglacial erosion formed deep channels with large longitudinal variations of bottom altitudes, filled then with various glacial sediments.

An erosion of the pre-Vistula in a vast valley during the two successive, Mazovian and Eemian interglacials and the Holocene, incised its channel in Tertiary deposits. In the same time the older channels, filled with sediments, and glaciotectonic structures were eroded.

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Received: 20.10.1988

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Wojciech MORAWSKI, Zdzisława SARNACKA

UKSZTAŁTOWANIE PODŁOŻA CZWARTORZĘDU NA TERENIE WARSZAWY I OKOLIC

Streszczenie

Wyniki wieloletnich badań geologicznych na terenie Warszawy zostały w ostatnich latach uzupełnione danymi uzyskanymi w ramach prac prowadzonych przy budowie Trasy Łazienkowskiej, Wisłostrady, metra oraz nowych osiedli mieszkaniowych — głównie Służewa i Ursynowa. Wszystkie te dane zostały zestawione w ramach opracowywania przez PIG arkuszy Warszawa Zachód i Warszawa Wschód *Szczegółowej mapy geologicznej Polski* w skali 1 : 50 000 i uzupełnione badaniami geoelektrycznymi oraz 23 wierceniami badawczymi. Zebrane dane pozwoliły na skonstruowanie szkicu ukształtowania podłoża osadów czwartorzędowych na terenie Warszawy i jej okolic (fig. 1) oraz przekrojów geologicznych (fig. 2—4).

Jako powierzchnię podczwartorzędową przyjęto strop osadów plioceńskich — serii pstrych iłów z mułkami i piaskami, natomiast seria tzw. preglacjału została zaliczona do czwartorzędu. Ukształtowanie powierzchni podczwartorzędowej jest na badanym obszarze bardzo zróżnicowane zarówno morfologicznie — deniwelacje sięgają 220 m, jak i genetycznie. Jak się wydaje położenie stropu osadów plioceńskich w rejonie Woli — Włoch — Opacza oraz Mokotowa — Wilanowa (60—80 m n.p.m.) jest zbliżone do sedymentacyjnego — pierwotnego. Na pozostałym obszarze opracowanego terenu powierzchnia podczwartorzędowa jest ukształtowana przez procesy dynamiczne: tektoniczne, glacitektoniczne, egzaracyjne oraz erozji subglacjalnej i erozji rzecznej. Procesy tektoniczne i glacitektoniczne uformowały tzw. fałdy warszawskie, wypiętrzające w centrum miasta iły plioceńskie aż do powierzchni terenu. Wydaje się, że niezależnie od procesów wcześniejszych, główne stru-

ktury fałdowe powstały w okresie recesji lądolodu stadiału maksymalnego zlodowacenia środkowopolskiego lub transgresji lądolodu stadiału mazowiecko-podlaskiego (Warty). Genezę zaburzeń należy wiązać z procesami glacitektonicznymi ukierunkowanymi układem naprężeń wywołanym procesami tektonicznymi w głębszym podłożu. Glacitektoniczną genezę mają również kry (porwaki) osadów trzeciorzędowych oraz wciśnięcia osadów plejstoceńskich w trzeciorzędowe. Struktury te zaburzają powierzchnię podczwartorzędową do głębokości 20—40 m p.p.m. (rejon Marek — Zielonki — Turowa) oraz poniżej 80 m p.p.m. (rejon Lipkowa). W wyniku erozji podlodowej powstały rynny subglacjalne tworzące wąskie rozcięcia osadów trzeciorzędowych o deniwelacjach dna do ponad 100 m i przebiegu N-S i NW-SE — ale niezgodnym z przebiegiem fałdów — sięgające od głębokości 0 m n.p.m. do 100 m p.p.m. Formy te prawdopodobnie powstały wieloetapowo, lecz główne rozcięcia dominujące w ukształtowaniu podłoża osadów czwartorzędowych należy wiązać z okresem stadiału maksymalnego zlodowacenia środkowopolskiego. We wschodniej części omawianego terenu — w dolinie Wisły, decydującym czynnikiem, który ukształtował obecną powierzchnię podczwartorzędową, była erozja w korycie Wisły z interglacjału mazowieckiego (do głębokości ok. 10 m n.p.m.) i eemskiego (do głębokości ok. 55—65 m n.p.m.), jak również z okresu zlodowacenia północnopolskiego i holocenu. Opisane procesy dynamiczne, które ukształtowały obecną powierzchnię podczwartorzędową, spowodowały również w poszczególnych obszarach znaczną, wtórną redukcję pierwotnego profilu osadów czwartorzędowych.

Войцех МОРАВСКИ, Здзислава САРНАЦКА

КОНФИГУРАЦИЯ ЧЕТВЕРТИЧНОГО ОСНОВАНИЯ НА ТЕРРИТОРИИ ВАРШАВЫ И ЕЕ ОКРЕСТНОСТЕЙ

Резюме

Результаты многолетних геологических исследованнй на территории Варшавы были за последние годы дополнены данными полученными в рамках работ проведенных при постройке Лазенковской Трассы, Вислострады, метро и новых жилищных селений — главным образом Служева и Урсынова. Все эти данные были составлены в рамках разработки Государственным Геологическим Институтом листов Варшава Запад и Варшава Восток Детальной Геологической Карты Польши в масштабе 1 : 50 000, а также дополнеиы геоэлектрическими исследованиями и 23 разведочными скважинами. Собранные данные сделали возможным составлеиие очерка конфигурации основания четвертичных осадков на территории Варшавы и ее окрестностей (фиг. 1), а также геологических разрезов (фиг. 2—4).

В качестве подчетвертичной поверхности принята кровля плиоценовых осадков — серии пестрых глин с суглинками и песками, зато серия прегляциала зачислена к четвертичному периоду. Конфигурация

подчетвертичной поверхности на исследованной территории является сильно дифференцированной как морфологически — денивеляции достигают 220 м, так и генетически. Кажется, что положение кровли плиоценовых осадков в районах: Воля - Влохы - Опач и Мокотув - Вилянув (60—80 м н.у.м.) похоже на седимеитационное — первичное. На остальной области исследованной территории подчетвертичная поверхность была формированна динамическими процессами: тектоническими, гляцитектоническими, экзарационными, а также подледной и речной эрозии. Тектонические и гляцитектонические процессы сформировали так называемые варшавские складки, выдвигающие в центре города плиоценовые или к поверхности. Кажется, что независимо от раньших процессов, главные складчатые структуры образовались в период отступания континентальиого ледника максимального стадиала центральнопольского оледенения или трансгрессии ледника мазовецко-подляского стадиала (Варты). Генезис нарушений следует связывать с гляцитектоническими процессами связанными с системой напряжений, вызванной тектоническими процессами в глубоком основаиии. Гляцитектонический генезис имеют тоже глыбы (отторженцы) третичных отложений, а также вдавления плейстоценовых осадков в третичные. Эти структуры нарушают подчетвертичную поверхность до глубины 20—40 м п.у.м. (район Марки — Зеленка — Турув), а также ниже 80 м п.у.м. (район Липкова). В результате подледной эрозии образовались подледные желобы образующие узкие рассочения третичных осадков с относительной высотой дня до свыше 100 м и направлением С-Ю и СЗ-ЮВ — но несогласным с направлением складок — достигающие глубины с 0 до 100 м п.у.м. Этн формы образовались вероятно в нескольких этапах, но главные рассечения, преобладающие в конфигурации, следует связывать с максимальным стадиалом центрального оледенения. В восточной части описыванной территории — в долине реки Вислы — преобладающим фактором в формировании современной подчетвертичной поверхности была эрозия в русле Вислы во время мазовецкого межледниковья (до глубины около 10 м н.у.м.) и ээмского межледниковья (до глубнны около 55—65 м н.у.м.), а также во время севернопольского оледенения и голоцена. Описанные динамнческие процессы, которые сформировали современную подчетвертичную поверхиость, вызвали также в отдельных районах значительную, вторичную редукцию первичного разреза четвертичных отложений.