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GEOGRAPHICAL STUDIES
SPECIAL ISSUE No. 6

EVOLUTION OF THE VISTULA RIVER VALLEY DURING THE LAST 15000 YEARS

PART IV

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ГЕОГРАФИЧЕСКИЕ ТРУДЫ
СПЕЦИАЛЬНОЕ ИЗДАНИЕ № 6

ЭВОЛЮЦИЯ ДОЛИНЫ РЕКИ ВИСЛЫ НА ПРОТЯЖЕНИИ ПОСЛЕДНИХ 15000 ЛЕТ

IV

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POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

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Editor:
LESZEK STARKEL

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LESZEK STARKEL

INTRODUCTION
PROGRESS OF RESEARCH ON THE EVOLUTION OF THE VISTULA RIVER VALLEY

In 1987 there was completed, and in 1988 prepared for edition the third synthetizing volume dealing with the evolution of the Vistula valley during the Lateglacial and the Holocene. However, studies of the various valley reaches did not stop. Developments in activities within the IGCP Project 158 were summarized in the excursion guide book of the symposium "Lateglacial and Holocene environmental changes – Vistula Basin 1988". This guidebook contains important research results (in particular those concerned with the Vistula valley near Cracow), together with new facts. In 1988 there also appeared a variety of papers. K. Klimek defined the age of the "mada" in the Vistula valley near Oświęcim, S. Alexandrowicz occupied himself with alluvia of the Prądnik river (a tributary to the Vistula), W. Niewiarowski documented the phases of erosion in the Drwęca river valley. Most works provide new data on the phases of "mada" accumulation. It was recognized that "mada" initiation occurred at the same time: 4990±120 BP in the Rudawa valley (Rutkowski *et al.* 1988) and 5150±130 BP in the Niedzica valley (Śnieszko, Kruk 1988). This fact may be correlated with the expansion of both settlement and economy of the Funnel Beaker culture (Kruk 1988). The successive spread of the Lusatian settlement is reflected in a new phase of "mada" deposition (2710±90 BP) in the surroundings of Oświęcim (Klimek 1988). The Roman period shows itself in a phase of increased flooding which led to the formation of a "black oak stratum". This has been dendrochronologically dated (Kalicki, Krąpiec 1988). To a second tree stump stratum an age of c. 1000 years BP is ascribed. The initiation of the dusty agricultural "mada" coincides with the phase of the Przeworsk culture in the 4th and 5th centuries (Kruk 1988). This "mada" is similar in age not only in the Vistula valley near Cracow (Kalicki, Starkel 1987), but also in its tributary valleys: in the Rudawa valley with a date of 1520±90 BP (Rutkowski *et al.* 1988) and in the Prądnik valley with a date of 1510±100 BP (Alexandrowicz 1988).

Papers in this volume demonstrate new research results which have been obtained mostly from the Vistula valley extending downstream of Cracow (Fig. 1). T. Kalicki presents a modified synthesis of the Vistula valley evolution between Cracow and Niepołomice. He documents a new phase of increased activity of the Vistula around 3000 years BP. At least three "mada" types of

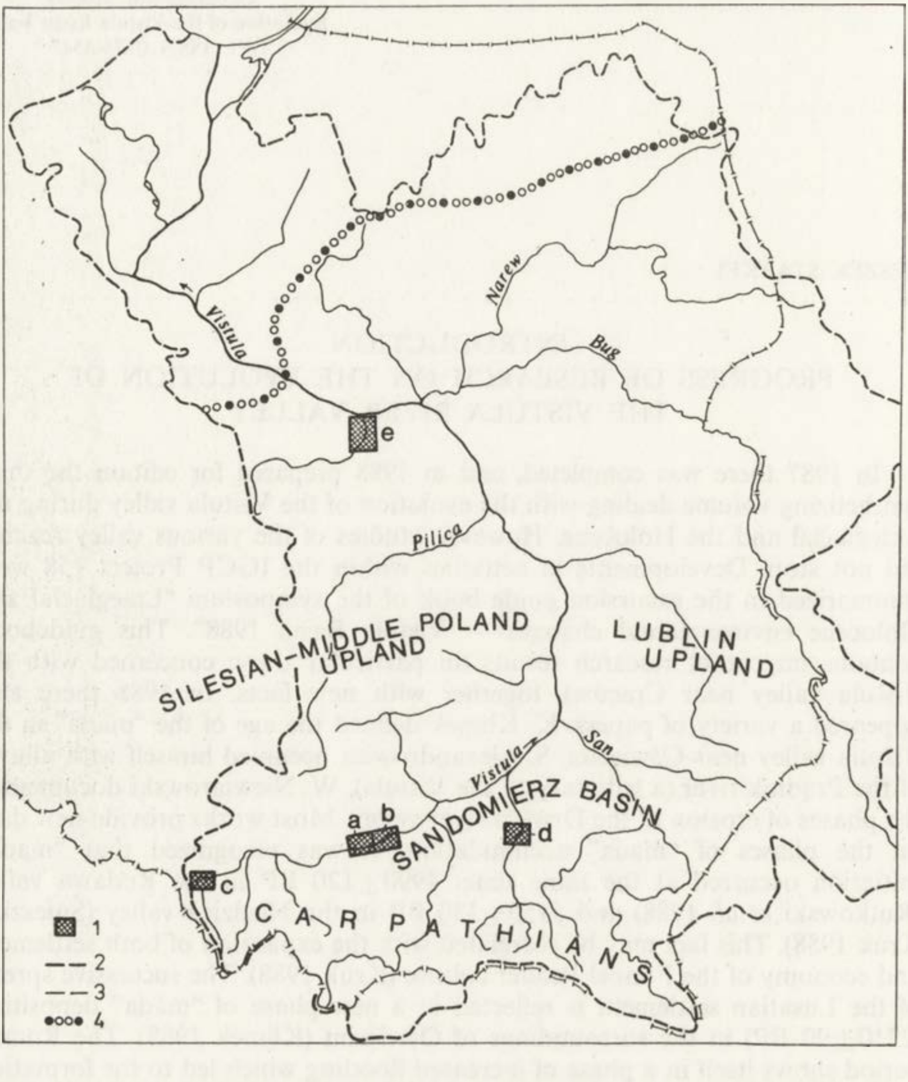

Fig. 1. Location of studies, presented in this volume in papers: *a* — by Kalicki and by Kalicki & Krąpiec; *b* — by Starkel *et al.* and by Baumgart-Kotarba; *c* and *d* — by Niedziałkowska; *e* — by Andrzejewski

Signs: *1* — location of areas; *2* — watershed; *3* — Polish frontier; *4* — maximum extent of the Vistulian ice sheet

differing age (overbank facies) were recognized there. L. Starkel and M. Baumgart-Kotarba working together with other persons identified and dated palaeochannel systems preserved in the Grobla Forest. These date from the Lateglacial onwards until the Atlantic decline time (comp. Gębica, Starkel 1987). Subsequent channel changes also were examined using detailed sedimentological analyses and air photointerpretation. D. Nalepka produced palynological and biostratigraphical evidence of lateglacial sites in the Vistula valley downstream of Cracow. S. W. Alexandrowicz examined the malacofauna obtained from some sites there. The paper by T. Kalicki and M. Krąpiec includes new dendrochronological datings on the black oaks. Consequently, flood phases were dated as: c. 3000, 2000–1800 and 1000 years BP.

On the basis of analysis of both grain size and abrasion E. Niedziałkowska was able to show that in the upper Vistula valley, within the Oświęcim Basin, and in the Wisłoka valley (comp. Fig. 1) there occur various facies dating from different periods. The properties of the same type of deposits are, however, out of all relation to the period of sedimentation.

Finally, L. Andrzejewski has undertaken palaeohydrological research on the lower Bzura valley which joins the Vistula valley beyond the maximum extent of the last inland ice, within the zone of the disputable Warsaw ice-dammed lake. At the Bzura river mouth there occurs the Kamion site at which "mada" twice dated at 14 590 ± 270 and 14 300 ± 300 years BP has been found to underlie a lateglacial dune on the supra-flood terrace (Manikowska 1985, 1988). This indicates that rapid valley deepening took place immediately after glacier retreat.

Preparing the next volume on the evolution of the Vistula valley I would like to stress that many problems still require a great deal of work. New techniques adapted and future sites will enrich and probably correct both existing stratigraphical schemes and palaeogeographical images.

I am grateful to all persons who have contributed to this volume, to Dr. S. Gilewska for translating the text into English, to Mrs M. Klimkowa for cartographic assistance and to Dr. T. Kalicki for secretarial help.

Cracow, July, 1989 *Leszek Starkel*

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Geographical Studies
Evolution of the Vistula River Valley
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TOMASZ KALICKI

THE EVOLUTION OF THE VISTULA RIVER VALLEY BETWEEN CRACOW AND NIEPOŁOMICE IN LATE VISTULIAN AND HOLOCENE TIMES

The study area occupies the western part of the Sandomierz Basin, i.e. the Vistula valley section, 19 km long, extending between Cracow and Niepołomice, and between 180 and 202 km of river length (Fig. 1). The Vistula catchment of 8765 km^2 to Niepołomice increases only by 671 km^2 below Cracow where the river is joined by the left-bank Prądnik and Dłubnia. The drainage basin includes three well defined regions: the Carpathians, the Racibórz-Oświęcim Basin and the Silesian-Cracow Upland. Because of the nature of the geographical environment within the catchment the major role in runoff formation is played by the Carpathians (Ziemońska 1973). The Vistula near Cracow has therefore a snowy-rainy regime being similar to that of the Carpathian rivers, with snowmelt-induced spring peak flows and rain-induced summer peak flows (Dynowski 1967). The range of the extreme recorded flows exceeds 8 m. The fifty-year mean discharge is 91.4 m^3/s, the maximum discharge is 2310 m^3/s and the minimum one is 14.4 m^3/s (Punzet 1981).

In the surroundings of Cracow the hydrographical pattern of the Vistula drainage basin was probably completed in the Eemian interglacial (Klimek 1972), although Starkel (1984) expressed the view that the whole upper Vistula system came into being already during the penultimate, Mazovian interglacial. Recent research on the Cracow Gate (Sokołowski, Wasylikowa 1984) shows that sheets dating from the Mid-Polish glaciation became deeply incised, deeper than during the penultimate interglacial. During the early Vistulian and the Older Pleniglacial sedimentation was dominant. At that time, the sheet of the loess-covered terrace, 15 – 25 m high, was formed by the Vistula in the vicinity of Nowa Huta. In the Interpleniglacial reactivated erosion led to the dissection of this terrace sheet. In the Younger Pleniglacial deterioration in climate coupled with drier conditions was associated with aggradation again, as probably shown by the deposition of the Prądnik and Dłubnia alluvial fans and of the Vistula terrace sheet, 8 – 10 m high. During the retreat of the last inland ice this sheet became dissected by the Vistula which began to form its floodplain, 4 – 5 m high. The latter became subject of detailed study.

Floodplain structure and evolution was poorly known until the late 1970s. The state of research and first advances that have arisen from the IGCP Project 158 were presented in earlier publications (Kalicki, Starkel 1987;

Kalicki 1988a,b). The present work synthetizes results of most recent research on the Vistula valley section described. The study included geomorphological mapping on the 1:10000 scale, as well as analysis of more than 3000 archival borings and of more than 100 special borings. In addition, archaeological and cartographic data from the 18th and 19th centuries were examined. Grain size analyses were made using sieving and the Casagrande aerometric method modified by Prószyński. Sedimentation parameters were calculated using R. J. Folk's and W. C. Ward's graphic method (1957). Carbonate content was determined using Scheibler's method, and organic matter content was established using Tiurin's method. Furthermore, pollen record, dendrochronological data and radiocarbon datings were applied. In this work use was made of the stratigraphic scheme for the Vistulian and the Holocene by L. Starkel (1977a,b).

VALLEY FLOOR MORPHOLOGY AND DEPOSITS

The Vistula floodplain increases in width from 3 km below the Cracow Gate to 6—7 km in the east. Its average altitude decreases from 202 to 191 m. The valley floor is a flat plain being interrupted by many sinuous cutoffs. In the southern part of the valley floor there clearly occurs a wide depression without palaeomeanders. It is drained by rivulets. In places, this depression includes alluvial fans which have been built up by the small tributaries. The Vistula valley was cut in Miocene clay. Its Quaternary infill is up to more than ten metres thick. The basal part of the gravel-and-sand series, 5—12 m thick, contains many silty intercalations which may represent the remnants of fossil abandoned channel fills. Sometimes these may also be fossil alluvial plains. Silts occur most frequently 1—4 m below the present Vistula level. Overlying is a sandy series, 1—6 m thick, being interpreted as point bars. The top series consists of "mada", 0.5—3 m thick, which covers almost the entire width of the valley floor. Below the high terrace edge in the north there extend peat bogs due to a rising ground water table near the edge. The peats show a high clay content because prior to the construction of dikes in the 19th century the entire width of the valley floor was affected by inundation. Evidence of it also are historical flood records (Beres 1938). In spite of the rather monotonous relief and structure of the valley floor several zones may be distinguished along the north-south line. Their detailed characteristics is contained in the paper by T. Kalicki and L. Starkel (1987). 14 sites lying in the different zones have been examined in detail (Fig. 1, 2).

The earliest deposits disclosed are probably formed of Upper Pleniglacial sands with gravels which were laid down by the braided Vistula at the Pleszów II site below the edge of the loess-covered terrace. Overlying are peaty silts and peat. The basal part of the silts has been dated at 13260±160 BP. At Rybitwy in the Drwień depression, on the levelled top of the sandy-gravelly deposits of the braided river probably dating from the Bølling there rests a thin layer of peat and peaty silts. Their basal part yielded a date of 11920±170 BP. These silts became covered with "mada" the accumulation of which began 9660±180 BP. The Allerød decline time is represented by a palaeomeander fragment at Łęg B (its basal fill is dated as 11090±120 BP) and by remnants of an abandoned channel fill at Branice—Stryjów which has been dated at

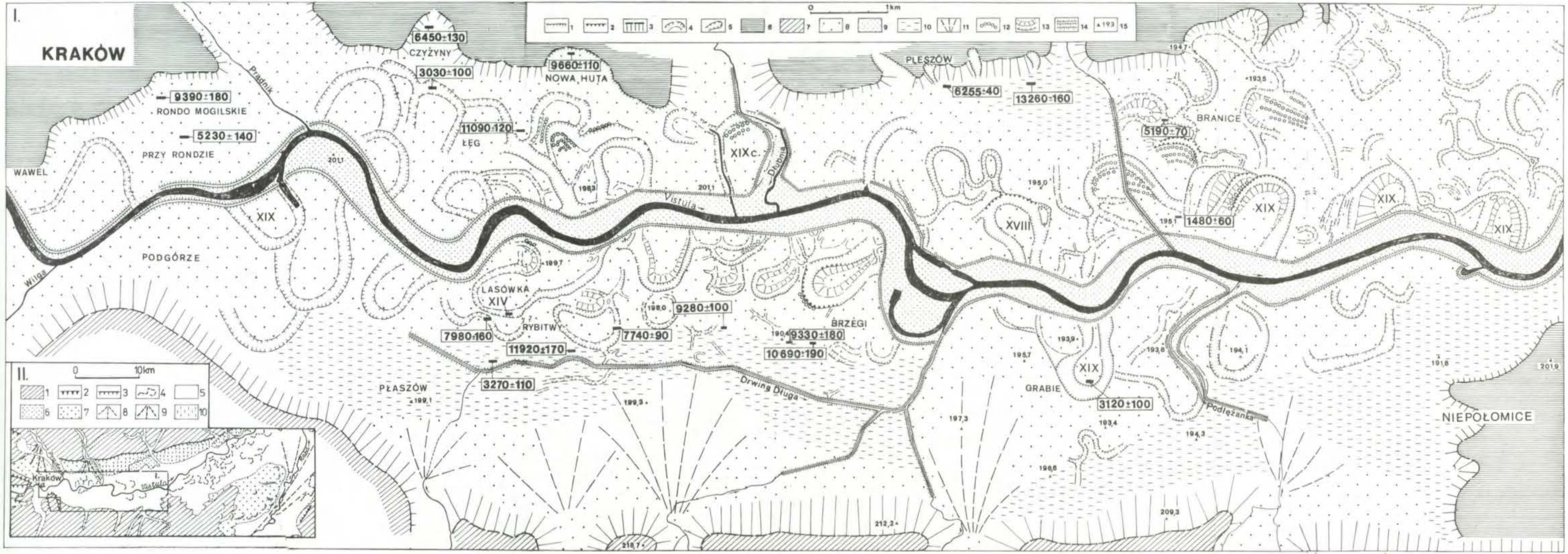

Fig. 1. I. Geomorphological map showing the Vistula valley floor between Cracow and Niepołomice

Edges: *1* — below 3 m, *2* — 3–5 m, *3* — above 5 m; *4* — palaeomeanders; *5* — small erosional valleys; *6* — higher terraces on the Vistula; *7* — Gdów Divide; *8* — Vistula valley floor; *9* — modern floodplain (inter-dike area); *10* — broad depressions interrupting the valley floor; *11* — alluvial fans; *12* — point bars; *13* — sloping surface on the convex meander side; *14* — dikes; *15* — altitude (m). Inside a box — radiocarbon datings

II. Geomorphological sketch to show the Vistula valley between Cracow and the Raba river mouth

1 — Proszów Plateau and Gdów Divide; *2* — tectonic scarps up to 100 m high; *3* — erosional edges more than 20 m high; *4* — palaeomeanders; *5* — lateglacial and Holocene floodplains; *6* — Younger Pleniglacial terrace; *7* — Older Pleniglacial terrace; *8* — Holocene alluvial fans; *9* — Vistulian alluvial fans; *10* — loess overlying the terrace sheets

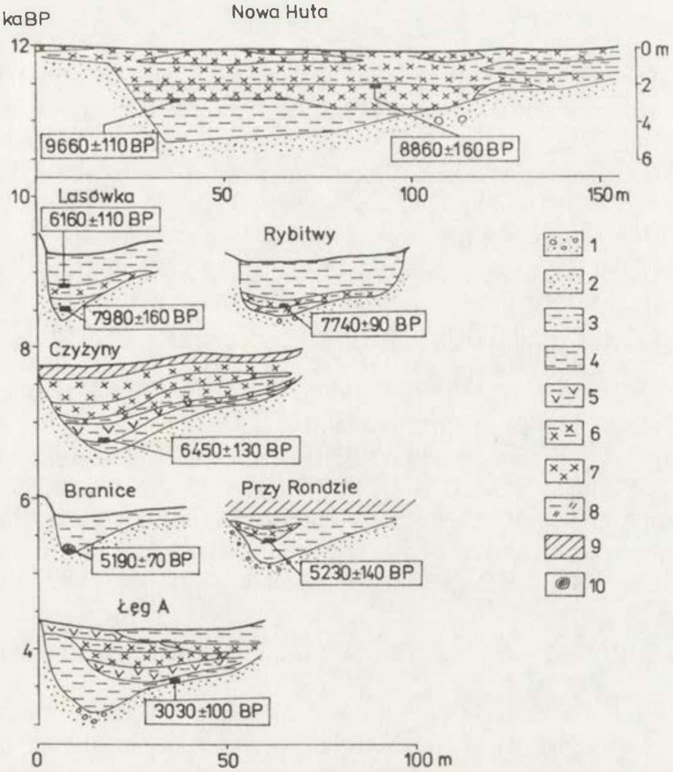

Fig. 2. Sections across the palaeomeanders of the Vistula varying in age
1 – sands-and-gravels; *2* – sands; *3* – sandy silts; *4* – silts; *5* – peaty silts; *6* – peats with clay; *7* – peats; *8* – gyttjas and gyttja-like silts; *9* – embankments; *10* – tree trunks

10920±230 BP (Kalicki, Starkel 1987). Further traces of those channels are probably the abundant silty intercalations which lie at a similar altitude to those at Branice – Stryjów. They occur in different parts of the valley floor. It is likely that the palaeomeanders found on the Rondo Mogilskie and in Nowa Huta also belong to the Allerød (Mamakowa 1970; Kalicki 1987). The palaeomeander fills are composed of silts and peat to which a Younger Dryas age has previously been ascribed (Kalicki 1987; Kalicki, Starkel 1987). On the Rondo these silts refer to the Younger Dryas, and the basal part of the peat bed has been dated at 9390±180 and 9660±110 BP respectively. The Allerød age of both palaeomeanders may be inferred from the Younger Dryas silty palaeomeander infill on the Rondo and from the fact that the cutoff in Nowa Huta probably is a continuous part of the cutoff at the Łęg B site with an Allerød date. This is backed up by morphological and cartographical analyses of the top channel facies deposits and by similar altitudes of both channel beds. Sand-and-gravel deposits of the braided river at Brzegi refer to the Younger Dryas. A tree trunk has been dated at 10630±190 BP there (Kalicki, Starkel 1987). Early Holocene sandy point bar deposits were found at Brzegi and Przewóz where the radiocarbon dates for plant remains are 9330±180 and 9280±100 BP respectively (Kalicki 1989). A Boreal system of small meanders survived at Lasówka and Rybitwy. These meanders became abandoned due to channel avulsion prior to 7980±160 BP. Peat sedimentation in this palaeomeander system became interrupted by clayey "mada" deposition 6160±110 BP. The next palaeomeander generation of early Atlantic age has been recognized at Pleszów (Wasylikowa *et al.* 1985) and at Czyżyny lying at the foot of the edge of the loess-covered terrace. The basal part of the peaty palaeomeander fills has been dated at 6255±40 and 6450±130 BP respectively. The late Atlantic meanders were cut off in the Atlantic decline time on the evidence of dates of 5190±70 BP at Branice and of 5230±140 BP at Przy Rondzie. The evidence for the Subboreal comes from a palaeomeander at Łęg A (3030±100 BP) and from a superficial peat bog at Płaszów with a date of 3270±110 BP for the basal part of the peat. At Grabie a dendrochronologically correlated generation of black oak trunks with a date of 3120±100 BP (Kalicki, Krąpiec in print) and single trunks of similar age also have been shown to belong to the period under review. Special investigation of the Subatlantic alluvia was carried out in the gravel pit at Branice—Stryjów (Kalicki, Starkel 1987). New research results have enabled the previous interpretation of the stratigraphy of alluvia to be changed and the three generation black oaks to be dated as: 2200—1800 BP, 1000 BP and 700 BP (Kalicki, Krąpiec 1988; this volume).

CHANGES IN THE VISTULA CHANNEL PATTERNS AND PARAMETERS

Plentiful radiocarbon dates made it possible to trace changes in the palaeochannel dimensions of the Vistula. However, it should be stressed that the dates refer to the initiation of the palaeomeander infilling. Thus it appears that an earlier date should be ascribed to the palaeomeanders. Hence periods of their functioning immediately fall before the date for the infilling. As can be seen from the last 200-year observations (Trafas 1975) meanders developed in periods of stability without high flood frequencies and magnitudes, whereas in the flood periods the meanders became cut off. For example, palaeomeanders containing infills which have been dated at 6400—6200 BP refer to the early Atlantic time (AT_1, AT_2). The present author believes that the palaeomeander dimensions are related to the meander-forming discharges. Parameter changes were slight just before the meanders became cut off or abandoned at the time of channel avulsion. Attempts to identify the age of the palaeomeanders with that of their infills give rise to serious errors, as shown by the work on the Hungarian Plain by G. Gabris (1985), where peak discharges reconstructed for lateglacial times appeared to be Boreal.

It is extremely difficult to establish the dimensions of the fossil cutoffs (comp. Florek 1978b) because of the poor survival of single meanders and less frequently of whole meander systems. In many ceses it is impossible to determine the point of inflection in the channel axis within the meanders, but especially in the case of single meanders preserved. For this reason, the results of measurement are error-laden and subjective. These are only proxy data. Measurements of the irregular Boreal and Atlantic meanders are fraught with specific difficulties. The meander banks had a dense vegetation binding the bank material with the roots so that the meander shapes clearly differ from those of the classical meanders. Consequently, the discussion of the channel

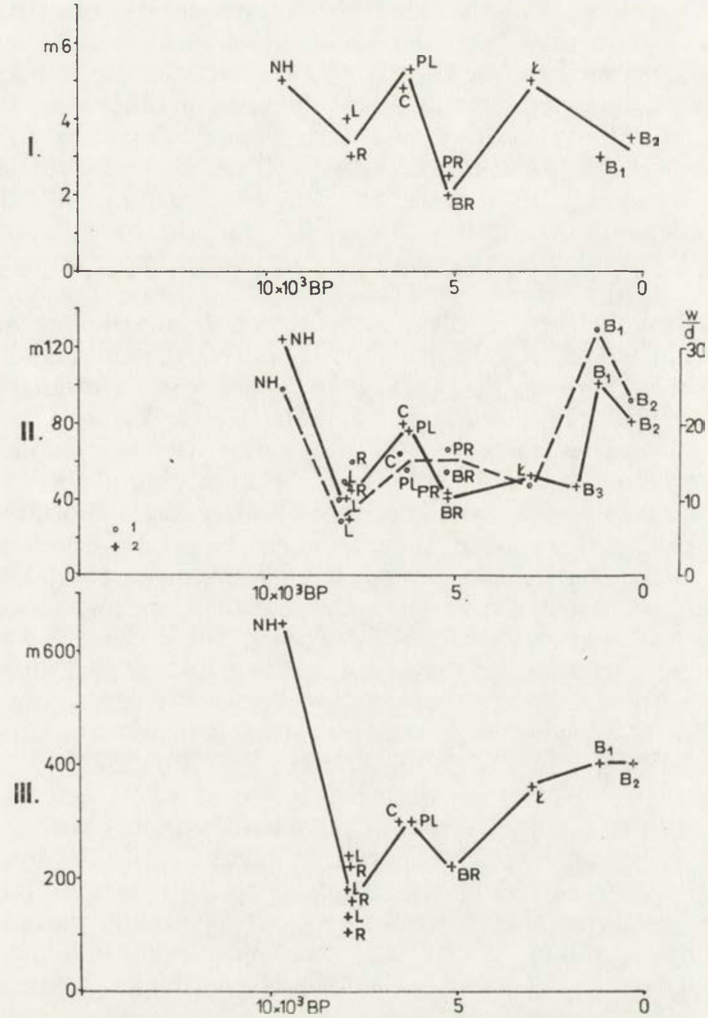

Fig. 3. Changes in Vistula channel parameters during the Lateglacial and the Holocene: depth (I), width (*w*) to depth (*d*) ratio – *1* and width – *2* (II), meander radii (III)

parameter changes of the Vistula is based only on the meander widths, radii and depths below the present-day surface. These data may be rather objectively determined (Fig. 3).

The earliest discernible superficial cutoffs in the surroundings of Cracow are represented by lateglacial meanders which probably developed in the Allerød (at Łęg B, Nowa Huta, Rondo Mogilskie). These bends are equivalent to the fossil meander fills dating from the Allerød/Younger Dryas transition (at Łęg B, Branice – Stryjów). The above meanders are marked by very large dimensions: widths over 100 m, radii exceeding 600 m and infills up to 5 m thick. Peaty silts (at Rybitwy) which have been dated at 11 920 ± 170 BP also may be interpreted as the overbank facies deposits of the already constricted Vistula channel. It appears that the braided Vistula channel has been replaced by a meandering one either in the Older Dryas decline time or at the beginning of the Allerød, since older deposits found to occur in the wide, flat-floored depressions at Rybitwy and Pleszów II bear witness to braiding. At that time, channel pattern changes also occurred 100 km downstream of Cracow (Mycielska-Dowgiałło 1987), in the San valley (Szumański 1986) and in the Wisłoka valley (Alexandrowicz *et al.* 1981). On the other rivers channel changes took place in different periods, an additional factor being the locally varied morphological conditions (Turkowska 1988). However, channel pattern changes occurred mainly in the Lateglacial, i.e. in the Bølling and in the Allerød. Such changes are evident on the rivers: Warta (Kozarski *et al.* 1988), Prosna (Rotnicki 1988), Ner (Turkowska 1988), Rhine (Brunnacker 1978), Theiss (Borsy, Felegyhazi 1983) and Schelde (Kiden, Verbruggen 1988).

In early Holocene times there functioned the narrow, sinuous channels having the smallest dimensions: widths of 30–50 m, radii of 100–250 m and infills, 3–4 m thick (at Lasówka and Rybitwy). The parameters quoted above clearly indicate a decrease in stream discharges at the beginning of the Holocene. Subsequent channel pattern changes took place around 8000 years BP. At that time, channels became wider, up to 80 m, and meander radii reached up to 300 m at Pleszów and Czyżyny. Those changes were due to wetter climatic conditions and to increasing stream discharges at the beginning of the Atlantic period. The successive channel change took place around 6500 years ago. The late Atlantic channels show smaller dimensions: widths of about 40 m and radii of about 200 m (at Branice, Przy Rondzie).

The successive channel change which occurred c. 5000 years ago was accompanied by a gradual increase in channel dimensions. Meander radii at first tended to increase up to 350 m (without increase in widths) down to 3000 years BP (at Łęg A), and probably even down to 2000 years BP (at Branice). Meander radii then rapidly increased to over 400 m, and meander widths doubled to exceed 100 m. At that time, a tendency toward braiding gradually developed. The cutoffs contain well defined central bars being superficial features. Similar central bars are shown on the old maps dating from the close of the 18th century.

Single palaeomeanders, palaeomeander systems and microforms which survived on the floodplain indicate lateral channel migrations in Lateglacial and Subboreal times, but especially during the Subatlantic period marked by a less dense vegetation cover. Locations of the well preserved point bars confirm such a movement and channel shifts. A characteristic property of these channels are high width to depth ratios. At those times, river incision was accompanied by the cut off of single classical meanders.

Systems of irregular, sinuous and narrow segments of the Vistula channel, from which traces of the lateral down-valley shift of single meanders are absent, survived from the Boreal and Atlantic periods. Typical properties of such channels are the lowest width to depth ratios. The above data indicate stability and long-termed stagnation. The cut off of single meanders (e.g. at Rybitwy) being probably due to floods of high magnitude can be seen only on the "senile" palaeomeanders which have a very narrow neck. In the period under review, aggradation was associated with channel avulsions. These have also been recognized in the surroundings of Cracow (Gębica, Starkel 1987), on the Great Hungarian Plain (Borsy, Felegyhazi 1983) and in the Rhine valley (Brunnacker 1978).

In the surroundings of Cracow there can be observed the typical parameter change being characteristic of many Polish rivers (Szumański 1983) and of the European rivers (e.g. Gabris 1985): large lateglacial meanders and small Holocene meanders. Though human activity probably is involved in the increase in abandoned channel dimensions, it appears that in the Vistula valley this phenomenon occurred already in the Subboreal, i.e. earlier than in the remaining river valleys, where dimensions tended to increase only in the last centuries (e.g. in the Wisłoka valley – Alexandrowicz *et al.* 1981). The increase in the dimensions of palaeochannels that functioned at the beginning of the Atlantic period, from 8000 to 6500 years BP, must be related to climatic changes.

SEDIMENTOLOGICAL CHARACTERISTICS OF THE DIFFERENT ALLUVIAL DEPOSITS OF DIFFERENT AGES

The materials collected enable three types of alluvial deposits to be identified: the channel, overbank and abandoned channel deposits (Fig. 4).

For the most part, the channel sediments is represented by sandy-gravelly and sandy deposits (point bars). Their sandy fraction (1.25 – 2.25 ∅) is best

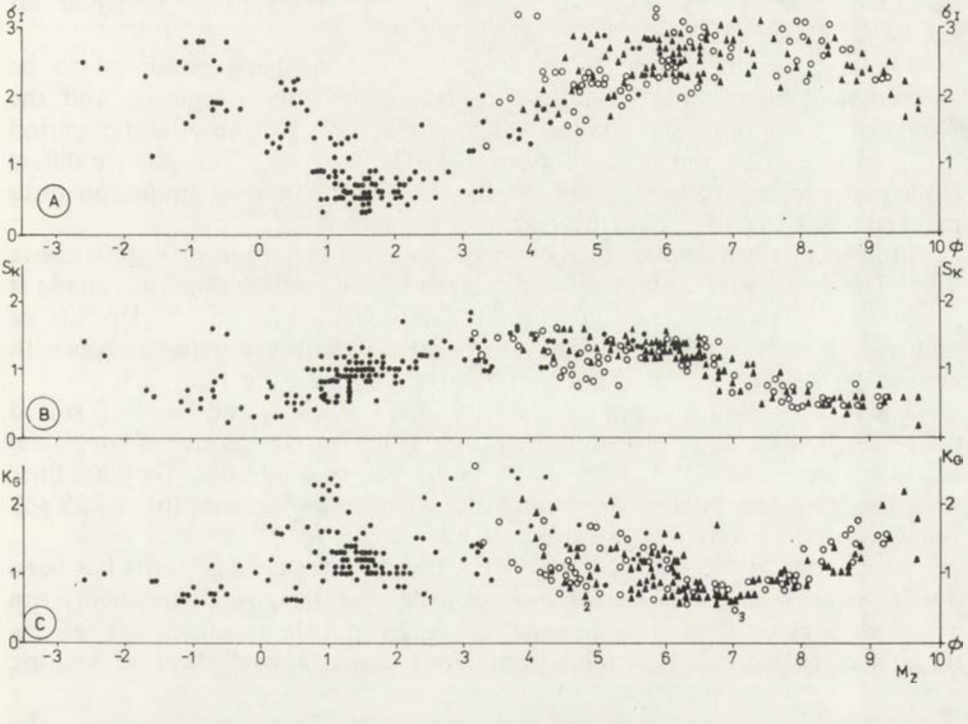

Fig. 4. Sedimentological characteristics of the Vistula alluvia: ratio of mean diameter *Mz* to standard deviation σ_I (*A*), to skewness S_K (*B*), to kurtosis K_G (*C*)

1 – channel deposits; *2* – overbank deposits; *3* – channel fill deposits sorted, whereas the coarser and finer fractions are poorly sorted (2 – 3 ∅). This is supported by both skewness and kurtosis. Skewness is positive (0 – 1) in fractions coarser than 2.25 ∅ and negative in fractions finer than 1.5 ∅. Kurtosis varies from 0.5 to 3.5. Differences are smallest in the fractions finer than 0 ∅.

The grain size of the overbank deposits ranges from 4 to 10 ∅. Sorting of all deposits is poor ($\sigma_I = 2-3$ ∅). It tends to improve in the coarsest and finest fractions, sometimes decreasing to 1.7. A clear boundary is formed by 6.5 ∅. Above this value skewness is negative, below this value it is positive. Kurtosis ranges from 0.6 to 2.2 showing minimum changes (0.6 – 1.5) within the section 6.5 – 9.0 ∅.

The properties of both channel deposits and overbank facies deposits are fairly similar to those recognized by E. Niedziałkowska in the Carpathian foreland (this volume). However, the overbank deposits are much finer (above 7.5 ∅) in the surroundings of Cracow, whereas those in the mountain foreland are not. This fact may be due to the greater distance of the Vistula near Cracow from the Carpathian margin and to the fining-downstream nature of the sediment.

The abandoned channel deposits are of both organic and mineral origin. Organic deposits, namely peats which frequently contain clay, peaty silts and less frequently gyttja tend to occur in a variety of cutoffs. In many cases the organic sedimentation became interrupted by mineral deposition (e.g. at Lasówka, Rybitwy, Łęg). In the profiles examined accumulation rates of organic deposits vary from 0.2 mm (in Nowa Huta) to 0.7 mm/year (at Lasówka, Pleszów).

The mean value obtained from all profiles has been estimated to be 0.3 mm/year on a millenial timescale throughout the Lateglacial and the Holocene. This rate increased to 0.4 mm/year only in the Atlantic period (8 – 7 ka years BP) and in the Subboreal (4 ka years BP). This picture differs from that presented by S. Żurek (1986) who argued that accumulation rates reached their maximum in the Subatlantic period.

Mz of the mineral abandoned channel fills tends to vary from 3 ∅ to above 9 ∅. The numerous datings on the organic abandoned channel fills made it possible to determine the ages of the clastic sediments. Such deposits of differing age are clearly varied. The lateglacial sediments group themselves with similar ∅ values (3.0 – 6.75 ∅) and with a poor sorting (1.5 – 2.5).

The Atlantic deposits are clearly finer (5.75 – 9.25 ∅) and less well sorted (2.0 – 3.5). Sediments recorded on the Rondo come into the cluster of lateglacial deposits. The Subatlantic sediments show transitory properties. They are finer than the lateglacial deposits but coarser than the Atlantic ones (6.0 – 7.25 ∅). Their sorting also shows transitory values of 2.5 to 2.75.

An analogous difference between Atlantic and lateglacial deposits has been noted in skewness and kurtosis. As a rule, the lateglacial sediments are positively skewed, whereas sediments of Atlantic age are negatively skewed. As regards kurtosis the lateglacial deposits are located “above” those of Atlantic age.

Based on the above differences is the attempt to characterize changes in the dusty and clayey deposits ($Mz \geqslant 4$ ∅) of both overbank deposits and abandoned channel deposits from the Lateglacial onwards down to the present day. For this purpose dated profiles have been chosen to determine the age of dusty deposits, and either the initiation or the end of their deposition (Fig. 5). Thus, several bounding dates (key dates) have been assessed. These separate certain intervals of time with appropriate to these properties of the dusty deposits. The key dates are as follows: 9660 BP – end of silt accumulation in Nowa Huta, at the same time, "mada" initiation at Rybitwy; 7980 BP – "mada" initiation on the Drwinka; 6690 and 6160 BP – initiation of mineral sedimentation at Łęg B and Lasówka; 5230 and 5190 BP – silt initiation in an Atlantic palaeomeander at Branice and Przy Rondzie. At the same time, many datings on deposits obtained from the gravel pit at Branice, but especially the dating on the profile B30 (1680±80 BP) enable the young age of the "mada" to be established. This means that the latter has been formed over the last 1500 years at the maximum.

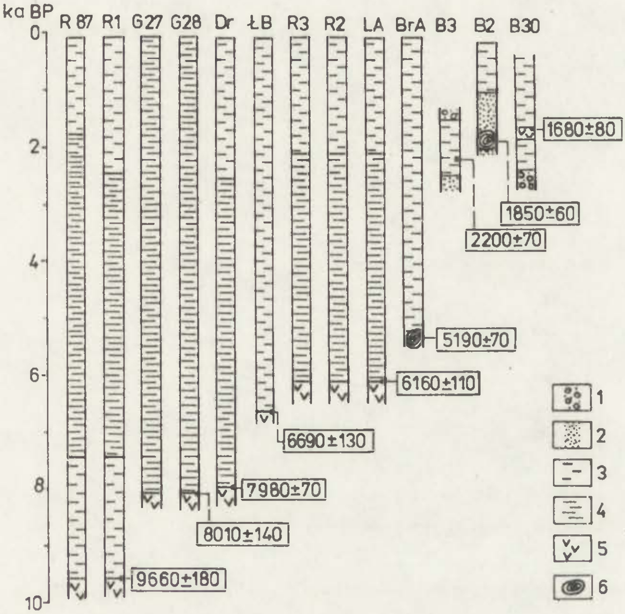

Fig. 5. Comparison of both "mada" profiles and channel fills

1 – gravels-and sands; *2* – sands; *3* – silts; *4* – clays; *5* – peats; *6* – tree trunks

Furthermore, sedimentation rates of the "mada" have been determined for six profiles (at Rybitwy, Branice, Lasówka, Drwinka) that provided dates for "mada" initiation. Its deposition came to an end on the entire Vistula floodplain in the mid-nineteenth century when floods became constrained to the inter-dike area by both channel correction and dike construction. For this reason 100 years were deducted from the radiocarbon date in the calculation. Assuming that sedimentation maintained a similar rate, being less well grounded in many profiles because of lateral channel migration, in all of the profiles there is evidence that the values ranging from 0.13 to 0.35 mm/year were very similar. In four profiles values were almost identical, i.e. 0.22–0.28 mm/year. Extreme values are proportional to distance from the active Vistula channel. It has been observed that the earlier the "mada" initiation the lower were its accumulation rates. This fact may be due to the gradual disappearance of the forest cover in the Vistula catchment. The rapid increase in the "mada" deposition rates in Subatlantic times was associated with the clearance of woodland for pasture and arable crops.

Differences between the Lateglacial and Holocene dusty deposits produce a characteristic pattern (Fig. 6). Below the bounding date of 9660 BP *Mz* of these deposits varies from 4.5 to 6.25 ∅. A characteristic feature of deposits

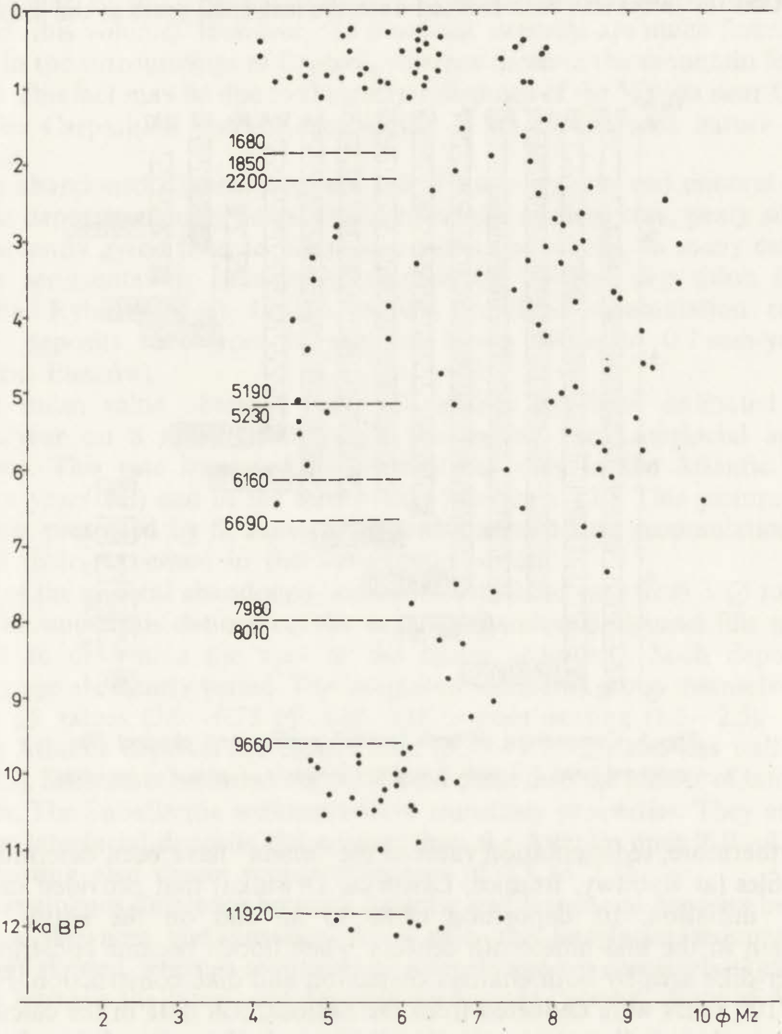

Fig. 6. Differentiation of mean diameter (*Mz*) of dusty sediments (abandoned channel deposits, overbank deposits) during the Lateglacial and the Holocene

which have been dated at c. 12 000 years are the lower *Mz* values (6.0 – 6.5 ∅) reaching 7.3 ∅ at the maximum. The latter value is smaller than that of the Younger Dryas deposits. Above the date of 9660 BP *Mz* is 6.5 – 7.25 ∅ at Rybitwy. The short-lasting accumulation of such sediments was followed by the deposition of very clayey deposits c. 8000 years BP (on the Drwinka). As a rule, *Mz* exceeds 8.5 ∅ to reach up to 10 ∅. Although these deposits occur in the immediate neighbourhood of the active channel these values do not drop below 7.4 (at Rybitwy). Sedimentation of those very clayey deposits lasted until c. 5000 years BP. Since that moment deposits have become more and more sandy. By 5000 years BP the deposits were fairly clayey (*Mz* = 6 – 8 ∅) (at Branice, Przy Rondzie). Subsequently, *Mz* decreased to 6 – 7 ∅ from between 2500 to 2000 years BP. This change has been observed in a variety of profiles (at Rybitwy, Lasówka). Deposits were clearly more sandy over the last 1500 years (at Branice – Stryjów). *Mz* = 5.0 – 6.5 ∅ was similar to that of the lateglacial deposits.

As already mentioned, a characteristic property are *Mz* values decreasing upward in the various profiles (at Rybitwy, Branice). This drop may reach 2 ∅. However, the absolute values tend to vary. The distribution of the profiles shows that the absolute ∅ values in the top "mada" clearly depend on the distance from the active channel and on the morphological location (Fig. 7).

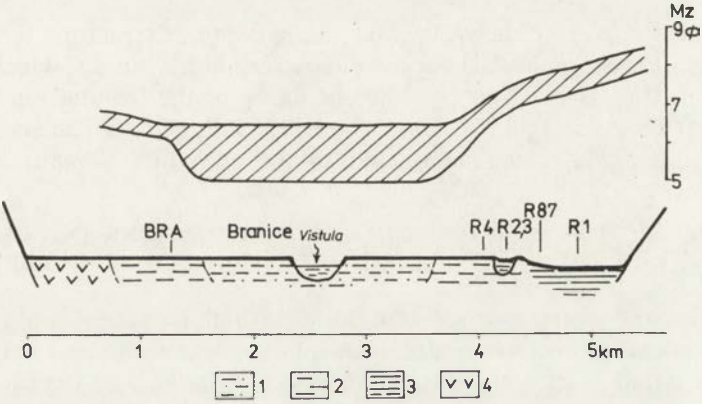

Fig. 7. Differentiation of mean diameter (*Mz*) of the "young mada" in a section across the Vistula valley

1 – dusty-sandy "mada"; *2* – dusty "mada"; *3* – clayey "mada"; *4* – peats

The highest values (7.5 – 8.5 ∅) are typical of "mada" occurring in the distal Drwinka depression. In the proximal zone the following values have been noted in the top "mada": 6.8 – 7.5 ∅ in the abandoned channel deposits and 6.2 ∅ in the overbank deposits. A sandy "mada" (*Mz* = 5.0 – 6.5 ∅) was laid down close to the historical channel at Branice – Stryjów. Farther off, on the northern side of the channel at Branice dusty "mada" (*Mz* = 6.5 ∅) was deposited again. At the foot of the edge of the loess-covered terrace there occur peat bogs due to a rise of ground water tables. The high clay content in the peat indicates flood incursions.

On the Vistula valley floor there occur several types of "mada". The "mada" is formed of dusty sediments which have been deposited by flood waters on the floodplain, i.e. on the plain itself and within the abandoned channels. The lateglacial "earliest mada" is sandy ($Mz = 5.5 - 6.0\ \varnothing$), whereas the early Holocene "mada" is dusty ($Mz = 6.5 - 7.25\ \varnothing$). It rests immediately either on channel deposits or on organic deposits. The second type includes clayey sediments Atlantic in age (as a rule, $Mz = 7.5\ \varnothing$, maximum $Mz = 10\ \varnothing$). This "old mada" became more and more dusty in the Subboreal. In the Drwień depression the "old mada" is superimposed on the "earliest mada" dating from the Lateglacial (at Brzegi) and from the Holocene (at Rybitwy). The boundary separating both types of the "mada" is very distinct. The third type includes the "young mada" which was accumulated over the last c. 1500 years. This "mada" covers the entire width of the valley floor liable to flooding in historical times (Beres 1938). Both sedimentary conditions and composition of the "young mada" tend to vary with distance from the active Vistula channel. Close to the channel this "mada" rests on alternating beds of sand and silt. This fact indicates a rapid increase in volatile discharges at the time of sedimentation. Thus, the above deposits are a transitory sediments of the natural levee type. The boundary between the "mada" and the underlying sediments is distinct and univocal, without intercalations in the older parts of the floodplain.

The "mada" covering the valley floor has a complex structure. It seems that the individual series of channel deposits are overlain by "mada" which varies in date. This in turn is overlain by different facies of the "young mada" dating from the last 1500 years and covering the entire valley floor. The accumulation of the "young mada" must be related to the activities of man.

THE REFLECTION OF BOTH CLIMATIC FLUCTUATIONS AND HUMAN ACTIVITY IN THE VALLEY FLOOR MORPHOLOGY AND IN ALLUVIA

The cooler and wetter periods with floods of high frequency and magnitude have an everlasting effect on both relief and alluvia (Starkel 1983). In such periods there had been a significant increase in erosion and deposition rates. Channel changes, formation of new inserted alluvial series, rapid changes in sediment patterns on the floodplain, as well as deposition of tree trunks are likely to have occurred then. In the Vistula valley near Cracow such events grouped themselves into rather short periods. These were divided by periods of both stability and rather uniform stream discharges being favourable for the development of mature meanders by the Vistula (Kalicki 1988a; Fig. 8).

The temperature rise and retreat of the inland ice after the last glacial maximum were responsible for the dissection of the higher terrace flat by the Vistula. The amelioration of climate at the beginning of the Allerød was associated with a change of the Vistula channel pattern from a braided to a meandering river system. The climatic deterioration in the Younger Dryas is marked by the abandonment of large meanders (at Łęg, Nowa Huta, Rondo Mogilskie, Branice – Stryjów). Consequently, the meandering Vistula has been replaced by a braided one. Aggradation also occurred (at Brzegi).

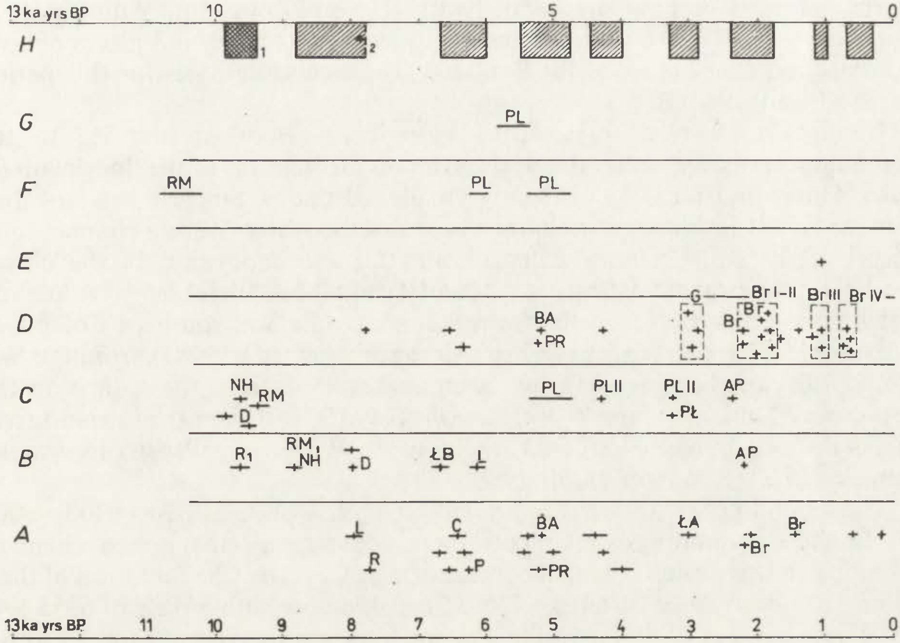

Fig. 8. Reflection of the Holocene climatic changes in both morphology and alluvia

A – cut off palaeomeanders and channel avulsions; *B* – superposition of the "mada" on organic deposits; *C* – peat initiation; *D* – tree trunks in the alluvia; *E* – cultural horizons beneath the "mada"; *F* – palaeobotanical data indicating a humid climate; *G* – palaeobotanical data indicating a dry climate; *H* – phase of peat initiation (*1*) and phases of increased activity of the Vistula (*2*)

The first Holocene changes in sedimentation type are noted in the Preboreal with bounding dates of 9840 and 9330 BP (Piottino phase). At that time, peat began to accumulate at many sites in the lateglacial large abandoned meanders in Nowa Huta (9660 ± 100 BP), on the Rondo Mogilskie (9330 ± 180 BP) and on the Drwinka (9520 ± 110 BP). Underlying are Younger Dryas silts and less frequently a gyttja. Peat accumulation indicates that fluvial processes subsided so that the meander systems became abandoned by the Vistula. Peat with a date of 9840 ± 140 BP also accumulated in the Drwinka depression (in the Niepołomice Forest region) (Starkel *et al.* 1988). In the surroundings of Cracow, in the Drwień depression, organic deposits became buried by the "oldest mada" (at Rybitwy) with a date of 9660 ± 180 BP due to channel avulsion.

The beginning of the Atlantic period was the first period of unquestionable increasing fluvial activity. At that time, clear channel pattern changes have involved the cut off of single, highly sinuous meanders (at Rybitwy with a date of 7740 ± 90 BP). However, the basal gyttja must be dated at greater than the above years. The whole palaeomeander system (at Lasówka with a date of 7980 ± 160 BP) then became abandoned, and the Vistula shifted to the north. At that time, "mada" was commonly deposited on the organic sediments (Rondo Mogilskie – beginning of the Atlantic period – Mamakowa 1970; Drwinka with a date of 7980 ± 80 BP – Gębica, Starkel 1987). In places, organic deposits became interbedded with clay (in Nowa Huta with a date of post 8860±160 BP). The above deposits contain tree trunks and pieces of both *Fraxinus* and *Quercus* wood (at Rybitwy). The bounding dates for this period are 8860 and 7980 BP.

Changes took place piecemeal. Widespread floods at first led to the accumulation of clay within the peats, even on the margins of the floodplain (in Nowa Huta) and locally of a sandy "mada" (Rondo). Single meanders then were cut off (at Rybitwy). Finally, avulsions of the whole Vistula channel took place c. 8000 BP. Channel shifts account for the deposition of the clayey "mada" on the organic sediments in a variety of places. Increased river activity in this period has been reported from the other valleys in southern Poland, as for example from the Wisłoka valley (Alexandrowicz *et al.* 1981), from the San valley (Ralska-Jasiewiczowa 1980; Szumański 1986), from the valleys in the loess-covered uplands (Jersak 1977; Śnieszko 1985), and from the lowland river valleys drained by the Ner (Turkowska 1988), Warta and Prosna (Kozarski, Rotnicki 1977; Kozarski *et al.* 1988).

The second period of increased river activity has been dated to 6700–6000 BP. In the surroundings of Cracow there occur many abandoned channels belonging to this period: the palaeomeanders at Czyżyny (the initiation of their infilling has been dated at 6450±130 BP), at Pleszów with a date of 6255±40 BP (Wasylikowa *et al.* 1985), in the Cracow Gate with a date of 6700±130 BP (Rutkowski 1987), 6560±80 BP and 6340±120 BP (Sokołowski, Wasylikowa 1984). At that time, peat ceased to accumulate in the abandoned channels at Łęg B (6690±130 BP), at Lasówka (6160±110 BP) and probably also at Rybitwy. *Fraxinus* trunks obtained from the palaeomeander fills also date from the period under review. A rising ground water table is indicated by the spread of *Alnus* at Pleszów (Wasylikowa *et al.* 1985). This period also began with "mada" deposition on the peaty cutoff fills located not far off of the active stream channel (at Łęg B). Subsequently, the cut off of meanders at Czyżyny and Pleszów was followed by channel shift to the south. As a consequence, the organic palaeomeander fills here became buried beneath the clayey "mada" (at Lasówka, Rybitwy). This phase also was recognized in the San valley (Szumański 1986) and in the Wisłoka valley, where many black oaks have been found to date from this period (Alexandrowicz *et al.* 1981).

Another phase of increased activity of the Vistula was dated to the Atlantic/Subboreal transition. It is likely that this period was twofold. Both single palaeomeanders and palaeomeander systems date from its first subperiod (5500–4800 BP), as for example the palaeomeander at Branice (5190±70 BP) and the palaeomeander fills at Przy Rondzie (5290±140 BP). More than ten kilometres to the east, in the Grobla Forest, there occur abandoned meanders which have been dated at 5460±110 and 5420±110 BP, together with a trough dated at 5090±90 BP (Starkel, Kalicki 1984; Gębica, Starkel 1987; Starkel *et al.*, this volume). There also is evidence for subsequent peat accumulation at Pleszów due to a rise of ground water tables from 5380±60 to 4750±35 BP (Wasylikowa *et al.* 1985). In these deposits there have also been found *Tilia* (at Branice) and *Alnus* trunks (Przy Rondzie).

The second subperiod (4500–4000 BP) is marked by the occurrence of palaeomeanders in the Cracow Gate which have been dated at 4410±180 and

4010±180 BP (Rutkowski 1987) and of palaeomeander infills containing *Fraxinus* trunks with a date of 4275±50 BP (Sokołowski, Wasylikowa 1984).

At the Pleszów II site peat accumulation came to an end only 4310±70 years BP. It seems that the above two subperiods correspond to one general phase of wetter conditions. In the other river valleys the Atlantic/Subboreal transition is acknowledged to be the time of rapidly increasing “mada” deposition (Falkowski 1975), of meander cut off (Kozarski, Rotnicki 1977; Kozarski *et al.* 1988), of the development of new series of alluvia (Florek 1978a) and of changes in sedimentation types (Śnieszko 1985).

In the surroundings of Cracow fluvial processes were reactivated again 3200–3000 years ago. This period showed itself in the cut off of meanders (at Łęg A with a date of 3030±100 BP), in the increased flooding on the evidence of both peat and clay accumulation at the Pleszów II site (3260±80 BP), in a rising ground water table which in turn led to peat accumulation in the Drwień depression (at Płaszów with a date of 3270±110 BP) and in the deposition of several dendrochronologically correlated oak trunks at Grabie with a date of 3120±100 BP (Kalicki, Krąpiec, in print) and of single trunks with a date of 2895±70 BP at Dąbie (Środoń 1980), 3060±80 BP at Branice and 2970±60 BP at the Kościuszko weir (Kalicki, Krąpiec, this volume). Traces of this phase are documented by palaeochannels and “mada” overlying both peat and tree trunks. Its traces also were noted in the other Vistula valley segments (Klimek 1987; Rutkowski 1987; Sokołowski 1987), and in the valleys drained by the San (Szumański 1985), Bóbr (Florek 1980), Prosna (Kozarski, Rotnicki 1977), Moszczenica (Kamiński 1984, 1989) and Ner (Turkowska 1988).

In the period from 2200 BP to 1800 years BP further channel pattern changes took place. These caused the formation of cutoffs in the period from 2200±70 BP to 1480±60 BP at Branice (Kalicki, Starkel 1987) and 2100±80 BP in the Cracow Gate (Rutkowski 1987). This rise of ground water tables was accompanied by peat initiation 2370±100 BP (Aleja Pokoju). However, peat accumulation became interrupted by deposition of sand and sand-and-gravel during floods of high magnitude. At that time, the older trunk generation at Branice (Kalicki, Krąpiec 1988, also this volume) came into being between 2200±120 BP and 1850±60 BP, and so did the single tree trunks which have been found at Przegorzały with a date of 1820±100 BP (Gradowski, Nalepka 1984) and at Salwator with a date of 1775±280 BP (Środoń 1980). This phase also shows itself in meander cut-off, in the burial of peat by “mada”, and in the deposition of black oak trunks, as for example in the Wisłoka valley (Alexandrowicz *et al.* 1981), in the Vistula valley near Tarnobrzeg (Mycielska-Dowgiałło 1987) and in the valleys of the Warta (Kozarski *et al.* 1988), Słupia (Florek 1986), Ner and Wolbórka (Turkowska 1988).

The youngest phase of increased river activity being documented by sediments was dated to 1100–1000 years BP. In this phase deposition of the younger trunk generation took place at Branice (1060±75 and 1070±120 BP) (Kalicki, Krąpiec 1988). At that time, dikes also were constructed. They obscured remains of settlement at Okół dating from the 9th century. The construction of dikes and the colonization of higher areas denotes repeatedly increased flood frequency and magnitude (Radwański 1972). Black oak trunks dating from the period discussed frequently occur in the valleys drained by the

Wisłoka, Ner, Nysa Kłodzka and Czarna Nida (Wroński 1974; Lindner 1977; Alexandrowicz *et al.* 1981; Turkowska 1988).

Also the Little Ice Age has been reflected in the increased fluvial activity. In the historical sources from the first half of the 14th century are mentioned changes of the Vistula channel near Rybitwy (Bąkowski 1902) and comparison of the old maps indicate a natural cut-off of meander in Holendry during the big floods at the close of 18th century (Trafas 1975). This period is also represented by youngest generation BIV of black oaks in Branice – Stryjów (Kalicki, Krąpiec, this volume) and mineralogenic intercalations in peats in the Cracow downtown (Radwański 1972).

In the Vistula valley near Cracow periods of increased river activity are well defined. They coincide with their analogues in central Europe, and even in the entire temperate zone (Starkel 1983) (Fig. 9). This agreement between phases is especially good until the decline of the Atlantic period (8800 – 8000, 6600 – 6000, 5500 – 4800 BP). At those times, the river regime was closely related to climatic fluctuations. Their traces have been recognized not only in

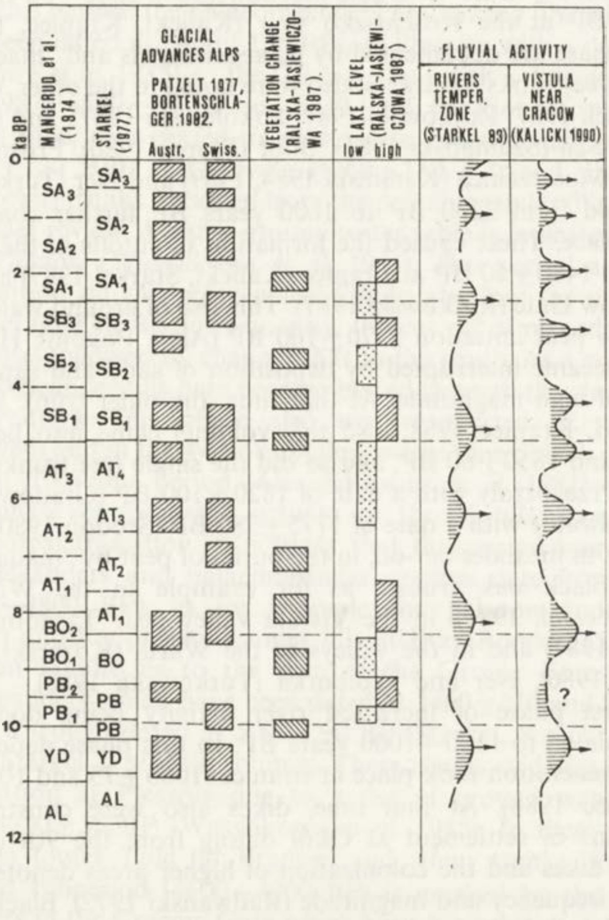

Fig. 9. Comparison of various indices of climatic changes in Europe and in the upper Vistula drainage basin

the Polish river valleys quoted above, but also in the valleys drained by the Nieman (Gaigalas, Dvareckas 1987), Danube (Fink 1977; Becker 1982), Rhine and Main (Brunnacker 1978; van der Woude 1981; Schirmer 1983, 1988) and by the Oulanka (Koutaniemi, Ronkainen 1983). Man's impact then became more and more important. However, it should be stressed that there is clear evidence for a climatic control in the Subboreal and Subatlantic phases (4500–4000, 3200–3000, 2200–1800 and 1100–1000 BP). These of course may also reflect human activities, as for example the increased "mada" sedimentation rates in the Oświęcim Basin from 3000 years BP onward (Klimek 1988). Evidence for a climatic control of the above mentioned phases is that of their synchroneity in the Rhine and Danube catchments (Fink 1977; Becker 1982), in Poland – in the upper Vistula valley (Klimek 1987; Rutkowski 1987; Sokołowski 1987; Mycielska-Dowgiałło 1987), in the upland valleys near Łódź and Miechów (Turkowska 1988; Śnieszko 1985), in the Słupia valley (Florek 1988), in the Warta valley (Kozarski *et al.* 1988) and in the Wisłoka valley (Alexandrowicz *et al.* 1981), in eastern Europe – in the Berezina and Dnieper valleys (studies carried out by the present author) and in the Oka valley (Aleksandrovski *et al.* 1987). These phases were recognized in catchments, where early human influence has been pronounced, as for example, those of the upper Vistula and of the central European rivers. They also were recognized in catchments that persisted almost unmodified by man until the present day, as for example, the Berezina drainage basin.

The anthropic pression in the Vistula catchment has been especially strong since the Neolithic decline time, from c. 3650 years onward. The Beskidy Mts then come to be settled (Corded Ceramic culture – Valde-Nowak 1988). The spread of Lusatian communities brought about agricultural intensification in the loess-covered upland areas (Kruk 1988). The clearance of woodland was accompanied by disturbances of the stream discharges. These resulted in both the gradual increase in meander dimensions and the development of a wide river channel containing many bars. Man's activities also are responsible for the deposition of the dusty-sandy "young mada" being similar to the lateglacial one. "Mada" deposition started 2500–2000 years ago. In the surroundings of Cracow, permanent settlements were located immediately on the floodplain in the drier periods including the Subboreal and the early Middle Ages, from the 7th to the 9th centuries (Radwański 1972). At Branice there were found more than the trunks hewn by man. One of them has yielded a date of 3060±80 BP. The dates for three tree trunks are 2260±80, 1850±60 and 1950±60 BP (Kalicki, Krąpiec, this volume). Because of the extensive clearance of floodplain woodlands the banks of the Vistula channel were not fixed so that the river channel freely migrated on the floodplain. In the wetter periods typical "black oak series" developed at Grabie and Branice. The date for the oldest series is 3000 years BP. The dates for the remaining ones are c. 2000 and 1000 years BP and 700 BP.

The present author would like to stress again that all of the Holocene phases of increased river activity recognized in the Vistula valley and in the other valleys cited coincide with those of climatic fluctuations (Starkel 1977b; Khotinski 1977). These phases are documented by the oscillations of both valley glaciers and lake levels, by landslide occurrence and by changes in vegetation (Starkel 1983; Ralska-Jasiewiczowa, Starkel 1988). The above changes are synchronous in western and central Europe and in areas farther east of the Vistula drainage basin. Changes have been noted in valleys of different sizes, on the rivers the springs of which are in the mountains, on the lowland rivers, in the drainage basins which have been transformed by man, and in catchments almost being in their natural state. For this reason, the present author cannot agree with Buch (1988), Buch and Heine (1988) who question the climatic control of the phases discussed. They also argue that the dynamic process-response model of river channel development was the only controlling factor. Considering synchronous changes in a great variety of valleys, it is difficult to appreciate just such a factor. Furthermore, what was the cause of synchronous changes in the other environments, as for example, valley glaciers, landslides and vegetation cover? The Danube channel change from a braided to a meandering river system and the tendency toward erosion in the surroundings of Regensburg studied by both authors took place c. 5000 years ago. Was it by accident? Perhaps it did be a climatic change after all?

THE DEVELOPMENT OF THE VISTULA VALLEY IN LATEGLACIAL AND HOLOCENE TIMES

The process of dissection of the higher terrace flat dating from the Younger Pleniglacial (Kozłowski 1969) started at quiet an early date, most likely immediately after the maximum of the last glacial. The rapid downcutting is documented by the low location of alluvia already during the Oldest Dryas with a date of 13 260±160 BP (at Pleszów II). At that time, the new alluvia lay 4 m below the top of alluvia forming the loess-covered terrace, but 18 m below the top of alluvia forming the Dłubnia alluvial fan (Fig. 10, 11). This early and deep dissection of the Vistula valley is confirmed by datings on a fossil soil (14 590±270 BP) underlying a dune at Kamion, and recorded from the palaeomeanders near Płock (14 390±160 BP) in the lower Vistula valley (Manikowska 1985; Florek *et al.* 1987). It is also supported by findings in the Sancygniówka valley, in the Nidzica valley (Śnieszko 1985, 1987) and in the middle San valley (Starkel 1960) within the upper Vistula catchment. Incision proceeded rapidly upstream as the inland ice retreated from Poland. This early and deep incision in the de-glacial phase is typical of a great number of valleys the lower reaches of which were blocked by the inland ice, for instance, the lower Vistula valley (Florek *et al.* 1987) and the Nieman valley (Vozniachuk, Valchyk 1978). Furthermore, it has been observed on the Rhine (Schirmer 1988) and on the Danube (Buch 1987) the headwaters of which were covered by an extensive glaciation.

In the Younger Pleniglacial the Vistula was a braided river with shallow (up to 2 m deep) and wide braids which survived below the edge of the loess-covered terrace at Pleszów II. These channels lay at a similar altitude to the present Vistula channel. The top of the alluvial sand and gravels reached up to 2 m above river level. From 13 000 BP to 12 000 BP incision was less rapid. The shallow (up to 2 m deep) and wide, sand-filled braids, as well as the top of the then deposited alluvia are seen to lie almost at a similar altitude to that of 13 000 years ago (at Rybitwy). The Vistula which retained its braided nature freely changed its channel across the entire width of the valley floor. This is indicated by sites located not far from both valley sides.

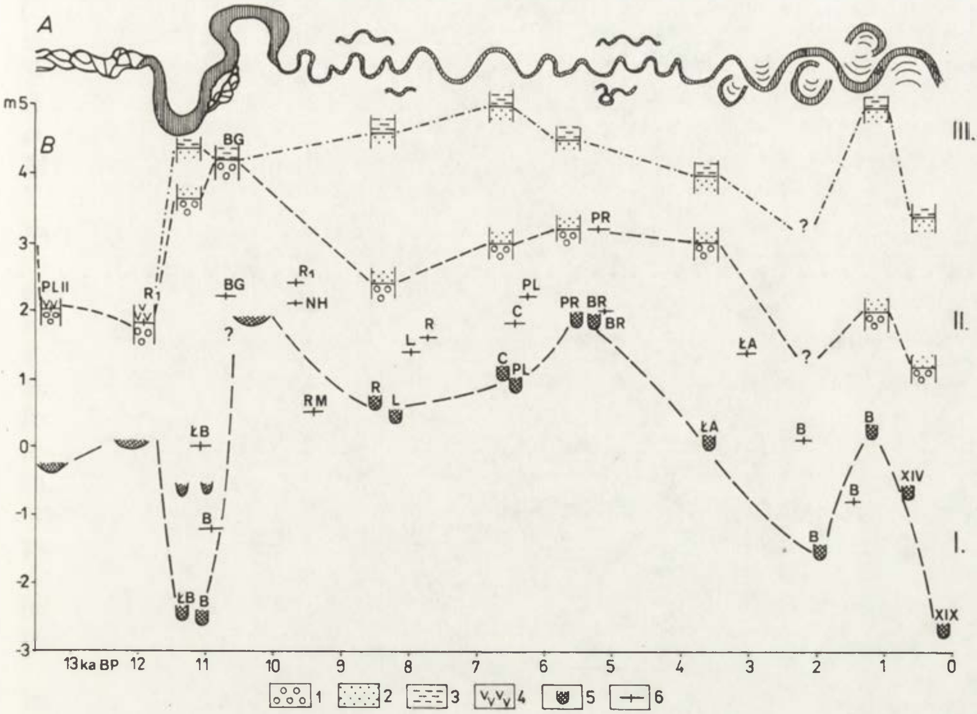

Fig. 10. Channel pattern changes (*A*) and vertical changes of the Vistula river channel (*B*) during the Lateglacial and the Holocene

1 – gravels; *2* – sands; *3* – "mada"; *4* – peats; *5* – basal part of abandoned channel fills; *6* – radiocarbon datings; *I* – oscillations of the channel level; *II* – oscillations of the top of channel deposits; *III* – oscillations of the top of point bar deposits

Changes at the opening of the Allerød show themselves most dramatically in the replacement of the braided channel by a meandering one (at Łęg B, Nowa Huta). Channel metamorphosis was associated with deep incision. The Allerød channels were 3 m below the present Vistula level and 8 m below the present alluvial plain (at Łęg B, Branice – Stryjów). At that time, the top of the bar-forming channel deposits was above 2 m higher than that of the braided river. Meanders were laterally migrating on the whole floodplain. There was a tendency toward both channel shift to the north and valley widening by the undercutting of the higher alluvial fans which have been built up by the Prądnik and by the Dłubnia (in Nowa Huta, Rondo Mogilskie).

The sudden deterioration in climate during the Younger Dryas was accompanied by the abandonment of channels and by the repeated formation of a braided Vistula. The sandy and gravelly alluvia referring to this period reached 4 m above the present Vistula level (at Brzegi). They also survived in the wide right-bank Drwień and Drwinka depressions. M. Bzowski (1973) interpreted them as being the former braided Vistula channel. It is likely that an anastomosing channel also functioned at that time (Drwinka). This supports E. Falkowski's view (1967) that braided channel formation took place in this period. The above process has been recognized in the Ahr and Rhine valleys

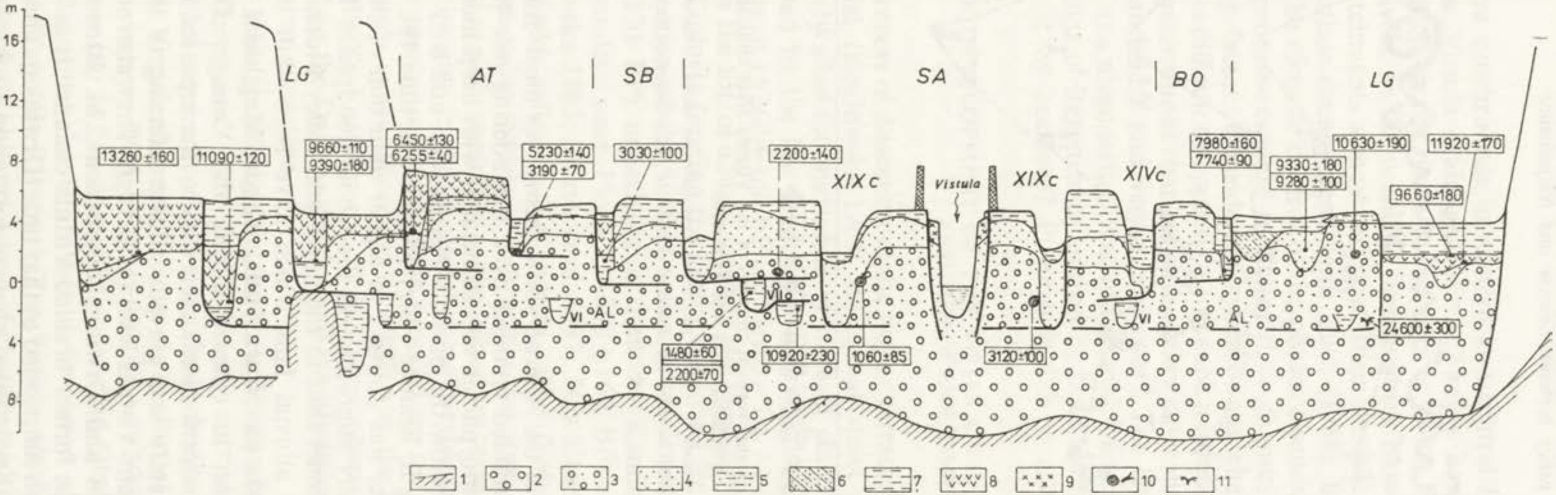

Fig. 11. Schematic section across the Vistula valley floor between Cracow and Niepołomice

1 — Miocene clay; *2* — gravels; *3* — gravels-and-sands; *4* — sands; *5* — sandy silts; *6* — sands with silty intercalations; *7* — silts and "mada"; *8* — peats; *9* — industrial "mada"; *10* — tree trunks; *11* — reindeer's antler.
Age designations: *AL* — Allerød, *AT* — Atlantic, *BO* — Boreal, *LG* — Lateglacial, *SB* — Subboreal, *SA* — Subatlantic

(Heine 1982). Furthermore, both aggradation and cut off meander due to increasing river activity were described in many valleys, as for example, in the Wisłoka valley (Alexandrowicz *et al.* 1981), in the upper San valley (Ralska-Jasiewiczowa 1972), in the Vistula valley (Sarnacka 1987; Niedziałkowska *et al.* 1985), in the Warta valley (Gonera 1986; Kozarski *et al.* 1988), in the Moszczenica valley (Kamiński 1989), in the Nieman valley (Vozniachuk, Valchyk 1978), in the Main valley (Schirmer 1983), and in the Belgium river valleys (Munaut, Paulissen 1973).

At the beginning of the Holocene the Vistula channel became constricted again (at Przewóz, Brzegi). This event was associated with erosion. In the Eoholocene and the Mesoholocene there was a permanent tendency toward slow aggradation. Channel beds and the surfaces of both channel facies deposits and point bar deposits were raised by more than 2 m. Channels dating from the Atlantic decline time lay up to 2 m above the Vistula level. A characteristic feature of these aggrading channels is the rather low lying sand-and-gravel top (about 3 m above the Vistula level), i.e. it lies at a similar altitude to the lateglacial channel fills. Another feature is the very thick series of point bar-forming sands. Channel avulsions were typical of this period. Avulsions took place in the wetter periods, i.e. at the beginning of the Atlantic (at Lasówka, Rybitwy), from 6600 BP to 6000 BP (at Czyżyny, Pleszów), and at the Atlantic/Subboreal transition (comp. above).

The beginning of the Subboreal coincides with the initiation of river incision. This process may be attributed to both climatic changes and increasing man-induced changes in the Vistula drainage basin. From the Neolithic period onward, the loess-covered areas were densely populated (Śnieszko 1985; Kruk 1988). In the Rudawa valley there developed the anthropogenic "mada" with a date of 4590±120 BP (Rutkowski 1984). In the lower Racławka valley organic "mada" was laid down 4990±120 and 5260±110 BP (Rutkowski *et al.* 1988). In the surroundings of Cracow the gradual transition from clayey "mada" to dusty "mada" deposition has been observed. These changes increased after 3000 years BP causing both intensive "mada" accumulation in the Oświęcim Basin (Klimek 1988) and changes in sedimentation type from organic "mada" to loessic "mada" in the Racławka valley (Rutkowski *et al.* 1988). Subboreal channels (at Łęg A) reach down to the Vistula level. This indicates that incision rates reached almost 2 m. The point bar surface lay then about 1 m lower. Incision caused the avulsions to disappear. In the wetter periods single meanders became cut off.

Widespread deforestation including that of the floodplain (at Branice) aided lateral channel migrations being associated with the formation of black oak clusters in the alluvia. Erosion reached its maximum c. 2000 years BP. Channels lay then about 1.5 m below the Vistula level, i.e. at a similar altitude to the Allerød channels (at Branice – Stryjów).

From the late Roman period onward until probably early medieval times, repeated aggradation was due to man's impact. Sediment supply into the river was greatly enhanced. This is supported by the increasing rates of "mada" deposition in the Prądnik valley (Alexandrowicz 1988). At that time, the Vistula channel which showed larger dimensions and traces of braiding rose by nearly 2 m to reach above the Vistula level. Like the Atlantic channels, the series of sandy point bar deposits is very well developed, lying at a similar altitude to the Atlantic stratum (at Branice – Stryjów).

Aggradation resulting in the high location of the Vistula channel caused the floods to rise during the subsequent wetter period at the beginning of the 10th century. Consequently, settlement expanded into the higher areas in the 10th and 11th centuries, and dikes were constructed at Okół in Cracow (Radwański 1972).

In the successive times incision of the Vistula channel took place. The channel bed dating from the beginning of the 14th century lay already 0.5 m below the Vistula level. The top of both channel deposits and point bar deposits also was lover by 2 m. It is likely that the tendency toward downcutting persisted down to the present day. It has also been recorded at the gauging stations in Cracow since the 19th century, though its absolute values seem to be everestimated. This progressive incision attained great depths. Channels which have artificially been cut off in the mid-19th century lie at similar altitude to the Allerød channels.

Channel correction undertaken on the Vistula in the mid-19th century as well as the construction of both dikes and weirs led to the total interruption of the natural development of the Vistula valley and channel in the surroundings of Cracow.

CONCLUSIONS

In the Vistula valley extending downstream of Cracow there became confirmed the characteristic picture of channel parameter changes from a braided river through large lateglacial palaeomeanders to small Holocene meanders. This sequence has also been recognized on the other Polish and central European rivers (Falkowski 1975; Kozarski 1983; Szumański 1983). During the Holocene, from 8000 BP onward until 6500 BP, the increase in palaeochannel dimensions reflected climatic control, whereas since c. 3000 years BP, i.e. earlier than on the other rivers it has become more dependent on human activity (Fig. 2, 3). This variability was governed by climate, vegetation cover and man. It is reflected in the flood-formed deposits corresponding to three types: lateglacial and Eoholocene sandy-dusty deposits, Mesoholocene clayey deposits and sandy-dusty deposits again dating from the last 1500 years (Fig. 6).

Characteristic features of the Holocene development of the Vistula valley section discussed is the lesser vertical stability of the river channel than that at the close of the Vistulian, as well as the deposition of successive inserted alluvial fills at an almost similar altitude. Further evidence for this regularity has been provided from the Oświęcim Basin (Klimek 1987), from the Cracow Gate (Rutkowski 1987), from the Hungarian Plain (Borsy, Felegyhazi 1983), from the Morava valley (Havliček 1984), from the Rhine and Main valleys (Schirmer 1983, 1988). The floodplain of the Vistula is composed of inserted fills of differing age which lie at an almost similar altitude (Fig. 11). Channel changes took place in the cooler and wetter periods being accompanied by a high flood frequency. Those changes appear to be synchronous throughout central Europe (comp. Starkel 1983). The data collected made it possible to distinguish a new phase with a date of 3200–3000 years BP for the Polish rivers. It is supported by evidence from the other Polish and European rivers. This phase corresponds to the Löbben glacial fluctuation in the Alps. Furthermore, the single phase at the Atlantic/Subboreal transition (Starkel 1983) became subdivided into two independent phases with dates of 5500–4800 BP and 4500–4000 BP. These phases coincide with the bipartite Rotmoos glacier oscillation in the Alps (Patzelt 1977; Bortenschlager 1982) and with vegetational changes (Khotinski 1977; Ralska-Jasiewiczowa 1987) (Fig. 8, 9).

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Geographical Studies
Evolution of the Vistula River Valley
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BLACK OAKS AND SUBATLANTIC ALLUVIA OF THE VISTULA IN THE BRANICE–STRYJÓW NEAR CRACOW

Quaternary deposits occurring in the Vistula valley near Cracow have been a subject of study since the 19th century. S. Zaręczny (1894), A. Pierzchała (1960), I. Kmietowicz-Drathowa (1964), M. Tyczyńska (1968) and J. Kozłowski (1969) agreed that the floodplain of the Vistula dates from the Lateglacial and the Holocene. Since the 19th century (Bieniasz 1888; Zaręczny 1894) many black oak trunks have been recognized in the alluvia of the Vistula at 6–7 m below the present surface. These trunks were believed to be either very old (from the beginning of the Holocene – Kmietowicz-Drathowa 1964) or young (from the beginning of the Subatlantic – Środoń 1952; Pierzchała 1960). The latter age was supported by the first datings: 2895±70 and 1775±280 BP (Środoń 1980) and 1820±100 BP (Tauber 1968). It is only in the 1980s that an intensification of research has occurred within the IGCP program concerned with the evolution of the Vistula valley during the last 15000 years (Starkel ed. 1982, 1987). The focus for research was the gravel pit at Branice–Stryjów, where many trunks and stumps hewn by man have been found (Starkel 1984; Kalicki, Starkel 1987; Kalicki, Krąpiec 1988; Kalicki *et al.*, 1989).

The first radiocarbon datings on deposits exposed in the gravel pit at Branice–Stryjów were made by M. F. Pazdur (comp. table in a paper by Kalicki and Starkel 1987). The black oak trunks used for dendrochronological studies were dated by T. Kuc in the Laboratory of the Institute of Nuclear Physics, Academy of Mining and Metallurgy, Cracow (comp. Appendix).

The gravel pit at Branice–Stryjów and Przylasek Rusiecki is located within the administrative boundary of Cracow, some 18 km to the east of the city center. The pit is on the floodplain, close to the active Vistula river channel.

MORPHOLOGY AND STRATIGRAPHY OF ALLUVIA

In the surroundings of the gravel pit there occur two cutoffs. The western "older" cutoff and the eastern "younger" cutoff became artificially cut off in the mid-19th century when channel correction was undertaken on the Vistula (Trafas 1975) (Fig. 1). The "older" cutoff is 80–150 m wide, the meander radius is c. 400 m. Meander scrolls are forming slightly inclined ridges of great radii. In its eastern part the channel became divided into two parts by a well defined

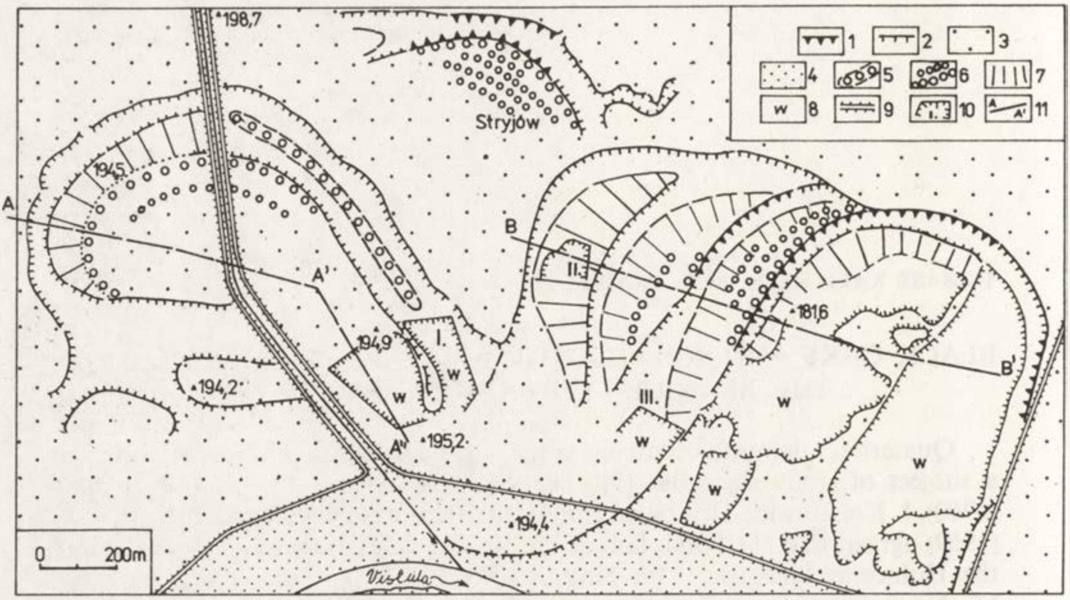

Fig. 1. Morphological map showing the gravel pit at Branice – Stryjów (by T. Kalicki)

Edges: *1* – above 3 m, *2* – below 3 m, *3* – floodplain; *4* – modern floodplain (inter-dike area); *5* – central bars; *6* – point bars; *7* – slope of the convex meander-side; *8* – water; *9* – dikes and railway embankments; *10* – pits; *11* – lines of sections (comp. Fig. 4); *I* – western exposures; *II* – eastern exposures; *III* – pit D 3

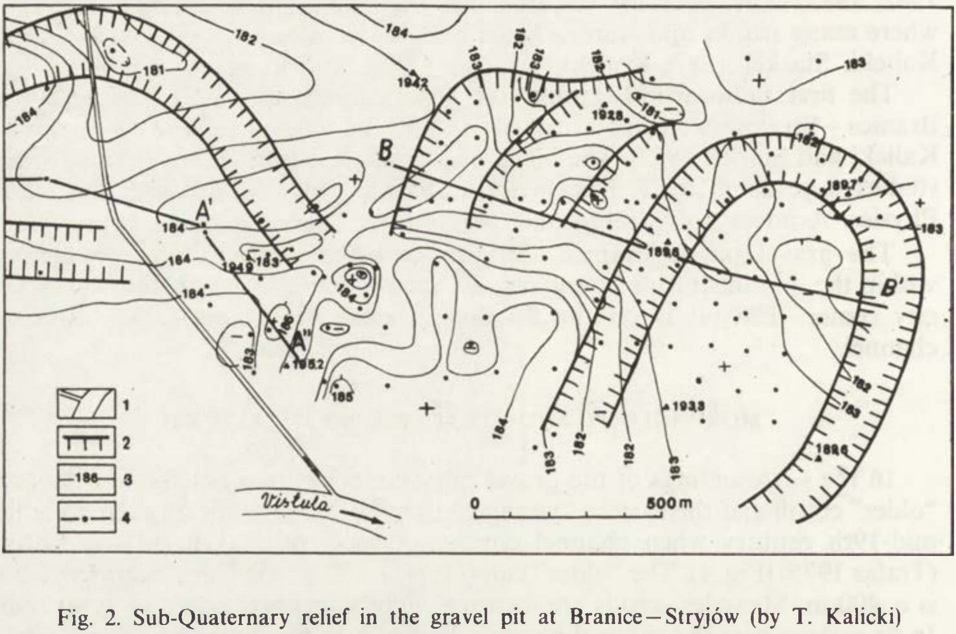

Fig. 2. Sub-Quaternary relief in the gravel pit at Branice – Stryjów (by T. Kalicki)

1 – streams; *2* – cutoff edges; *3* – isohypses of the top surface of Miocene clays; *4* – borings and sections (comp. Fig. 4)

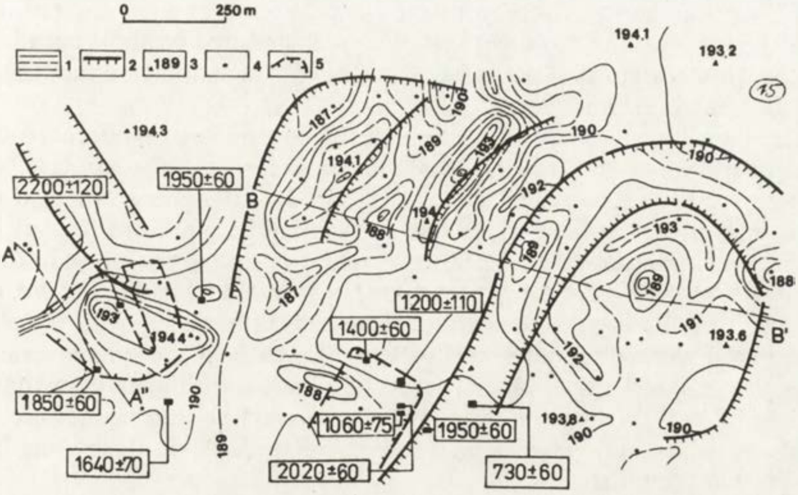

Fig. 3. Topography of the top channel deposits in the gravel pit at Branice – Stryjów (by T. Kalicki)

1 – isohypses of the top channel deposits; *2* – cutoff edges; *3* – height a.s.l.; *4* – borings; *5* – scarps; A' – A" and B – B' – lines of geological sections (comp. Fig. 4); inside box – radiocarbon datings BP on the black oaks

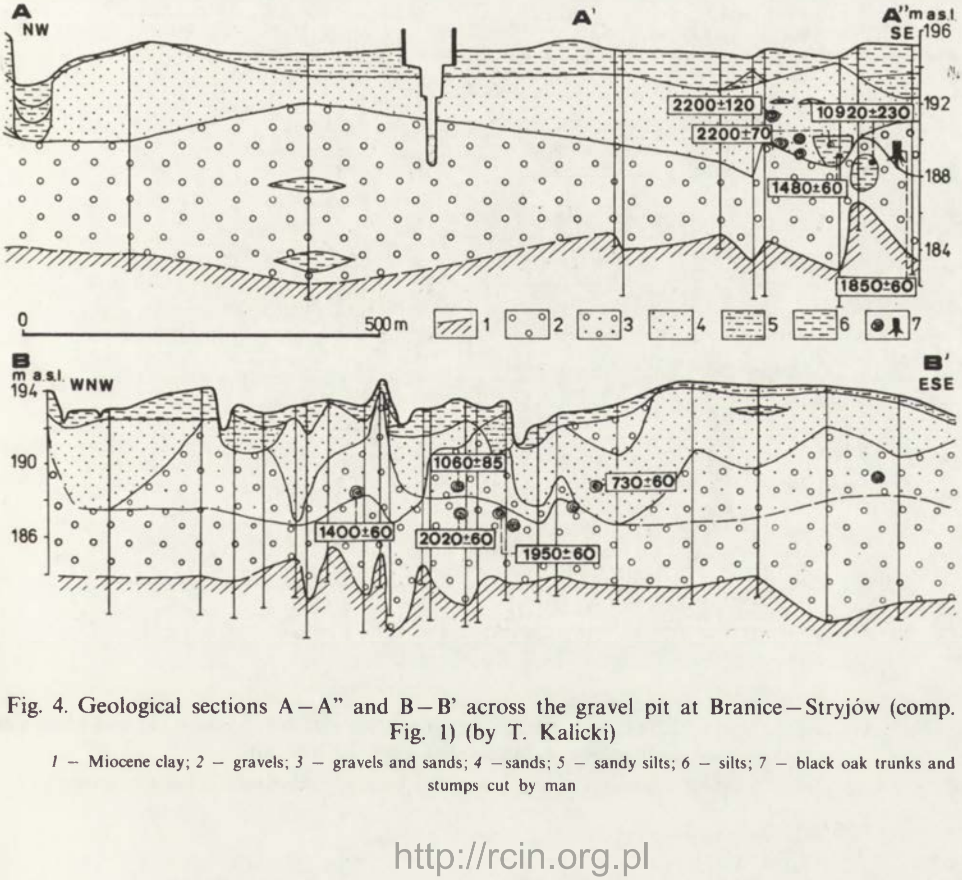

Fig. 4. Geological sections A – A" and B – B' across the gravel pit at Branice – Stryjów (comp. Fig. 1) (by T. Kalicki)

1 – Miocene clay; *2* – gravels; *3* – gravels and sands; *4* – sands; *5* – sandy silts; *6* – silts; *7* – black oak trunks and stumps cut by man central bar. Remnants of the "younger" cutoff are 80 m wide, the radius being 400 m. To the west the "younger" cutoff is accompanied by three parallel edges, together with troughs and point bar zones. These facts indicate that the former meander shifted downstream.

A dense network of borings enabled the top of both Miocene rocks and channel deposits to be reconstructed. The varied relief of the Miocene substratum here shows differences of up to 5 m (Fig. 2) and, among others, a sinuous trough. However, the latter does not correspond in planform to that of both cutoffs. Alluvia are up to 9 – 12 m thick. Their basal part is formed of a gravel series, 4 – 8 m thick. Overlying are sands (3 – 5 m) and "mada" (1.5 – 3 m) (Fig. 3, 4). The irregular top of the channel deposits is in harmony with the planform of cutoffs, of channel courses and of bars. The top of the gravel series being genetically related to the "older" cutoff lies some 2 m higher than that of the "younger" cutoff. Within the latter the successively younger edges are accompanied by swales and ridges which indicate channel shift. There has been no channel shift downstream.

Since in the eastern part the pit which goes below the water table is not kept dry by pumping, exposures were mainly examined in its western part.

The gravel series which has been investigated in detail (profiles B2, 12, 15, 25, 26) contained 38 – 73% of gravels (as a rule, more than 40% — Fig. 5, 6, 7).

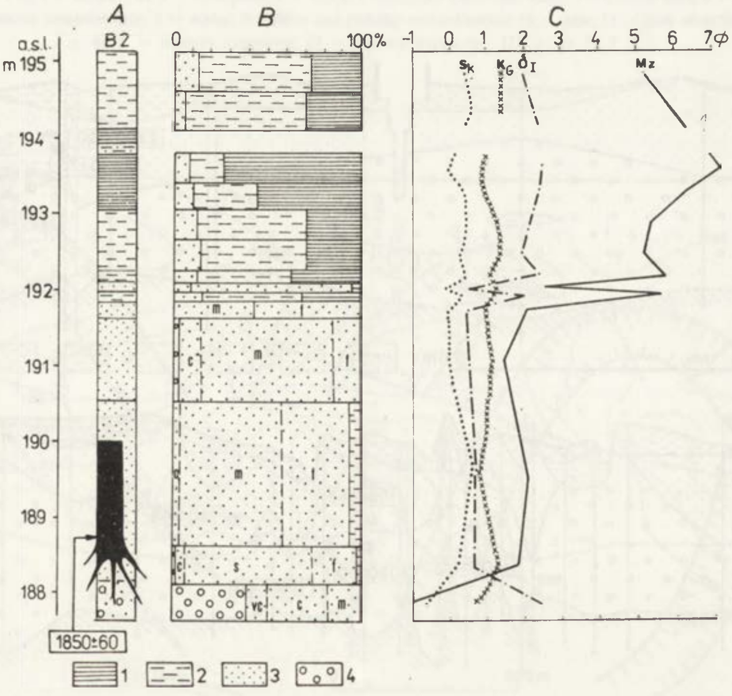

Fig. 5. Geological section B2 (*A*) at Branice – Stryjów, grain size composition (*B*) and grain size distribution parameters (*C*) (by T. Kalicki)

1 — clays; *2* — silts; *3* — sands: *vc* — very coarse, *c* — coarse, *m* — medium, *f* — fine; *4* — gravels

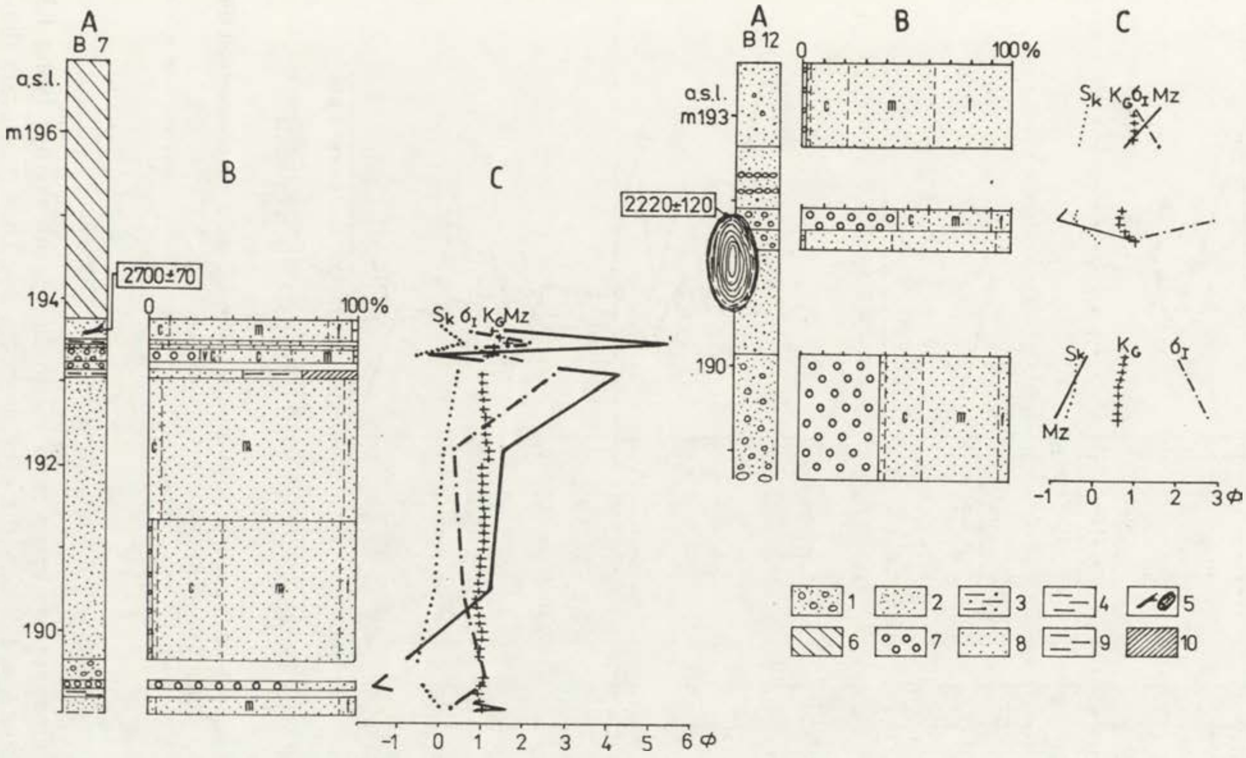

Fig. 6. Geological profiles B7 and B12 (*A*) at Branice–Stryjów, grain size composition (*B*) and grain size distribution parameters (*C*) (by T. Kalicki)

1 – gravels and sands; *2* – sands; *3* – sandy silts; *4* – silts; *5* – black oak boughs and trunks; *6* – embankments. Fractions: *7* – gravel; *8* – sand: *vc*, *c*, *m*, *f* – abbreviations are as for Fig. 5; *9* – dust; *10* – clay

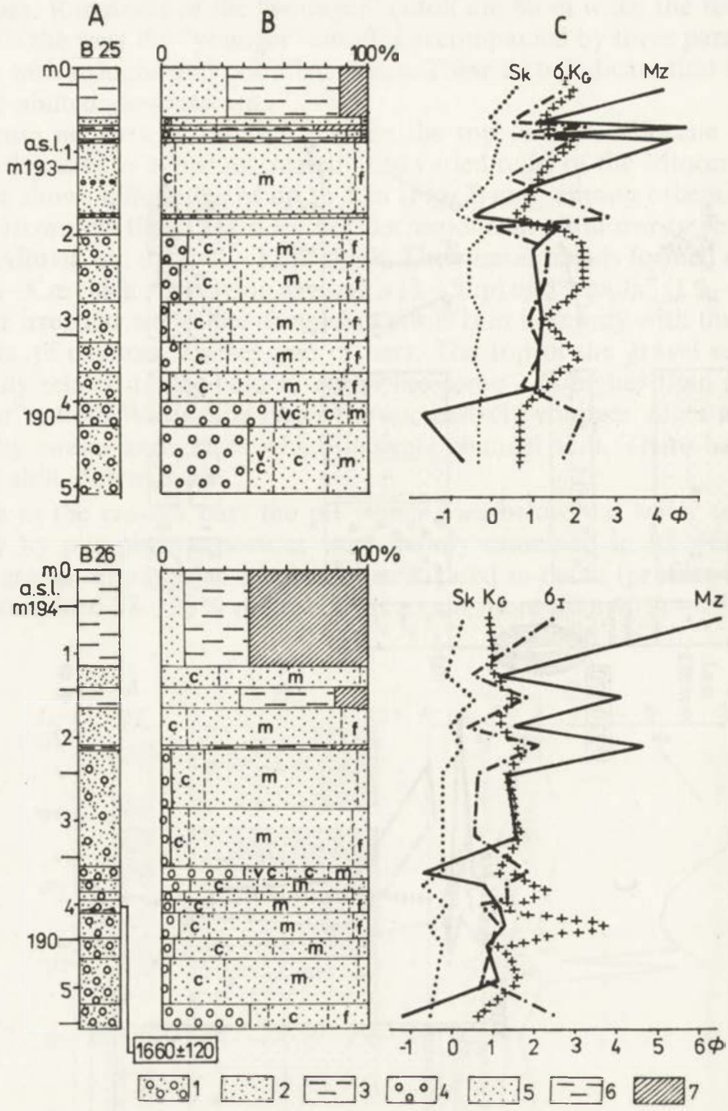

Fig. 7. Geological profiles B25 and B26 (*A*) at Branice–Stryjów, grain size composition (*B*) and grain size distribution parameters (*C*) (by T. Kalicki)

1 – gravels and sands; *2* – sands; *3* – silts. Fractions: *4* – gravel; *5* – sand: *vc, c, m, f* – abbreviations are as for Fig. 5; *6* – dust; *7* – clay

Mean grain diameter *Mz* varies from 0.7 to 2.6 ∅, the average being 1.3 ∅. The sorting index is 1.8–2.8, the average being 2.4. Thus it appears that the gravel series is very poorly and poorly sorted. Gravels mostly comprise Carpathian sandstones with a small admixture of Jurassic flints and limestones (Rutkowski, Sokołowski 1983).

The gravel series includes dusty intercalations. These were disclosed by

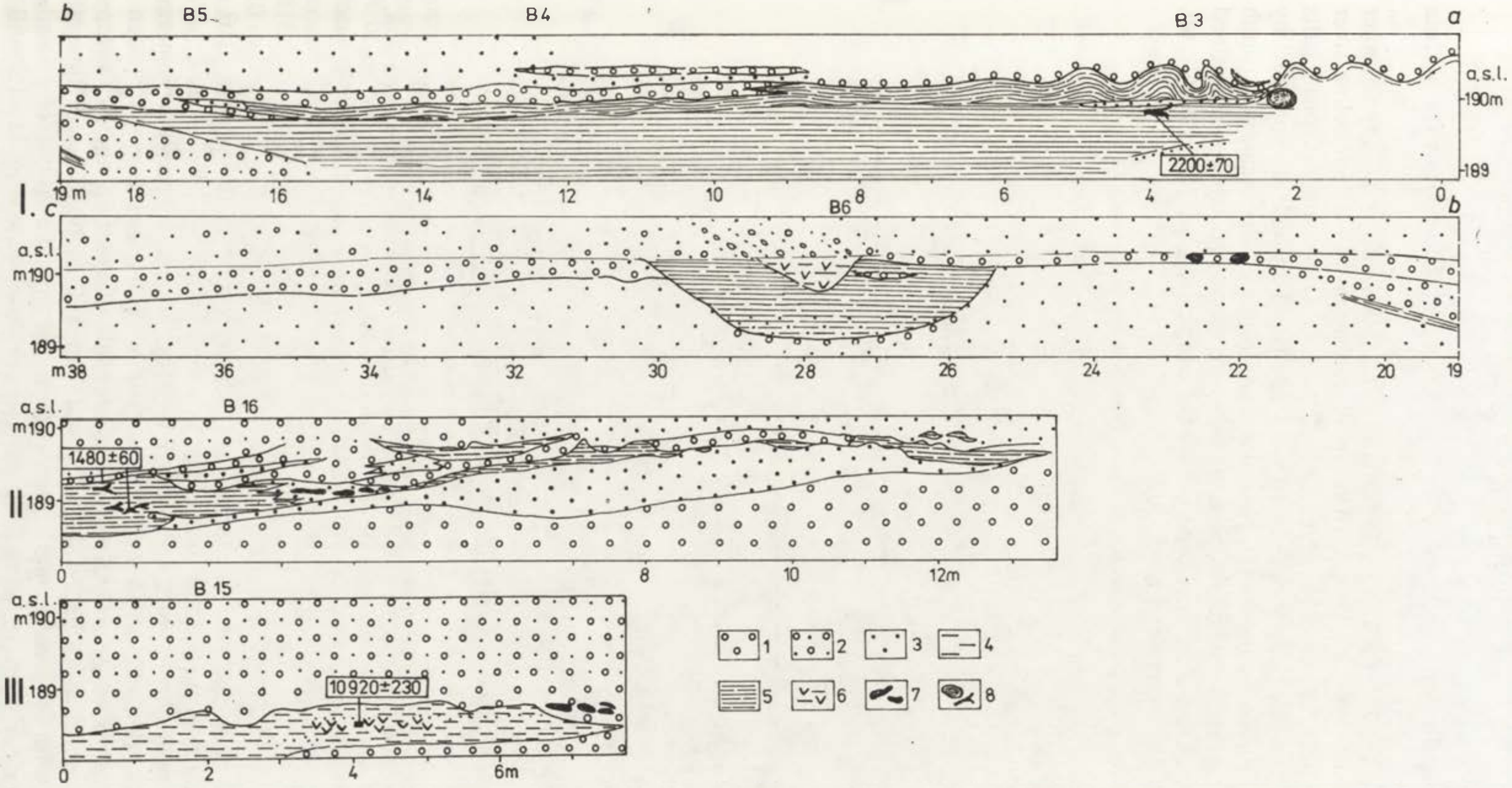

Fig. 8. Detailed profiles of the palaeomeander fills at Branice – Stryjów: profiles of Subatlantic deposits B3 – B6 (I) and B16 (II) and of lateglacial deposits B15 (III) (by L. Starkel 1984, completed)

1 – gravels; *2* – gravels and sands; *3* – sands; *4* – silts; *5* – clays; *6* – peaty silts; *7* – clay balls; *8* – trunks and boughs borings at depths of 6.2 – 8.8, 4.4 – 4.6, 1.7 – 3.8 m and 0.8 m below the Vistula level.

In the profile B15 (at 188.5 – 189 m a.s.l.) dusty silts ($Mz = 5.7$ Ø), together with sandy silts ($Mz = 3.7 - 4.2$ Ø) occur at depths of 0.6 – 1.5 m below river level. These silts are poorly sorted ($\sigma_1 = 2.0 - 2.4$). Overlying are peaty silts ($Mz = 6.2$ Ø) which gave a date of 10920 ± 230 BP. This date is supported by a lateglacial pollen spectrum (D. Nalepka, this volume). Silts occupy a trough cut into the gravels. At the same time, silts are truncated by a well defined surface. The fossil channel can, therefore, be related to the Lateglacial, probably to the Allerød (Fig. 8, 9).

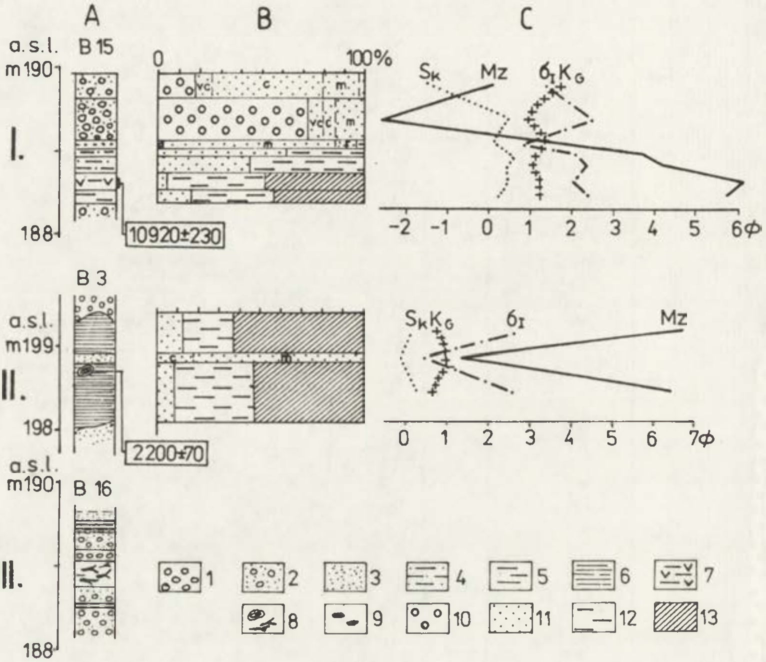

Fig. 9. Geological profiles B15, B3 and B16 (*A*) of the palaeomeander fills at Branice – Stryjów, grain size composition (*B*) and grain size distribution parameters (*C*) (by T. Kalicki)

1 — gravels; *2* — gravels and sands; *3* — sands; *4* — sandy silts; *5* — silts; *6* — clays; *7* — peaty silts; *8* — boughs; *9* — clay balls. Fractions: *10* — gravel; *11* — sand: *vc, c, m, f* — abbreviations are as for Fig. 5; *12* — dust; *13* — clay

Some 30 m to the west silts and clays were recorded in the profiles B16, B3-6 and others in the western side of the exposure at 188.5 – 190.5 m a.s.l., i.e. from 1.5 m below to 0.3 m above river level (Fig. 10, 11). In previous papers (Starkel 1984; Kalicki, Starkel 1987) the profiles B3-4 and B16 have been interpreted as various inserted palaeomeander fills of differing age. However, the distribution of both deposits and exposures makes it possible to connect the profiles with each other and to reconstruct the possible course of a fossil cutoff being clearly developed as a meander, some 40 m wide (Fig. 11). Its infill

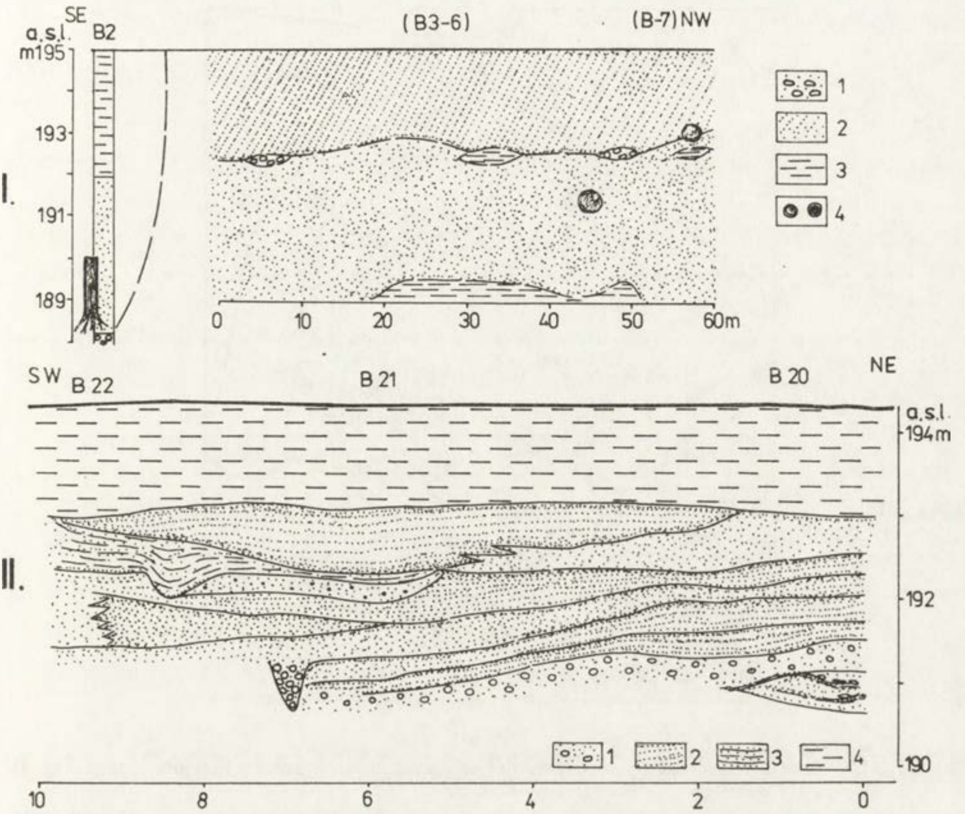

Fig. 10. Geological sections across both the exposures on the "western side" (I) and the point bar zone of the "older" cutoff (II) at Branice – Stryjów (by T. Kalicki)

I: *1* – gravels and sands; *2* – sands; *3* – silty and clayey palaeomeander fills and "mada"; *4* – black oak trunks. II: *1* – gravels and sands; *2* – sands; *3* – sands with silts; *4* – silts

(profile B3) consists of very fine clayey silts ($Mz = 6.4 - 6.7$ ∅) which are very poorly sorted ($\sigma_I = 2.6$). In the profile B16 these silts interfinger with gravels. A hewn piece of wood which probably comes from a palisade, was found in these silts (B3). It yielded a date of 2200±70 BP. A dating of 1480±60 BP (comp. Fig. 8) was obtained on another piece of wood recorded in the profile B16. This infill is also truncated and covered with pebbles and cobbles, up to 10 cm in diameter. The above palaeomeander infill appears to belong to a horizon the base of which lies below river level, but the top occurs above the Vistula level. This horizon should be ascribed to a period of deep channel incision that took place around 2000 years ago (Fig. 8, 9).

The above quoted palaeomeander fills being inserted into the gravels are truncated by well defined erosional surfaces which are covered with younger channel deposits. The latter are already related to the "older" surficial cutoff generation. The presence of an erosional surface at 189 – 190 m a.s.l. is documented by channel lag deposits (B7), silty intercalations, balls and many

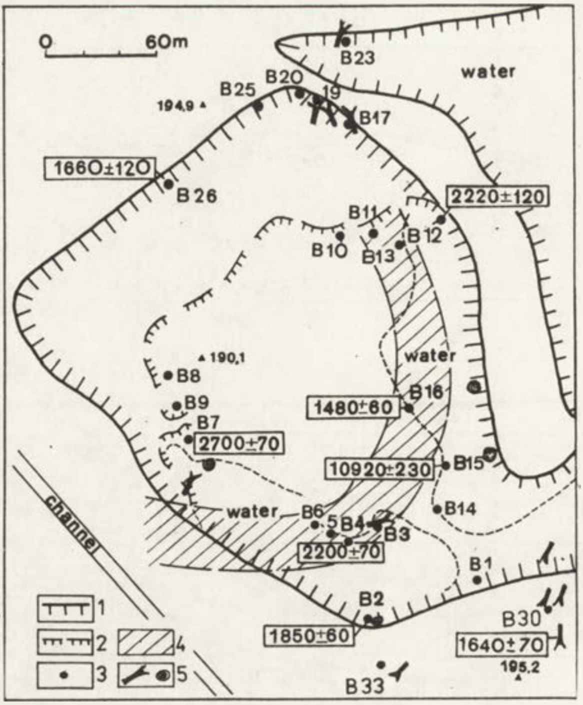

Fig. 11. Map showing the western exposures in the gravel pit at Branice – Stryjów (comp. Fig. 1) (by T. Kalicki)

1 – pit scarps; *2* – scarps of the older pit; *3* – working profiles; *4* – outline of the fossil palaeomeander; *5* – black oak trunks and direction of their position

tree trunks occurring at this level. Their directions may be related to the "older" cutoff (Fig. 6, 12). The infill of the latter includes three depositional units the sequence of which is typical of a meandering river (profiles B25, 26; Fig. 7, 13). The lower channel unit is sandy, with a small admixture of gravels. In places, the beds are exceptionally gravelly. Mean diameter oscillates around 1 ∅, sorting is moderate or poor ($\sigma_I = 0.7-1.4$). The overlying almost pure sands are well sorted ($\sigma_I = 0.4-0.6$) point bar deposits ($Mz = 1.5-2.0$ ∅). Both units are separated by interbedded gravels, plant detritus, silts and tree trunks at 191 – 193 m a.s.l. According to K. Wasylikowa, the macrofossils included *Fagus*, *Quercus*, *Carpinus and Potamogeton* fruits; pollen of *Pinus*, *Picea*, *Alnus*, *Tilia*, *Ulmus*, *Abies*, *Carpinus* and *Fraxinus* also were present. The above deposit indicates the former high position of the Vistula channel. Datings on the poorly preserved plant remains (2700 ± 70 and 1660 ± 120 BP) and on an oak trunk (2200 ± 120 BP) revealed that the materials have been redeposited from the washed older sediments (Fig. 6).

On the irregular top of both channel deposits and point bar deposits there rest overbank deposits (B1, B2, B20, B25, B30, B26; Fig. 5, 13, 14). These are highly varied at the bottom, where plentiful sandy and silty intercalations tend

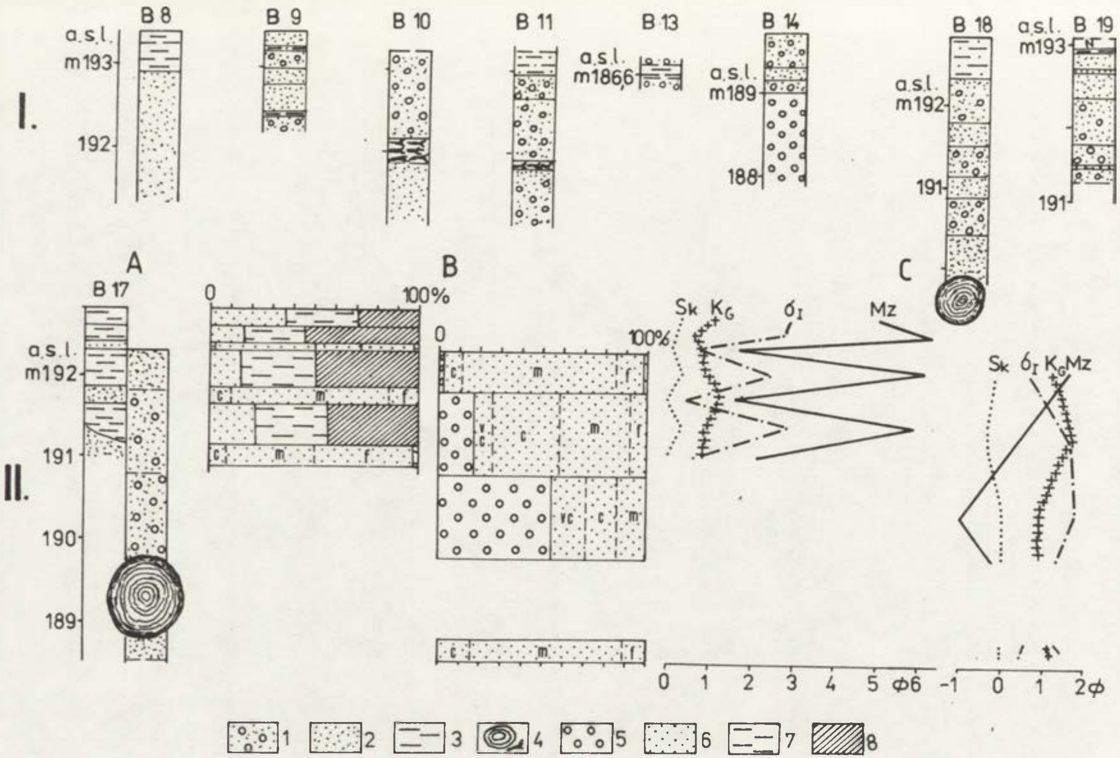

Fig. 12. (I) Geological profiles B8, B9, B10, B11, B13, B14, B18, B19 and (II) profile B17 (*A*), grain size composition (*B*) and grain size distribution parameters (*C*) at Branice–Stryjów (by T. Kalicki)

1 – gravels and sands; *2* – sands; *3* – silts; *4* – black oak trunks and boughs. Fractions: *5* – gravel; *6* – sand: *vc*, *c*, *m*, *f* – abbreviations are as for Fig. 5; *7* – dust; *8* – clay

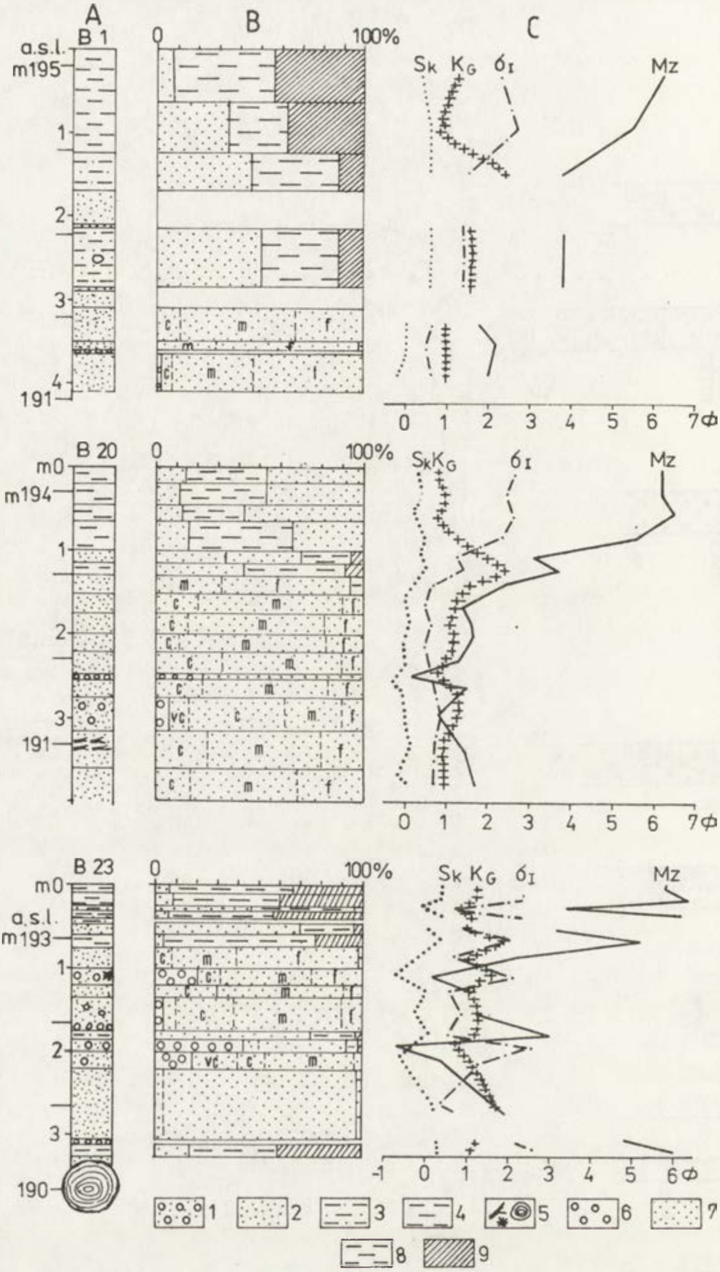

Fig. 13. Geological profiles B1, B20 and B23 (*A*) at Branice – Stryjów, grain size composition (*B*) and grain size distribution parameters (*C*) (by T. Kalicki)

1 – gravels and sands; *2* – sands; *3* – sandy silts; *4* – silts; *5* – boughs, trunks and broken ceramics. Fractions: *6* – gravel; *7* – sand: *vc*, *c*, *m*, *f* – abbreviations are as for Fig. 5; *8* – dust; *9* – clay

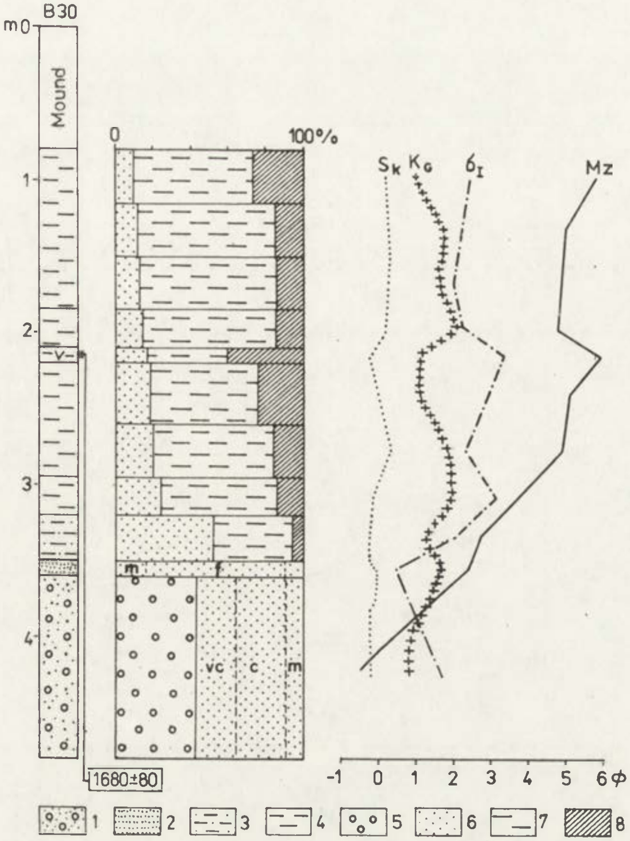

Fig. 14. Geological profile B30, grain size composition and grain size distribution parameters (by T. Kalicki)

1 — gravels and sands; *2* — sands; *3* — sandy silts; *4* — silts. Fractions: *5* — gravel; *6* — sand: *vc*, *c*, *m*, *f* — abbreviations are as for Fig. 5; *7* — dust; *8* — clay

to occur. Overlying is a dusty-sandy "mada" ($Mz = 5.6-7.3\ \varnothing$) being very poorly sorted ($\sigma_I =$ c. 2.5). The silty-peaty intercalation in the "mada" which fill a shallow channel cut into the gravels gave a date of 1680 ± 80 BP (Fig. 14). It indicates a young age of the "mada" at Branice – Stryjów. "Mada" deposition took place during the last 1500 years (comp. Kalicki, this volume).

The "older" cutoff is occupied by very poorly sorted ($\sigma_I = 2.4$) silts ($Mz = 5.2-6.4\ \varnothing$) and sands. Gravelly intercalations indicate flood incursions from the nearby active Vistula channel.

In the eastern part of the gravel pit a sandy-silty infill of the oldest trough which accompanies the "younger" cutoff has been found (B27, 28; Fig. 15). In the space of exposures a trough is visible. It is filled with very poorly sorted ($\sigma_I = 2.3-2.8$) clayey silts ($Mz = 6.3-7.6\ \varnothing$) (B29). Underlying are sands showing both a cross bedding and a trough cross bedding. The proportion of gravels is small ($Mz = 1.8\ \varnothing$).

The moderately sorted ($\sigma_I = 0.8$) sands may be considered as the top series of the channel deposits.

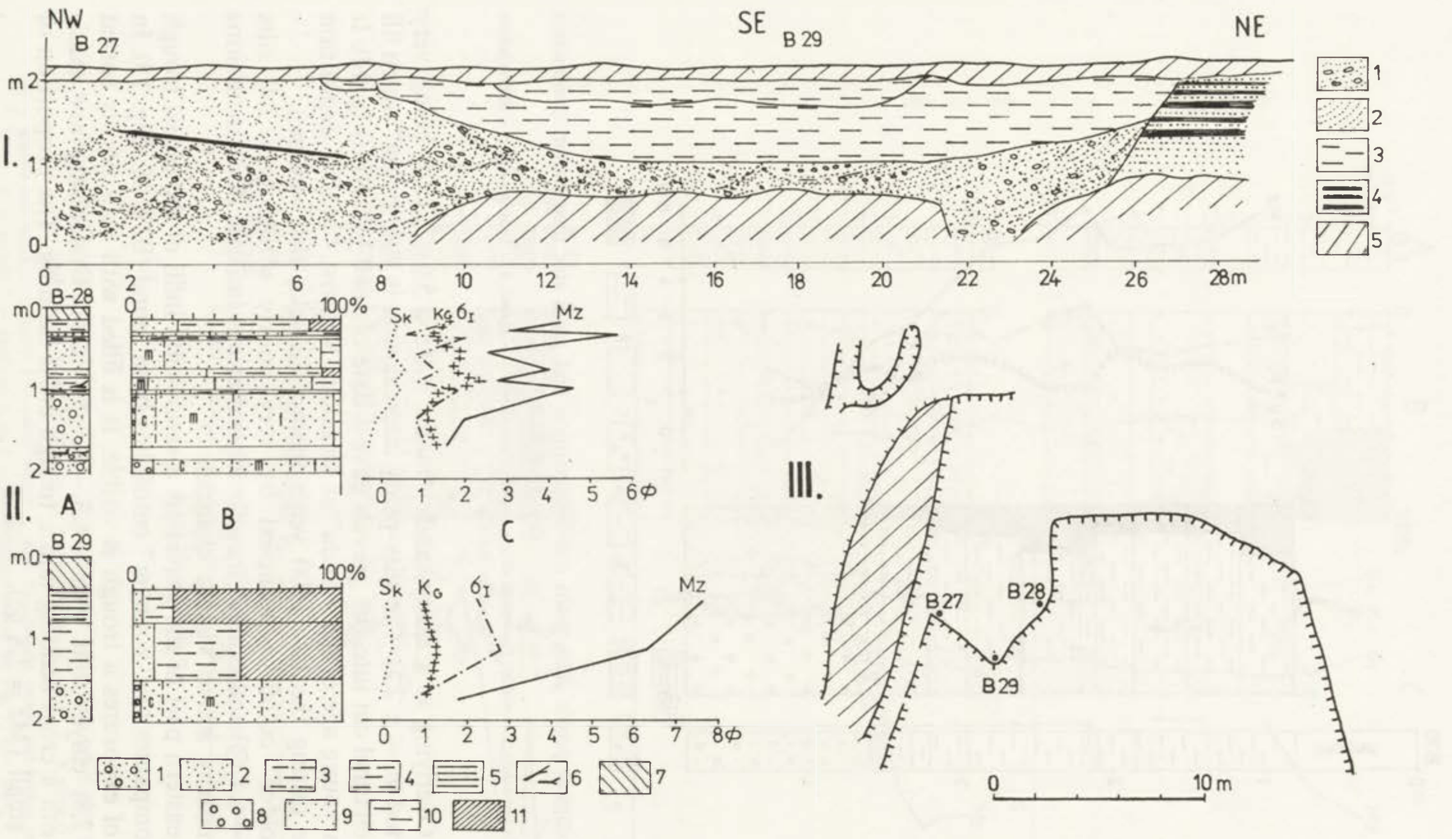

Fig. 15. Eastern exposures in the gravel pit at Branice–Stryjów (comp. Fig. 1) (by T. Kalicki)

I. Geological section: *1* – sands and gravels; *2* – sands; *3* – silts; *4* – silty and clayey intercalations; *5* – embankment. II. Geological profiles B28 and B29 (*A*), grain size composition (*B*) and grain size distribution parameters (*C*): *1* – sands and gravels; *2* – sands; *3* – sandy silts; *4* – silts; *5* – clays; *6* – boughs; *7* – embankment. Fractions: *8* – gravel; *9* – sand: *c*, *m*, *f* – abbreviations are as for Fig. 5; *10* – dust; *11* – clay. III. Map showing the exposures

DENDROCHRONOLOGY

In the gravel pit at Branice – Stryjów many subfossil oak trunks have been found in the sandy-gravelly deposits at different depths (Fig. 4). The majority of trunks had well preserved root systems, fragments of boughs and, occasionally, also sapwood and the bark. These had obviously been transported but a very short distance. However, trunks aligned parallel to the direction of visible meanders and the occurrence of trunks in the younger channel deposits (Fig. 4, 11) indicate that in many cases redeposition took place. The trunks reached up to 1.3 m in diameter (measured 1 m above the roots), and they were up to 18 m long. The fallen trees grew from between 80 and 340 years.

For the purpose of dendrochronological studies, 61 slices of oak trunks have been obtained, 1.0 – 1.5 m above the roots. Tree ring widths were scanned with an accuracy of 1/100 mm by means of the Krąpiec apparatus with a computer registration. On each of the slices tree ring width was measured along 2 to 4 core radii. For the correlation of the dendrochronological curves a computer correlation program by A. Krawczyk (of the Institute of Geology and Mineral Resources, Academy of Mining and Metallurgy) based on M. Baillie's and J. Pilcher's method (1973) was used. The result of both visual comparison and computer correlation are three floating chronologies: BI – II, BIII and BIV (Fig. 16).

The floating chronology BI – II covers 316 years. Evidence has been yielded by 18 trunks, with 80 to 313 rings. In part, sapwood was preserved in three trunks out of the 18 trunks: b16 – 11 rings, b46 – 10 rings, b10 – 9 rings and b28 – 1 ring. Within the chronology BI – II two groups of trunks have been

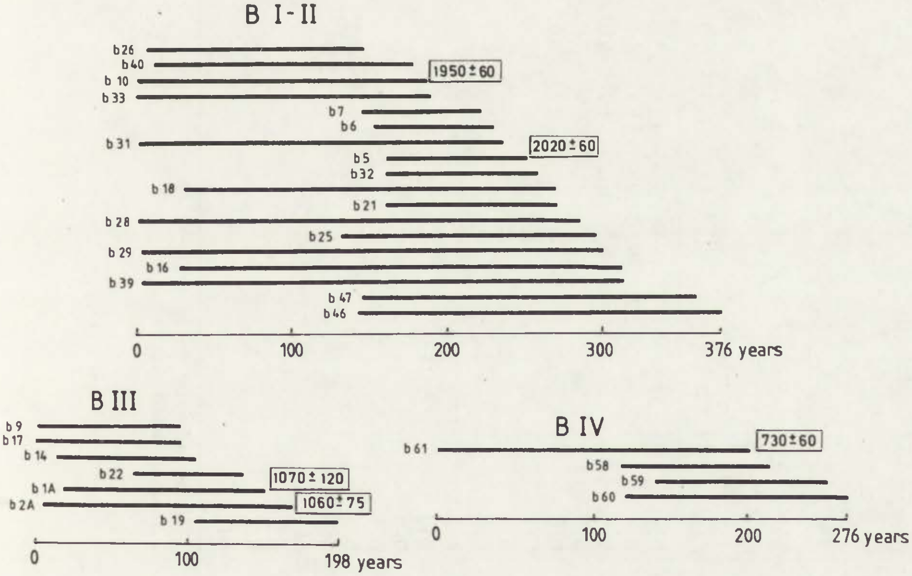

Fig. 16. Periodical ranges of the black oaks within the floating chronologies BI – II, BIII and BIV (by M. Krąpiec)

Table 1. Comparison of values of the *t*-Student coefficient of the individual pairs of dendrochronological curves within the chronology BI–II (by M. Krąpiec)

	b39	b29	b28	b16	b18	b31	b33	b10	b25	b40	b26	b21	b32	b5	b6	b7	b46	b47
b39		23.41	16.58	11.18	8.15	12.47	10.60	9.62	10.06	9.09	3.27	5.22	8.15	5.82	6.09	5.25	4.49	3.43
b29			12.76	9.58	6.95	11.31	9.80	8.31	7.76	8.46	*	4.01	6.30	3.65	5.12	3.51	4.60	3.01
b28				10.04	10.29	8.91	9.03	7.88	7.76	7.60	4.28	5.20	6.23	5.77	5.77	3.49	4.01	+
b16					10.74	9.90	9.07	7.70	5.50	7.64	3.58	4.54	3.42	4.26	3.30	3.42	4.14	3.83
b18						6.22	6.67	5.21	*	5.26	3.14	3.52	3.68	*	*	*	*	*
b31							11.98	9.59	4.19	7.79	4.44	*	3.17	*	4.12	*	5.21	*
b33								16.20	*	10.39	4.24	–	–	–	–	–	–	–
b10									*	10.21	4.31	–	–	–	–	–	–	–
b25										–	–	6.71	5.33	4.78	5.84	6.07	6.41	4.84
b40											*	–	–	–	–	–	–	–
b26												–	–	–	–	–	–	–
b21													5.85	*	4.64	4.18	3.36	3.42
b32														5.32	4.65	6.77	4.11	4.00
b5															5.99	4.96	4.51	4.74
b6																6.78	5.46	3.65
b7																	4.63	4.39
b46																		10.89
b47																		

– time range up to 50 years.
* *t* value below 3.0.

distinguished: BI (b5, b6, b7, b21, b25, b46, b47) and BII (b10, b16, b18, b29, b31, b33, b39, b40). The BI and BII trees began to grow almost at the same time, the BII trees expanded some 150 years earlier than those grouped into BI. This may indicate the establishment of oak trees on the young floodplain. All curves correspond closely in spacing, the values of the *t* coefficient being especially high (Tab. 1). The correlation is supported by the presence of the W-signature within BI (Fig. 17). The outer tree rings of three trunks have been radiocarbon dated at: b5 – 2020±60 BP, b10 – 1950±60 BP and b39 – 1880±80 BP. Thus it appears that the chronology BI – II covers the period from 2200 to 1830 years BP. The chronology obtained has been correlated with Becker's chronology (1981). Thus, the only significant value of the *t* coefficient = 4.19 for 201 BC – 175 AD was got. During this period the correlated curves correspond fairly in spacing.

Fig. 17. Dendrochronological curves with the W-signature within the floating chronology BI – II (by M. Krąpiec)

The chronology BIII was constructed on the basis of seven trunks. It covers 198 years (Fig. 16). All dendrochronological curves here correspond closely in spacing. The value of the *t* coefficient varies from 3.6 to 15.5 (Tab. 2). The outer tree rings of two trunks have been radiocarbon dated at: b1A – 1070±120 BP and b2A – 1060±75 BP. The floating chronology BIII thus covers the period from 1230 to 1030 BP. Comparison of BIII with Becker's chronology (1981) revealed that the *t* value is 3.97 for AD 957–1154, and that the curves fairly coincide.

Table 2. Comparison of values of the *t*-Student coefficient of the individual pairs of dendrochronological curves within the chronology BIII (by M. Krąpiec)

	b2A	b1A	b17	b19	b9	b14	b22
b2A		9.63	6.04	5.0	7.08	4.97	4.23
b1A			5.41	3.87	8.10	5.27	3.75
b17				–	14.09	5.11	5.62
b19					–	–	3.62
b9						4.44	7.89
b14							*
b22							

– time range up to 50 years.
* *t* value below 3.0.

The floating chronology BIV was constructed on the basis of four trunks. It covers 267 years (Fig. 16). The *t* coefficient for the individual pairs of curves ranges from 5.07 to 8.65. The outer rings of the trunk b61 have been ^{14}C dated at 730±60 years BP. It is likely that this chronology covers the period from 930 to 670 BP. The chronology obtained was correlated with Becker's chronology (1981). It appears that the *t* value is 3.78 for the period from AD 1227 to 1493.

The remaining trunks which do not fall into BI–II and BIII date from other periods. This is confirmed by ^{14}C datings on the trunks: b3 – 1230±60 BP, b4 – 1400±60 BP and b42 – 1640±70 BP.

Earlier studies carried out in the western part of the gravel pit revealed the presence of more than ten stumps hewn by man. Two stumps were dated at 1850±60 BP and 1950±60 BP (Starkel 1984). These stumps have been cut down with axes, 0.5–1.5 m above the roots. It is likely that the trees were growing on a sandy "mada" the remnants of which frequently survived among the roots. Furthermore, dates of 3060±80 BP (b15) and of 2260±80 BP (b36) were obtained for other stumps hewn by man. The latter have been disclosed in the exposure D3.

Distinctive differences in the distribution of two generation tree trunks may be observed (Fig. 3). The older trunks (BI–II) are to be found in the whole gravel pit, whereas the younger trunks (BIII), as well as trunks dated at 1200±110 BP and 1400±60 BP occur only in the "younger" cutoff. It is noteworthy that in this cutoff successively younger trunks are traceable from west to east. Their ages range from 1640±70 BP in the oldest and westernmost trough to 730±60 BP in the youngest trough which became cut off in the 19th century.

SUMMARY

The above data make it possible to reconstruct the scheme of the succession of deposits being exposed in the gravel pit at Branice (Fig. 18). In its western part there may be distinguished three series of deposits which indicate aggradation. Gravels, together with an Allerød palaeomeander infill became truncated by a migrating Subatlantic channel which has been dated at 2200–1480 BP.

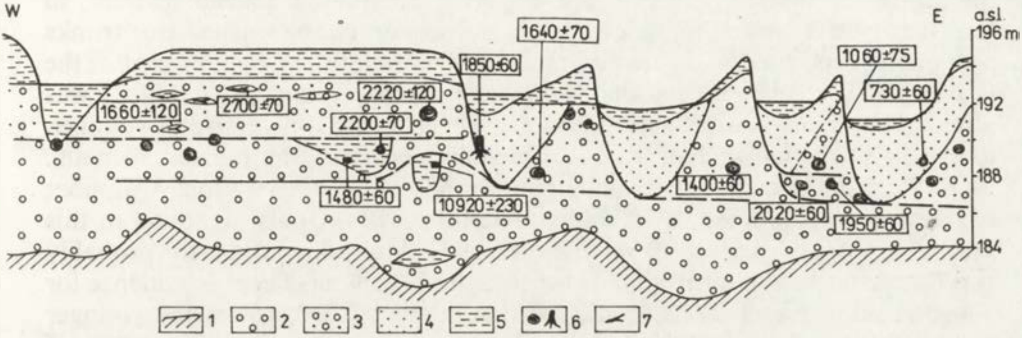

Fig. 18. Stratigraphical scheme of alluvia exposed in the gravel pit at Branice – Stryjów (by T. Kalicki)

1 – Miocene clay; *2* – gravels; *3* – gravels and sands; *4* – sands; *5* – silts and "mada"; *6* – black oak trunks and stumps cut by man; *7* – plant detritus

Subsequent incision of the Vistula commenced at the onset of the Subboreal to reach its postglacial maximum around 2000 BP (Kalicki, this volume). At that time, pattern changes of the Vistula river channel took place on the evidence of datings on both a fossil channel infill at Branice – Stryjów (profile B3-4; 2200 ± 70 BP) and a meander infill found in the Cracow Gate (2100 ± 80 BP) (Rutkowski 1987). At the same time, the rise of the ground water table shows itself in peat initiation in the troughs of the cutoffs, with a date of 2370 ± 100 BP. However, peat accumulation became interrupted by the deposition of sand and sand-and-gravels during floods of high magnitude (Kalicki, this volume). There also were deposited the older fallen trees at Branice – Stryjów (BI – II with a date of c. 2000 BP (AD 100) and the single trunks found at Przegorzały in the Cracow Gate (1820 ± 100 BP; Tauber 1968), at Salwator (1775 ± 280 BP; Środoń 1980), at Ściejowice (Krąpiec, 1988), in the Oświęcim Basin, at Smolice and Podolsze, and downstream of Cracow in the surroundings of Tarnobrzeg (1850 ± 35BP; Mycielska-Dowgiałło 1972). These data point to wetter climatic conditions from c. 2200 BP to 1800 BP which were accompanied by increasing river activity. Furthermore this phase has been recognized in the drainage basins of the Rhine and the Danube, with a maximum of tree trunk accumulation then in the alluvia (Becker 1981). It also was stated in the other European river valleys (Starkel 1983).

At the time when the Vistula river channel was deeply incised (2000 – 1800 BP) widespread clearance of the floodplain woodland took place. This change in the land use pattern may probably be related to the spread of settlement on the loess-covered terrace. Pottery was well developed there on the evidence of a great number of furnaces (Godłowska 1984). Deforestation of the floodplain began as early as c. 3000 years BP. It could have had a significant morphological impact on this area, since it aided the free lateral migration of the meanders (Kalicki, this volume).

It is likely that from the late Roman period onward increasing human activity in the Vistula catchment gave rise to a well defined aggradation being of the order of 3 – 4 m (Fig. 18). Evidence of this process is provided by the upper series of sediments occupying the "older" superficial cutoff. This migrating channel cut across the lower lying Subatlantic palaeomeander, so that the river reworked its older alluvia. Subsequently, the washed tree trunks became incorporated with the new channel deposits. In the eastern part of the gravel pit there are exposed deposits occupying the "younger" cutoff. It was already associated with slow erosion. There occur successively younger, inserted alluvia which have been formed by the river shifting downstream. These deposits contain trunks belonging to the younger generation. A number of tree trunks belonging to the older generation (BI – II) also is found in this area. They were derived from the washed older alluvia which probably survived beneath the third, shallowest trough in the west. There is evidence for it in the sequence of tree trunks recorded in the pit D3, where the younger trunks (BIII) occur at a shallow depth. They were first excavated. Deposition of the fallen trees may be related to the beginning of a successively wetter phase in the 11th century. According to K. Radwański (1972), this century saw the spread of settlements hitherto located on the floodplain of the Vistula onto the higher terrace, as well as the construction of dikes in Cracow. The falls of the individual trees may be correlated with the dates of flood occurrence in the Vistula valley which have been established on historical records (*Wyjątki*..., 1965). This phase also was identified in the other valleys, as for example, in southern Germany, in the Berezyna valley (Kalicki, in preparation), in the Vistula valley within the Oświęcim Basiu (Niedziałkowska *et al.* 1985), in the Wisłoka valley (Alexandrowicz *et al.* 1981) and in the upland valleys (Lindner 1977).

The falls of the youngest trunks (BIV) should be related to the beginning of the successive climatic deterioration, i.e. to the Little Ice Age. This phase also showed itself in the deposition of mineral intercalations in the peat bogs near Cracow since the close of the 15th century (Radwański 1972).

Presumably, the plentiful tree trunks which have been found in the gravel pit, but especially in its eastern part, brought about channel changes of the "younger" cutoff (Fig. 19). Trunks accumulated in the convex part of the meander. Consequently, accumulation speeded up on the point bars, and sinuosity of the meander tended to increase. The meander became cut off by flooding and perhaps by ice jams. Such a scheme of the development of the "younger" meander is documented by black oak trunks aligned mainly west-east at the trough inlets (Fig. 3, 19). Furthermore, oaks decreasing in ages from west to east make it possible to determine both the time boundaries and the velocity of channel changes. River channel changes brought about by a great number of floating tree trunks are known to occur on the Russian rivers (Domogashev, Sergutin 1987).

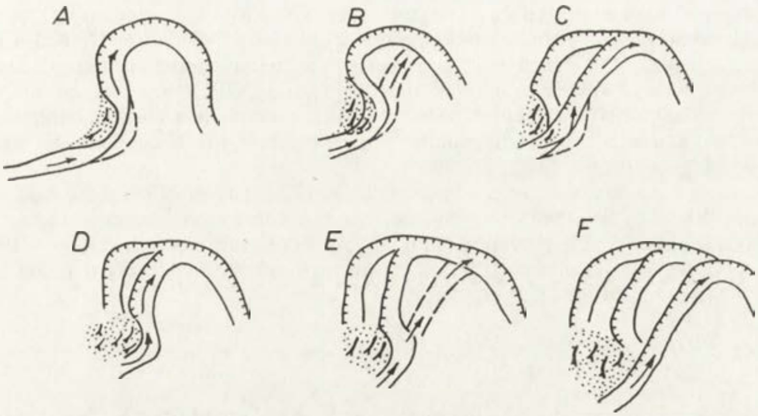

Fig. 19. Model proposed for chute cut-offs within the "younger" cutoff at Branice – Stryjów (by T. Kalicki)

APPENDIX

TADEUSZ KUC

PROCEDURE OF RADIOCARBON DATING IN THE CRACOW LABORATORY

The ^{14}C measurement method applied in the laboratory is liquid scintillation counting on synthetized benzene in a LSC spectrometer TRI-CARB model 3320 (Packard International).

Usually 15 – 20 g of wood, mechanically cut into small chips, are chemically pretreated, according to the following procedure: 4% HCl, 80°C, overnight; 4% NaOH, 80°C, overnight; 4% HCl, 80°C, several hours; each step being separated by rinsing with distilled water. Finally, samples are dried for several hours at c. 110°C in a temperature-controlled oven. Combustion is carried out in a pressurized vessel filled with pure oxygen (Grabczak *et al.* 1983), and the subsequent separation of CO_2 from O_2 and other contaminants (mainly H_2O) is done in a cryogenic-vacuum line consisting of two liquid nitrogen cooled traps and two traps kept at a temperature of –70°C, respectively. Desiccated CO_2 is converted to benzene in the laboratory-produced synthesis line

Table 3. Comparison of radiocarbon datings on black oak trunks made in the Cracow Laboratory (by T. Kuc)

Laboratory code	Trunk number	Radiocarbon age in years BP
KR 18/19	b1A	1070 ± 120
KR 20/22	b2A	1060 ± 75
KR 33/33A	b3	1230 ± 60
KR 34/35	b4	1400 ± 60
KR 36/37	b5	2020 ± 60
KR 38/39	b10	1950 ± 60
KR 49/50	b23	1040 ± 40
KR 80/82	b61	730 ± 60
KR 83/84	b42	1640 ± 70
KR 47	b15	3060 ± 80
KR 52	b36	2260 ± 80
KR 55	b39	1880 ± 80

applying the well-known procedure of transforming CO_2 to Li_2C_2 and acetylene. The final trimerization takes place on a commercially produced catalyst KC-Perlkator Di (Kali-Chemie AG, Germany). C. 2 g of C_6H_6 weighed in a "laboratory-made" teflon-copper vial (Kuc, Różański 1979) and mixed with 50 µl of toluene solution of 100:1 PPO and POPOP are counted for 2000 – 3000 minutes, sequentially at 100-minute intervals (50 µl of the scintillation cocktail contains 2.5 mg of PPO). Standard and background are counted in each batch of 4 to 6 samples. The measurement chamber is refrigerated at 6°C.

Radiocarbon dates are calculated based on the 95% activity of NBS oxalic acid as modern standard and the Libby half-life (5568 ± 30) and reported with counting error including variations in the sample, standard and background. Standard activity is normalized to $^{13}C = -19^{\circ}/_{00}$ PDB, according to Craig (1961). Determination of ^{13}C for each sample is routinely done on Micromass 602 C (VG Micromass Ltd) (Tab. 3).

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LATEGLACIAL AND EARLY HOLOCENE POLLEN DIAGRAMS IN THE WESTERN PART OF THE SANDOMIERZ BASIN PRELIMINARY RESULTS

Palaeobotanical researches were carried out in the western part of the Sandomierz Basin between Cracow and the Niepołomice Forest (Puszcza Niepołomicka). The article contains preliminary results of pollen analysis made of the Vistula oxbow fills and palaeochannel fills at Pleszów (Pl 86-1), Branice (B 15), Grobla (G 3 bis), on the Drwinka river (Dr 10), of the peat bog at Podłęże (Pł 17, Pł 40), and of the peat bog Wielkie Błoto (or Błoto) near Szarów (Pel 4) (Fig. 1).

METHODS

Materials for this study were collected during the investigation of both abandoned channel fills and peats. Studies aimed at the reconstruction of the Vistula river channel changes were conducted by P. Gębica and L. Starkel (1987), and by T. Kalicki and L. Starkel (1987). Profiles Pl 86-1, Pł 17, G 3bis were obtained using the Więckowski corer, Pł 40 and Pel 4 were obtained by means of the 8 cm diameter Instorf corer, whereas Dr 10 and B 15 were taken from the outcrops. Profiles were described according to the Troels-Smith's system (1955) using a simplified version of symbols on the diagrams.

The samples were acetolysed by Erdtman's method (Faegri and Iversen 1975). Mineral constituents were removed by decanting and hydrofluoric acid treatment. Samples obtained from Pl 86-1, Pel 4, G 3 bis, Pł 17 and Dr 10 were taken with an 1 cm^2 sampler; tablets containing *Lycopodium* spores were added in order to calculate the sporomorph concentration (Stockmarr 1971).

Simplified pollen diagrams (Fig. 2–8) show the results of pollen analysis. The percentage calculations of trees and herbs were based on the sum AP+NAP excluding aquatics, reedswamps and spores.

DESCRIPTION OF INVESTIGATED SITES AND SEDIMENTS

One profile (Pl 86-1) was taken at the Pleszów site (Fig. 1) being situated in the westernmost part of the Sandomierz Basin. It originated in a palaeochannel located close to the loess-covered terrace edge, c. 2 km east of the Neolithic

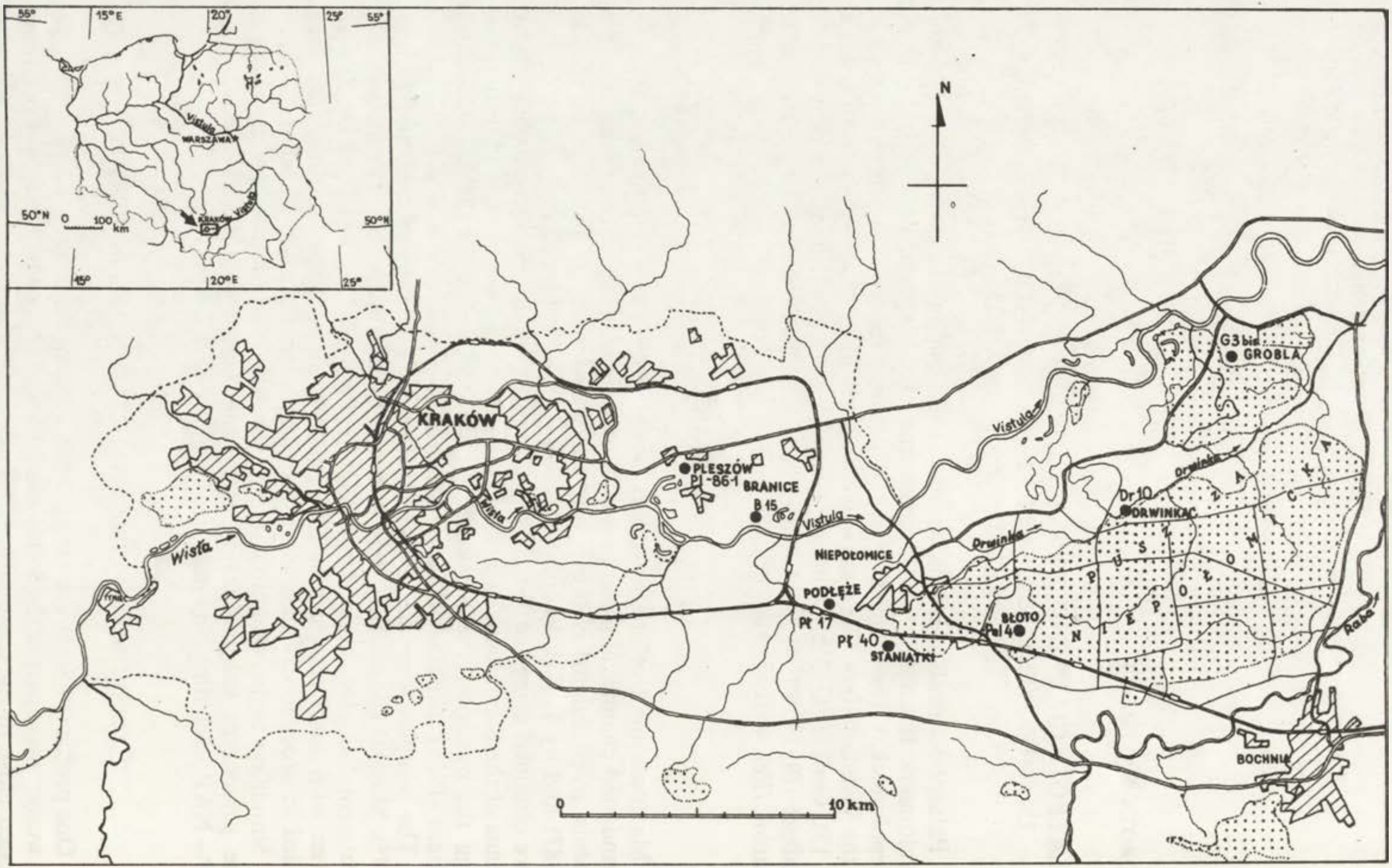


Fig. 1. Map showing the location of the sites examined

Pleszów site, where the relations between man and the natural environment were studied in detail (Wasylikowa *et al.* 1985). The sediment, 4.30 m thick, generally includes peats (Th), gyttja (Ld), gyttja with silt and peat (Ld, Ag, Th) and sand (Ga). Pieces of charcoal (anth.) and broken molluscan shells (part. test. moll.) are visible there. The material obtained from the central core segment was analysed every 3 – 10 cm. Only a few samples were examined from the upper and bottom parts.

In the fossil palaeochannel at Branice (Starkel 1984; Kalicki, Starkel 1987) the profile B 15 was taken from clays and silts (As/Ag), 45 cm thick, and from clays and silts with peats (As/Ag, Th) and sand (As/Ag, Th, Ga) lying between two gravel horizons (Gg) exposed in the gravel pit. The profile was analysed every 5 cm.

The core G 3 bis which was obtained from the oxbow lake at Grobla (Gębica, Starkel 1987; Starkel *et al.* 1988) in the northern part of the Niepołomice Forest contained peaty silts (Th, Ag) interbedded with sterile clays (As) and sands (Ga). Pieces of charcoal are visible there. About 1 m of sediments was examined by pollen analysis, one sample every 10 cm.

The profile Dr 10 was collected from the Vistula palaeochannel fills which are exposed in the present bank of the Drwinka river (Gębica, Starkel 1987) situated between the northern and southern parst of Niepołomice Forest. The sediment, 117 cm thick, is composed of clays and silts (As/Ag), peats (Th), peaty silts (Th, Ag) and gyttja (Ld). It was analysed every 3 – 5 cm.

Two profiles (Pł 17, Pł 40) were taken from the peat bog at Podłęże (Lipka *et al.* 1975) near the south-western periphery of the Niepołomice Forest at distances of some hundred metres from each other. Bottom sediments consisting of peats (Th), gyttja (Ld), clays and silts (As/Ag), gyttja with silts (Ld,

Table 1. ^{14}C dates for the profiles examined

Site	Symbol	Number of sample	Depth	Age BP
Pleszów	Pl 86-1	Gd-2692	0.48 – 0.51	3 260 ± 80
		Gd-5143	1.23 – 1.28	4 310 ± 70
		Gd-4157	3.06 – 3.11	11 570 ± 130
		Gd-2693	3.45 – 3.55	12 540 ± 150
Branice	B 15	Gd-2087	0.10 – 0.30	10 920 ± 230
Grobla	G 3bis	Gd-1787	2.07 – 2.12	10 520 ± 110
Drwinka	Dr 10	Gd-3135	0.47 – 0.54	7 980 ± 70
		Gd-5055	0.71 – 0.75	9 520 ± 110
		Gd-1849	0.75 – 0.79	8 760 ± 90
Podłężówka	Pł 17	Gd-5147	0.69 – 0.73	7 430 ± 80
		Gd-2676	1.88 – 1.91	11 850 ± 170
		Gd-2677	2.32 – 2.35	12 650 ± 200
Podłężówka	Pł 40	Gd-2590	3.09 – 3.14	11 420 ± 150
Wielkie Błoto w Szarowie	Pel 4	Gd-4236	0.22 – 0.27	9 250 ± 170
		Gd-4243	0.27 – 0.30	11 250 ± 250
		Gd-2794	0.41 – 0.47	10 550 ± 170

Ag) and peaty silts (Th, Ag) were analysed in both cores: a section, 1.20 m thick, from Pł 17 every 30 cm and from Pł 40, c. 0.40 m thick, every 2 – 7 cm.

A c. 50 cm core containing peats (Th), gyttja (Ld) and sand (Ga) with gyttja, clay and peat (Ld, As, Th) was taken from the peat bog Wielkie Błoto near Szarów (Lipka 1973; Nalepka 1989). This sediment (Pel 4) was analysed every 2 and 3 cm.

RADIOCARBON DATING

All of the profiles cited were dated by the radiocarbon method (Tab. 1). The datings were made by M. F. Pazdur in the ^{14}C Laboratory in Gliwice. At the present stage of palynological research, the ^{14}C dates are the main ground for distinguishing the chronozones in the pollen diagrams and for their mutual correlations. Both ^{14}C dates and palynological results do agree together. Only the date of 11 250 ± 150 years BP (GD-4243) for the profile Pel 4 is too old when compared with the palynological results because the dated material was taken at the boundary of different sediments. The date of 9520 ± 110 years BP (GD-5055) for the profile Dr 10 refers to rebedded sediments.

DEVELOPMENT OF THE VEGETATION

THE BØLLING CHRONOZONE

This zone is described on the basis of the whole diagram Pł 17 (Fig. 2) and of the deepest sample obtained from Pl 86-1 (Fig. 3).

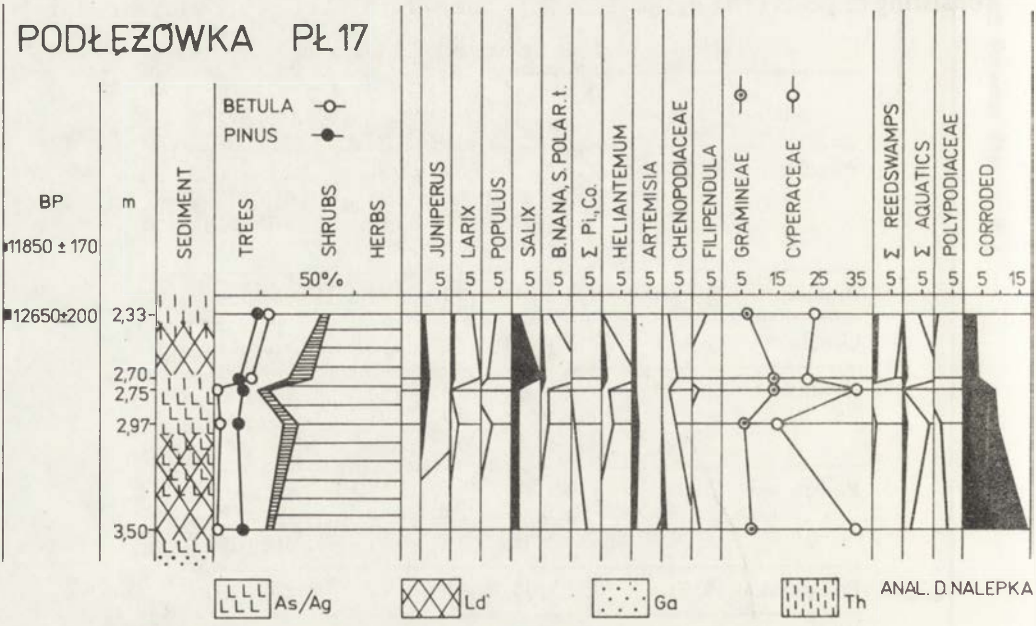


Fig. 2. Simplified pollen diagram from the Podłężówka 17 site

Pi., Co – Picea + Corylus; As/Ag – Argilla steatodes or *A. granosa; Ld – Limus detrituosus; Ga – Grana arenosa; Th – Turfa herbacea*

The described horizon is bipartite. The older part was probably treeless. The percentage of pine pollen (*Pinus*) is c. 3 – 15, and that of birch (*Betula*) is 2 – 5. Single pollen grains of the larch (*Larix*) are present. Heliophilous shrubs of juniper (*Juniperus*), small arctic-type willows (*Salix polaris* type) and herb communities with *Helianthemum*, *Chenopodiaceae* and *Artemisia* occupied open sites. *Betula nana* also was present.

A spread of scattered trees (AP increases to 35%) is visible in the younger part (prior to 12 650 BP). This is due to the expansion of birch (*Betula*), poplar (*Populus*), larch (*Larix*) and probably pine (*Pinus*).

THE ALLERØD CHRONOZONE

This zone is described on the basis of two samples obtained from Pl 86-1 (Fig. 3) at the depth of 3.07 – 3.12 m and from the whole diagram Pł 40 (Fig. 4).

The vegetation at first was similar to that in the younger part of the Bølling chronozone, may be it contained only a greater amount of *Hippophaë* (Pl 86-1). The role played by pine (*Pinus*) and birch (*Betula*) then increased, and probably poplars (*Populus*), willows (*Salix*) and *Hippophaë* spread out. *Betula nana*, *Helianthemum*, *Artemisia* and *Chenopodiaceae* became more important. *Urtica* and *Filipendula* appeared in the more shaded places. This change in the local vegetation resulted in an open forest-dominated landscape.

The diagram Pł 40 may be interpreted as a reflection of the spread of pine-birch forest (high AP curve) with larch and poplar and the presence of heliophilous juniper shrubs, as well as herb communities with *Artemisia* and *Helianthemum*. This profile was included in the Allerød chronozone, though it distinguishes itself by the presence of alder (*Alnus*) and hazel (*Corylus*) pollen which probably comes from a far distance or from a secondary bed.

THE YOUNGER DRYAS CHRONOZONE

This zone is described on the basis of the bottom part of the profiles Pel 4, G 3bis, B 15 (Fig. 5, 6, 7).

The landscape was dominated by the open pine (*Pinus*) forest with birch (*Betula*), a small number of larch (*Larix*) and may be aspen (*Populus tremula*?). Willows (*Salix*) and poplars (*Populus*) were present. *Juniperus*, *Hippophaë* and the herbaceous heliophytes *Artemisia*, *Chenopodiaceae*, *Sanguisorba officinalis* and *Selaginella* occupied open areas. *Filipendula* and *Urtica* were flourishing, and *Betula nana* and arctic-type willows of *Salix polaris* type occurred on the peat bog. At the turn of the Younger Dryas and Preboreal there was a short-lasting expansion of birch. The participation of willows (*Salix*), poplars (*Populus*), *Betula nana* and *Salix polaris* type decreased.

THE PREBOREAL CHRONOZONE

This zone is characterized on the basis of four profiles: the bottom section of Dr 10 (Fig. 8), the central section of G 3bis and Pl 86-1 (Fig. 6, 3), and the upper section of Pel 4 (Fig. 5).

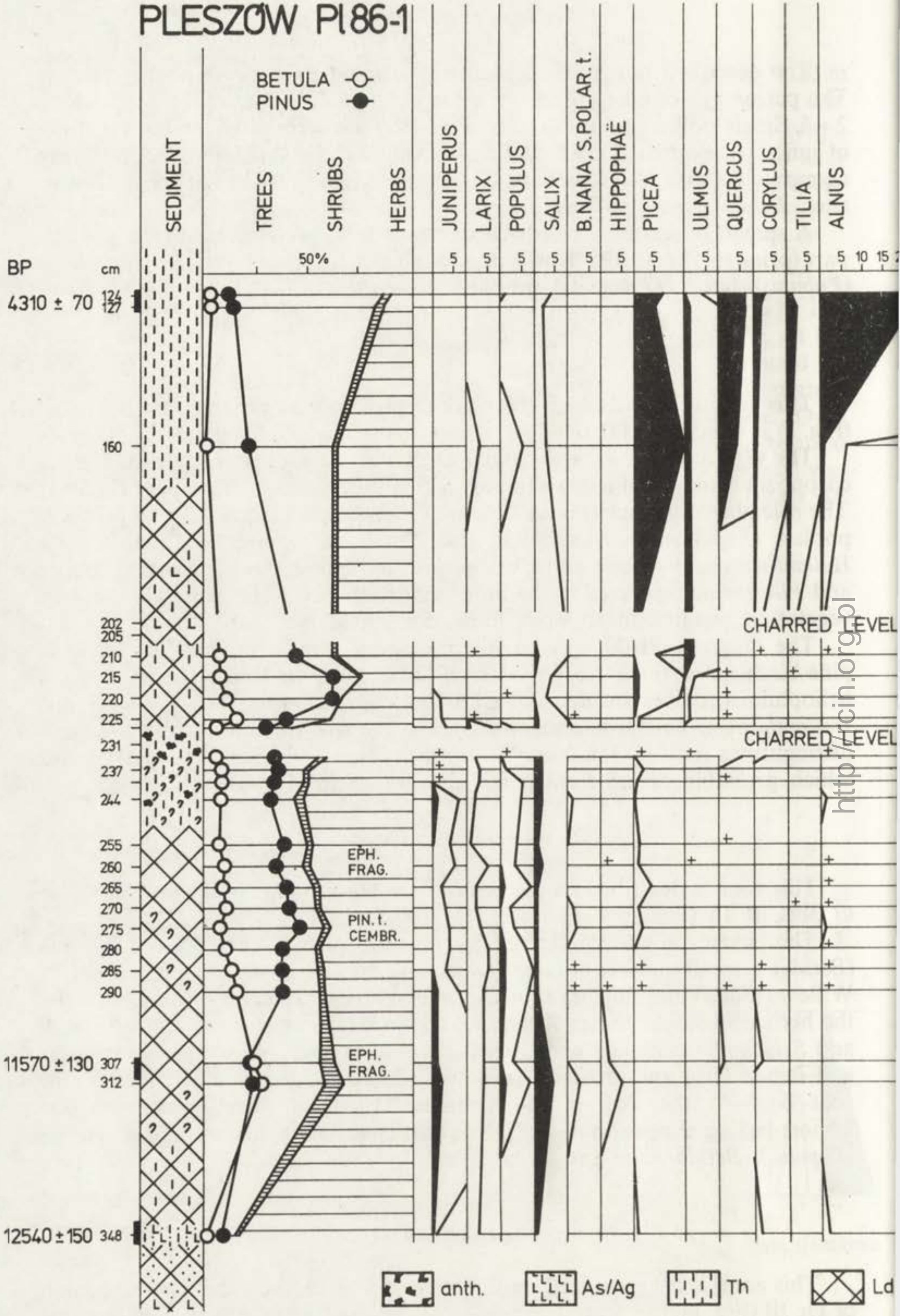
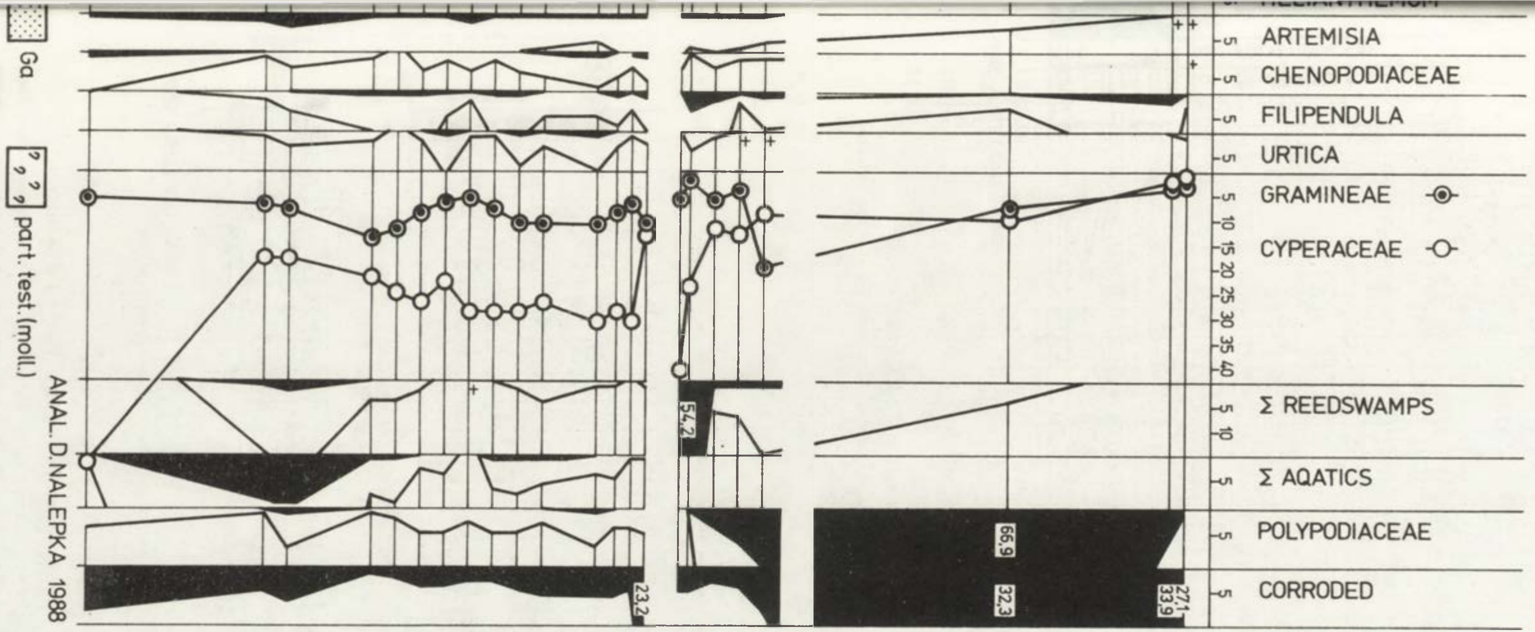


Fig. 3. Simplified pollen

anth. – anthrax; As/Ag – Argilla steatodes or A. granosa; Th – Turfa



gram from the Pleszów 86-1 site

acea; Ld – *Limus detrituosus*; Ga – *Grana arenosa*; part. test. (moll.) – *particulae testarum (molluscorum)*

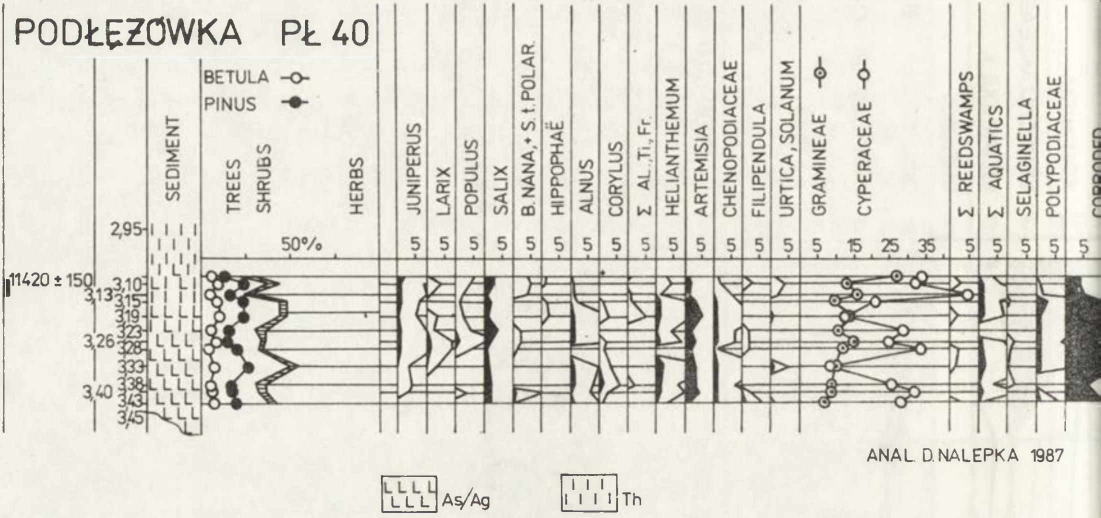


Fig. 4. Simplified pollen diagram from the Podłężówka 40 site

Al., Ti., Fr. — *Alnus* + *Tilia* + *Fraxinus*; *As/Ag* — *Argilla steatodes* or *A. granosa*; *Th* — *Turfa herbacea*

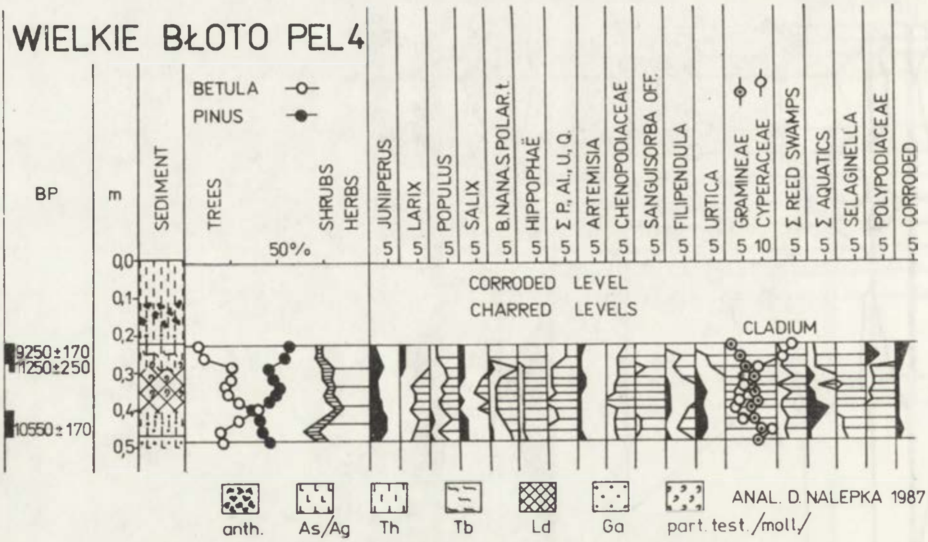


Fig. 5. Simplified pollen diagram from the Wielkie Błoto Pel 4 site

P., Al., U., Q. — *Picea* + *Alnus* + *Ulmus* + *Quercus*; *anth.* — anthrax; *As/Ag* — *Argilla steatodes* or *A. granosa*; *Th* — *Turfa herbacea*; *Tb.* — *Turfa bryophytica*; *Ld* — *Limus detrituosus*; *Ga* — *Grana arenosa*; *part. test.* (*moll.*) — *particulae testarum* (*moll-luscorum*)

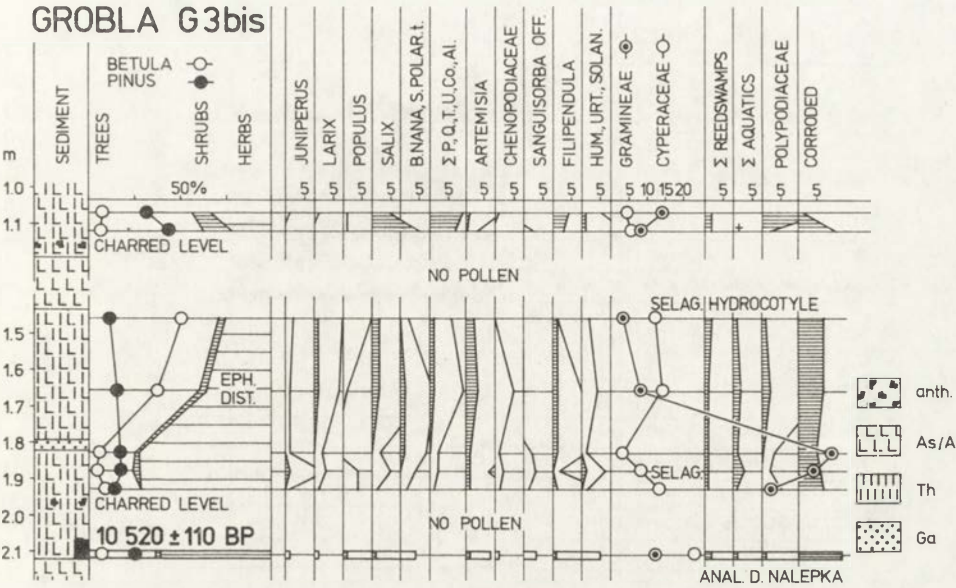


Fig. 6. Simplified pollen diagram from the Grobla G 3bis site

P., Q., T., U., Co., Al. — Picea + Quercus + Tilia + Ulmus + Corylus + Alnus; anth. — anthrax; *As/Ag — Argilla steatodes* or *A. granosa; Th — Turfa herbacea; Ga — Grana arenosa*

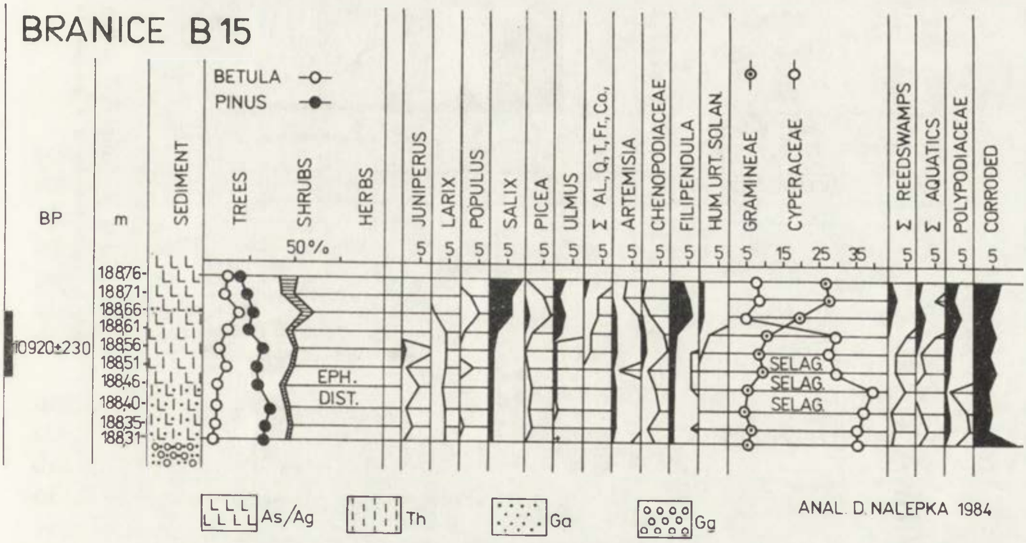


Fig. 7. Simplified pollen diagram from the Branice B 15 site

Al., Q., T., Fr., Co. — Alnus + Quercus + Tilia + Fraxinus + Corylus; As/Ag — Argilla steatodes or *A. granosa; Th — Turfa herbacea; Ga — Grana arenosa; Gg — Grana glareosa*

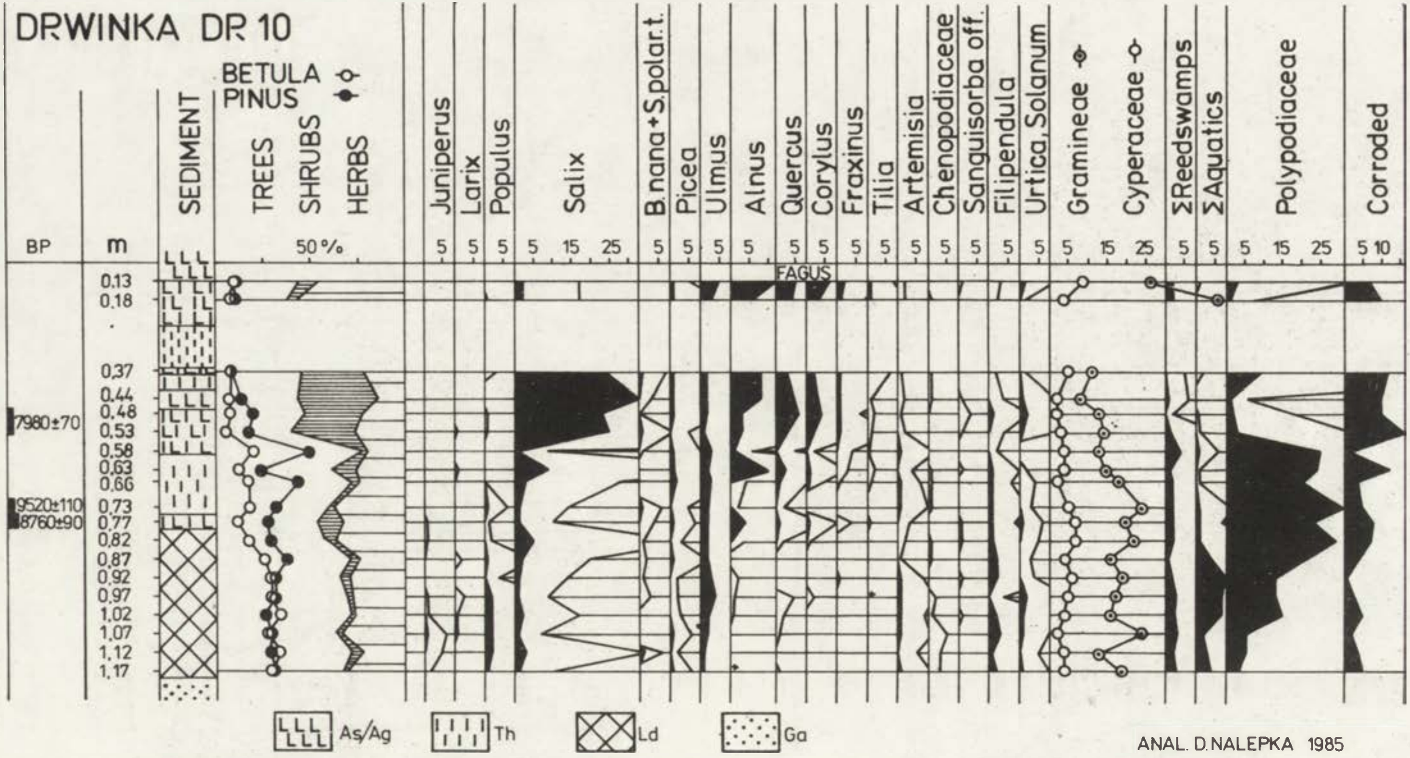


Fig. 8. Simplified pollen diagram from the Drwinka Dr 10 site

As/Ag — Argilla steatodes or *A. granosa*; *Th — Turfa herbacea*; *Ld — Limus detrituosus*; *Ga — Grana arenosa*

The spread of pine (*Pinus*) and probably the beginning of spruce (*Picea*) and elm (*Ulmus*) expansions indicate the beginning of the Holocene. The pine-birch forest still played the major role at that time. The elm spread which preceded that of the other trees was a characteristic feature of that time. Riverine elm forests began probably to form. *Hippophaë* retreated and so probably did *Betula nana* and the *Salix polaris* type. Juniper (*Juniperus*), poplar (*Populus*) and larch (*Larix*) decreased in amount. The appearance of *Cladium* pollen indicates climatic rise of temperature.

THE BOREAL CHRONOZONE

This zone is recorded in the upper part of B 15 (Fig. 7), in the central part of Dr 10 (Fig. 8) and in the upper part of G 3bis (Fig. 6).

A distinct change took place in the forest composition. This is expressed in the expansion of alder (*Alnus*) and the appearance of oak (*Quercus*), hazel (*Corylus*), ash (*Fraxinus*), lime (*Tilia*) and (*Viburnum*).

THE ATLANTIC CHRONOZONE

The diagram Dr 10 (Fig. 8) beginning with the horizon dated at 7900 BP shows the wider spread of both oak (*Quercus*) and hazel (*Corylus*) to be followed by the expansion of lime (*Tilia*). The youngest sample analysed so far belongs to this chronozone and probably to its earlier part because it does not contain indicators of man's activity.

SUMMARY

The article presents the preliminary results of pollen analysis made of seven cores which have been obtained from deposits occurring in the western part of the Sandomierz Basin. The pollen record is incomplete because of the presence of several pollen free levels in the oxbow fills and peat bogs due to destruction by peat exploitation, drainage works and peat burning. The lack of continuous pollen sequences caused the present author to use ^{14}C dates to correlate the individual short profiles with each other and to refer them tentatively to the different chronozones (Mangerud *et al.* 1974).

Pollen diagrams illustrate the vegetational history from the Bølling onward until the earliest part of the Atlantic period. The vegetation developed from the stage of treeless communities through the open pine forest to the domination of deciduous mixed woodland with termophilous trees, but still without the traces of man. At the present stage of research no detailed characteristics of the vegetation is possible.

Oxbow lake sediments tend to date the palaeochannels of the Vistula river which were active from the Bølling onward until the Preboreal time.

Translated by the author

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BOTH MALACOFAUNA AND AGE OF THE LACUSTRINE CHALK OCCURRING IN THE NIEPOŁOMICE FOREST

Late Quaternary lacustrine deposits occurring in the Niepołomice Forest were known already in the second half of the 19th century. The lacustrine chalk on the peat bog Błoto near Szarów has been found and described by M. Raciborski (1886) as the "Niepołomice Pelite". He was aware of the presence of abundant plant remains including the *Gryogonites* of *Characeae* along with molluscan shells in the "pelite". However, the precise location of the above profile was unknown, so that during the last one hundred years the lacustrine chalk has not been examined in detail. Its only sample in which malacofauna was abundant was preserved in the Museum of Natural History, Polish Academy of Sciences, in Cracow. The profile discussed was found again in 1986 during the field work carried out by the present author, together with Dr. K. Lipka.

The lacustrine chalk is exposed in the southern part of the peat bog, in the edges of a melioration ditch. Its distribution was established by shallow borings which aided the detailed geological survey. Samples for malacological analysis have been obtained from 18 cores and from the ditch bed (their total number is 20). Samples for both ^{14}C datings and the palynological analysis made by D. Nalepka (this volume) were taken from a core situated 20 km east of the exposure of lacustrine deposits.

Lacustrine chalk and a calcareous gyttja occur not only on the peat bog at Szarów (Fig. 1). Similar deposits have been encountered at Podłęże near Niepołomice, in the Drwinka depression and on a small peat bog at Mokrzyca near Brzesko (some 10 km east of the Niepołomice Forest).

The author is indebted to Dr. E. Stworzewicz for rendering accessible the archival sample with mollusca coming from the "Niepołomice Pelite". This sample was taken by Professor M. Raciborski more than one hundred years ago. In June, 1927 Professor W. Szafer handed it over to the collection of the Museum of Natural History of PAU in Cracow. Nine species of water snails and molluscs occur in this sample. All of these taxa also have been found in the new materials. Borings on the peat bog Błoto at Szarów were made by the authors of the detailed geological map (Mgr. J. Płończyński and Mgr. L. Łopuszyński), whereas the borings at Mokrzyca were made by Mgr. P. Radzki and Mgr. P. Gębica. Deposits occurring at Szarów were radiocarbon dated by Assistant Professor M. Pazdur in the Radiocarbon Laboratory of the Institute of Physics, Silesian Technical University in Gliwice. The present author acknowledges the financial help by the Geological Firm in Cracow.

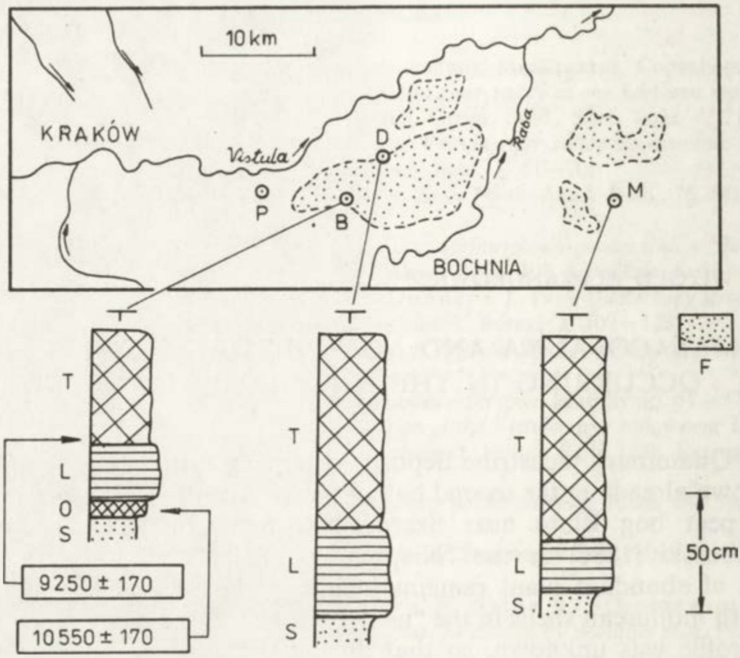

Fig. 1. Profiles of both lacustrine chalk and calcareous gyttja found in the Niepołomice Forest region

P – site in the Podłężówka river valley; *B* – Szarów site ("Niepołomice Pelite"); *D* – exposure in the Drwinka river valley; *M* – Mokrzyca site; *F* – woodland. Lithological symbols: *S* – sands; *O* – silt with plant detritus; *L* – lacustrine deposits; *T* – peats

EXPOSURES AND PROFILES

The "Niepołomice Pelite" site at Szarów is situated about 1 km to the north of the southern margin of the peat bog Błoto. On the bed and in the edges of a melioration ditch running nearly southward over a distance of 30 m the peat is underlain by an ash-grey lacustrine chalk which shows a rather high compactness. Borings made in the surroundings of this exposure revealed that beneath the peat the chalk is forming a band, above 30 m wide, which extends WNW–ESE over a distance of more than 120 m. The chalk is up to 30 cm thick. Its depth is greatest in the profiles located close to the exposure, west of the ditch. East of the ditch the chalk is up to 20 cm thick, to decrease to several centimetres at the borders of the chalk extent. The lithostratigraphical profile includes upward the following strata (Fig. 1, B):

1) fine and medium-grained grey sands (*S*);

2) dark-grey dusty sands with abundant plant detritus, passing into peaty silts; these deposits, up to 6 cm thick, were penetrated only in a few borings located close to the exposure (*O*);

3) light-grey, ash-grey and whitish-grey lacustrine chalk, lighter in the lower part, in the upper part including darker intercalations rich in plant remains; the

chalk varies in thickness from a few cm to 30 cm, in the majority of profiles it is 10–20 cm thick (*L*);

4) peat varying in the degree of decomposition, in places this is a moss peat at the base; peat overlying the lacustrine chalk is up to 1.80 m thick, frequently 1.00–1.50 m thick, locally it decreases in thickness to 25 cm (*T*).

The age of the lacustrine chalk has been determined in one boring in which the base of these deposits was encountered at a depth of more than 40 cm. In the profile discussed peat occurred at a depth of 29 cm, chalk at 41 cm, silt and sands with abundant plant detritus at 47 cm. Underlying were fine sands. Three samples have been dated:

1) the lower part of the peat at depths of 22–27 cm, with a date of 9250±250 years BP (Gd-4236);

2) sands and silts with plant detritus at depths of 41–47 cm, with a date of 10 550±170 years BP (Gd-2794);

3) a transitory bed from chalk to the overlying peat, this is a calcareous deposit with many intercalations and bands including abundant plant remains (depths of 27–32 cm), with a date of 11 250±250 years BP (Gd-4243).

The first two dates (1 and 2) provide reliable lower and upper bounding ages of the lacustrine clay. The third date is not representative and unreliable because of the high calcium carbonate content in the sample. An admixture of this component may cause the apparent age effect which has been noted in the radiochronometric analyses of the calcareous gyttjas (Pazdur 1982). Consequently, the lacustrine deposit discussed, i.e. the "Niepołomice Pelite" represents the Younger Dryas decline time and the Preboreal phase of the Holocene or at least its earliest part.

Calcareous gyttjas were disclosed in a peat bog which occupies the Podłężówka river valley in the surroundings of Podłęże, nearby the western periphery of the Niepołomice Forest (Fig. 1, P). They vary in thickness which may exceed 2 m. Overlying peats are 1.50–3.60 m thick (Lipka *et al.* 1975). The age of the calcareous gyttja has been determined on radiocarbon/pollen analytical grounds as the Bølling and the Allerød (Nalepka, this volume). Malacological studies have not been carried out there.

A calcareous gyttja is exposed in the Drwinka river valley extending in the northern part of the Niepołomice Forest (Fig. 1, D). This site has been described by P. Gębica and L. Starkel (1987). The gyttja rests on sands, and it is more than 30 cm thick. Overlying are peats or peaty silts. The upper bounding age of the lacustrine deposits was determined by two datings on the base of the peats which show an inversion: 9520±110 years BP (Gd-5055) and 8760±90 years BP (Gd-1849). The palynological analysis made by D. Nalepka (this volume) shows that these deposits were laid down during the lower Holocene, mainly in the Preboreal phase.

A light-grey and grey lacustrine chalk with some plants remains occurs in the small peat bog at Mokrzyca, c. 6 km north of Brzesko (Fig. 1, M). This chalk rests on sands and it is capped with a slightly decomposed peat and peaty silts, about 1 m thick. The lacustrine deposits are up to 20 cm thick, and they are very limited in extent. The deposits discussed have not been dated neither by the radiochronometrical nor by the palynological method. However, the malacological analysis revealed the presence of a fauna being typical of the Younger Dryas and the Preboreal phase of the Holocene.

THE CHARACTERISTICS OF SPECIES

The malacofauna preserved in the lacustrine chalk within the Niepołomice Forest contains 20 taxa including 4 species of land snails, 11 species of water snails (one of them includes two subspecies) and 5 species of molluscs. The individual taxa show a different ecological valency. Some of them are peculiar to certain well-characterized types of water bodies or of a climatic zone. Thus it is possible to reconstruct the palaeogeographical conditions under which the carbonate lacustrine deposits developed (Alexandrowicz 1988).

Vallonia pulchella (Müller) – is living in open habitats, on moist or medium moist meadows, also on the steppe, and on the rocky or debris covered slopes; it extends as far north as the polar circle.

Carychium minimum Müller – this hygrophilous species occurs on damp meadows and in scrubs occupying the valley floors, in moist woodland and in swampy environments; this Eurosiberian element reaches as far as the polar circle.

Vetigo geyeri Lindholm – this calciphilous species is characteristic of very moist habitats; it is living on damp meadows and among mosses mainly in the Alps and in northern Europe, in Scandinavia it extends beyond the polar circle.

Succinea putris (Linnaeus) – is peculiar to very moist and damp meadows, mires and scrubs, mostly to the banks of both rivers and various water bodies; it reaches as far as the northern extremes of Europe.

Valvata cristata Müller – is living in small, shallow water bodies with abundant growth of water plants and in the periodically disappearing basins, on lake shores and in the bays of slowly flowing rivers; in Scandinavia it extends as far as the polar circle.

Valvata piscinalis (Müller) – occurs on the slimy beds of various water bodies; it shows a wide geographical extent.

Physa fontinalis (Linnaeus) – this eurytopic species is noted to occur in different permanent water bodies, e.g. in oxbows, lakes and rivers; on the Scandinavian Peninsula it extends as far north as the 63 parallel.

Lymnaea stagnalis (Linnaeus) – is living in both small and large water bodies, as well as in rivers slowly flowing among an abundant plant cover; it is marked by a wide extension.

Lymnaea (*Radix*) *peregra ovata* (Draparnaud) – prefers water bodies of different sizes, with abundant growth of water plants, but especially small lakes and oxbows; it reaches as far as the northern extremes of Europe.

Lymnaea (*Galba*) *truncatula* (Müller) – this is a typical amphibiotic species developing in shallow periodic water bodies, on the emerging lake and bay shores, on marshland and on damp, episodically inundated meadows; in Scandinavia it reaches as far as the northern extreme of the continent.

Bathyomphalus contortus (Linnaeus) – occurs in permanent water bodies with abundant growth of water plants, but especially in small lakes, oxbows and in the bays of great lakes; its northern extent is beyond the polar circle.

Gyraulus riparius (Westerlund) – lives in small and shallow, permanent water bodies with abundant growth of water plants, and even in the permanent swampy zones; this is an Eurosiberian element reaching as far as the polar circle.

Gyraulus laevis (Alder) – this species is to be found in various permanent water bodies, especially in both great and small lakes and in oxbows; it reaches as far north as the polar circle, and even beyond it.

Armiger crista (Linnaeus) – in the material described this polytypical species is represented by two forms: *A. crista nautileus* and *A. crista cristatus*; it prefers permanent water bodies with abundant growth of water plants, but especially small lakes and oxbows, as well as lake bays and coastal zones with abundant vegetation; this taxon shows a wide extent, on the Scandinavian Peninsula it reaches as far as the polar circle.

Hippeutis complanatus (Linnaeus) – prefers stagnant waters, it is noted to occur in permanent water bodies such as lakes, small lakes and oxbows; it reaches as far north as the middle part of the Scandinavian Peninsula.

Sphaerium corneum (Linnaeus) – this eurytopic species is to be found in both lakes and oxbows, in the bays of slowly flowing rivers, and even on permanent, inundated marshland; it reaches as far as northern Scandinavia.

Pisidium milium Held – is living in water bodies having a slimy bottom, in both stagnant and slowly running waters; this taxon reaches as far as the polar circle.

Pisidium nitidum Jenyns – occurs in permanent lake basins of varying size, in oxbows, in rivers and in small streams, especially in their lentic reaches; this taxon reaches beyond the polar circle.

Pisidium lillieborgi Clessin – this species is typical of lakes, it also occurs in small lakes and oxbows; it reaches as far as the northern extremes of Europe.

Pisidium obtusale lapponicum Clessin – at present this taxon is not noted neither in Poland nor in central Europe; it is found in the small, periodic water bodies and on flooded marshland; it is characteristic of the cold climate zone.

MOLLUSCAN ASSEMBLAGES

In the described profiles of lacustrine carbonate deposits there occur molluscan assemblages including various amounts of taxa. Fauna has been found to be most abundant at Szarów, less species are contained in the samples taken from Mokrzyca, whereas the fauna exposed in the Drwinka valley is very poor.

The lacustrine chalk at Szarów, i.e. the "Niepołomice Pelite" contains a rich and characteristic molluscan assemblage. The malacofauna is identical in the whole profile, and it does not show any differences throughout the basin. It represents an assemblage which has been described on the basis of 20 samples (Fig. 2).

The structure of the molluscan assemblage takes into account constance (C) and dominance (D) of each taxon (Alexandrowicz 1988). Two species, namely *Lymnaea peregra ovata* and *Gyraulus laevis* are marked by the highest values of these indices (C5 – D5), and the third species – *Armiger crista nautileus* is only by one class of dominance (C5 – D4) smaller. The above taxa may be acknowledged to be the major components of the association, since they determine its character (defining species – Hässlein 1960; Körnig 1966; Alexandrowicz 1988). The next four species reach mean values of the constance and dominance indices: *Pisidium obtusale lapponicum* (C4 – D3), *Lymnaea*

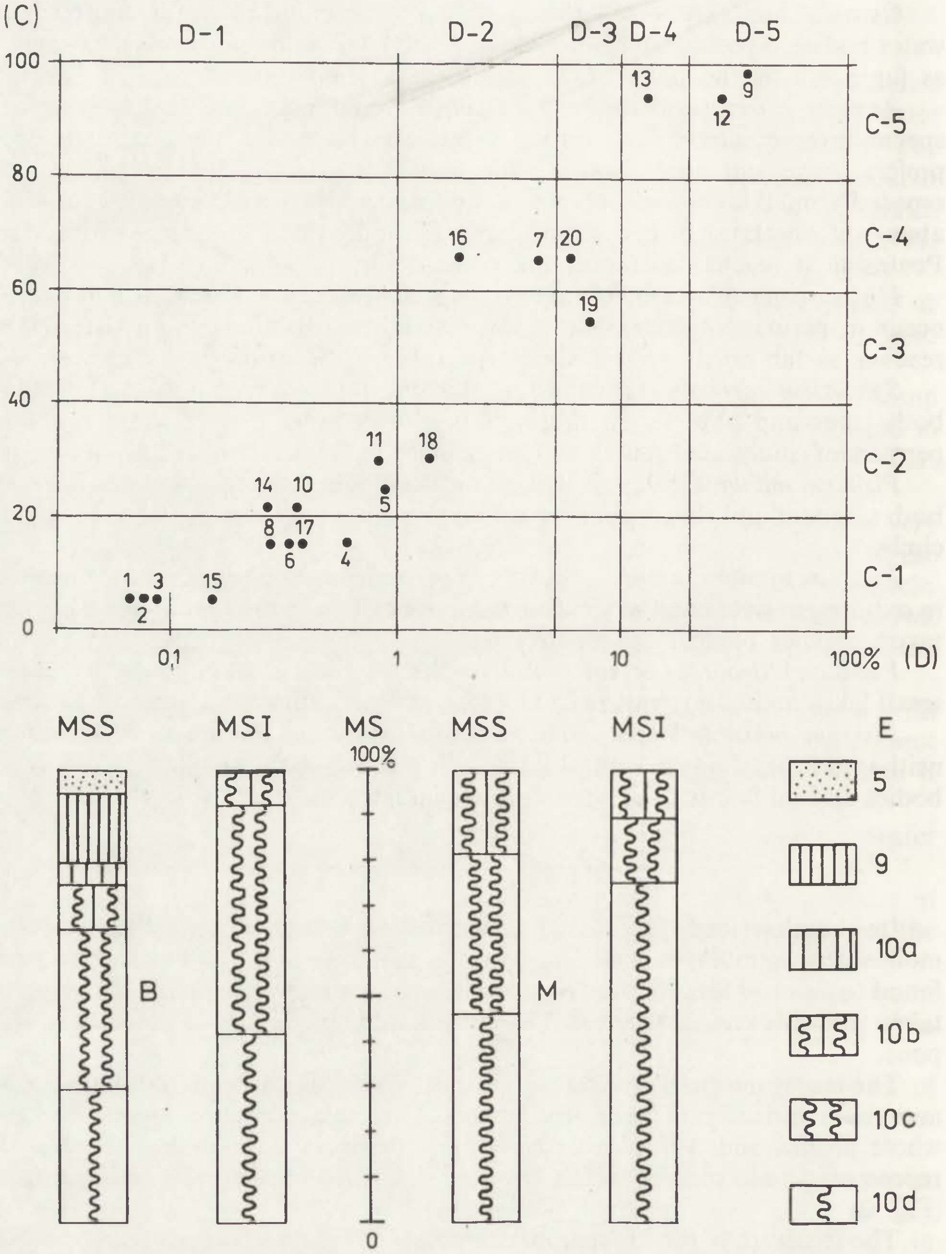

Fig. 2. Characteristics of molluscan assemblages at Szarów and Mokrzyca

C–D – structure of the molluscan assemblage at Szarów; *1–20* – species of mollusca (numbers are as for Table 1); *C-1–C-5* – constance groups; *D-1–D-5* – dominance groups (comp. Table 1); *MS* – malacospectra; *MSS* – malacospectrum of species; *MSI* – malacospectrum of individuals; *B* – malacospectra of molluscan assemblages at Mokrzyça; *E* – key to symbols used in the malacospectra; *5, 9, 10a, 10b, 10c, 10d* – ecological groups explained in the text *stagnalis* and *Sphaerium corneum* (C4 – D2), and *Pisidium lillieborgi* (C3 – D3). These are characteristic species which, together with those quoted above indicate the conditions under which the carbonate deposits developed. The remaining species are much reduced, and some of them may be treated as accessory elements (Fig. 2, CD).

Malacological spectra of the molluscan assemblage discussed take account of the groups of species living in water bodies of different types which have been described by B. Sparks, A. Piechocki, V. Ložek and by the present author (Alexandrowicz 1988). This list was completed with the ecological groups of the land fauna which has been arranged, according to Ložek's nomenclature (1964): 5 – open ground snails living in habitats with varying humidity; 6 – hygrophilous snails being typical of very moist and various shaded habitats; 10 – water snails; 10a – amphibiotic species preferring both periodic water bodies, and swampy and moist habitats; 10b – species occurring in shallow, periodic water bodies; 10c – mollusca typical of permanent, shallow water bodies with abundant growth of water plants; 10d – mollusca living in various water bodies, mainly in stagnant water.

The malacospectrum of species (MSS) shows that species of permanent water bodies (65%) are dominant. The latter clearly predominate (90%) in the malacospectrum of individuals (MSI). In both spectra there prevail mollusca being typical of shallow water bodies with abundant growth of water plants (group 10c). Mollusca living in periodic water bodies are a subordinate component, the remaining three ecological groups are represented by single specimens (Fig. 2, B).

All of the molluscan species cited show a wide geographical extent. They may be arranged only into two groups as regards their modern northward extent (Sparks 1969; Alexandrowicz 1988), namely: N4 – species reaching as far north as the 63 parallel, and even beyond it, i.e. reaching as far as the middle part of the Scandinavian Peninsula; N5 – species reaching as far as the northern extremes of Scandinavia. The first group includes 35% of taxa, the second one – 65% of taxa.

The fauna of the carbonate deposits being exposed in the Drwinka river valley is yet poorly examined. Three samples have been obtained out of which only one contained single shells or broken shells of *Valvata cristata*, *Lymnaea* sp., *Gyraulus laevis* and *Pisidium* sp. All taxa mentioned above are known at the Szarów site. However, the small amount of the material does not enable the assemblage to be characterized.

The lacustrine chalk at Mokrzyca contains a rather abundant malacofauna. 11 species of snails and molluscs being represented by almost 200 specimens have been identified in the samples obtained from two cores: *Valvata cristata* – III, *Valvata piscinalis* – II, *Lymnaea peregra ovata* – II, *Gyraulus riparius* – I, *Gyraulus laevis* – IV, *Armiger crista nautileus* – III, *Hippeutis complanatus* – I, *Pisidium milium* – I, *Pisidium nitidum* – IV, *Pisidium lillieborgi* – IV, *Pisidium obtusale lapponicum* – II (the quantity of specimens is indicated by symbols which are explained in Table 1).

The assemblage described includes only water mollusca belonging to the ecological groups 10b, 10c, 10d. Three taxa tend to occur most frequently: *Gyraulus laevis*, *Pisidium nitidum* and *P. lillieborgi*. Their shells total 65% of the

Table 1. List of species identified in the lacustrine chalk at Szarów

No.	E	Taxon	C	D	n
1	5	*Vallonia pulchella*	1	1	I
2	9	*Carychium minimum*	1	1	I
3	9	*Vertigo geyeri*	1	1	I
4	9	*Succinea putris*	1	1	II
5	10	*Valvata cristata*	2	1	III
6	10	*Physa fontinalis*	1	1	II
7	10	*Lymnaea stagnalis*	4	2	IV
8	10	*Lymnaea truncatula*	1	1	II
9	10	*Lymnaea peregra ovata*	5	5	VI
10	10	*Bathyomphalus contortus*	1	1	II
11	10	*Gyraulus riparius*	2	1	III
12	10	*Gyraulus laevis*	5	5	VI
13	10	*Armiger crista nautileus*	5	4	V
14	10	*Armiger crista cristatus*	1	1	II
15	10	*Hippeutis complanatus*	1	1	I
16	10	*Sphaerium corneum*	4	2	III
17	10	*Pisidium milium*	1	1	II
18	10	*Pisidium nitidum*	2	2	III
19	10	*Pisidium lillieborgi*	3	3	IV
20	10	*Pisidium obtusale lapponicum*	4	3	IV

1 – 20 – number refer to species (comp. Fig. 2); E – ecological groups explained in the text; C (1 – 5) – constance indices; D (1 – 5) – dominance indices; n – quantity of specimens – symbols on the logarithmic scale (Alexandrowicz 1988): I – 1 – 3, II – 4 – 9, III – 10 – 31, IV – 32 – 99, V – 100 – 316, VI – 317 – 999.

specimens counted. In the malacospectra MSS and MSI snails and molluscs living in permanent water bodies are clearly dominant, with predominant euryecological elements (Fig. 2, M). The majority of taxa (73%) reaches far to the north at the present time (group N5), the remaining taxa reach as far as the middle part of Scandinavia (group N4).

INTERPRETATION AND CONCLUSIONS

The evolution of the Vistula river valley below Cracow (between Cracow and the Raba river mouth) during the last 15 000 years has been reconstructed by T. Kalicki, L. Starkel (1987), P. Gębica, L. Starkel (1987), T. Kalicki (this volume) and by L. Starkel *et al.* (this volume). Toward the end of the Vistulian the valley floor was either at the present water table or 1 – 2 m lower than the latter. At that time, the major channel pattern change took place. The Vistula changed from a multilimbed to a meandering river. Both changes in current location and the cut off of the limbs and meanders were favourable for the formation of a great number of depressions, of abandoned channels and of oxbows on the valley floor. Some of them became completely isolated, and they were occupied by small lakes which in turn became filled with mineral and organic deposits. Subsequently, the abundant growth of water plants led to the formation of peat bogs. Similar small water bodies existed in the tributary valleys (Alexandrowicz *et al.* 1981).

In Lateglacial and Holocene times conditions were favourable for the sedimentation of carbonate deposits. The subsequent climatic amelioration and abundant growth of plants gradually speeded up chemical denudation, which affected mainly the waste sheet and loose sedimentes accumulated in the former periglacial zone. Great quantities of mobilized calcium carbonate tended to enrich both underground and surface waters. This phenomenon is not reflected in the course of fluvial sedimentation, whereas in the lakes and small water bodies being isolated from the supply of terrigenic material the precipitation of calcium carbonate could take place. It was stimulated by the presence of plants such as *Chara* and *Potamogeton*. Calcium carbonate, together with the organic matter was the major component of deposits forming the lacustrine chalk and calcareous gyttjas. Lacustrine deposits of these types have been recognized at several places in the Niepołomice Forest.

In the surroundings of Szarów the lacustrine chalk occupies a small depression which probably forms part of an abandoned Vistula channel or oxbow. This depression came into being during the Younger Dryas on the broad floodplain when the river gradually shifted to the north. The oldest depression fill which includes a lense of the basal dusty sands and peaty silts has been dated at 10 550 ± 170 years BP. Subsequently, lacustrine chalk began to accumulate in the water body, where conditions were favourable for the growth of *Characeae*. The molluscan assemblage indicates a permanent shallow water body with abundant growth of plants. Water table fluctuations are documented by the presence of several species being indicative of periodically emerging habitats. The basin was surrounded by moist or damp meadows and by peat bogs being favourable for the development of a hygrophilous malacofauna.

The molluscan assemblage described may be used as good indicators of past climatic conditions. It exclusively includes species which show a wide geographical extent, living among others in the cold climate zone. According to the scheme for the interpretation of water faunas (Johansen 1904; Menzel 1910; Alexandrowicz 1988) this malacofauna corresponds to assemblages with *Gyraulus laevis*, and in part also with *Lymnaea peregra* which have been recognized at Roztoki near Jasło (Alexandrowicz 1987). It shows the following features:

1) the exclusive presence of taxa belonging to the palaeoclimatic groups N5 and N4;

2) the dominance of species living in modern times in both temperate and cold climate zones;

3) the presence of *Pisidium obtusale lapponicum* — this taxon is at present lacking in Poland and in central Europe, it is typical of deposits dating from the cold Pleistocene phases;

4) the lack of species mainly living in the temperate zone, being characteristic of the Holocene deposits: *Bithynia tentaculata*, *Gyraulus albus*, *Anisus vorticulus*, *Pisidium moitessierianum*.

The molluscan assemblage at Szarów corresponds to the water fauna which at present lives in the high geographical latitudes, within the zone of birch forests and of birch-pine forests (Johansen 1904). This conclusion is confirmed by the results of the palynological analysis (Nalepka, this volume).

Peats overlying the lacustrine chalk have been dated at 9250±170 years BP. This record shows that the lacustrine deposits formed during 800–1400 years. Their mean sedimentation rate did not exceed 2–3 mm over 10 years. This coincides with data for the lacustrine chalks that have been recorded in the surroundings of Krosno and Jasło (Gerlach *et al.* 1972; Alexandrowicz 1981; Wójcik 1987), i.e. for deposits laid down in small, very shallow water bodies. The accumulation of carbonate deposits was speeded up in the furrow lakes and in lakes occupying the thaw basins of North and West Poland. These became filled in lateglacial and early Holocene times (Alexandrowicz, Nowaczyk 1982).

The lacustrine chalk at Mokrzyca revealed a molluscan assemblage being essentially the same as that at Szarów. This indicates that at both sites deposits which formed in similar water bodies represent the same or nearly the same period. Calcareous gyttjas exposed in the Drwinka river valley also were shown by radiocarbon dating to belong to the early Holocene, whereas gyttjas occurring on the peat bog in the Podłężówka river valley represent an older period, i.e. the Bølling–Allerød (Nalepka, this volume).

It is likely that the small water bodies containing lacustrine chalk with a great number of molluscan shells occupied many abandoned channels and cutoffs which developed on the Vistula valley floor. Conditions being favourable for the formation of such basins and deposits prevailed mostly in the interstadial phases of the late Vistulian and in the lower Holocene. Both increasing humidity of climate in the Atlantic phase and man's impact in the successive phases of the Holocene resulted in the increased flood frequency and magnitude, and in the accelerated aggradation (Ralska-Jasiewiczowa, Starkel 1988). Under such conditions the formation of calcareous deposits came to an end and "mada" accumulation took place on the wide valley floor (Kalicki, this volume).

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EWA NIEDZIAŁKOWSKA, AGATA PODGÓRSKA-TKACZ

EVOLUTION OF BOTH THE VISTULA FLOODPLAIN AND LATEGLACIAL – EARLY HOLOCENE PALAEOCHANNEL SYSTEMS IN THE GROBLA FOREST (SANDOMIERZ BASIN)

HISTORY AND RESEARCH PROGRAM (*L. Starkel*)

Between Niepołomice and the Raba river mouth, the Vistula is shifting from its central position in the valley floor, 6 – 7 km wide, toward the northern valley side (Fig. 1). In places, the river has destroyed the left-bank loess-covered terrace the small remnants of which (severed spurs) occur on the right bank

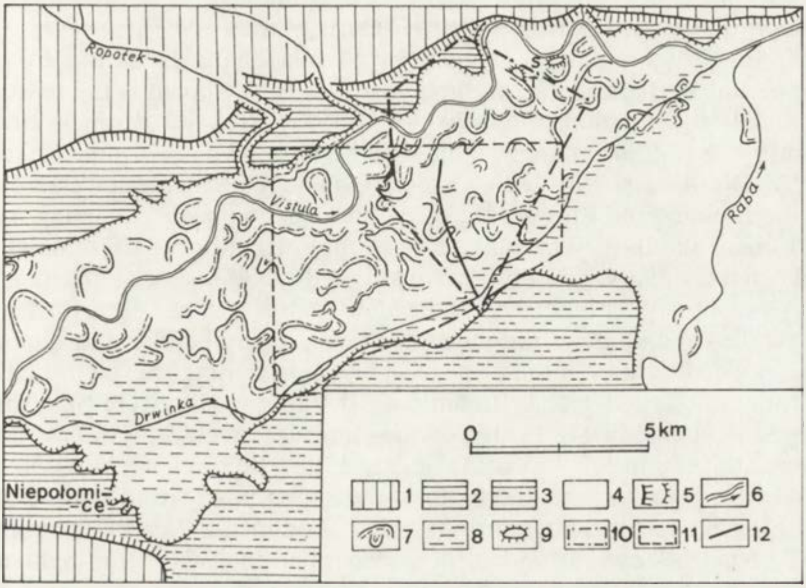

Fig. 1. Geomorphological scheme to show the Vistula valley floor between Niepołomice and the Raba river mouth (by P. Gębica and L. Starkel 1987)

1 – plateaus; *2* – higher terrace (loess-covered on the left bank); *3* – higher, sandy fan built up by the Raba; *4* – Holocene valley floor; *5* – scarps and edges; *6* – Vistula river channel; *7* – abandoned channels; *8* – marginal depression of the Drwinka river; *9* – severed spurs of the Vistulian loess-covered terrace: *T* – Trawniki, *S* – Skała; *10* – area shown in Fig. 2; *11* – area covered by air photo-interpretation: *12* – line of the detailed geological transect (Fig. 3)

(Starkel 1967). Palaeomeander systems present in the south, in the Grobla Forest, have been previously examined by M. Bzowski (1973). He ascribed a lateglacial age to the marginal Drwinka depression and a Holocene age to several palaeomeander systems. He also stated that channel avulsion took place in historical times, this fact being derived from archaeological data (Żaki *et al.* 1970). It was believed that channel avulsions were governed by young subsidence. S. Połtowicz (1967) suggested that evidence for it may be erosional troughs lying 50 m deeper than the Vistula channel at the Raba river mouth, although in the western part of the Sandomierz Basin the base of alluvia lies constantly 10–20 m deeper than the present river channels. However, new borings have shown that the presence of such deep troughs is unlikely there (personal communication by P. Gębica).

In 1982–1983 at first 14 test borings and then 13 additional borings have been sunken and analysed by L. Starkel, together with Mgr T. Kalicki, Assit. Prof. K. Wasylikowa and Mgr D. Nalepka of the Institute of Botany, Polish Academy of Sciences (Starkel, Kalicki 1984). These borings yielded organic remains of which pollen analysis (D. Nalepka) and five radiocarbon datings were carried out in Gliwice. It appeared that the floodplain is a complex feature including older fragments with a Younger Dryas flora which has been dated at 10 520 ± 110 years BP. The well preserved meander system predates 5420 ± 100 years BP in its marginal parts. The last channel that existed prior to the Vistula channel avulsion to the north probably became abandoned several hundred years before peat initiation 4380 ± 110 years BP. These data, together with the new geomorphological map by P. Gębica are contained in the second volume – monograph of the Vistula valley (Gębica, Starkel 1987).

The presence of a unique system of Vistula channels dating from the Atlantic period that are due to channel avulsion to the north is the reason for very detailed investigation. On May 4–8, 1987, Prof. K. Rotnicki and his collaborators Dr Z. Młynarczyk and Dr K. Borówko have undertaken 15 borings, 5–10 m deep, with their own equipment. These were sunk across the Vistula floodplain and the Atlantic abandoned channels occurring in the Grobla Forest, and in the Drwinka depression. Furthermore, 228 samples have been collected for analysis of both grain size and the abrasion of quartz grains, of calcium carbonate content and of organic matter content. Ten further ^{14}C datings on the organic horizons, analyses of clay mineral content in the profile G 26 and pollen analyses of the profile G3 bis (representing the Younger Dryas decline time) have been made. Preliminary research results were published in the excursion guide-book of the symposium "Lateglacial and Holocene Environmental Changes – Vistula Basin 1988" (Starkel, Gębica, Nalepka 1988). At this symposium there also were presented results of detailed sedimentological-statistical research (Starkel, Podgórska-Tkacz), of grain abrasion (E. Niedziałkowska) and of palaeochannel analysis in the light of air photo-interpretation (Baumgart-Kotarba). Results revealed the great complexity of both relief and structure of the apparently monotonous Holocene alluvial plain.

As the initiator of the above studies I am extremely grateful to all persons who have participated in the solution of the problems of both age and origin of the alluvial palaeoplain in the Grobla Forest. In particular it is important to acknowledge the contribution of Mgr Dorota

Nalepka and of her supervisor Prof. Dr Krystyna Wasylikowa (Institute of Botany, Polish Academy of Sciences) who made the pollen analyses, of Assist. Prof. Dr Mieczysław Pazdur (Silesian Technical University in Gliwice) who carried out the ^{14}C analyses, of Prof. Dr Karol Rotnicki (Institute of Quaternary Research UAM in Poznań) who sunk the borings, of Prof. Dr Alojzy Kowalkowski (Geographical Institute WSP in Kielce) who made pH and other analyses, of Miss Ewa Basta who analysed the grain size composition, of Mrs Maria Klimek who draw the figures, and finally of Dr Tomasz Kalicki and of Mgr Izydor Kasza who were of invaluable help during the field work.

THE RELIEF OF THE VALLEY FLOOR (*P. Gębica*)

In the right-bank Vistula valley section which rises 3 – 4 m above mean river level there may be distinguished two depressions alternating with higher grounds (Fig. 2).

To the south the Drwinka depression is about 2 km wide. Its flat floor at 183 – 184 m a.s.l. without palaeomeanders is occupied by moist meadows and an oak-hornbeam forest in its northern part. Underlying are flood-formed clays, 1 – 2 m thick, which may rest on peat and gyttja overlying sand. In the south there extends the dune-covered Pleistocene alluvial fan built up by the Raba.

Fig. 2. Geomorphological map showing the Grobla Forest region (by P. Gębica, in: L. Starkel *et al.* 1988)

1 – 3 – erosional edges: *1* – below 6 m, *2* – 6 – 10 m, *3* – above 10 m; *4* – palaeochanneles; *5* – gullies; *6* – Pleniglacial loess-covered terrace plain; *7* – Holocene floodplain; *8* – floodbasins; *9* – natural levees; *10* – convex slope of palaeochannel; *11* – wide depression zones interrupting the floodplain; *12* – Drwinka depression; *13* – elevated zones; *14* – alluvial fans; *15* – embankments; *16* – line of the detailed geological transect (with numbers of borings)

To the north a higher zone at 184.5–185.5 m a.s.l. is 1.5 km wide. It bears an oak-hornbeam forest and shows the best developed palaeomeander system in the valley section examined. This system consists of both a central trough and cut off palaeomeanders having less clearly developed edges. Meander radii (*r*) vary from 120 m to 235 m, channel widths (*w*) range from 45 m to 55 m. These meanders are cut across by the central trough, 45–65 m wide. In places, where the convex edges are slightly inclined channel widths increase up to 75 m. Apart from the sinuous sections (*r* = 125–165 m) with low gradients, straight sections tend to occur. Alongside the channel, with edges up to several decimetres high, there extend natural levees, some 0.5 m high. The great channel width and straight sections indicate that the younger central trough was formed during a period of both increasing stream discharges and an immature channel, i.e. prior to the avulsion of the Vistula channel toward the edge of the loess-covered terrace in the north. To the west this system is joined by two crevasses with the young meanders of the Vistula. Flood incursions are indicated by the presence of top sandy dusts and clays, 0.5–0.8 m thick. These pass eastward into a clayey "mada" (Karkanis 1973).

To the north of the Grobla Forest there occurs the next moist depression at 183–184 m a.s.l. without palaeomeanders. This depression is up to 1 km wide. Underlying are clays and peat. In the west young dusty and sandy splay deposits are superimposed on the clayey infill of the lateglacial depression.

Close to the Vistula, outside both dikes, there extends another higher ground at 184–185 m a.s.l. It is interrupted by cutoffs. Channel widths vary from 50 m to 90 m, meander radii range from 245 m to 400 m. These meanders were cut off during the last two hundred years (Trafas 1975). In the west these cutoffs are connected by crevasses with the palaeomeanders developed in the Grobla Forest.

ALLUVIAL SERIES AND THEIR AGES (*L. Starkel*)

Results of borings sunken along the north-south line in the Grobla Forest and in the Drwinka depression made it possible to distinguish several lithological-facial units. These were subsequently verified by detailed sedimentological analyses. Radiocarbon datings (Tab. 1) gave data for both the ages of units and the arrangement of series of the successive alluvial fills.

The following series and units (Fig. 3) may be identified:

A. Lateglacial series forming the early Holocene floodplain (northern part):
  Aa. Channel deposit unit predating the Younger Dryas – at depths of less than 2 m (borings G 3, 4, 15, 16),
  Ab. Unit composed of organic silts and "mada" forming the Younger Dryas and early Holocene floodplain at 182–184 m a.s.l. (borings G 3, 4, 16), with a date of 10 520±110 years BP; the pollen spectrum (comp. Starkel *et al.* 1988; D. Nalepka, this volume) shows that above this date the percentage of tree pollen increases from 25 to 70 at depths of 1.95 m to 1.45 m; at a depth of 1.10 m there increases the frequency of pollen of warm-demanding trees;
B. Series disclosed in the Drwinka depression (borings G 27, 28):

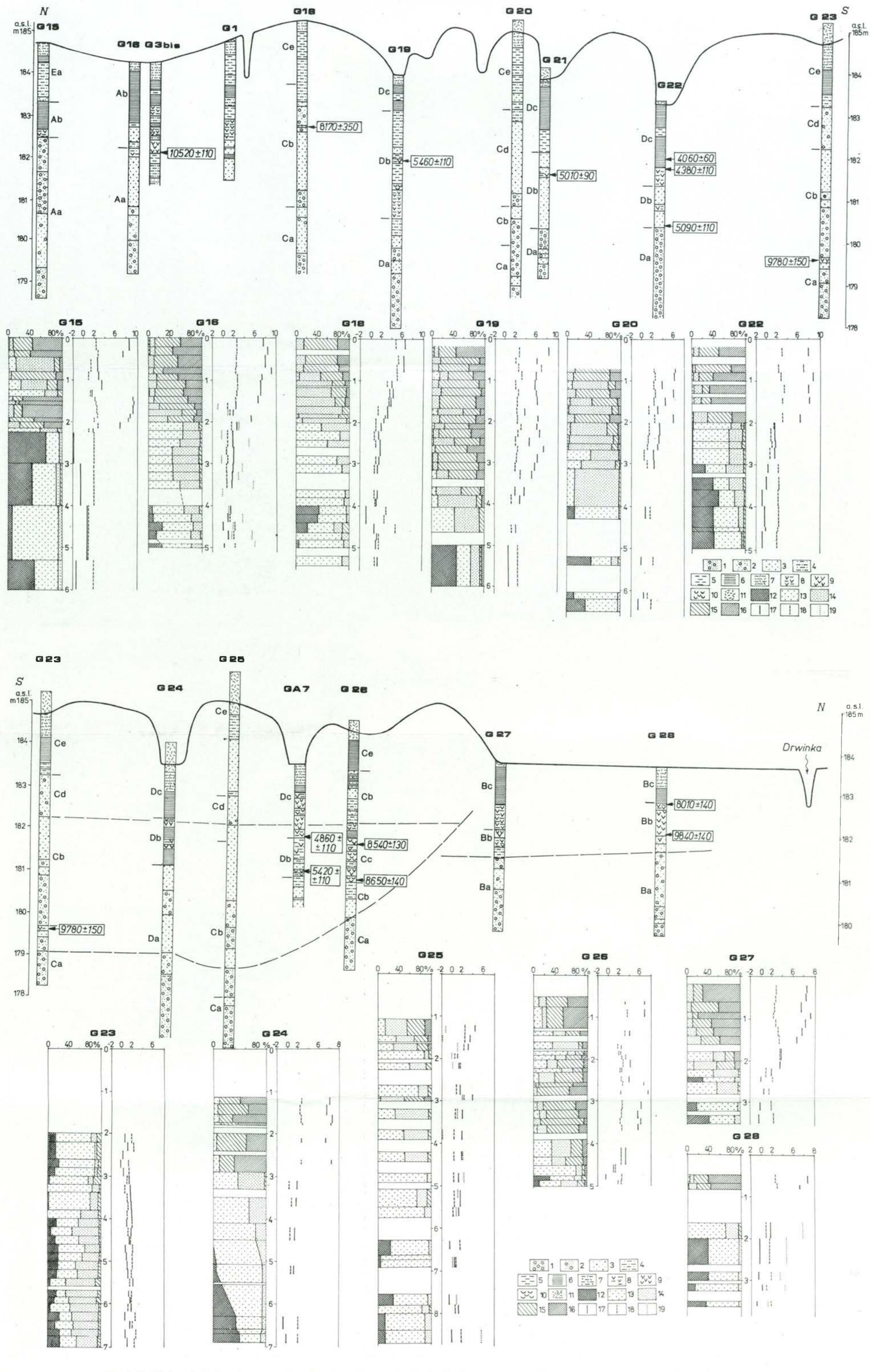

Fig. 3. Detailed geological section across the palaeochannel system in the Grobla Forest, together with sedimentological characteristics and radiocarbon datings (comp. Fig. 1, 2) (by L. Starkel, E. Niedziałkowska, A. Podgórska-Tkacz)

Profiles: *1* — gravels-and-sand; *2* — sand with fine gravel admixture; *3* — sands; *4* — sandy silts; *5* — loams; *6* — clays; *7* — humic horizons; *8* — organic muds; *9* — peat; *10* — gyttja; *11* — anthropogenic deposits. **Grain size composition:** *12* — gravel; *13* — coarse sand ($Mz = -1$ to $+2\varnothing$); *14* — fine sand ($Mz = +2$ to $+4\varnothing$); *15* — silts; *16* — clay, *17* — mean grain size; *18* — standard deviation (sorting index); *19* — abrasion index (Wo). Series of deposits are indicated by letters (comp. text)

Table 1. Collection of the radiocarbon datings

Profile No.	Type of material	Depth (cm)	Laboratory No.	Date BP	Comments
G3 bis/1	peat	207 – 212	Gd-1787	10520 ± 110	peat layer on the floodplain
GA 7/1	mud with woods	193 – 198	Gd-2268	5420 ± 110	abandoned channel's filling
GA 7/2	woods in sands	246 – 248	Gd-2269	3990 ± 260	false date bottom of the abandoned channel
GA 2/4	peat	170 – 174	Gd-2185	4860 ± 110	abandoned channel's filling
GB 6	peat	141 – 146	Gd-2338	4380 ± 110	abandoned channel's filling
G 18/1	sticks in mud	245 – 250	Gd-4102	8170 ± 350	possible redeposition
G 19/1	peaty mud	200 – 205	Gd-2733	5460 ± 110	abandoned channel's filling
G 19/2	wood	340 – 342	Gd-4170	3900 ± 270	possible redeposition
G 21/1	mud with sticks	250 – 257	Gd-4168	5010 ± 90	possible redeposition
G 22/1	wood in sands	290 – 298	Gd-2758	5090 ± 110	possible redeposition
G 22/2	peaty mud	133 – 140	Gd-5222	4060 ± 60	abandoned channel's filling
G 23/1	mud with woods	560 – 570	Gd-2732	9780 ± 150	possible redeposition
G 26/1	peaty mud	295 – 300	Gd-2731	8540 ± 130	peat layer on the floodplain
G 26/2	gyttja	380 – 390	Gd-4169	8650 ± 140	peat layer on the floodplain
G 28/1	peat	157 – 162	Gd-2730	9840 ± 140	depression's filling
G 28/2	peat	80 – 85	Gd-2757	8010 ± 140	depression's filling

Ba. Unit including Younger Dryas channel deposits (sand and gravel) beneath a depth of 2 m,

Bb. Brown Holocene carex peat, 0.6 – 1.2 m thick, passing into gyttja at the base; the basal peat gave a date of 9840 ± 140 years BP, the top peat has been dated at 8010 ± 140 years BP,

Bc. Atlantic "mada" unit, 0.8 – 1.5 m thick;

C. Series of early Holocene inserted channel fills lying at least at 178 – 179 m a.s.l. (6 – 7 m deeper than the present plain at c. 185 m a.s.l.) in the Grobla Forest:

Ca. Unit containing pre-Holocene channel gravel and sand, at top being probably reworked by the Holocene Vistula; this unit occurs at depths of more than 4.5 – 8 m (borings G 18, 20, 23, 25, 26),

Cb. Unit comprising channel deposits (sand and gravel) dating from the Preboreal, Boreal and early Atlantic periods; these deposits are underlain by channel lag deposits at different depths, but overlain by abandoned channel deposits (profiles G 18, 20, 23, 25, 26); a date of 9780 ± 150 years BP was determined for the intercalated basal silts (boring G 23), whereas pieces of wood which have been obtained from point bar deposits (G 18) were dated at 8170±350 years BP,

Cc. Unit including Boreal abandoned channel fills recorded in G 26 at depths of 2.55–3.95 m; this unit is composed of gyttja, peaty silts and clays; the basal sediment was dated at 8650±140 years BP; at a depth of 2.95 the fills gave a date of 8540±130 years BP,

Cd. Unit including younger, sandy channel deposits (underlain by channel lag deposits) of the meandering river of Atlantic age, average depths of 2–4 m (borings G 20, 23, 25, 26),

Ce. Overbank "mada" unit dating from the earlier part of the Atlantic period; this unit is dated by abandoned channel fills (borings G 20, 23, 25, 26);

D. Series of infills of the palaeomeanders which became abandoned in Atlantic decline times (Fig. 4):

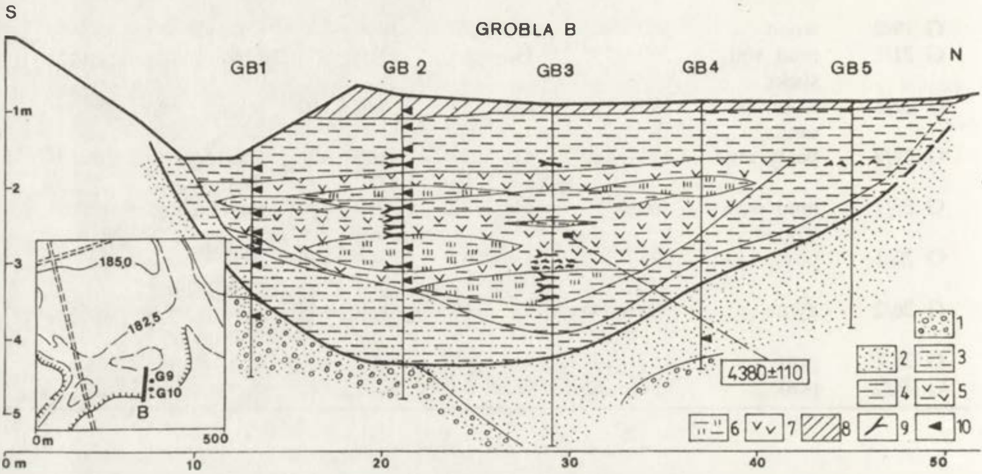

Fig. 4. Section GB of the youngest palaeochannel among those which became abandoned in the Atlantic decline time (by T. Kalicki)

1 – gravels and sands; *2* – sands; *3* – sandy silts; *4* – silts and clays; *5* – organic muds; *6* – gyttja; *7* – peat; *8* – soils (humic horizon); *9* – pieces of wood; *10* – analysed samples

Da. Channel gravel unit, with basal sand occurring at depths of more than 2.80–4 m (borings G 19, 21, 22, 24),

Db. Unit comprising fills of the active cutoffs, 1–2.5 m thick; these fills are formed of gyttja and peaty silts interbedded with clayey silts and sands (borings G 19, 21, 22, 24; sections across the cutoffs GA, Gb and others); the older abandoned channel fills have been dated at 5460±110 years BP (boring 19 – at a depth of about 1.5 m above the base of silts) and at 5420±110 years BP (basal fills of the GA cutoff belonging to the younger generation). Infills of the younger system were dated as: 5090±110 years BP (basal bed in profile G 22) and 4380±110 years BP (middle part of the infill recorded in GB). These dates refer to peaty silts including macrofossils. Thus it is possible that the sediments became redeposited, and an older age has been ascribed to them. However, the coincidence of a sequence of eight dates with the abandoned channel system suggest that they may be relied upon.

Dc. Unit composed of younger overbank deposits occupying the palaeochannels. These deposits are forming a continuous clayey sheet, 1 – 2 m thick, in all of the profiles quoted above (comp. Db);

E. Series of both infills and superimposed deposits dating from the Neoholocene:

Ea. Overbank deposit unit composed of a slightly sandy "mada" (boring G 15) overlying the lateglacial – early Holocene series (series A); it probably belongs to the system of the Neoholocene Vistula the channel of which shifted to the north.

CHARACTERISTICS OF GRAIN SIZE PARAMETERS OF VARIOUS FACIES DEPOSITS (*A. Podgórska-Tkacz, L. Starkel*)

Grain size analysis made of samples which have been obtained from the earlier borings were supplemented by some 230 analyses of samples taken from the profiles G 15 – G 28. The determination of the grain size of deposits was achieved by sieving and areometric measurements in the Laboratory of the Department of Geomorphology and Hydrology, Polish Academy of Sciences, in Cracow. Further samples taken from the profiles G 21, 23 and 26 were analysed in Prof. Kowalkowski's pedological laboratory in Kielce (mainly pH and carbonate content).

Graphs of mean grain diameter, standard deviation, kurtosis and skewness indicate that the properties of the deposits examined are characteristic of the principal facies of fluvial sediments. Series of deposits of differing age are alike. Lateglacial deposits do not contain fine sand being typical of point bars and natural levees (Fig. 5).

Mz of the channel deposits varies from -1.9 to 4.2 ∅, and they are well to poorly sorted ($\sigma_1 = 0.3-3.1$). Both channel lag deposits and intercalations of fine materials (2 – 4 ∅) are very poorly sorted. The latter may be interpreted as a suspended sediment which rests on the top of the central bars. Skewness of the channel deposits varies from -0.9 (very negatively skewed deposits) to $+0.7$ (almost normal distribution). Kurtosis ranges from 0.5 to 5.9. Its lowest values correspond to the extreme values of Mz.

There is clear similarity between channel deposits predating the Younger Dryas (Aa, Ca) and those dating from the Younger Dryas (Ba) and from the early Holocene (Cb, Da) ($Mz = -1$ to $+2$ ∅, $\sigma_1 = 0.5-2.2$). Only the top series of sand dating from the later part of the Atlantic period (Cd) does contain more suspended sediment ($Mz = 0-5$ ∅).

Mz of the overbank facies deposits varies greatly from 1.9 to 9.5 ∅ and so does the sorting degree. Coarse sediments are better sorted (0.5 – 2), sediments finer than 5 ∅ are less well sorted (2 – 3.7). Skewness ranges from -0.7 to $+0.7$, i.e. from negatively skewed deposits coarser than 6 ∅ to positively skewed deposits finer than 6 ∅. Kurtosis varies from 0.4 to 4.5. Above $Mz = 5$ ∅ kurtosis changes from 0.5 to 1 (almost normal distribution). Below 5 ∅ the curves of grain size distribution are extremely leptokurtic.

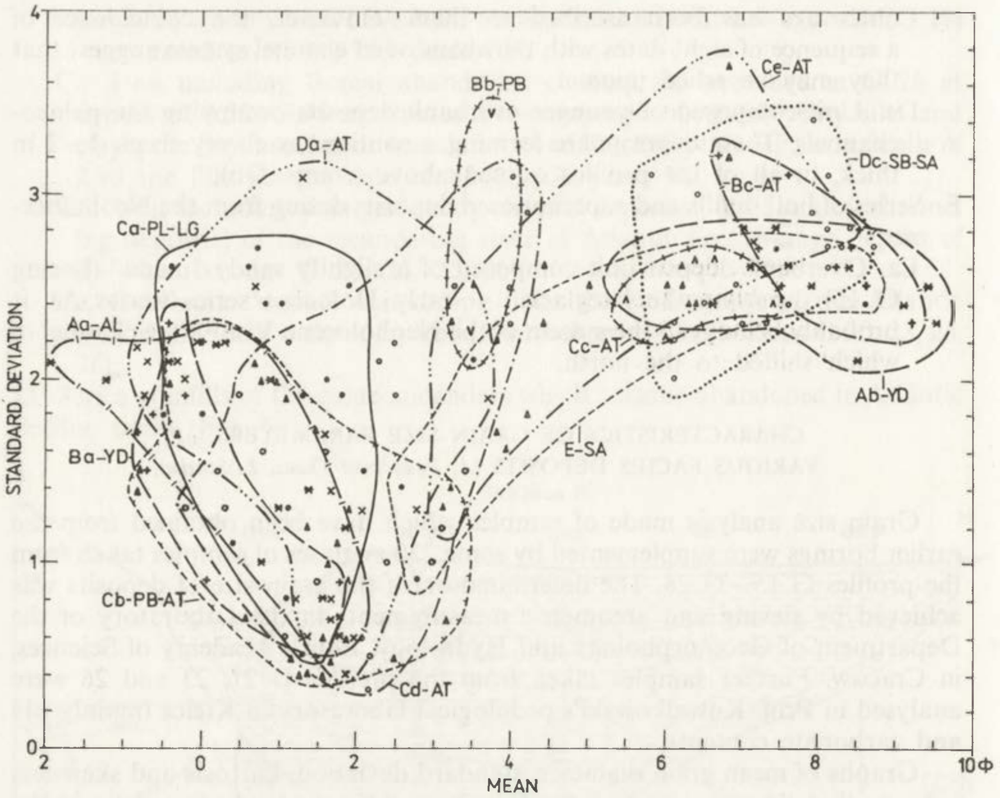

Fig. 5. Mean grain size and standard deviation of alluvial sediments in the Grobla Forest transect. First letters indicate series and units of deposits (e.g. Aa, Ab, Ba etc. – cf. in the text). Age designations: *Pl* – Pleniglacial; *LG* – Lateglacial; *AL* – Allerød; *YD* – Younger Dryas; *PB* – Preboreal; *AT* – late Boreal – Atlantic; *SB* – Subboreal; *SA* – Subatlantic

Overbank facies units of different ages show greater variations than those of the channel facies. In the Drwinka depression, the early Holocene "mada" (Bb, Bc) becomes finer upward (3 – 9.5 ∅), the Lateglacial – Eoholocene "mada" (Ab) and Boreal channel fills (Cc) also are fine (5.5 – 9.5 ∅) and poorly sorted (2.2 – 2.8). The Atlantic "mada" forming the surface of the floodplain contains well sorted (even below 1.0) and coarser materials. These are evidence of both lateral channel migrations and levee formation. Levees sometimes still occupy the valley floor. The younger "mada" (Ea) shows similar properties (G 15). Upward changes in the composition of palaeochannel fills dating from the Atlantic decline time (G 22) indicate the change from river transported deposit (Db; 1.5 – 8 ∅) to floodbasin "mada" (Dc; 6 – 9 ∅).

Of special interest is the graph G 26 which shows that both sandy bar deposits and the younger, late Atlantic "mada" are superimposed on a Boreal abandoned channel fill.

In general, there are no contrasts in the lithological properties of various facies of inserted series of differing age, although they tend to vary in thickness and altitude. The largest scale variation in facies has been found to occur in the palaeomeander system of the Vistula dating from the Atlantic decline time.

CHARACTERISTICS OF QUARTZ GRAIN ABRASION IN VARIOUS TYPES OF DEPOSITS OF DIFFERING AGE (*E. Niedzialkowska*)

Analysis of quartz grain abrasion was made of 46 samples each of which has been collected from a different bed in the profiles 16, 24, 25 and 28. The abrasion of quartz grains in the fraction 0.75 – 0.5 mm, which most frequently occurs in the deposits, was examined using the automatic graniformameter.

Quartz grain abrasion is characterized graphically by the abrasion index *Wo* versus standard deviation (Niedziałkowska, this volume). Channel deposits predating the Younger Dryas (profile 16, series Aa) are marked by a highly variable abrasion index ($Wo = 680 - 1000$) and by a low homogeneity ($\sigma_0 = 4.5 - 6.6$, Fig. 6). On the contrary, channel deposits dating from the Younger Dryas (profile 28, series Ba) contain better abraded quartz grains ($Wo = 750 - 970$), and the deposits are more homogeneous ($\sigma_0 = 3.8 - 6.2$). This suggests that the older sediments became reworked during the Younger Dryas. Morphoselection led to the increase in both abrasion and homogeneity of the deposits.

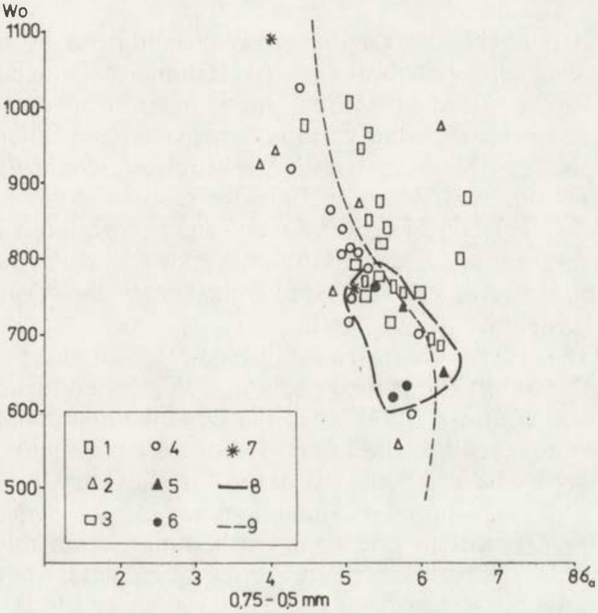

Fig. 6. Ratio of abrasion index (*Wo*) to standard deviation (σ_0) in the fraction 0.75 – 0.5 mm (by E. Niedziałkowska)

Channel deposits dating from the: *1* — Allerød; *2* — Younger Dryas; *3* — Preboreal and Atlantic; *4* — earlier half of the Atlantic. Overbank deposits dating from the: *5* — Younger Dryas; *6* — Atlantic. Channel fill deposits dating from: *7* — various phases of the Holocene. *8* — line separating lateglacial deposits from the Holocene ones; *9* — cluster of overbank deposits

Sediments representing the early Holocene (PB – BO, AT) and the early part of the Atlantic period (profile 25; units Ca, Cb and Cd; profile 24, unit Da) show less varied values of the abrasion index ($Wo = 700 - 920$) and of the homogeneity index ($\sigma_0 = 4.7 - 6.0$). This indicates smaller variations and similarity of deposits dating from both periods. Comparison of the Holocene deposits with the lateglacial channel deposits revealed a lower abrasion degree and their greater homogeneity.

Overbank deposits and channel fill deposits of differing age are characterized by low values of both *Wo* (600 – 770) and homogeneity ($\sigma_0 = 3.0 - 6.3$).

In general, channel deposits contain better abraded quartz grains. Values of their abrasion index show greater variations than those of the overbank deposits. This property also has been observed to occur in deposits laid down by the Upper Wisłoka and by the upper Vistula (Niedziałkowska, this volume). In spite of the small number of samples analysed, comparison of the abrasion index of deposits in the Grobla Forest with similar types of deposits of both the Wisłoka and the upper Vistula shows that their properties are essentially the same. They are characterized by a slightly better abrasion and by a lower homogeneity. Comparison of the deposits examined with those of the Vistula which have been disclosed downstream, farther off in the Sandomierz Basin (Mycielska-Dowgiałło 1978) revealed that the quartz grains analysed by the present author are less well abraded.

CONCLUSIONS (*L. Starkel*)

An integral part of this work is the study of landforms by remote sensing techniques. However, the contribution by M. Baumgart-Kotarba (this volume) extended markedly so that it makes up a separate paper now. Several palaeochannel categories showing various dimensions and different ages have been distinguished by the latter author. She also recognized multilimbed channel patterns in both woodland and meadows. Some of these channels have been identified as lateglacial braided systems being reproduced in the "mada" sheets. They correspond to the distribution of series A and B. Another part has been interpreted as crevasse splays spreading across the Vistula floodplain from meander breaches.

The concept of successive inserted infills by P. Gębica and L. Starkel (1987) is supported by the results of detailed geomorphological and geological studies (Fig. 7). During the Younger Dryas when the Drwinka depression was used by the braided Vistula (series Ba) the accumulation of both "mada" and organic deposits took place in the northern part of the Vistula valley floor (series A). At the beginning of the Holocene channel incision by 2 – 3 m has occurred (borings G 17 – G 27) on the evidence of washed alluvia which gave a date of 9780 ± 150 years BP. Deposition of the series C indicates that this channel system was already abandoned prior to 8650 ± 140 years BP. Bars which have been dated at 8170 ± 350 years BP formed on the northern fringe of the wide, early Holocene erosional valley. However, these bars may be younger features including redeposited older materials. Atlantic meander systems are composed of older elements which became cut off and abandoned prior to 5460 ± 110 years BP, and of a younger trough with irregular parameters. The latter became abandoned prior to 5090 ± 110 years BP. At that time, avulsion of the Vistula channel to the north took place. The connection between this system and the young Vistula became obscured by "mada" accumulation of splay type. Close to the crevasse breaches, the "mada" is dusty and sandy. At distal site, it is notably finer and comprises clay. The superposition of crevasse splay deposits is well illustrated by the boring G 15, whereas the vertical accretion

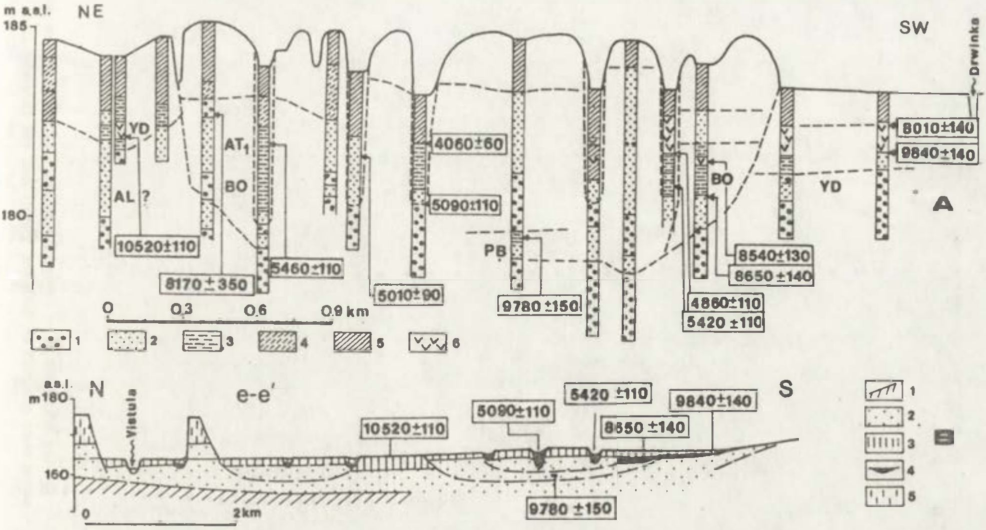

Fig. 7. Section across the Grobla Forest (by L. Starkel)

A — section across the old palaeochannel systems (along the line shown in Fig. 1, 3): *1* — gravels; *2* — sands; *3* — silts; *4* — loams (mixed); *5* — clays; *6* — organic horizons. *B* — general section across the Vistula valley: *1* — Miocene clay; *2* — channel facies deposits; *3* — overbank facies deposits; *4* — organic layers and channel fills; *5* — loesses

under backswamp conditions during the Atlantic period is documented by borings G 27—28 and by image interpretation (Baumgart-Kotarba, this volume). Avulsion of the Vistula channel to the north caused the crevasse splays to obscure the former continuity of the palaeochannel which probably extended upstream as far as Wola Zabierzowska. It also was associated with the accumulation of a clayey "mada" in the cut off palaeomeanders. According to M. Baumgart-Kotarba, the above system of Atlantic palaeochannels also includes single channels that occur to the north-west, close to the present Vistula channel. This hypothesis needs further support as datings are lacking, although channel dimensions are similar. It is unlikely that the second limb of the Vistula continued to the north and that the dimensions of both channels were controlled by stream discharges being equal to those of the whole Vistula. It appears that in Atlantic times the channel-forming discharges must have been twice greater than those of the remaining periods of the Holocene.

Detailed studies carried out in the Grobla Forest made it possible to recognize the mechanisms of both alluvial plain growth and hydrological changes. Some of them may have induced a "threshold" type response inducing facies changes and channel avulsions. Such periods included the onset of the Holocene (changes from braided to meandering channels which have been supported by Falkowski 1975), the period from 8700 to 8000 years BP (channel changes and "mada" initiation) and the Atlantic decline time (5500—5000 year BP) during which at first meander cut off and then channel avulsion took place (Fig. 8). These facts are confirmed by the results of studies carried out in the other valley sections of the Vistula, in its tributary valleys (Starkel 1982, 1987; Kalicki, this volume), and in the central European valleys (Schirmer 1983; Starkel 1983).

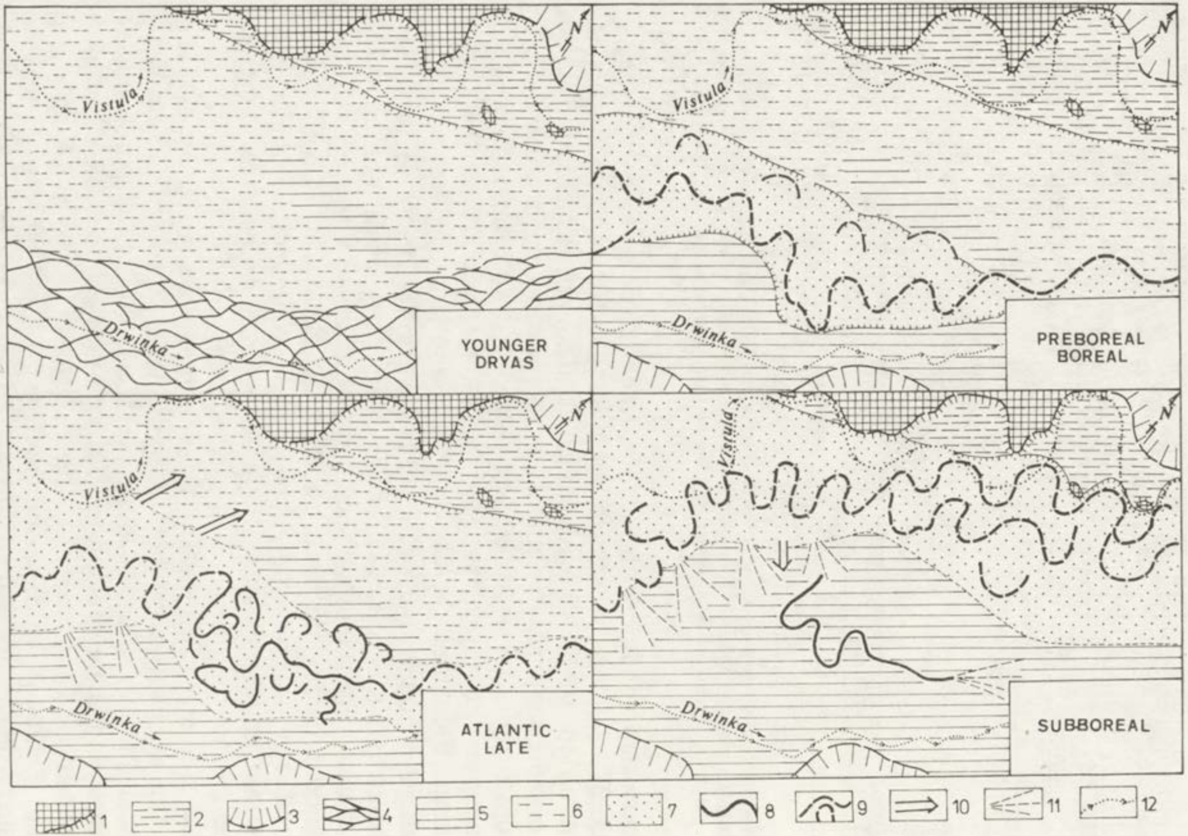

Fig. 8. Palaeogeographical reconstructions of the Vistula valley floor from the Younger Dryas onward until the Subboreal (by L. Starkel)

1 – existing loess-covered terrace; *2* – former extent of the loess-covered terrace; *3* – valley-sides; *4* – braided river pattern; *5* – existing floodplain; *6* – former floodplain; *7* – active part of the floodplain; *8* – existing channels; *9* – former channels; *10* – transfluence during floods; *11* – crevasse splays; *12* – active river channels of both the Vistula and the Drwinka

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THE ALLUVIAL PLAIN OF THE VISTULA RIVER NEAR THE GROBLA FOREST IN THE LIGHT OF AIR PHOTO-INTERPRETATION

The detailed air photo-interpretation covered an area of about 55 km^2 to the east of Zabierzów Bocheński. This forested area is named Las Grobla (Grobla Forest). Air photographs on a scale of 1:9400 taken on 27 August, 1973 are of a good quality. They made possible the delineation of the boundaries of meander loops, of zones with channel patterns being typical of braided rivers, and of trough assemblages the shapes of which enable the overbank accumulation – crevasse splays with the apex on the outside of the meander – to be reconstructed. Despite of single examples, landforms of point bar type, i.e. scrolls indicating the laterally shifting meanders, have not been recorded.

This interpretation then was compiled in the form of an uncontrolled mosaic. Its transfer to a 1:10 000 topographical map remains difficult because a special equipment is not available. For the reconstruction of events that took place in the Vistula valley the mutual relation of the landforms is essential. On the basis of such a mosaic it is possible to make a complete analysis.

This work is not the first interpretation of the Vistula valley section discussed. A map showing the alluvial plain interrupted by meanders, which extends between Cracow and the Raba river mouth, has been drawn by K. Trafas in 1975 on the basis of photographic coverages on the scales of 1:19 500 and 1:18 700 taken in 1972. The use of photographs on scales greater than 1:10 000 made possible the recognition of the mutual relation between various meanders preserved. It also enabled the complex structure of the alluvial plain, i.e. the superposition of splay deposits which are related to different meander generations, to be interpreted.

METHODICAL REMARKS

It should be stressed that image interpretation was possible not only under agricultural use, where the system of fields and roads, and even of settlements closely relates to the preserved parts of the meander loops, but of the forested area Las Grobla and of the meliorated meadows within the Drwinka depression (Photo 1–6). In forested terrain the course of both small troughs and crevasses is reflected by distinct openings in the woodland. The latter are

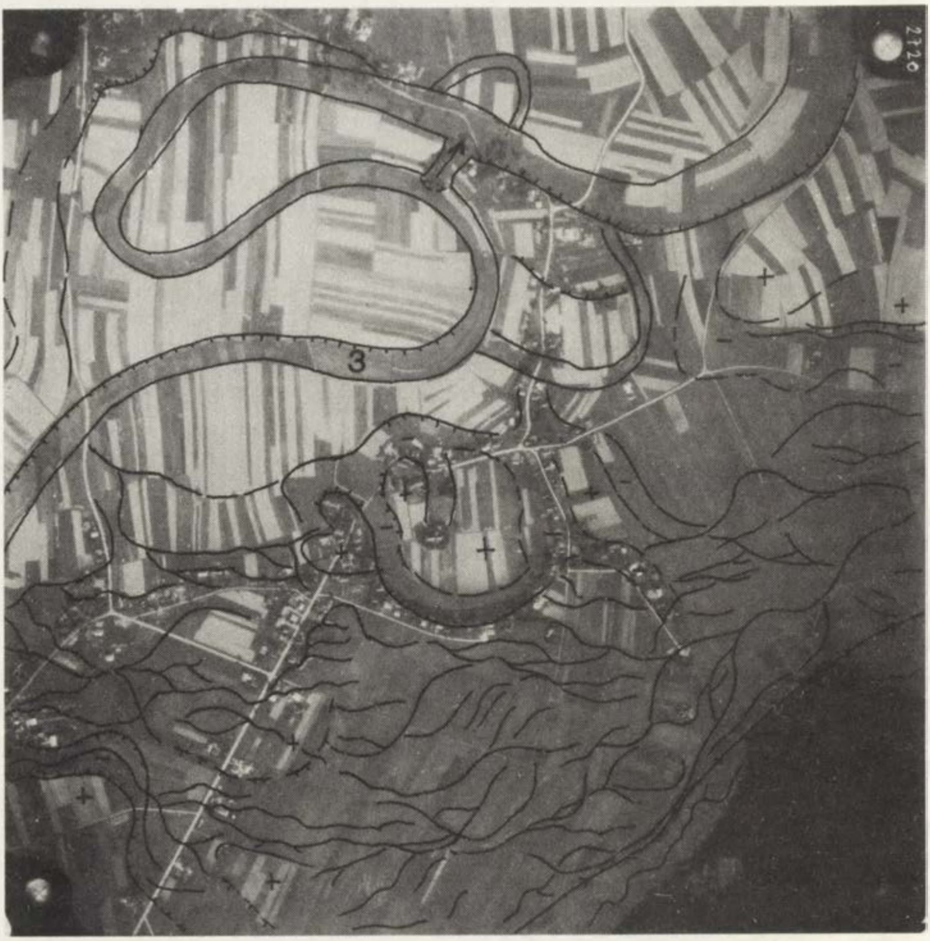

Photo 1. System of meanders to the south of Zabierzów Bocheński village represents the 3rd channel generation. In southern part of photograph braided channel pattern and transitional channels with braided and sinuous pattern. (Air photograph from 1973, with interpretation)

forming a pattern which resembles the troughs of a braided river. In the deforested areas the extension of this trough system are small depressions being either light-toned (drier) or dark-toned (wetter or with a higher organic matter content). In places, this system of the low sinuosity troughs is superimposed on the system of great meanders. Meadows the boundaries of which correspond to those of the meandering channels in forested terrain reveal a subparallel network of low sinuosity troughs which cut across the meandering channel. These troughs show a different phototone, and depressions may frequently be percepted by using a stereoscope. The co-occurrence of different landforms indicates the superposition of different processes modelling the alluvial plain. Overbank sedimentation due to flooding of this plain through crevasses is responsible for the vertical accretion of the floodplain. The boundaries of this accumulation can be determined by analysing the distribution of a system of

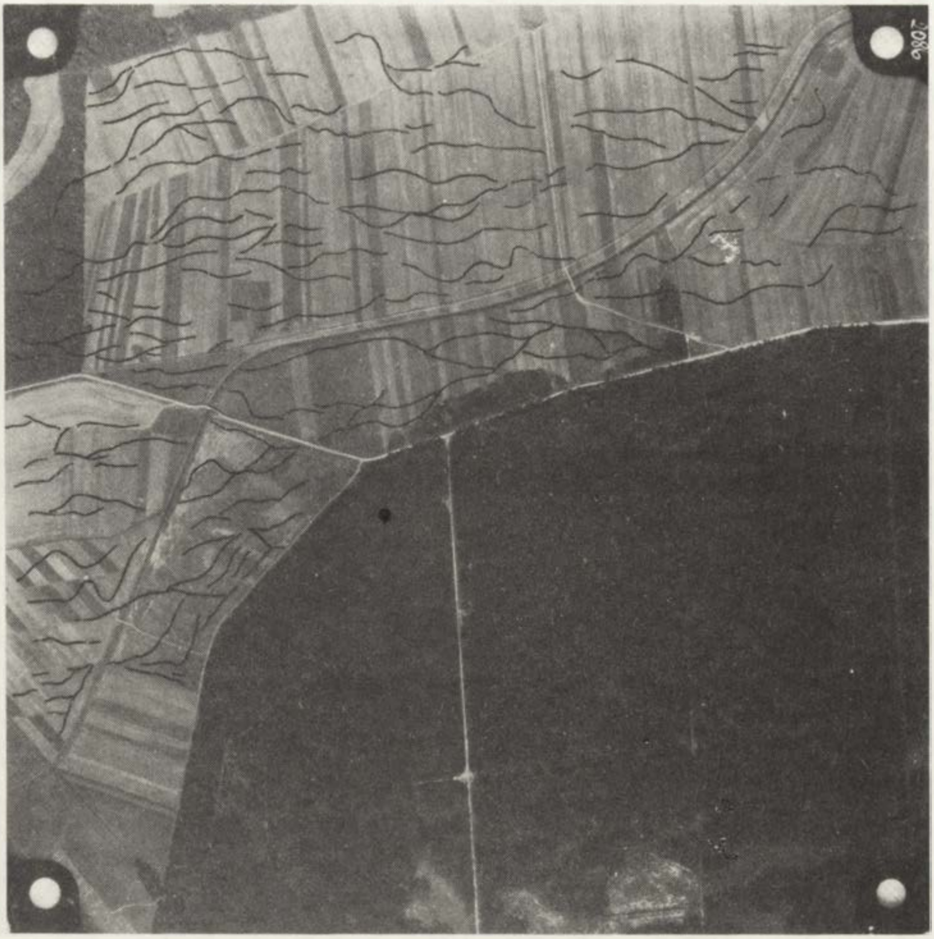

Photo 2. The Drwinka Depression with ditch. Braided river pattern is visible by using stereoscope, dark-tone in more humid bottom of troughs. In southern part the forest overgrown Vistulian terrace (Niepołomice Forest). (Air photograph from 1973, with interpretation)

both small troughs and intervening bars. This accumulation is superimposed on the older system of inactive meanders which in part became obliterated. This mode of overbank deposition is well documented by photo-interpretation.

Another problem concerns the reconstruction of braided channels. Shallow borings made in areas, which show a well visible network of troughs and bars the pattern of which is typical of a braided river, disclosed the presence of coarse sand underlying a 1 – 1.5 m layer of heavy clays, and even of dark organic fine clays (Karkanis 1973; Starkel *et al.* 1988). The pertinent question in regard to this is why is the braided system visible on the air photograph both in tonal difference patterns and, locally, in the networks of depressions and "islands" being typical of the braided river pattern. As an answer to the latter shallow borings (1.4 m deep) were made in the axis of such a trough and on an "island".

Photo 3. Systems of meanders to the north of Zabierzów Bocheński. Meanders of 4th channel generation ($\bar{w} = 92 \pm 22$ m) give opportunity to reconstruct larger and more stable discharges in comparison to older 3rd channel generation ($\bar{w} = 63 \pm 20$ m). 4th channel generation probably is of Subboreal age

RESULTS OF AIR PHOTO-INTERPRETATION

On the basis of channel pattern analysis two channel types can be distinguished: braided river channels and meandering river channels. Furthermore, photo-interpretation made it possible to trace the braided river pattern in two areas described by M. Bzowski (1973) and by P. Gębica (this volume), as well as the landforms due to high floodwaters which caused breaches of the meanders. In many places it is possible to recognize both apexes of crevasse splays and splay deposits accumulated in the form of very elongated alluvial fans the relief of which resembles a braided pattern. Thus, the image clearly indicates which meander and which meander generation was the source area of splay deposits. The superposition of younger crevasse splays on the earlier formed meanders also is visible.

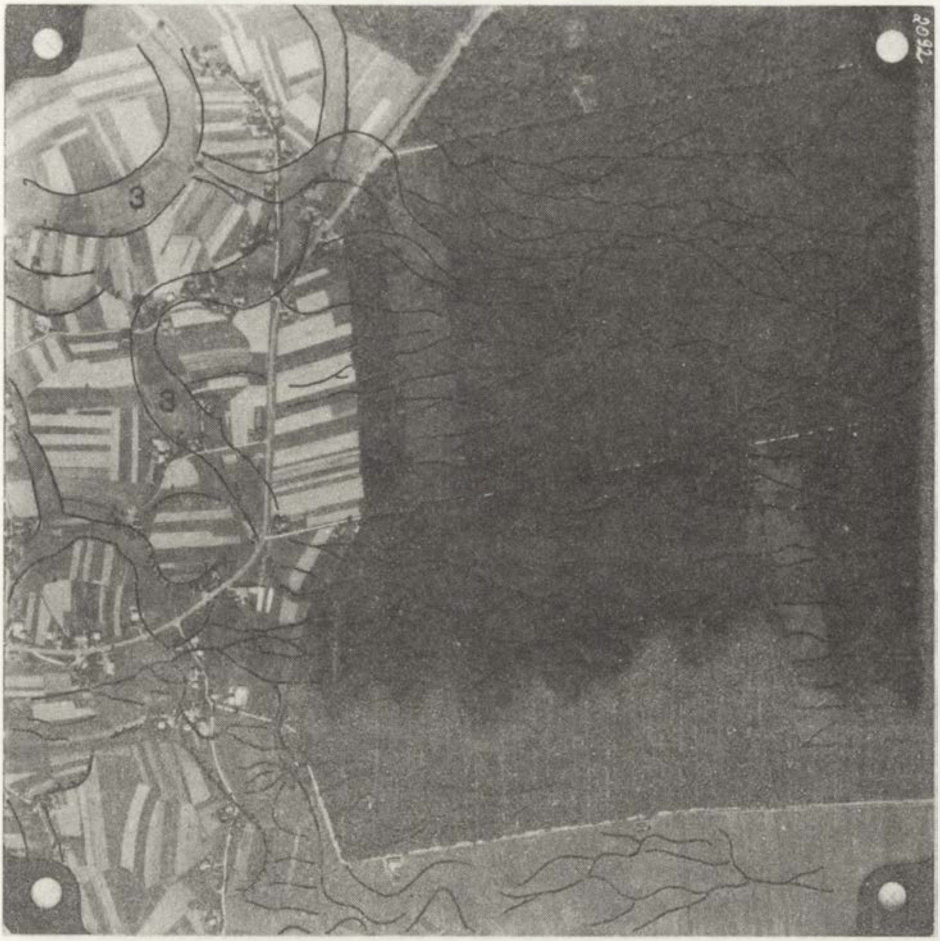

Photo 4. Meanders of 3rd channel generation in vicinity of Chobot village, eastern fringe of Grobla Forest, and crevasse splays (in the forest). In forest terrain the course of troughs and crevasses is reflected by openings in the woodland

BRAIDED RIVER CHANNELS

The well defined network of both troughs and bars within the Drwinka depression to the south of the study area, and on the meadows and pastures to the north of Las Grobla locally passes into low sinuosity channels, 100 – 200 m wide, being deeper than the cut scarps (Fig. 1). The purpose of field work was to explain why the braided system is visible on the air photograph, although these areas are underlain by a sheet of dark clays, more than 1 m thick, which may be interbedded with peat or silts (Karkanis 1973; Starkel *et al.* 1988). Borings were made in the axis of a braided trough and on the nearby "island". The height difference between the trough and the bar was 0.35 m over 5 m distance (Fig. 2). The local relief of the top series of coarse sand-and-gravel (granulometric curves E_5, E_6, F_4) is only 0.15 m. The clayey sheet which rests

Photo 5. Meanders of 3rd channel generation of the Atlantic age in the Grobla Forest. Localization of profile with borings (compare Fig. 1 and 2 in Starkel *et al.* paper, this volume)

on the braided river deposits, together with the characteristic assemblage of troughs and bars attains a uniform thickness of 0.8 – 1.0 m. This sheet is by 0.2 m thicker only on the bar. Such a distribution indicates sedimentation of floodbasin deposits from stagnant water. The above deposits did not reduce the existing relief, they even increased the differences. Hence the answer to the above methodical question is as follows: the local relief of the former braided river plain which was probably formed by the lateglacial Vistula became fixed, and even enhanced by the accumulation of organic clays under backswamp conditions. The late Vistulian age of the braided river system is supported by radiocarbon dates of 10 520 ± 110 BP and 9840 ± 140 BP (Gębica, Starkel 1987; Starkel *et al.* this volume).

Braided river deposits are marked by $M_{50} = 1.7 - 2.2\ \varnothing$. Only the sample taken from depths of 1.2 – 1.4 m showed the following parameters: $Mz = 2.3$

Photo 6. System of meanders and crevasse splays in Hadyna Forest. The numbers related to sequence of channel generations

$\varnothing$, $So = 1.5\ \varnothing$ and $S_K = +0.3$. In the trough the material is slightly coarser than that on the bar, whereas the clayey deposit overlying the braided river sand consists of a silty clay which contains 63–73% of particles finer than 0.002 mm. These parameters indicate sedimentation under backswamp conditions. It seems probable that the sedimentation of the clayey deposit continued throughout the Holocene. Even during the floods of 1960 and 1970 the Grobla Forest was covered with water which reached c. 1 m above the earth surface (comp. photography in Bzowski's paper, 1973). Backswamp deposits may be interpreted as the most distal accumulation in relation to splay deposits. Thus, the major phase of clay deposition within the Drwinka depression coincides with that of floods of high frequency and magnitude, i.e. with the long Atlantic period. Radiocarbon dates greater than 5000 years BP show that the well developed meander system within the Grobla Forest gradually ceased to function (Gębica, Starkel 1987; Starkel *et al.* this volume).


LAS HADYNA
Wisła
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16
3
10520±110
1
18
8170±350
19
5460±110
20
21
5010±90
22
5090±110
23
G R O B L A
L A S
GA
5420±110
26
8650±140
27
28
9840±140
Zabierzów Bocheński
0
1
2km
1
2
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4
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6
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8
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a
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26

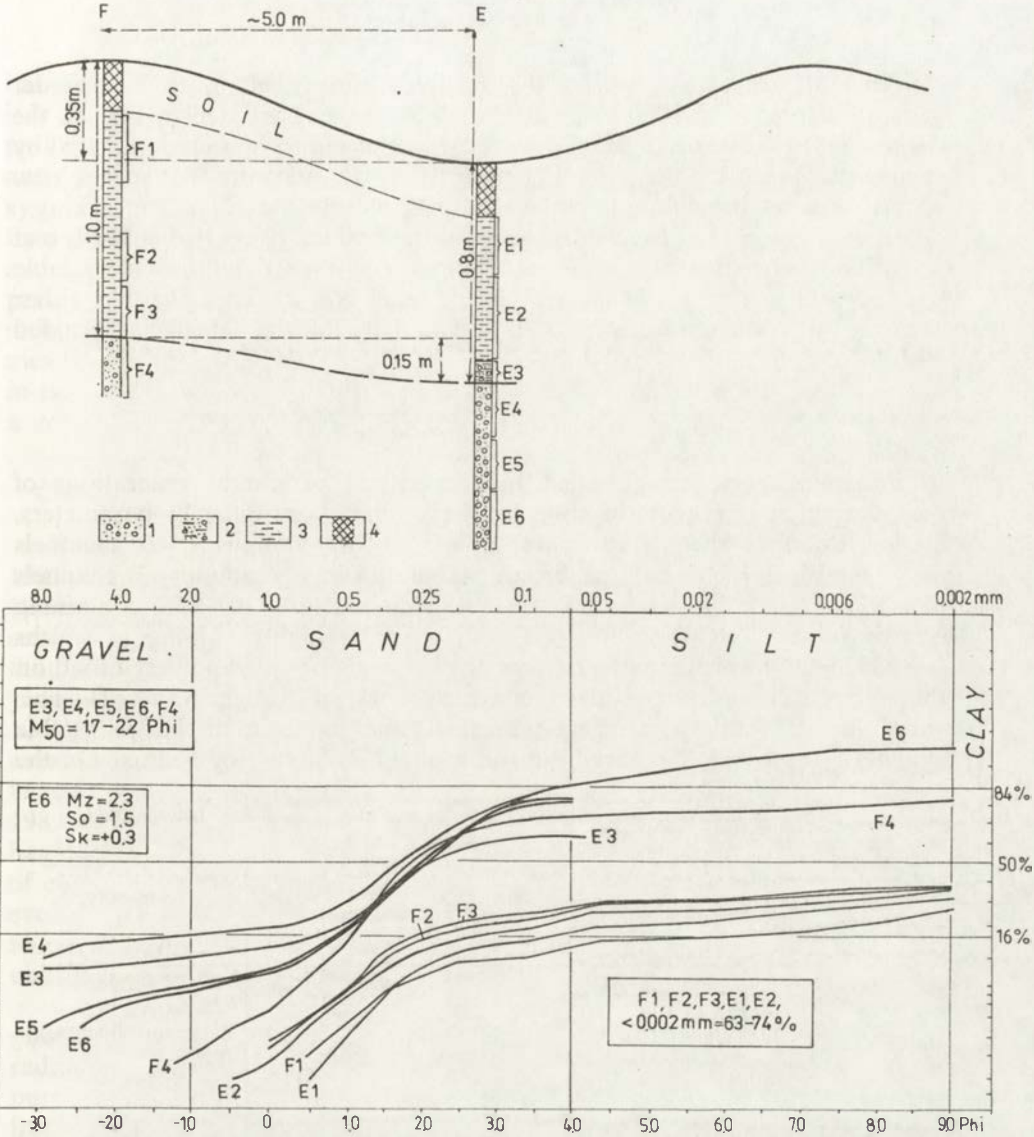

Fig. 2. Location of two borings in the Drwinka depression which document the sandy-gravelly braided river, together with the overlying floodbasin mud. *1* — coarse sand with gravel; *2* — mud with sand and gravel; *3* — organic mud; *4* — soil. Granulometric curves refer to the profiles E and F. Thick line — braided channel deposit; thin line — flood basin deposit

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Fig. 1. Map — photo-interpretation mosaic showing the Vistula valley floor to the east of Zabierzów Bocheński (based on photographic coverages on the scale of c. 1:9400 taken on August 27, 1973)

1 — traces of troughs of the late-Vistulian braided river; *2* — both broad and narrow channels with islands probably of Holocene age; *3* — Atlantic meandering channel generations within the Grobla Forest, as well as a channel with similar parameters near Zabierzów Bocheński and within the Hadyna Forest; *4* — meandering channels of greatest widths indicating high and uniform stream discharges; *5* — unstable meandering channels indicating variable stream discharges; *6* — stable meandering channels probably dating from the early Middle Ages; *7* — unstable meandering channels dating from the 18th – 19th centuries; *8* — crevasse splays; *9* — well defined and less well defined edges; *10* — boundaries of well defined and less well defined meanders: *a* — young, *b* — old, hanging; *11* — crevasses; *12* — traces of scrolls on the point bar; *13* — present-day Vistula channel with embankment; *14* — Drwinka canal, *15* — roads; *16* — loess-covered Vistulian terrace, 16 m high; *17* — location of borings; *18* — profile line, together with ^{14}C dates within the Grobla Forest (*vide* Starkel *et al.*, this volume)

Since the meanders within the Hadyna Forest belong to a meander generation predating 5000 years BP (such a view is presented in Fig. 1), the depression to the north of the Grobla Forest seems to have been dominated by sedimentation during the Atlantic period. However, no proof that such a view is true has yet been found because datings on the top clays are lacking.

In the light of the photo-interpretation the braided rivers had either broad and deeper, low sinuosity channels or narrower, sinuous channels of variable widths, with characteristic islands (Fig. 1, *vide* No. 2). This phase is either younger or contemporaneous with the activity of the lateglacial braided Vistula.

GENERATIONS OF MEANDERING CHANNELS

Photo-interpretation revealed the occurrence of several generations of meandering channel patterns (Fig. 1). These generations differ by parameters, as for example the narrow, stable and highly sinuous (>2) channels ($\bar{w} = 66 \pm 16$, $\bar{w} = 63 \pm 20$), the broad, stable and highly sinuous (3) channels ($\bar{w} = 92 \pm 22$), the locally broad, unstable channels ($\bar{w} = 107 \pm 56$) containing one or more troughs on the bed, and channels highly varying in widths ($\bar{w} = 372 \pm 207$) which may be narrow, with a single trough, and very broad on the adjacent point bar, with a dense network of troughs (Tab. 1). This variability of width parameters indicates either uniform discharges (stable channels) or variable discharges (unstable channels of varying widths). On the

Table 1. Meandering channel parameters for channel generations distinguished on the map (generations 2–7; Fig. 1)

Meandering channel systems	Widths (m)			Max. curvature radii (m)			Sinuosity l/d (km/km)
	N	$\bar{w}$	σ	N	$\bar{r}$	σ	
2nd generation	70	75	32	15	184	128	3.2/1.4 = 2.28; 2.2/1.1 = 2 Zabierzów Bocheński 10/4 = 2.5; Las Grobla 7.8/4 = 1.95;
3rd generation	100	63	20	36	242	53	Las Grobla* 13.4/3 = 4.4; Las Hadyna* 6/2.2 = 2.7
4th generation	19	92	22	2	290	14	6/2 = 3
5th generation	35	107	56	10	220	12	3.4/2.1 = 1.61; 2.6/1.6 = 1.62
6th generation	20	66	16	5	170	23	3/1.4 = 2.14
7th generation	22	372	207	2	–	–	7.2/3 = 2.4

N – quantity of measurements,
$\bar{w}$ – mean channel width,
$\bar{r}$ – mean radius of maximum curvature,
l – length of meandering channel in a given section,
d – length of section for which sinuosity was estimated,
* – sinuosity estimated on the basis of the partially reconstructed channel course taking into account all of the earlier cut off bends,
σ – standard deviation.

basis of stable channels being fashioned probably by more uniform discharges it is possible to reconstruct both wetter periods (broader channels) and less wet periods (narrower channels). Both parameters of the different meander systems and their mutual relation enabled the relative chronology of the meander systems to be established, since undercutting/overhanging, cut off, connection by a crevasse indicate lateral overflows and the repeated use of a part of the system probably at the time of floods of high magnitude. The distance from the present-day river also is of importance in establishing the local chronology, although this rule is not valid throughout the map area. Zones of preserved meander systems alternate with those of the braided system. The latter survived in two parallel running zones including the southern Drwinka depression and a zone to the north of the Grobla Forest.

CHANNEL GENERATIONS INTERRUPTING THE VISTULA ALLUVIAL PLAIN

Results of earlier work on the ages of palaeomeanders (Kalicki, Starkel 1987; Gębica, Starkel 1987; Rutkowski 1987; Sokołowski 1987; Starkel *et al.* 1988; Kalicki 1988) refer rather to periods when the meander systems gradually ceased to function. Radiocarbon datings on abandoned channel fills indicate that within the Grobla Forest such a process took place mainly prior to 5000 years BP, and from between 1800 BP and 1400 BP. Earlier dates of 10 500 – 9000 years BP have been obtained from organic clays and peats either overlying the braided river deposits or occupying the very broad channel bends. On the basis of archaeological evidence (Radwański *fide* Kalicki, Starkel 1987) the decreasing activity of the younger meander systems in historical times has been dated at between the 10th and 14th centuries. A penetrating analysis of early cartographic data by K. Trafas (1975) made it possible to trace the evolution of the meanders from 1775 onward until 1852. The latter phase came to an end in the late half of the 19th century when channel correction was undertaken on the Vistula.

Channel generations shown in the map were discovered by the detailed photo-interpretation: it is relative chronology, whereas the existing radiocarbon dates can help to establish the absolute chronology. For this purpose datings on channel fills recorded in the map area are best suited. Apart from the well known and ^{14}C dated Atlantic channel system within the Grobla Forest (lithology and stratigraphy, this volume), other meandering channels marked by different parameters were recorded. Generally, it can be concluded that they postdate the very well preserved meander system occurring near Zabierzów Bocheński. Since the above meandering channel system is similar to that within the Grobla Forest it has been included into the same generation on the evidence of similar parameters: $\bar{w} = 63 \pm 20$, sinuosity 2.5 – 2 and meander radius $\bar{r} = 242 \pm 53$. According to P. Gębica, the Atlantic meanders within the Grobla Forest are 45 – 65 m broad (this volume). The meander system occurring north of the Grobla Forest (Hadyna Forest) also has been interpreted as the 3rd generation lying close to the 19th c. channel (7th generation). However, it predates both the 6th generation and a broad loop of an unknown age (5th generation). Apart from the similar parameters and their relation to the other generations, no ^{14}C datings on the meanders within the Hadyna Forest are available. It is necessary to ascertain whether the above meanders were connected with the system developed in the central part of the Grobla Forest or whether they are somewhat younger, and if so, whether they were used by the Vistula just after the abandonment of the central system within the Grobla Forest.

The absolute ages of the younger meander generations (4th, 5th, 6th) with their variable discharge properties had to be inferred from other analogues including sections of the Vistula valley lying 20–40 km in the west (upstream of the study area) and in the east (downstream of the study area) (Rutkowski 1987; Sokołowski 1987). This attempt to establish the absolute chronology of events is only a hypothesis which may be confirmed or rejected by future work.

Variations in the parameters of different meander generations which have been recorded by photo-interpretation, as well as published radiocarbon dates for the Vistula valley near Cracow made it possible to reconstruct the following course of fluvial activity from the late Vistulian onward down to the present day. Numbers in the chronology refer to successive signs in the map legend (1–7; Fig. 1):

1. Sandy-gravelly braided river, with troughs and bars, straying across the Vistula valley floor prior to 10 500 years BP (the properties of deposits are shown in Fig. 2; samples E_5, E_6, F_4).

2. The transition of the braided channel into broad meandering channels encircling the islands took place in the Younger Dryas and at the beginning of the Holocene (Starkel *et al.* 1988). The earlier transition of the braided into meandering rivers either in the Older Dryas decline time or at the beginning of the Allerød has been documented by T. Kalicki (this volume) on evidence of a date of 11 090 ± 120 years BP on an Allerød meander. It is likely that such changes repeatedly occurred in late Vistulian decline times. It also is probable that the braided river system and the newly forming either broad, low sinuosity troughs or rather narrow troughs encircling the islands co-existed in the Younger Dryas. However, in Table 1 parameters of the 2nd channel generation represent the average value of both channel types.

3. Meandering river with stable, rather narrow ($\bar{w} = 63 \pm 20$ m) and highly sinuous (2–2.5; 4.4 at the maximum) channels. This pattern functioned already prior to 8000 years BP to reach its optimum from between 7000 and 6000 years BP. It gradually ceased to function prior to 5000 years BP. This chronology is documented by a set of radiocarbon datings on deposits obtained from borings in the Grobla Forest (Starkel *et al.* 1988; Starkel *et al.*, this volume).

4. Stable meandering river the discharges of which were higher than those in Atlantic times. This river shows the highest sinuosity (3, $\bar{w} = 92 \pm 22$). In the study area the exact age of this meander generation is unknown. Comparison with the valley sections situated upstream of Cracow (Rutkowski 1987) and downstream of the Dunajec river mouth (Sokołowski 1987) may suggest that this system gradually ceased to function prior to 3000 years BP.

5. The successive meander system gives evidence of unstable stream discharges. These are documented by variable width parameters ($\bar{w} = 107 \pm 56$ m) and by the occurrence of two or more troughs within the channels indicating a tendency toward metamorphosis of the virtually meandering channel. This period of unstable discharges also is proved by datings on tree trunks found downstream of Cracow (1950–2200 years BP; Kalicki, Krąpiec 1988) and upstream of Cracow (1800–1645 years BP; Rutkowski 1987). This

system may represent a cooler and wetter phase which correlates to the Löbben glacial fluctuation in the Alps. This phase also has been recognized by A. Obidowicz (1988) in the Podhale. Accordin to T. Kalicki and L. Starkel (1987), during the period from 2500 BP to 1500 BP the Vistula system was deeper incised than the Atlantic system and the medieval one.

6. The penultimate meander system includes rather narrow and stable channels ($\bar{w} = 66 \pm 16$ m, $r = 170 \pm 23$) occurring close to the present-day channel. By comparison with the other valley sections this system may represent the early Middle Ages, since it gradually ceased to function during the 10th–14th centuries (Kalicki, Starkel 1987).

7. The youngest system of large meanders the parameters of which are variable – from rather narrow channels with single troughs in the bends to very broad channels on the point bars – indicate highly variable stream discharges ($\bar{w} = 372 \pm 207$ m). This system is well documented by cartographic data (Trafas 1975). It developed during the period from 1775 to 1850. It is acknowledged to be the time of climatic deterioration named the Little Ice Age in the Alps.

OVERBANK DEPOSITS – CREVASSE SPLAYS

Air photo-interpretation made it possible to determine the boundary of crevasse splays and of "crevasses" through which overflow from the meandering channel onto the adjacent alluvial plain took place. One should be aware that the image obtained also depends upon the angle of illumination during the flight. On the successive photographs, but especially on the adjacent parallel strips the same area seems to be dissected either by a dense or by a less dense trough network. Density is less important. The fact that such landform assemblages can be recorded is of fundamental importance. The photographs also indicate which breached meander was the source area of splay deposits.

Photo-interpretation was supplemented by field work in woodland. It appeared that the microrelief of the alluvial plain detectable from the air shows height differences of up to 1 m, most frequently of 0.3–0.5 m. The troughs are up to 1–5 m wide, whereas the intervening "bars" may be 20–100 m wide. The troughs are dry, swampy or drained by rivulets the small channels of which are 0.2–1 m wide.

Several borings (*A–D*) were made within the crevasse splay zone at different distances from the meander edge (5th meander generation): at 10 m – boring *A*, at 70 m – boring *B*, at 130 m – boring *C* and in the adjacent flat-floored trough, 4 m wide and 0.7–0.8 m deep. Along its whole length the profile *A–B–C* is accompanied by this low sinousity trough. At c. 120 m distance from the meander edge boring *D* was sunk in the trough (Fig. 3). In the light of borings and grain size composition the splay deposits are up to 2.4–2.8 m thick.

Results of the granulometric analysis revealed that the deposit discussed is fining with distance. Its variability also increases with distance from the apex of the crevasse splay.

At a distance of 10 m from the meandering channel bank there may be distinguished both channel deposits at depths of 2.3–2.7 m (samples A9, A10, A11; $M_{50} = +3.5$ to $+3.8$ ∅, comp. Fig. 3 – diagram *A*) and finer deposits at

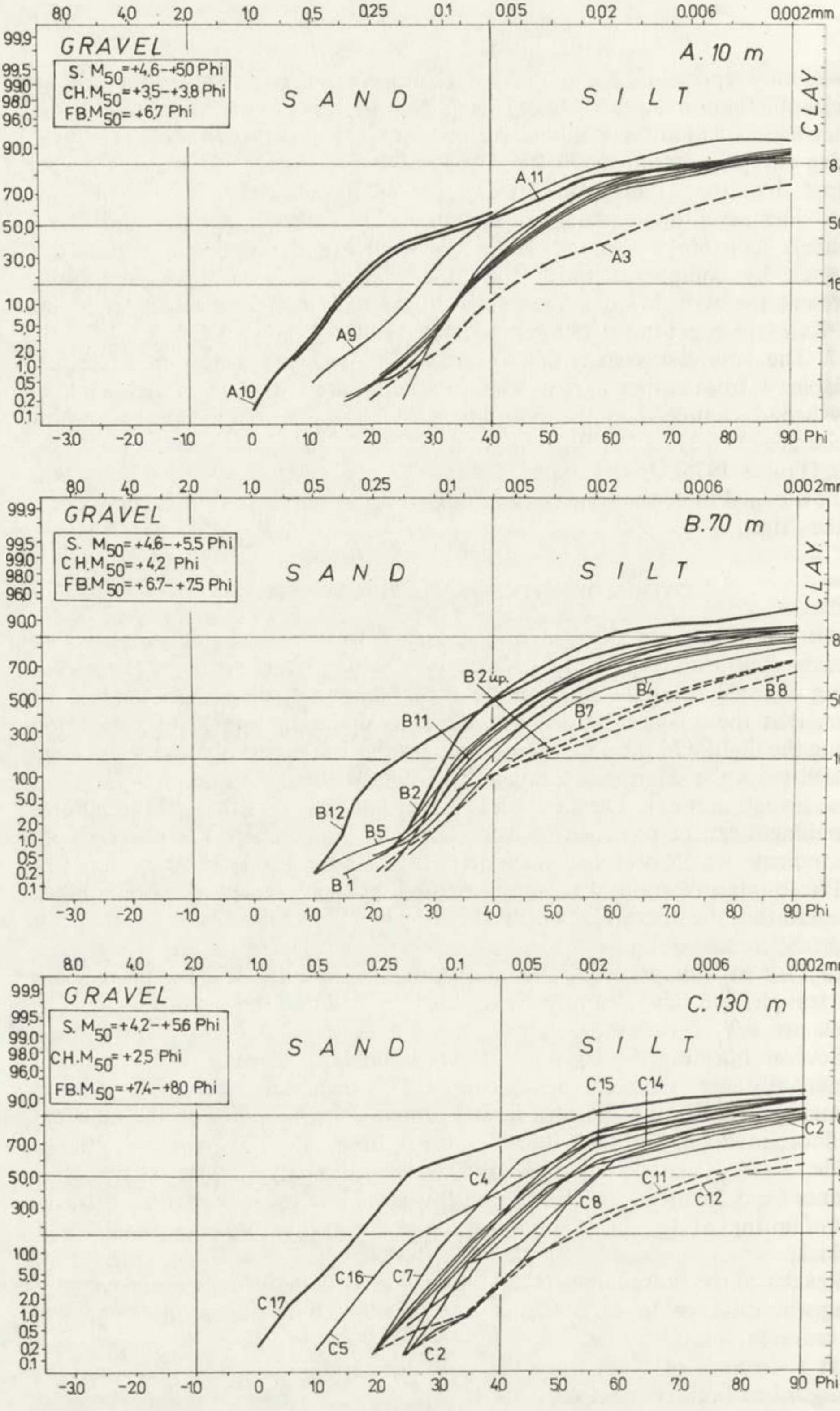

Fig. 3. Granulometric curves documenting splay deposits disclosed in the borings *A – C* within the Hadyna Forest. For location of borings see Figure 1. Thick line – channel deposit (CH); thin line – splay deposit (S); broken line – flood basin deposit (FB)

depths of 0.25–2.3 m ($M_{50} = +4.6$ to $+5.0$ ∅) which have been recognized as splay deposits. Only one sample obtained from depths of 1.15–1.35 m (*A3*) indicates the deposition of clayey sediments ($M_{50} = +6.7$ ∅).

At a distance of 70 m splay deposits are marked by $M_{50} = +4.6$ to $+5.5$ ∅. Only three samples at depths of 0.4–0.6 m (upper *B2*), of 1.45–1.65 m (*B7*) and of 1.65–1.75 m (*B8*) indicate clay deposition ($M_{50} = +6.7$ to $+7.5$ ∅) in the floodbasins (Fig. 3B).

At a distance of 130 m channel deposits ($M_{50} = +2.5$ ∅) were disclosed at depths of below 2.9 m (*C17*). Overlying are splay deposits ($M_{50} = +4.2$ to $+5.6$ ∅). These are interbedded with clay ($M_{50} = +7.4$ to $+8.0$ ∅) at depths of 1.90–2.05 m (*C11*) and of 2.05–2.22 m (*C12*).

Thus it appears that both the percentage of fine materials in the splay deposits and the amount of clayey intercalations due to deposition from stagnant water on the floodplain are increasing with distance from the river channel.

Interpretation was fraught with difficulties. It was hard to delineate the boundaries of ancient braided channels, of splay deposits and of landforms. Their distributional patterns are clearly visible close to the meanders which supplied the splay-forming water and material. At great distances from the meandering channels exceeding 1 km vertical accretion by splay took place locally. A similar pattern also may indicate a braided river channel the features of which are being reproduced by the clays laid down under backswamp conditions. Geomorphological observations were combined with analysis of the soil map by M. Karkanis (1973), of the vegetation map by Z. Denisiuk *et al.* (1976), and of tables containing data on the grain size composition of deposits disclosed by borings which aided the soil survey.

Thus it was possible to delineate the boundaries of areas showing a similar "braided" pattern. The heavy backswamp clays are occupied by *Circaeo-Alnetum* and by the transitional community from *Circaeo-Alnetum* to *Tilio-Carpinetum*, whereas the crevasse splays are dominated by *Tilio-Carpinetum typicum*, with either the variant *Convallaria maialis-Poa memoralis* or the variant *Aegopodium podagragia*. The distal parts of the splay deposits carry mostly *Tilio-Carpinetum stachyetosum.*

CONCLUSIONS

The obtained spatial image yielded clues at to the mechanism of development of the alluvial plain of the Vistula. During the last Lateglacial this plain was fashioned by a shallow and broad braided river, whereas during the Holocene it was formed by different meander generations. This image also revealed that the alluvial plain of a meandering river developed by its vertical accretion during floods. The floodwaters were able to break out of the meandering channel, to transport across the plain mostly silty and clayey sediments and to lay them down in the form of extensive crevasse splays. The overlying splay deposits are up to 2.8 m thick.

The present author has the following conception of the mechanism of superposition of the crevasses splays on the inactive meander loops which became filled mostly with clayey deposits: During floods of high magnitude being accompanied by breaches of the meanders and the spread of sediments, mostly of silty clays, the entire Grobla Forest was under water. Sequences of crevasse splays indicate stream discharges at which the overflowing water proved competent to transport material of a mean diameter of 4.5 – 5 ∅. As flood flows decreased the inactive meanders remained filled with water. This condition was favourable for the slow deposition of suspended material, i.e. of clays containing organic matter.

Comparison of channel deposits of the meandering Vistula with those of the braided Vistula revealed essential hydrodynamic differences. These are documented by the grain size composition of sediments disclosed by borings (*A* – *D*, *E* – *F*). Channel deposits of the meandering river are clearly finer and better sorted than those of the lateglacial braided Vistula. On Visher's graph showing the meandering river deposits there may be distinguished both the bed load and the suspended sediment, whereas that of the braided river is composed of coarse sand and gravels forming the channel bed material.

The present author would like to stress that the air photo-interpretation on the scale of 1 : 9400 which depicts the course of meanders in the Grobla Forest is very similar to the excellent 1 : 16 000 geomorphological map by M. Bzowski (1973). The latter is based on classical mapping in forested area.

This work puts new questions in regard to the ages of different meander generations. In this sense the present author proposed for acceptance or rejection a chronology of fluvial activity which may stimulate further research.

Finally, the present author would like to thank Professor L. Starkel for drawing her into the discussion on the palaeomeanders developed in the Grobla Forest. Air photo-interpretation gave great impetus to search for an answer to the events recognized, and to write this paper instead of a small contribution to the collective work on the Grobla Forest (this volume).

She also is indebted to Mgr P. Gębica and Dr T. Kalicki for discussion, to Mgr I. Kasza for making the grain size analysis, and to Mrs M. Klimkowa for cartographic assistance.

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THE TEXTURAL DIVERSITY OF UPPER QUATERNARY FLUVIAL DEPOSITS IN THE CARPATHIAN FORELAND

Studies of fluvial deposits have been carried out in two valleys extending in the Carpathian foreland: in the Wisłoka valley within the Sandomierz Basin and in the upper Vistula valley within the Oświęcim Basin (Fig. 1). The detailed characteristics of the Wisłoka valley morphology and infills, of both their ages and genesis, has been published in an earlier work edited by L. Starkel (Alexandrowicz *et al.* 1981). Deposits occurring in the upper Vistula valley were studied by E. Gilot *et al.* (1982) and by E. Niedziałkowska *et al.* (1985). The following are the important problems of additional specialized study that have been used to analyse the sediments:

1) comparison of both grain size and abrasion parameters of various types of ancient deposits dating from different periods of both the Vistulian and the Holocene;

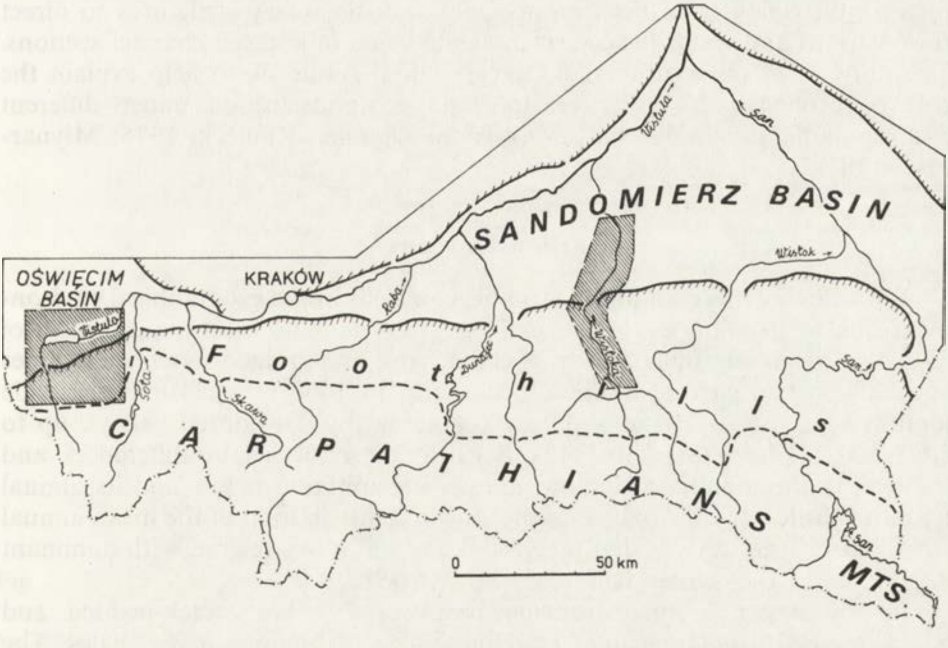


Fig. 1. Location of the study areas

2) characteristics of both grain size and abrasion of the modern deposits and conditions under which such deposits occur in relation to the channel; comparison of modern deposits with the fossil ones;

3) determination of the course of sedimentation, especially that of channel fill deposits and of alluvial fan deposits.

This study is designed to show whether the two textural properties of fluvial deposits, i.e. grain size and quartz abrasions, are dependent on the period of sedimentation or whether these were controlled by the geographical environment.

The literature on textural properties of deposits (mainly grain size) is vast. In order to identify the different depositional environments, their typical features, and to reconstruct the palaeogeographical conditions of sedimentation (Vaškovska 1971) grain size is usually analysed. Sometimes abrasion, heavy mineral content and petrographic composition of deposits also has been described. Based on the grain size and abrasion parameters are the attempts made to reconstruct the long-termed palaeohydrodynamic conditions of rivers, as for example, during the Quaternary (Antczak 1986; Mycielska-Dowgiałło 1987).

A. Kostrzewski (1970, 1984), N. D. Smith (1974), B. M. Osovietskiy (1982), M. Church and R. Kellerhals (1978) and others argued that in the different terrace levels and channels both downstream grain size reduction and increase in the abrasion degree takes place. The fining of deposits which depends on the fluvial dynamics takes place by leaps. Essential grain size changes may not occur within one geomorphological zone.

Another approach (Folk, Ward 1957; Bridge 1978; Levey 1978; Nanson 1980; Bridge, Jarvis 1982; Eschner and Kircher 1984) has been concerned with relating the analyses of both grain size and sedimentary structures to direct observations and water flow measurements made in selected channel sections. The purpose of observations and experimental studies is to help explain the role of processes of both abrasion and morphoselection under different hydrodynamic conditions prevailing in the channel (Kaniecki 1975; Młynarczyk 1985).

THE STUDY AREA

Both catchments contain remarkable contrasts in the geographical environment due to location in the Carpathian arc. The Wisłoka drainage basin of 3915 km^2 is largely underlain by less resistant, fine-grained flysch sandstones and shales. The narrow mountain zone (up to 1000 m a.s.l.) and the wide foothill zone (up to 560 m a.s.l.) are cut across by flat-floored valleys, up to 200–500 m deep (Starkel 1972). Because of small height differences and location in the mountain shadow, annual precipitation is low and its annual pattern is little varied. Analysis of the seasonal distribution of the mean annual stream discharges reveals that the Wisłoka has a snowy regime, with dominant discharges in the winter half year (Punzet 1983).

In the upper Vistula drainage basin of 297 km^2 thick-bedded and coarse-grained sandstones and conglomerates predominate over shales. The resistant sandstones give rise to a coarse debris. The mountains (up to 1250 m

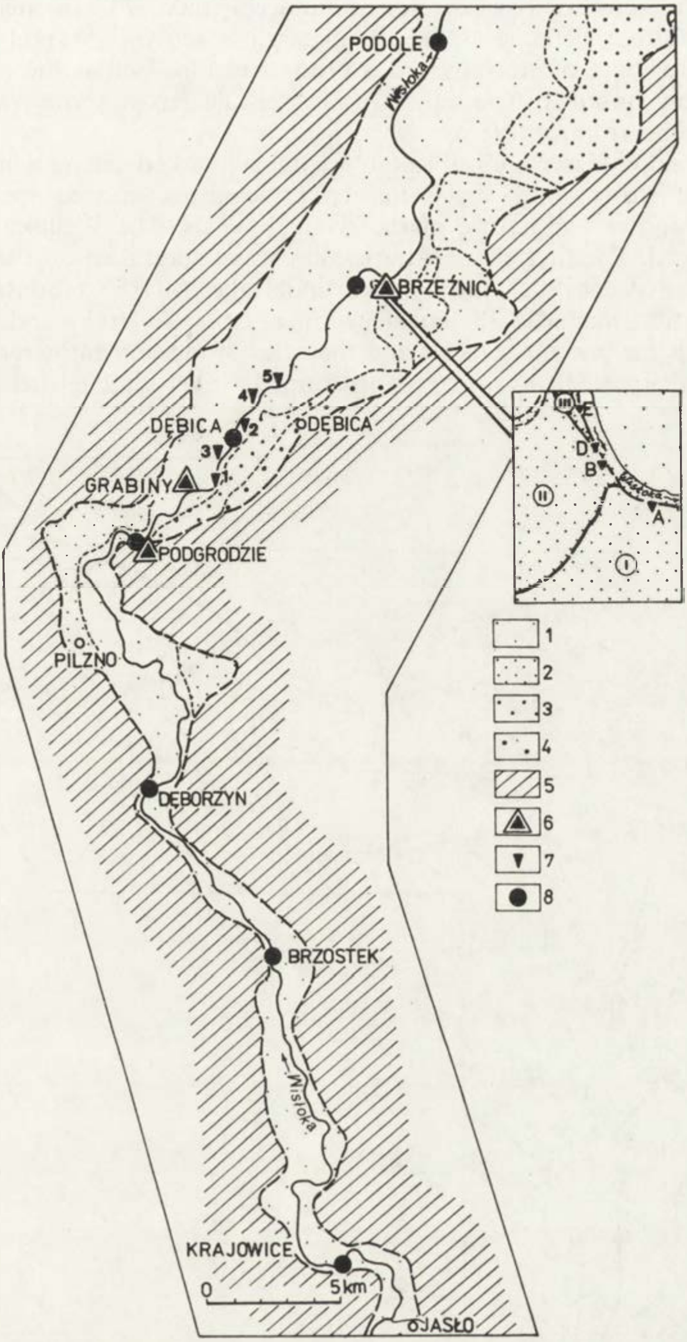


Fig. 2. Schematic geomorphological map showing the Wisłoka valley (based on the 1:500 000 *Geomorphological map of Poland*)

1 — Holocene floodplain; *2* — Vistulian terrace level; *3* — terrace level dating from the Mid-Polish glaciation; *4* — terrace level dating from the Cracovian glaciation; *5* — valley-sides; *6* — distribution of sites examined; *7* — sites of modern flood-formed deposits; *8* — location of gravel bars examined a.s.l.) are characterized by steep slopes and deeply (600–700 m) incised valleys, whereas the foothill zone (330–550 m a.s.l.) is narrow (Starkel 1972). The summer maximum of precipitation is pronounced, as well as the high diurnal precipitation amounts. Consequently, the Vistula has a snowy-rainy hydrological regime (Punzet 1983).

Man's activity is responsible for the most marked changes in the composition of the natural vegetation cover (changes in tree species, forest clearance) and in the nature of the river channels. The Wisłoka channel is non-regulated. The first channel correction was undertaken on the Vistula in the 1930s. Successive channel works undertaken in the mountainous and foothill sections included the construction of concrete banks and weirs. This caused both the current velocity and the rates of incision to increase (Klimek 1983). Furthermore, gravel extraction from the river channel led to its local

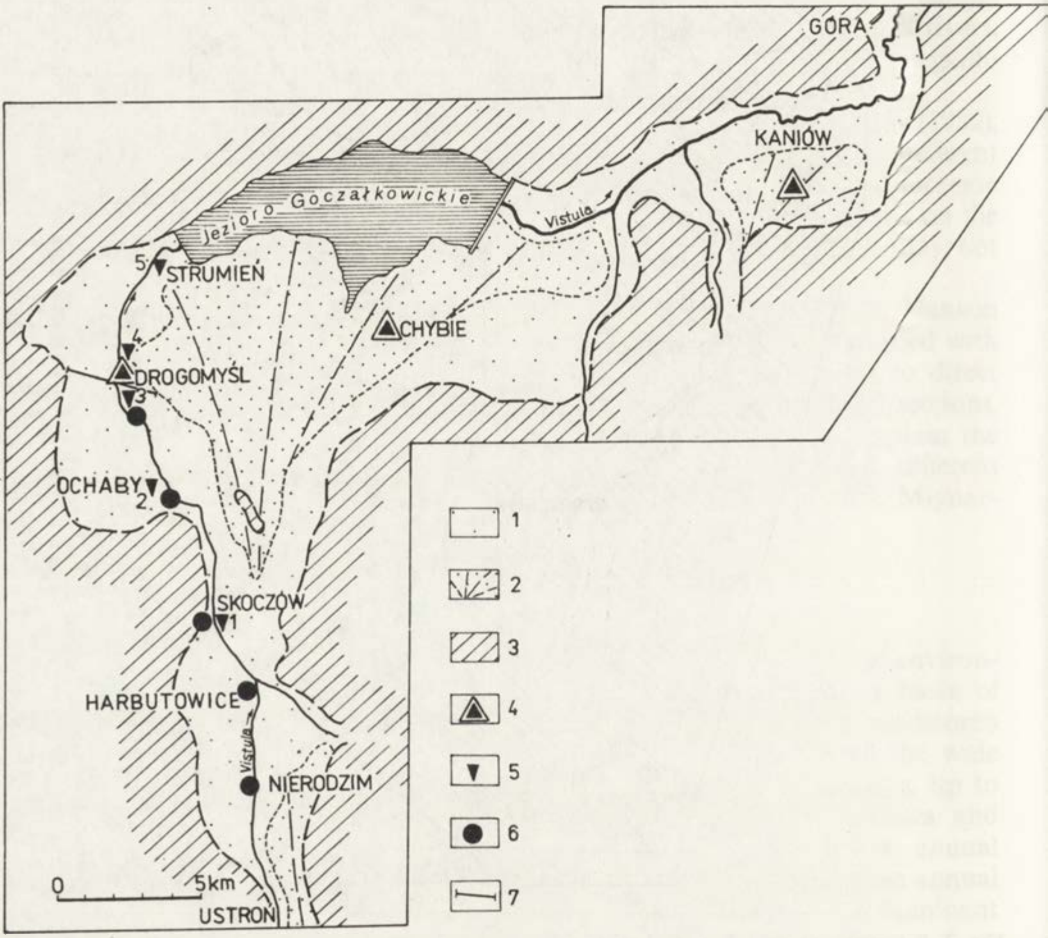


Fig. 3. Schematic geomorphological map showing the upper Vistula valley

1 – Holocene floodplain; *2* – Vistulian terrace level – alluvial fan; *3* – valley-sides; *4* – distribution of sites examined; *5* – sites of modern flood-formed deposits; *6* – location of gravel bars examined; *7* – sections deepening. Headwater erosion commences, sometimes showing considerable rates (Froehlich 1982). In places, exploitation of the bed material is intensive in the Wisłoka valley (Klimek, Starkel 1974).

Beyond the Carpathian Foothills three well exposed sites: Brzeźnica, Grabiny and Podgrodzie have been examined in detail in the Wisłoka valley (Fig. 2).

In the upper Vistula valley materials have been collected at the Drogomyśl site including an exposure and borings made across the floodplain (Fig. 3). Additional data were supplied by a boring at Kaniów and by a dug section at Chybie.

Studies of modern deposits gave data for comparison with the fossil sediments. The term "modern deposits" covers both sediments that are being accumulated in the river channel and on the floodplain during a concrete flood, as well as lateral gravel bar deposits which became exposed at low water levels.

METHODS OF STUDY

FIELD WORK

Samples have been obtained from each discernible stratum, at least 1 cm thick, in the exposures, whereas from the cores samples were taken, where lithological changes became evident.

Sampling was done on the bar surface. Gravels were collected from 1 × 1 m squares located in the central part of the form chosen. Gravels then were placed together in size classes each of 1 ∅ units by the direct measurement of the *b* diameter. Subsequently, each gravel class was weighed out. Particles finer than 8.0 mm were collected into bags and shaken through a standard set of sieves in the laboratory.

LABORATORY ANALYSES

Samples were analysed by sieving and hydrometer techniques to determine their grain size parameters (Stoch, Sikora 1979). Particles, 8.0 – 0.71 mm in diameter, were shaken through sieves with holes corresponding to divisions of the c. 0.5 ∅ scale.

The abrasion of quartz grains was mechanically analysed using the automatic GW-02 graniformameter. Since very fine particles were abundant in the deposits examined, this analysis was made in the finer fractions: 1.02 – 0.75 mm 0.75 – 0.5 mm and depending upon the highest frequency of occurrence. Analyses were made of 610 samples in the 0.75 – 0.5 mm fraction and of 415 samples in the 1.02 – 0.75 mm fraction. The abrasion of the 0.75 – 0.5 mm grains was interpreted in greater detail.

THE ELABORATION OF RESULTS

Corresponding percentile values of various grain size intervals were derived from graphs and the following grain size parameters using Folk's and Ward's formulae (1957):

- mean diameter (Mz),
- inclusive graphic standard deviation (σ_I),
- inclusive graphic skewness (Sk_I),
- graphic kurtosis (K_G).

The degree of quartz grain abrasion has been described using Krygowski's abrasion index *Wo* (1964). For the determination of the internal differentiation of the samples in respect of abrasion Rotnicki's equation (personal communication) has been used. It defines the standard deviation for grouped data being described by the symbol σ_0 and named the homogeneity index:

$$\sigma_0 = c\sqrt{\frac{\Sigma fm^2}{\Sigma f} - \left[\frac{\Sigma fm}{\Sigma f}\right]^2 - 0.083},$$

where:

f = mean quantity of grains in a given class ($\Sigma f = 100$),
m = reference of the size class in the sample,
c = interval (accepted $c = 2$).

The Sheppard correction (0.083) was adapted (Mills 1952). Lower values of the index indicate the greater homogeneity of the sample in respect of the abrasion degree. Higher values denote a greater differentiation.

According to J. R. L. Allen's classification (1965) which has been modified (Starkel, Thornes 1981) and supplemented (Teisseyre 1985) the following types of fossil deposits were identified:

1. Channel deposits (ch) including channel-lag deposits (ch-l) and bar deposits which were laid down in the river channel below bankfull stages. Bar deposits comprise central bar deposits and point bar deposits.

2. Overbank deposits (ob) accumulated outside the channel to form the floodplain; these include:
- levee deposits (ob-l) consisting of bed material and the coarsest suspended sediment accumulated outside the channel,
- floodbasin or backswamp deposits (ob-fb) composed of fine suspended sediment being accumulated beyond the natural levees during floods,
- floodplain deposits (ob-fp) being accumulated outside the natural levees by flowing water.

3. Transitory deposits include:
- channel fill deposits (cf) formed of mineral or organic materials accumulated in the abandoned or cut off channel,
- alluvial fan deposits (tf) laid down by tributaries on the floor of the main valley.

The ages of the materials collected have precisely been determined by many radiocarbon datings (Alexandrowicz *et al.* 1981; Gilot *et al.* 1982; Niedziałkowska *et al.* 1985). The two valleys examined show distinct contrasts in both ages and types of deposits (Tab. 1) due to the different types of sedimentation there. In the Wisłoka valley, the lateral development of the valley floor by undercutting of the earlier sheets and by deposition of the successively younger sediments was dominant (Alexandrowicz *et al.* 1981). Consequently, great variations in both ages and depositional environments do exist. The Vistula

Table 1. List of different types of fluvial deposits varying in age, occurring in the valleys of both the Wisłoka and the upper Vistula

		PL1	IPL	PL2	LG	PB-BO	AT	SB-SA	SA2
ch	Wisłoka	Brzeźnica B 51	–	Brzeźnica A 32	Brzeźnica B 26	–	–	Brzeźnica D 10 Grabiny 6	Grabiny 69
	Wisła	–	–	–	–	–	–	–	Drogomyśl 66
ob	Wisłoka	–	–	–	–	–	Brzeźnica B 3	–	Brzeźnica E 18
	Wisła	–	–	Kaniów 30 Chybie 5	–	–	–	–	Drogomyśl 24
cf	Wisłoka	–	Brzeźnica B 4	Brzeźnica A 2 Podgrodzie 10	Podgrodzie 2	Podgrodzie 10	–	–	Grabiny 15 Brzeźnica D 15
	Wisła	–	Kaniów 1 Chybie 1	–	Drogomyśl 5	–	–	–	–
tf	Wisłoka	–	–	–	–	–	Podgrodzie 108	–	–
	Wisła	–	–	–	–	–	–	–	–

Abbreviations – type of deposit: ch – channel deposit, ob – overbank deposit, cf – channel fill deposit, tf – alluvial fan deposit; age designations: PL1 – Older Pleniglacial, IPL – Interpleniglacial, PL2 – Younger Pleniglacial, LG – Lateglacial, PB-BO – Preboreal-Boreal, AT – Atlantic, SB-SA – Subboreal-Subatlantic, SA2 – Younger Subatlantic (c. last millenium). Number indicates the total number of samples.

valley which extends in the subsiding mountain foreland represents an other type of sedimentation during which the vertical accretion of the valley floor was dominant (Niedziałkowska *et al.* 1985).

SELECTED EXAMPLES OF DIFFERENT TYPES OF FLUVIAL DEPOSITS

On the basis of the detailed analysis of sedimentary structures, of the macroscopic grain size determination in the deposits, of the spatial distribution of strata and of their location in the vertical profile different types of fluvial deposits have been determined. Additions are the results of grain size analysis and the location of samples on the CM Passega diagram.

Brzeźnica A – There occur typical sandy braided river deposits dating from the Younger Pleniglacial (Fig. 4). These are medium and fine sands including laminae of dusty sands, and even of clayey dusts (Fig. 5). Mz ranges from 1.3 to 3.2 $\varnothing$. Sorting improves upward from poor ($\sigma_I = 1.6$) to well ($\sigma_I = 0.4$). The laminated dusty sands are characterized by $Mz = 4.6 - 7.0$ $\varnothing$. They are very poorly sorted ($\sigma_I = 2.5$). Stratification of the deposits is less well developed, only some strata show a horizontal lamination. Strata decrease upward in thickness (Fig. 5). Properties of the deposits indicate a channel environment with decreasing dynamics. Both individual strata and mean grain diameters become reduced upward (Fig. 5).

Brzeźnica B – Worthy of note are channel deposits (a bar) which have been laid down by the meandering river in lateglacial times. These deposits are extensively exposed in a cross-section, some 200 m long (Fig. 4). The deposits show predominantly a tabular cross-bedding, locally alternating with a horizo-

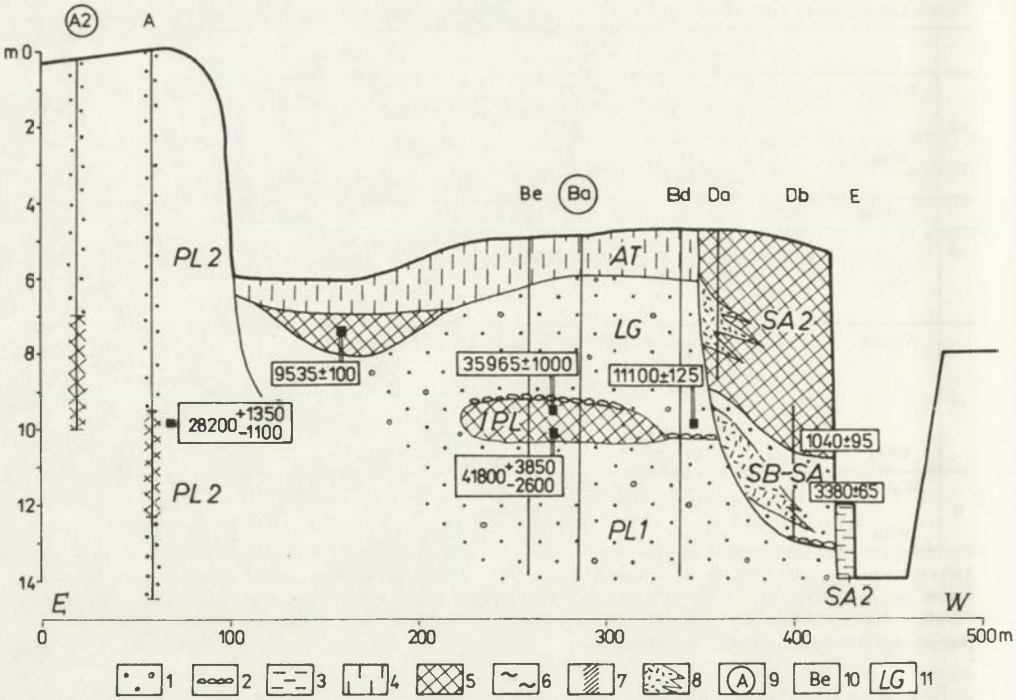


Fig. 4. Brzeźnica site – schematic section across the exposure

1 – channel deposits; *2* – channel-lag deposit; *3* – levee deposit; *4* – floodbasin and floodplain deposit; *5* – channel fill deposit; *6* – alluvial fan deposit; *7* – redeposited Miocene clay; *8* – slump; *9* – profiles discussed in the text; *10* – other profiles; *11* – abbreviations are as for Table 1

ntal lamination. The fining upward of sediments is accompanied by increasing thicknesses of strata (Fig. 6).

The basal coarse sediments contrast with the fine top deposits (Fig. 6). In the gravel pit the basal sands include gravels the proportion of which decreases from 23% in the channel-lag deposit to 3% in the overlying strata. Mz varies from -0.6 to 1.3 $\varnothing$ (Fig. 6). The deposit is moderately to very poorly sorted. The fine-grained top deposits include strata of fine sand which is fining upward ($Mz = 1.8-3.0\ \varnothing$). These deposits are well to moderately well sorted. The variable Wo ranges from 660 to 950. Contrasts between the top and basal parts of the deposits are least in the marginal part of the point bar. In the cross-section, grains become somewhat finer downstream and sorting also improves there, whereas the abrasion degree does not show any essential changes. Only in the marginal part of the bar there decreases the range of the Wo values. Better abraded grains may suggest morphoselection. Both minimum and maximum values of the grain size index and of the abrasion index (Tab. 2) show that their differentiation is greater in each of the vertical profiles of the point bar than in the cross-section examined.

Grabiny – Channel deposits were laid down by a meandering river the channel of which was rapidly shifting and deepened (Fig. 7). These young,

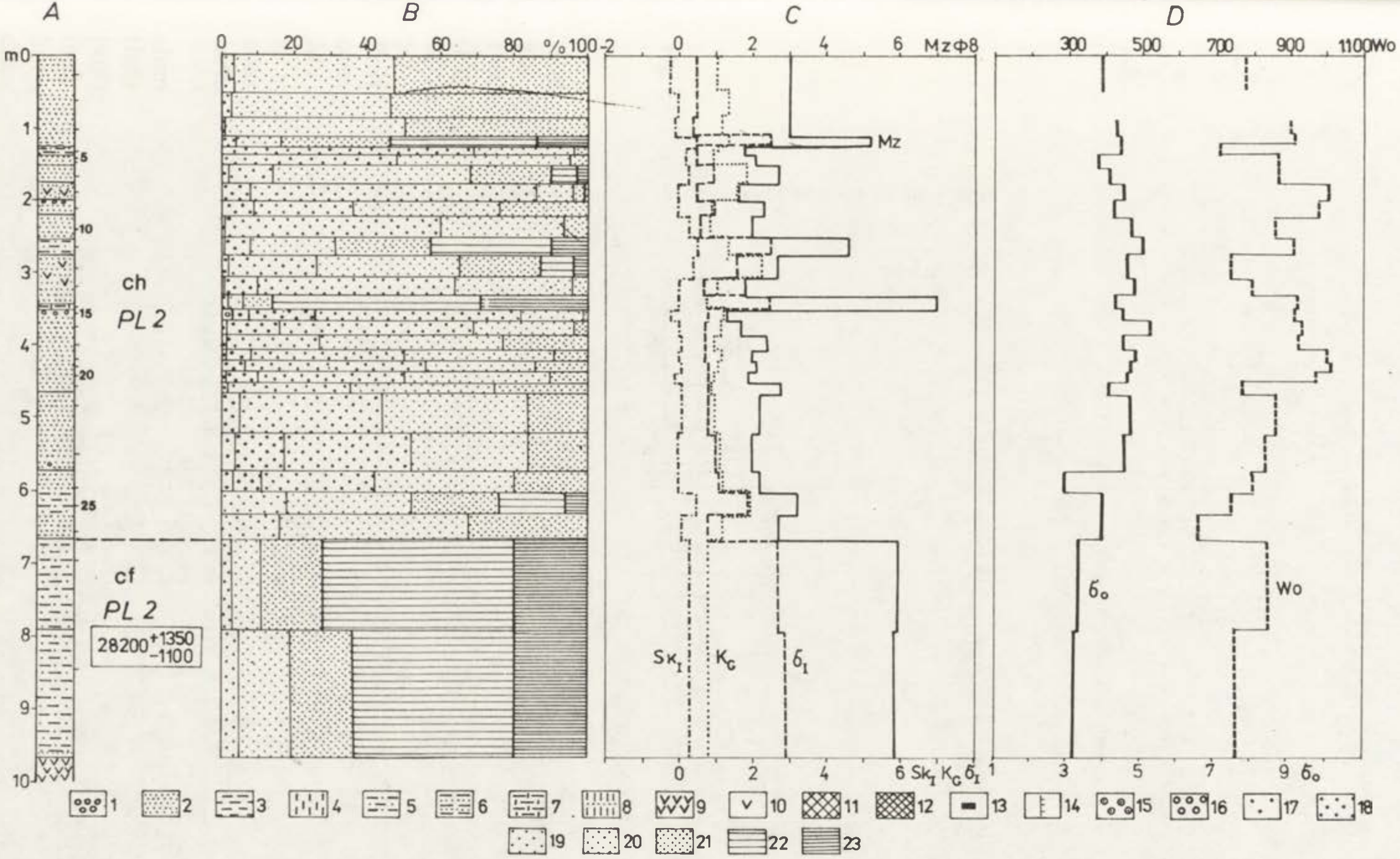


Fig. 5. Brzeźnica A site — profile

A — lithology: *1* — cobbles and pebbles; *2* — sand; *3* — dust; *4* — clay; *5* — dusty sand; *6* — sandy dust; *7* — clayey dust; *8* — dusty clay; *9* — peat; *10* — organic admixtures; *11* — modern soil; *12* — fossil soil; *13* — location of radiocarbon dated samples, other dates refer to the nearby corresponding level; *14* — place at which samples were taken. *B* — grain size graph: *15* — coarse gravel; *16* — fine gravel; *17* — very coarse sand; *18* — coarse sand; *19* — medium sand; *20* — fine sand; *21* — very fine sand; *22* — dust; *23* — clay. *C* — linear graph of grain size indices: *Mz* — mean diameter; σ_1 — inclusive graphic standard deviation; Sk_1 — inclusive graphic skewness; K_G — graphic kurtosis. *D* — linear graph of abrasion indices: *Wo* — abrasion index; σ_0 — homogeneity index

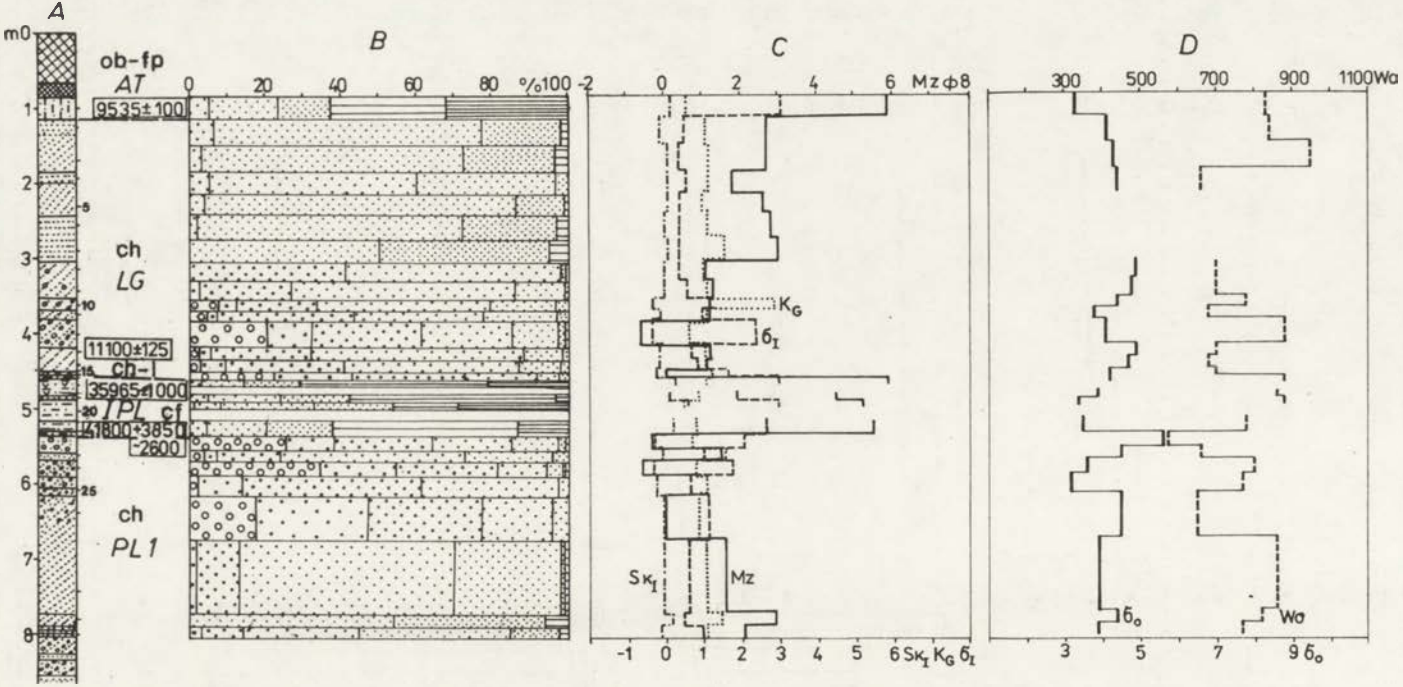


Fig. 6. Brzeźnica Ba site – profile. Explanations as in Figure 5

Table 2. Minimum and maximum of both grain size indices and abrasion indices of a lateglacial point bar at Brzeźnica B site

Profiles		Mz [∅]	σ_1	Sk_1	K_G	Wo	σ_0
t	Bd	1.4 – 2.2	0.5 – 0.7	−0.1 – 0.2	1.0 – 1.3	680 – 820	4.0 – 5.4
o	Ba	1.8 – 3.0	0.4 – 0.6	−0.1 – 0.1	1.0 – 1.2	660 – 950	4.1 – 4.4
p	Be	2.1 – 3.3	0.6 – 2.2	−0.1 – −0.5	1.0 – 2.0	810 – 940	3.2 – 3.8
b	Bd	−0.5 – 1.4	0.8 – 2.5	−0.4 – 0.0	0.8 – 1.4	700 – 790	4.0 – 4.5
a	Ba	−0.6 – 1.3	0.7 – 2.4	−0.3 – −0.1	0.6 – 2.9	680 – 880	3.8 – 4.9
s e	Be	1.3 – 1.6	0.6 – 1.0	−0.1 – 0.1	1.0 – 1.5	780 – 860	3.5 – 3.6

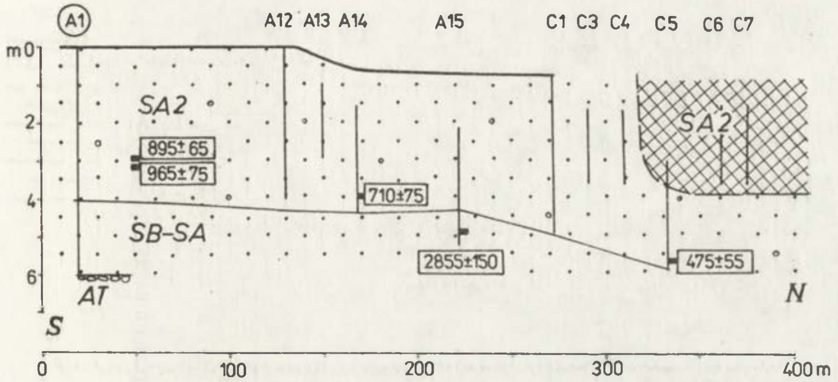


Fig. 7. Gabiny site – schematic geological section across the exposure. Explanations as in Figure 4

twofold deposits accumulated over the last millenium. They show either a flat, parallel lamination or a tabular cross-bedding, and they tend to vary in thickness. The coarser the deposits, the greater are the thicknesses of strata (Fig. 8). Sandy-and-gravelly strata which predominate in the basal part consist of coarse and medium sand. The percentage of gravels decreases upward from 50 in the base to 18 toward the top (Fig. 8). Mz varies from −1.4 to 0.4 ∅. Sorting improves upward from 2.7 to 1.7. The top series includes strata composed of medium and fine sands. Grains are fining upward there from $Mz = 2.2$ ∅ to $Mz = 4.7$ ∅. The above changes are accompanied by changes in sorting from moderate to very poor. Better abraded grains occur in the coarse basal sediments ($Wo = 850-930$). The finer top deposits are characterized by the presence of less well abraded grains ($Wo = 760-880$).

Analysis of the individual profiles in the section discussed indicates that channel shift was accompanied by the clear fining upward of sediments, by their better sorting and by notable changes from negatively skewed deposits to positively skewed deposits. This indicates that depositional conditions of the finer fractions have improved. A characteristic property is the highly variable kurtosis ranging from low values to exceptionally high values in every profile discussed (Tab. 3). In the section, the increasing minimum values of kurtosis were associated with channel shift and incision. This may indicate that the river

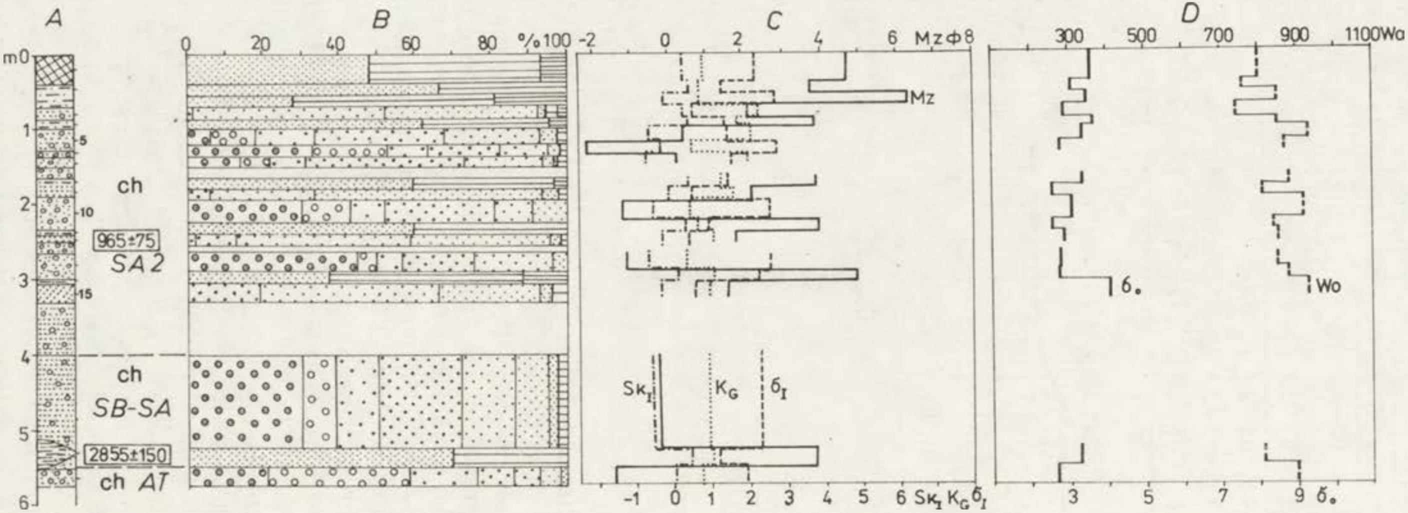


Fig. 8. Grabiny A1 site. Explanations as in Figure 5

Table 3. Minimum and maximum values of both grain size indices and abrasion indices of a Younger Subatlantic point bar at Grabiny site

Profiles	Mz [$\varnothing$]	σ_1	Sk_1	K_G	Wo	σ_0
A1	−2.1 − 6.3	0.6 − 2.9	−0.6 − 0.5	0.6 − 2.4	740 − 930	2.6 − 4.1
A12	1.7 − 4.9	0.4 − 2.1	−0.2 − 0.7	1.0 − 2.9	630 − 960	1.8 − 4.3
A13	1.7 − 5.0	0.3 − 2.7	−0.3 − 0.6	0.9 − 3.4	800 − 940	2.4 − 3.5
C1	0.2 − 5.5	0.4 − 2.7	−0.2 − 0.5	0.7 − 3.1	770 − 950	2.2 − 4.0
C3	1.4 − 2.9	0.5 − 1.6	−0.1 − 0.5	0.9 − 2.6	830 − 960	2.1 − 3.2
C4	1.7 − 3.0	0.5 − 1.8	−0.2 − 0.5	1.0 − 3.6	870 − 980	2.4 − 3.0
C5	0.8 − 3.6	0.5 − 1.4	−0.2 − 0.5	1.1 − 3.1	840 − 980	2.6 − 3.3

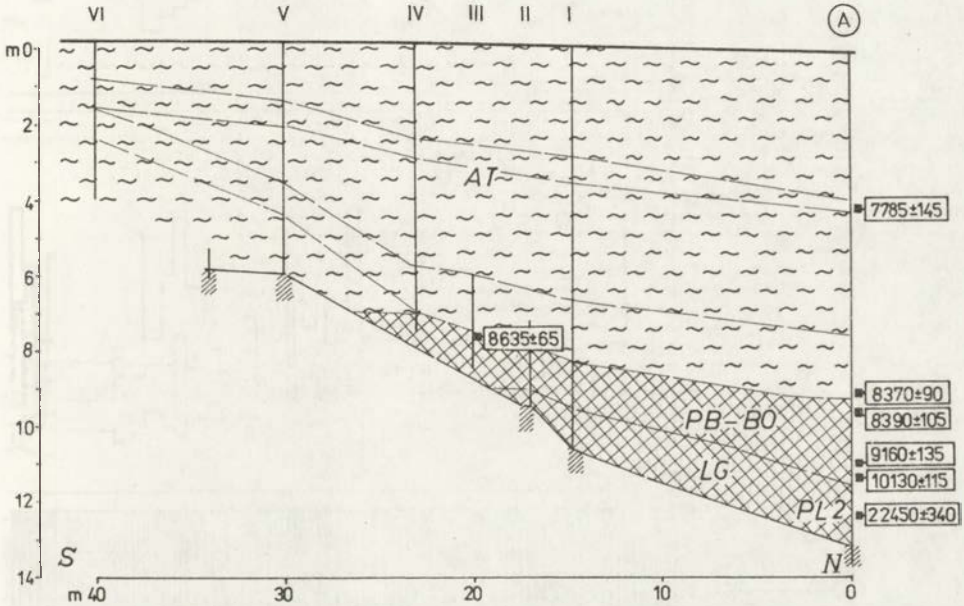
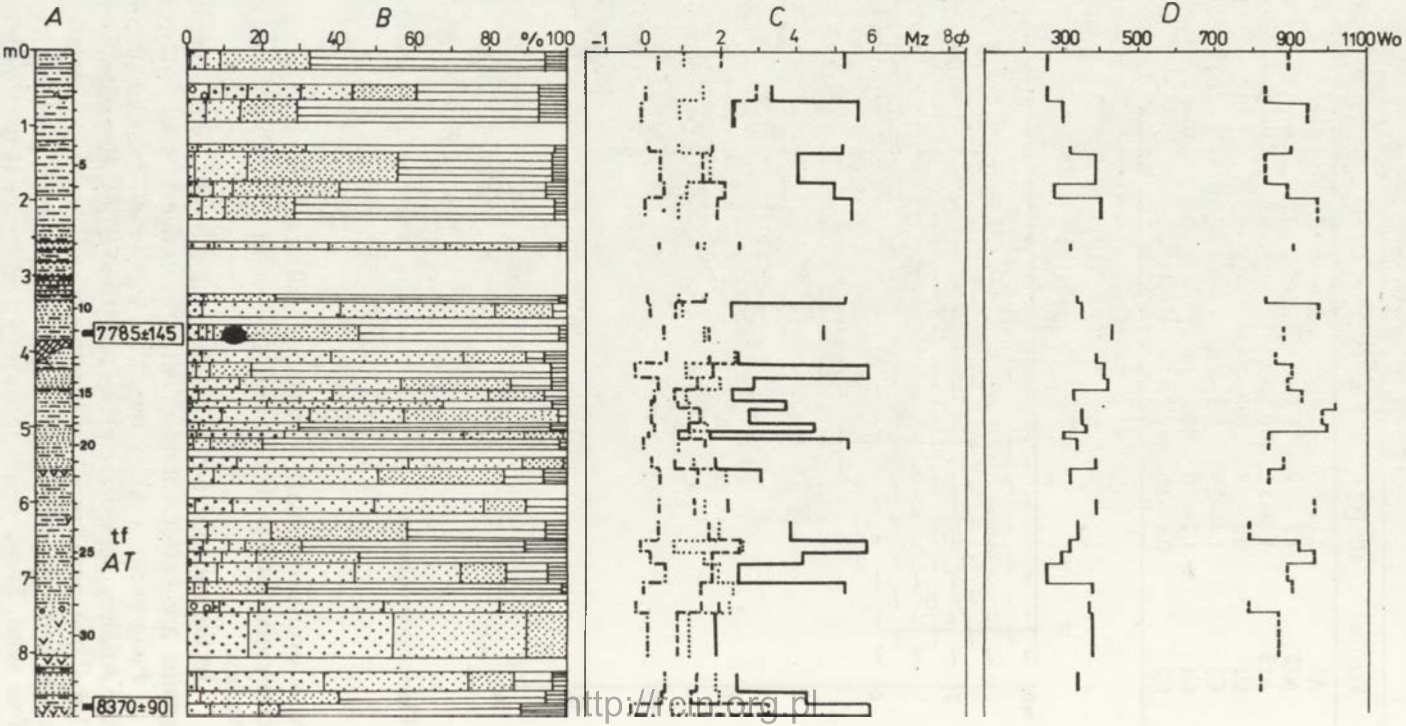


Fig. 9. Podgrodzie site – schematic geological section across the alluvial fan deposit. Explanations as in Figure 4

was overloaded with suspended sediment. Identical properties do show the contemporaneous meandering river deposits at Drogomyśl in the upper Vistula valley.

In the successive profiles the abrasion index tends to increase slightly. The grains are better rounded, and the range of the *Wo* values is smaller.

Podgrodzie – Only remnants of alluvial fan deposits (Fig. 9) dating from the Atlantic period are preserved there. These deposits are fining upward (Fig. 10). Their basal series is coarse-grained, and sandy strata showing a tabular cross-bedding predominate there. They are composed of medium, fine and very fine sand. Some strata include gravel traces (Fig. 10). Mz varies from 1.7 to 3.9 $\varnothing$. The highly variable sorting ranges from moderate ($\sigma_\mathrm{I} = 0.8$) to poor and very poor ($\sigma_\mathrm{I} = 2.9$).


A
B
C
D
m0
1
2
3
4
5
6
7
8
5
10
15
20
25
30
7785±145
8370±90
tf
AT
0
20
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80
%100
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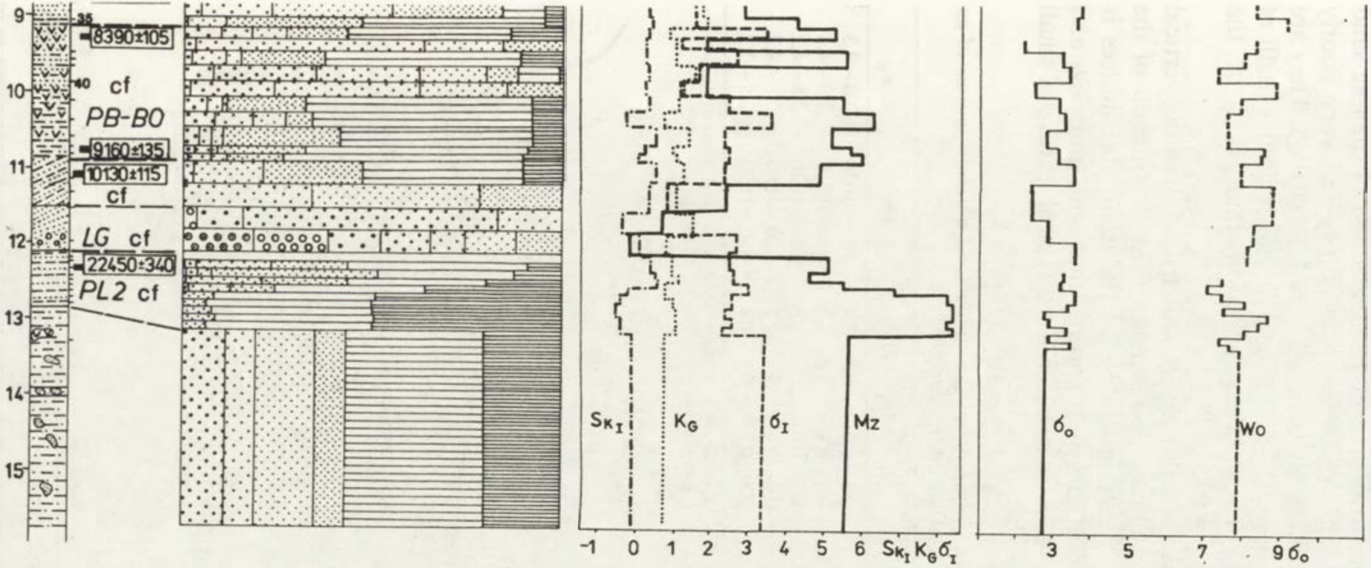

Fig. 10. Podgrodzie site – profile. Explanations as in Figure 5

The top series is finer, and it includes predominantly sandy dust and dusty sands. A flat parallel lamination dominates there. However, a great number of strata, but especially the topmost ones do not show sedimentary structures at all. In some cases this may be due to pedogenic processes. *Mz* of the fine sand and dust (up to 40%) is 3.3 – 4.0 ∅. This deposit is poorly and very poorly sorted ($\sigma_1 = 1.5 - 2.9$). *Mz* of the sandy dusts varies from 4.2 to 6.0 ∅. They are poorly and very poorly sorted ($\sigma_1 = 1.2 - 3.3$). The *Wo* values (790 – 1020) of the coarse-grained strata point to a better abrasion than that of the fine-grained stratified strata ($Wo = 830 - 990$).

In the long profile the sequence of sediments is similar to that in the vertical profile, only strata decrease in thickness downstream (Fig. 9). In each of the profiles analysed, the diversity of extreme values of the grain size indices is greater than that in the long profile (Tab. 4). It appears that both grain size and sorting do not essentially change downstream. This is a typical feature of small alluvial fans.

Table 4. Minimum and maximum values of both grain size indices and abrasion indices of an Atlantic alluvial fan at Podgrodzie site

Profiles	*Mz* [∅]	σ_1	Sk_1	K_G	*Wo*	σ_0
A	1.7 – 6.0	0.8 – 3.3	– 0.3 – 0.6	0.8 – 2.4	790 – 1020	2.6 – 4.3
AI	1.2 – 5.7	0.6 – 2.4	– 0.4 – 0.4	1.0 – 3.2	910 – 1050	2.9 – 4.3
AIV	2.2 – 6.3	0.7 – 2.9	0.1 – 0.6	0.7 – 1.8	770 – 1030	2.8 – 4.2
AV	1.6 – 5.4	0.7 – 2.8	– 0.4 – 0.6	0.7 – 2.1	850 – 1080	2.5 – 4.7
AVI	2.6 – 6.3	0.9 – 2.8	– 0.2 – 0.5	0.8 – 1.7	830 – 1020	2.5 – 3.2

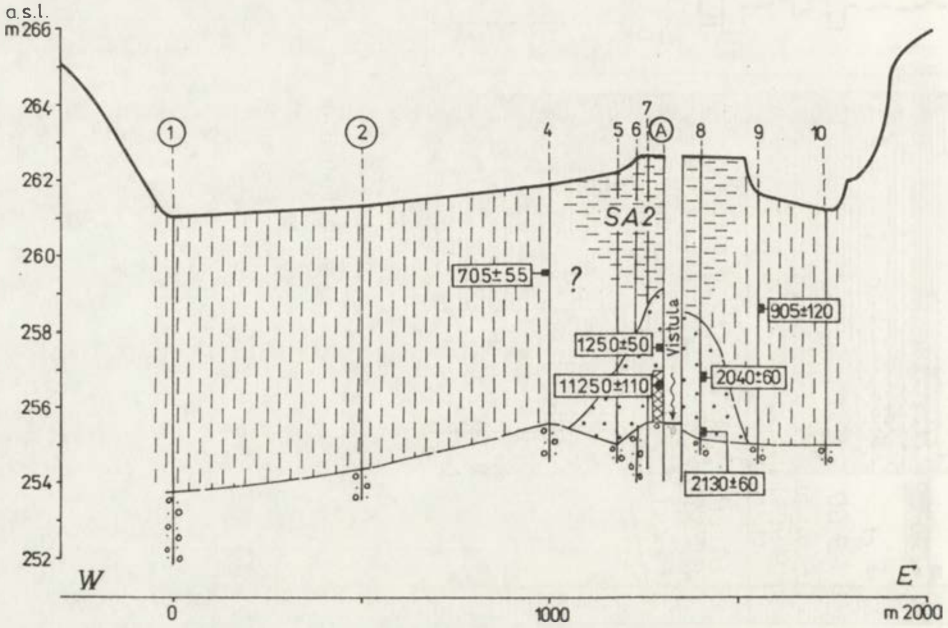

Fig. 11. Drogomyśl site – schematic geological section across the floodplain. Explanations as in Figure 4

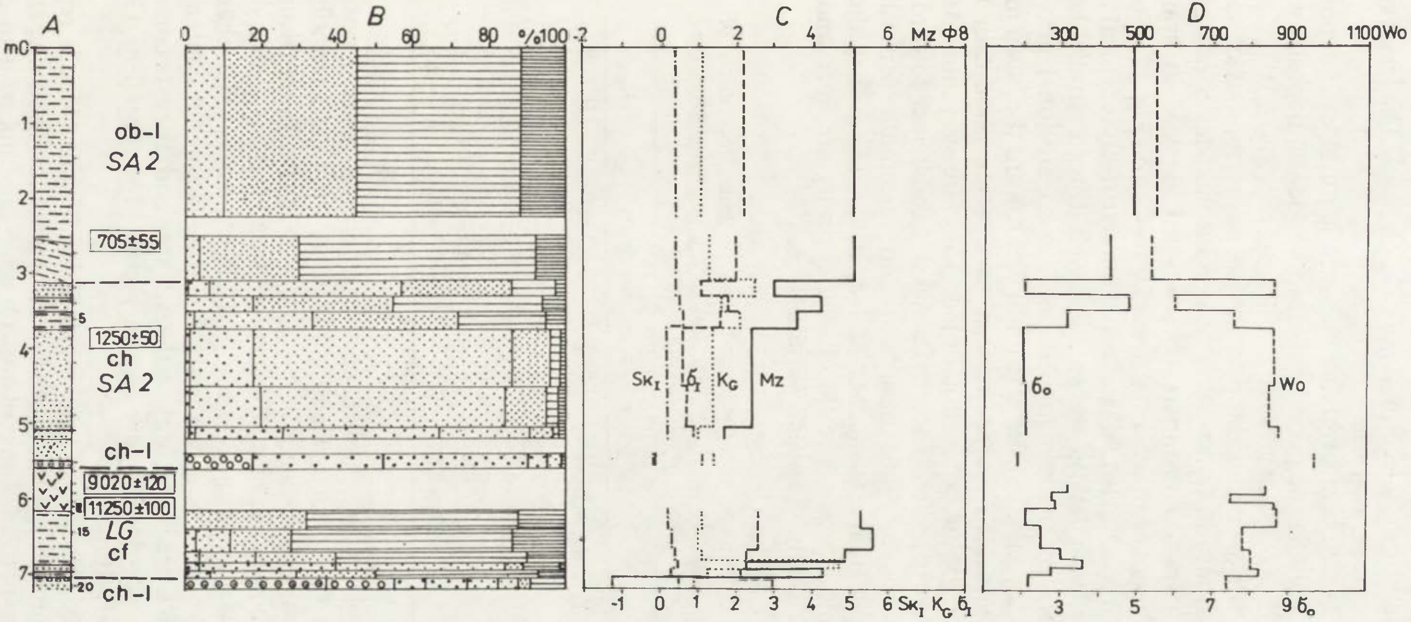

Fig. 12. Drogomyśl site – profile. Explanations as in Figure 5

Values of the abrasion index show slight changes in the long profile. This is specially true of the maximum *Wo* values, whereas the variable minimum *Wo* values suggest that morphoselection of grains took place. The less well abraded grains were transported a greater distance.

Drogomyśl – There occur overbank deposits. Natural levee deposits dating from the younger Subatlantic period pass into floodbasin deposits which have been recognized in a section across the floodplain (Fig. 11).

The levee deposit overlying the point bar deposits consists of sandy dusts which pass upward into dusty sands. This deposit includes bands of very fine sand, especially in its topmost part. The upward increase in grain sizes is reflected in the *Mz* values which vary from 5.9 to 4.1 ∅ (Fig. 12). Sorting also improves upward from 2.2 to 1.9. The low *Wo* index (540) is typical of angular quartz grains. The levee deposit shows a less well defined parallel lamination.

The floodbasin deposits rest immediately on an erosional gravel surface (Fig. 11). Deposits increase in thickness up to 7 m toward the basin margins. In profiles which are located in the western part of the floodplain the fining upward of the floodbasin deposits is noted. They are very fine (*Mz* = 6.0 – 7.0 ∅) and very poorly sorted (Tab. 5). Particles become finer toward the basin margins as indicated by both minimum and maximum *Mz* values. The decreasing ranges of the extreme *Mz* and σ_1 values show that the deposits become more homogeneous. The floodbasin deposits are finer and less well sorted than those of the adjacent natural levees.

Table 5. Minimum and maximum values of grain size indices of overbank deposits at Drogomyśl site. A – levee deposits; 1 – 7 – floodbasin deposits

Profiles	*Mz* [∅]	σ_1	Sk_1	K_G
A	4.1 – 5.9	1.9 – 2.3	0.3 – 0.6	1.0 – 1.9
7	5.6 – 6.3	2.6 – 2.8	0.2 – 0.5	1.0 – 1.9
6	4.5 – 7.0	2.4 – 4.0	0.1 – 0.6	1.0 – 2.3
5	4.8 – 6.4	2.0 – 3.0	0.1 – 0.6	1.0 – 1.5
4	4.5 – 8.4	2.4 – 4.3	0.2 – 0.5	0.9 – 1.5
2	4.7 – 7.2	2.4 – 3.9	0.3 – 0.6	0.9 – 1.7
1	5.8 – 7.4	2.3 – 4.2	0.3 – 0.6	1.2 – 2.3

Another example of overbank deposits are braided river deposits dating from the Younger Pleniglacial. These are forming the top of the alluvial fans built up by the braided Vistula (Chybie site) and by the Biała (Kaniów site). Such deposits are composed of sandy dusty and clayey dusty strata. At the top there occur less well developed sandy and clayey bands. The characteristic brown colour of the deposits is due to the high organic matter content. For the most part, deposits are fine (*Mz* = 5.0 – 6.2 ∅), and they become coarser upward. Sorting is poor at the base and very poor at the top (Fig. 13). Quartz grains are less well abraded.

Channel fill deposits belong to two sub-facies. The first one is represented by abandoned channel fills due to the slow sedimentation from suspension and to the abundant growth of water plants. Organic deposits tend to dominate. They comprise both peaty laminae and strata, as well as thin dusty clayey

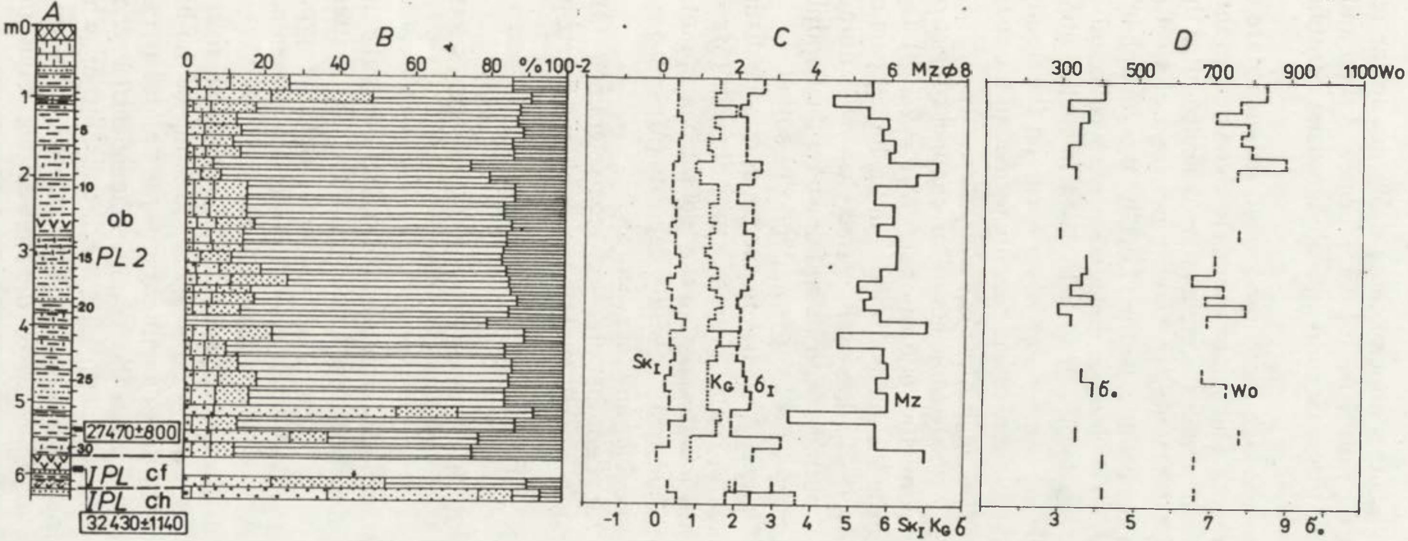

Fig. 13. Kaniów site – profile. Explanations as in Figure 5

strata and lenses of very fine sands (sites: Brzeźnica B, Podgrodzie and Drogomyśl).

The second group includes mineral channel fills due to the reactivation of the river channel. For the most part, these are formed of sand and sandy dusts without organic matter (sites: Grabiny and Podgrodzie). Stratification is less well defined.

Modern deposits – the high discharge-formed sediments are characteristic of the channel environment which corresponds to a concrete event with defined parameters. In the Wisłoka valley samples were collected after the peak flows recorded in 1980 and 1983. Water levels were in excess of 1–4 m above low level depending upon the channel widths. Locally, the floodplain was covered with water. After the 1985 flood samples also were collected in the upper Vistula valley. The water level was then by 2–4 m higher above low level. Flood deposited sediments were observed to occur on the floodplain only at one site. On the contrary, lateral gravel bars are formed of the coarsest deposits being transported only at high stream discharges.

The high discharge-formed sediments in the channel consist of sand which sometimes includes an admixture of dust or clay ($Mz = 2.2\ \varnothing$). Deposits which accumulate either far from the main current or in the higher part of the channel are finer ($Mz = 3.0-4.1\ \varnothing$), less well sorted, less well abraded and less homogeneous. On the contrary, deposits laid down on the floodplain are much finer (clayey dusts) ($Mz = 6.6-6.9\ \varnothing$) and poorly sorted.

On the fresh sandy-gravelly bar two minor zones may be distinguished: the proximal zone is marked by coarse, gravelly-sandy deposits ($Mz = 2.2$ to $-0.6\ \varnothing$), the properties of which correspond to those of the basal point bar deposits; the distal zone shows finer, mainly sandy deposits ($Mz = 0.8-1.5\ \varnothing$) being similar to the top series of point bar deposits.

Gravelly lateral bar deposits are very coarse-grained ($Mz = -6.0$ to $-3.7\ \varnothing$). These are poorly sorted cobbles and pebbles. Quartz grains are less well abraded.

CHARACTERISTICS OF DIFFERENT TYPES OF DEPOSITS BASED ON GRAIN SIZE INDICES

The grain size indices describing the distribution make it possible to compare with each other different grain sizes. On the scatter diagram of standard deviation versus mean grain diameter different types of ancient deposits of differing age and of modern deposits are presented in order to define their properties, similarities and differences.

Older Pleniglacial channel deposits of the braided river show great variations in Mz values, from -2.0 to $+5.1\ \varnothing$, owing to the highly variable dynamics of water flow in the different parts of the braided river channel. The sandy braided river dating from the Younger Pleniglacial is characterized by finer deposits ($Mz = 1.3-7.0\ \varnothing$), the better sorting of which indicates moderate and less varied stream discharges (Fig. 14A). At the same time, very fine materials showing properties of the non-current environment became deposited in the less active parts of the river channel.

Channel deposits of the lateglacial meandering river are marked by the

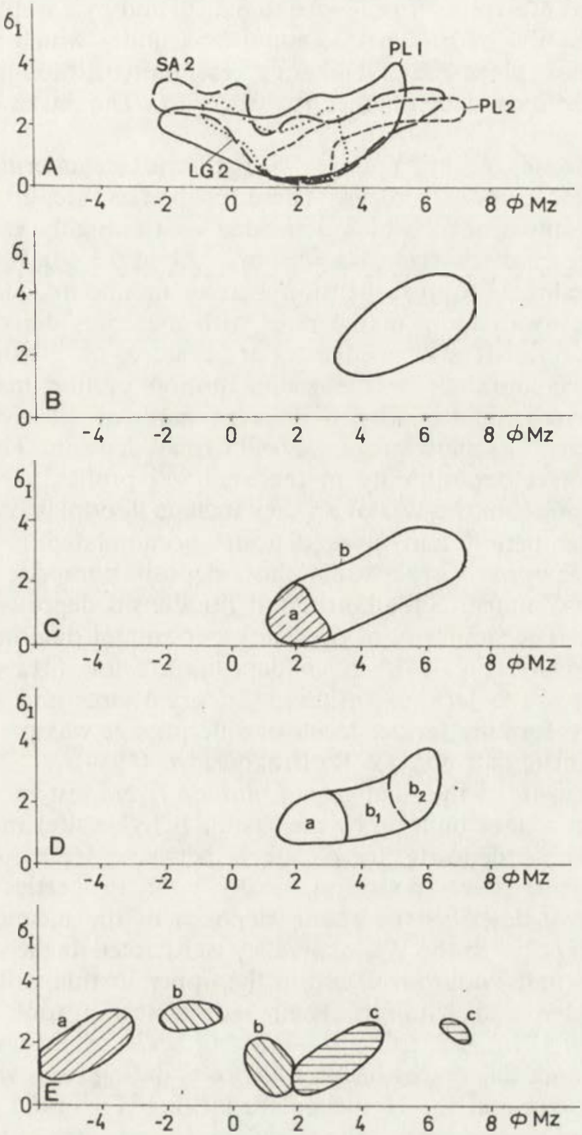

Fig. 14. Comparison of grain size properties of different types of fluvial deposits — standard deviation σ_1 versus mean diameter *Mz*

A — channel deposits (abbreviations are as for Table 1); *B* — overbank deposits; *C* — channel fill deposits: *a* — accumulated by running water, *b* — sedimentation from suspension; *D* — alluvial fan deposits: *a* — coarse deposits, b_1 — medium-grained deposits, b_2 — fine deposits; *E* — modern deposits: *a* — lateral gravel bars deposits, *b* — sandy-gravelly bar deposits, *c* — high discharge-formed deposits in the channel and on the floodplain least differentiated Mz values (from −0.6 to 3.3 ∅) and by a well sorting. These facts indicate that the hydrodynamic conditions under which transport and sedimentation took place did not change essentially, although in this case channel shift was not accompanied by incision. The latter is typical of meandering rivers.

Channel deposits of the Younger Subatlantic meandering river show similar properties in both valleys. These properties are characteristic of deposits the accumulation of which depended on the highly variable current velocities and stream discharges ($Mz =$ from −2.1 to 6.3 ∅). It is noteworthy that samples of sediment from suspension increase in amount. This fact may be explained by the overloading of the river with materials derived from both slopes and undermined terrace edges. Furthermore, as incision proceeded conditions were favourable for the sedimentation of fine materials (being similar to the overbank deposits) in different parts of the river channel.

Channel-lag deposits show properties of channel deposits. These constitute the coarsest channel deposit only in the analysed profile.

Overbank deposits in the Wisłoka valley include floodplain deposits dating from the Atlantic period and levee deposits accumulated in the Younger Subatlantic. In the upper Vistula valley those deposits comprise levee deposits belonging to the Younger Subatlantic and floodbasin deposits accumulated outside the levee. The similarity of overbank deposits of differing age in both valleys is noteworthy (Fig. 14B). Such deposits are fine ($Mz = 3.6-7.4$ ∅) and poorly sorted. The lack of variations in grain sizes and sorting of the overbank deposits forming terrace levels of differing age was previously stated by L. Koutaniemi (1980) and G. R. Brakenridge (1984).

Overbank deposits of the Pleniglacial braided rivers rest on the surface of the extensive alluvial fans built up by the Vistula (Chybie site) and by the Biała (Kaniów site). These deposits are clustered between $Mz = 3.4$ ∅ and 7.2 ∅ (Fig. 14B). Sorting is very poor and, locally, poor. Properties are similar to those of the above described overbank deposits of the meandering rivers.

Channel fill deposits in the Wisłoka valley were noted at the sites Brzeźnica A, B, D, Grabiny and Podgrodzie, and in the upper Vistula valley at the sites Drogomyśl, Chybie and Kaniów. Their sedimentation took place in the following periods: IPL, PL2, LG, PB−BO and SA2 (age designations are as for Table 1). Distinct differences between deposits dating from various periods of both the Vistulian and the Holocene are lacking (Fig. 14C). However, the twofold division of these deposits due to different conditions of both transport and sedimentation is clearly visible. The first group *a* comprises more coarse-grained deposits ($Mz = -0.2$ to $+3.1$ ∅). As fining proceeds changes from very poor and poor to moderate, and even well sorting occur. Properties are identical with those of the channel deposits in similar fractions. This fact may indicate that either a cutoff or an abandoned channel fragment became reoccupied by the river.

The second group of deposits *b* is characterized by small diameters ($Mz = 3.5-8.3$ ∅). For the most part, sorting is very poor. Some coarser samples are poorly sorted. Properties of the above sediments from suspension in the oxbows resemble those of the overbank deposits.

Alluvial fan deposits dating from the Atlantic period have been described only at Podgrodzie. These deposits show a twofold division (Fig. 14D). The first group consists of coarser deposits *a* ($Mz = 1.7-3.1$ Ø) being moderately and poorly sorted. They accumulated in channels interrupting the alluvial fan surface.

The second group *b* is composed of poorly and very poorly sorted deposits the *Mz* values of which range from 3.3 Ø to 6.0 Ø. These may be subdivided into two parts. The first one b_1 includes deposits the *Mz* of which varies from 3.3 Ø to 4.7 Ø. Sorting is moderate and poor. The decreasing mean diameter indicates that their depositional environment showed tendencies toward decreasing current velocities. It is likely that their accumulation took place close to the channel on the flat alluvial fan surface. This sediment may correspond to a levee deposit. The second part b_2 includes sediments with *Mz* of between 5.0 and 6.0 Ø. Sorting is poor and very poor. These properties are typical of deposits accumulated in a non-current environment. It seems that their sedimentation from suspension took place in depressions extending outside the levees. The extent of the deposits discussed is greater than that of the coarser sediments b_1.

The flood-formed deposits in the Vistula channel and on the floodplain *c* show small variations in grain size and sorting. There is a "region of overlap" between those deposits and the channel deposits having a given *Mz* (Fig. 14E). Deposits laid down by the Wisłoka appear to be similarly clustered, although some of them are placed into the group of fine and very fine grains which display characteristics of overbank sediments.

Because of channel incision during the last century (Klimek 1974; Alexandrowicz *et al.* 1981), deposits forming the modern gravel bars *a* in both rivers are marked by *Mz* greater than that of the coarsest fossil deposits. Consequently, the "armoured" channel tends to shift only slightly at high discharges. Sediments forming the new sandy-gravelly bar *b* display characteristics of channel deposits.

THE CHARACTERISTICS OF DIFFERENT TYPES OF FLUVIAL SEDIMENTS BASED ON ABRASION INDICES

In order to characterize the different types of fluvial deposits, analysis of quartz grain abrasion also was made. The grain shape and abrasion depend upon many external factors, such as parent material, source of supply and distance of grain transport. They also depend upon internal factors, i.e. the mode of transport, selection during transport and sedimentation, and type of channel bed (Gradziński *et al.* 1986). The aim of the present analysis of plentiful data which were related to different depositional subenvironments of known ages is to recognize factors and their effects on a river.

The characteristics of deposits is based on scatter diagrams of abrasion index *Wo* versus standard deviation σ_0. This analysis made in the fractions 0.75 – 0.5 mm and 1.02 – 0.75 mm shows that the coarser grains are better abraded (higher *Wo* values) and more homogeneous (low values of the homogeneity index). It appears that the coarser the fraction, the greater is both the abrasion degree and the homogeneity of the deposit examined. This rule was already stated by earlier workers (e.g. Pettijohn *et al.* 1972; Kostrzewski 1975; Kaniecki 1975; Tishchenko 1986).

Channel deposits come into clusters of *Wo* around 600–1000 (Fig. 15A). Such deposits laid down by the braided rivers during the Older and Younger Pleniglacial are characterized by the largest range of *Wo* values. The *Wo* of channel deposits of the lateglacial meandering river is less varied, and that of channel deposits accumulated by both the Wisłoka and the upper Vistula in upper Subatlantic times is least varied. The present author ascribes the successive periods of increase in grain abrasion during both the Vistulian and the Holocene to the reworking of the deposits by the river. A similar phenomenon has been observed by E. Mycielska-Dowgiałło (1978) in the Vistula deposits within the Sandomierz Basin. Further evidence is supplied by the fact that the younger the deposit, the greater is its homogeneity.

The *Wo* values (530–930) of overbank deposits occurring in both valleys examined appear to be the lowest for all of the fossil sediments quoted above. Overbank deposits are less homogeneous (Fig. 15B).

Differences in quartz grain abrasion due to various sedimentation conditions of the channel fill deposits are clearly visible. Palaeomeander fills *b* which accumulated under quiet conditions from suspension during various periods of the Vistulian and of the Holocene in both valleys show low *Wo* values (700–930). Like the channel deposits, sediments laid down by running water in the oxbows (Fig. 15C) are marked by better abraded grains (*Wo* = 800–1040).

Alluvial fan deposits contain well abraded quartz grains (*Wo* = 770–1085). Their *Wo* values are less varied. Abrasion analysis made of the different fan profiles indicates that morphoselection of grains took place on the fan surface during transport. The less well abraded grains (Fig. 15D) tended to be transported over greater distances. This fact has previously been observed by A. Kaniecki (1975) and by Z. Młynarczyk (1985).

The modern flood-formed deposits in the Vistula valley are marked by very low *Wo* values which vary from 360 to 715 (Fig. 15E), whereas those in the Wisłoka valley show higher *Wo* values ranging from 650 to 900. For deposits overlying the gravel bars reverse is true. Bar deposits of the Wisłoka are poorly abraded (*Wo* = 480–700), whereas those of the Vistula are better rounded (*Wo* = 690–780) (Fig. 15F). The present author explains the above differences by various conditions of transport and sedimentation prevailing during peak flows and low flows in the non-regulated Wisłoka channel and in the corrected channel of the upper Vistula. Samples taken from the sandy-gravelly bar *a* show well rounded grains (*Wo* = 860–975) which display characteristics of channel deposits (Fig. 15F).

SUMMARY

This work considers deposits accumulated in the mountain foreland, where the reduction of both gradients and river energy takes place. Table 1 clearly shows that different types of deposits prevailed in the various periods of both the Vistulian and the Holocene. Because of the small amount of profiles examined, especially in the upper Vistula valley, it is impossible to draw far

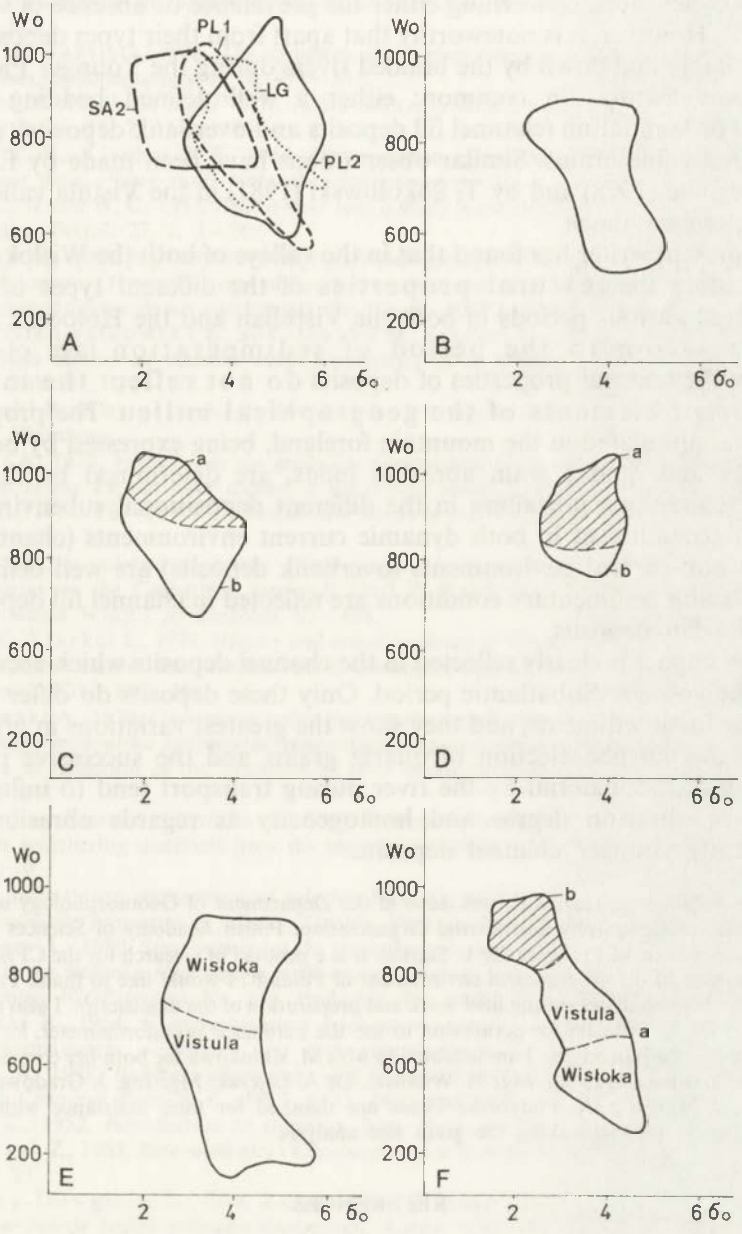

Fig. 15. Comparison of abrasion properties of different types of fluvial deposits — abrasion index *Wo* versus standard deviation σ_0

A — channel deposits (abbreviations are as for Table 1); *B* — overbank deposits; *C* — channel fill deposits: *a* — accumulated by running water, *b* — sedimentation from suspension; *D* — alluvial fan deposits: *a* — profile V, *b* — profile A (comp. Fig. 9); *E* — modern high discharge-formed deposits in the channel and on the floodplain; *F* — modern deposits: *a* — gravel bars deposits, *b* — sandy-gravelly bar deposits reaching conclusions concerning either the prevalence or absence of some type of deposit. However, it is noteworthy that apart from their types deposits which were probably laid down by the braided rivers during the Younger Pleniglacial show some features in common: either a well defined bedding (channel deposits) or lamination (channel fill deposits and overbank deposits), as well as exceptionally fine grains. Similar observations have been made by E. Mycielska-Dowgiałło (1978) and by T. Sokołowski (1981) in the Vistula valley within the Sandomierz Basin.

The present writer has found that in the valleys of both the Wisłoka and the upper Vistula the textural properties of the different types of deposits dating from various periods of both the Vistulian and the Holocene are out of all relation to the period of sedimentation (age of deposit). Similarly the textural properties of deposits do not reflect the influence of different elements of the geographical milieu. The properties of deposits accumulated in the mountain foreland, being expressed by both grain size index and quartz grain abrasion index, are determined by the hydrodynamic conditions prevailing in the different depositional subenvironments. Deposits accumulated in both dynamic current environments (channel deposits) and non-current environments (overbank deposits) are well defined. The highly variable sedimentary conditions are reflected in channel fill deposits and in alluvial fan deposits.

Man's impact is clearly reflected in the channel deposits which accumulated during the younger Subatlantic period. Only these deposits do differ from the remaining fossil sediments, and they show the greatest variations in grain sizes.

Both the morphoselection of quartz grains and the successive phases of reworking of the material by the river during transport tend to influence the increase in abrasion degree and homogeneity as regards abrasion in the subsequently younger channel deposits.

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THE COURSE OF FLUVIAL PROCESSES IN THE LOWER BZURA RIVER VALLEY DURING THE LAST 15000 YEARS

Research on the lower sections of tributary valleys which join the lower Vistula valley was long carried out by the present author (Andrzejewski 1984, 1985, 1986). This study has attempted to recognize the major fluvial tendencies either toward aggradation or degradation, as well as the role played by climatic changes and base level changes of the Vistula. Fluvial systems are complex features. Other important controls are lithology, neotectonic movements and human activities increasing in the last millenia. The qualitative approach to the reconstruction of general palaeohydrological tendencies (Schumm 1977; Florek 1982; Starkel 1982, 1983; Kozarski 1983) is of particular interest.

One reason for choosing the lower Bzura river valley for palaeohydrological study is its location beyond Vistulian ice limits, within the zone of the extensive Warsaw ice-dammed lake of this glaciation. In addition, valley incision concurrent with the ice retreat was very rapid there on the evidence of “mada” (c. 14.5 ka BP) underlying a dune on the first supra-flood terrace of the Vistula at Kamion (Manikowska 1985).

The Bzura flows to the Vistula in the western part of the Warsaw Basin. This paper examines the valley reach, 25 km long, downstream of Sochaczew (Fig. 1, see inset).

MORPHOGENIC CHARACTERISTICS OF THE LOWER BZURA VALLEY

In the vicinity of Sochaczew, the narrow Bzura valley is deeply entrenched at the contact of two lithological-geological units: a morainic plateau at 88–91 m a.s.l. dating from the Mid-Polish glaciation in the east and a plain at 83–85 m a.s.l. which probably is a meltwater deposit in the west. Its remnant is preserved as an “island” within a somewhat lower level at 81–82 m a.s.l. coinciding with the Warsaw ice-dammed lake. The Bzura valley is incised into the pro-glacial lake plain north of Sochaczew, below the Utrata river mouth.

In its lowermost reach the river dissects only the Vistula terraces. The Bzura at first undercuts its own alluvial fan in the west. This fan represents an infilling of a depression which was eroded into the pro-glacial lake plain. D. Adamiec (*fide* Laskowska-Wysoczańska 1964) named this depression the great Bzura meander. Downstream of Plecewice, the Bzura at first dissects the

Otwock terrace at 71 – 73 m a.s.l., and then the jonit lower Falenice-Praga terrace (Baraniecka, Konecka-Betley 1987; Wiśniewski 1987). In the neighbourhood of the Bzura valley this joint terrace is an extensive level which descends from 70 – 71 m a.s.l. (at the contact with the Otwock terrace) to 68 – 69 m a.s.l. near Kamion. Further downstream the Bzura drains the Vistula floodplain which splits into two leaves.

In the reach examined, 16 – 18 km long, the present Bzura valley is 500 – 1500 m wide. The valley floor has a varied relief. To the west the Vistula terraces show a form assemblage which also corresponds genetically to the activity of the Bzura. There occur well defined palaeomeanders and their fragments of varying geometry, point bars, undermined edges, and remnants of both channels and depositional forms produced by the braided river. In places, fluvial landforms are blurred by well developed dunes and wind-blown sands.

The earliest element of the fluvial relief is the so-called great Bzura meander, with a radius of c. 2 km between Helenka and Młodzieszyn. It interrupts the pro-glacial lake plain. The meander bed, up to 1 km wide, comprises shallow, irregular swales which contain biogenic fills, up to 1.5 m thick, and small ridges composed of vari-grained sands. These show variable structural-textural properties. The above facts are indicators of the erosional and depositional activity of the Bzura. They suggest that downstream of the deeply entrenched valley the multilimbed river built up an extensive alluvial fan. Subsequent evolution of both the Bzura valley and the Vistula valley led to the destruction of its north-eastern part. At this stage the Bzura was a multilimbed distributive fluvial system (Schumm 1977). Intense deposition in

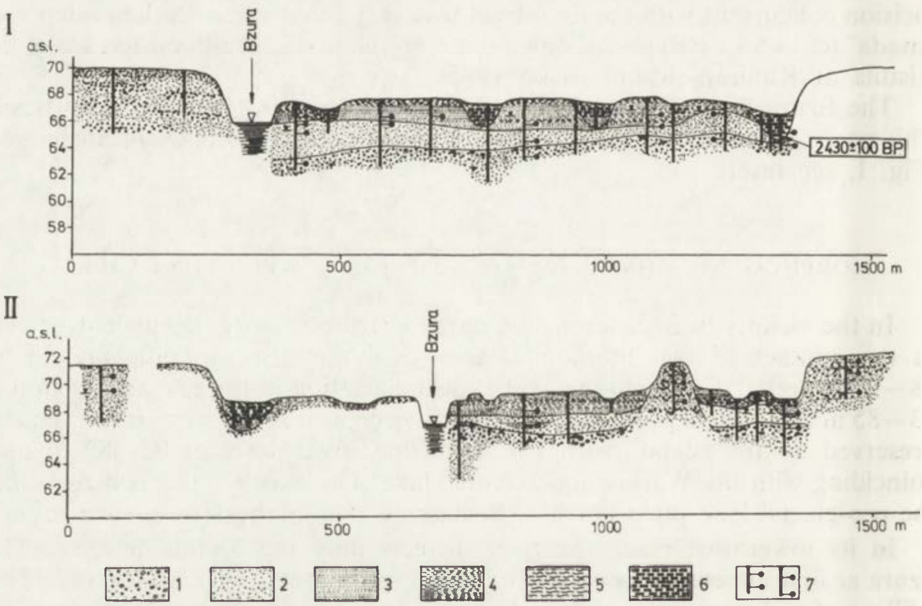

Fig. 2. Geological sections I and II

1 – coarse sands and gravels; *2* – medium sands; *3* – fine sands; *4* – silts; *5* – clays; *6* – peat; *7* – location of both shallow borings and sites from which samples were obtained

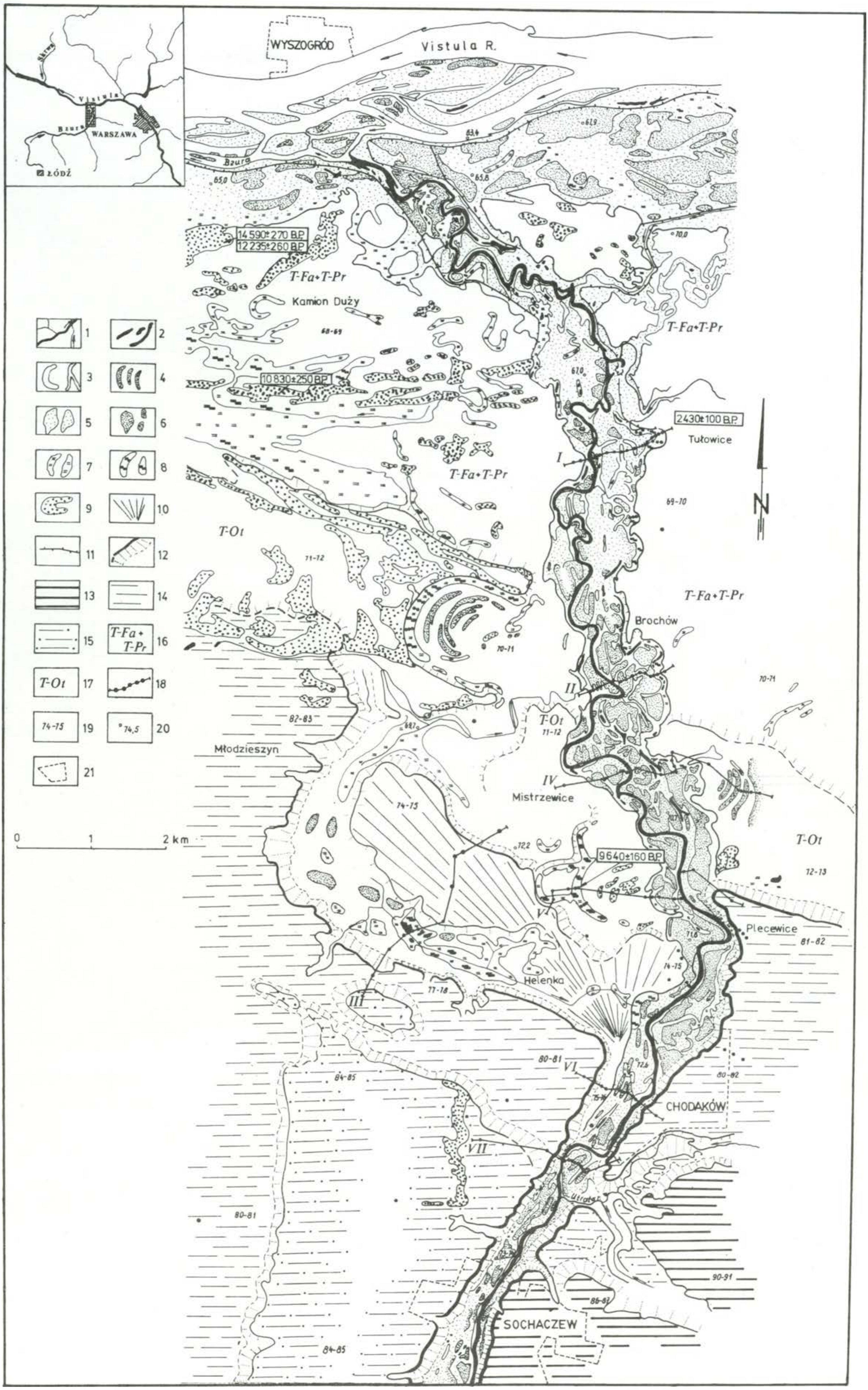

Fig. 1. Morphogenic map showing the lower Bzura valley section

1 — rivers; *2* — lakes; *3* — palaeochannels; *4* — point bars; *5* — main floodplain level; *6* — supra-flood terrace level within the Bzura valley; *7* — damp grounds; *8* — peat; *9* — dunes; *10* — alluvial fan built up by the Bzura; *11* — dikes; *12* — main slopes; *13* — morainic plateau; *14* — Warsaw ice-dammed lake level; *15* — higher depositional level within the ice-dammed lake; *16* — Falenice-Praga terrace; *17* — Otwock terrace; *18* — location of both shallow borings and sections; *19* — mean altitude (m); *20* — height a.s.l.; *21* — town

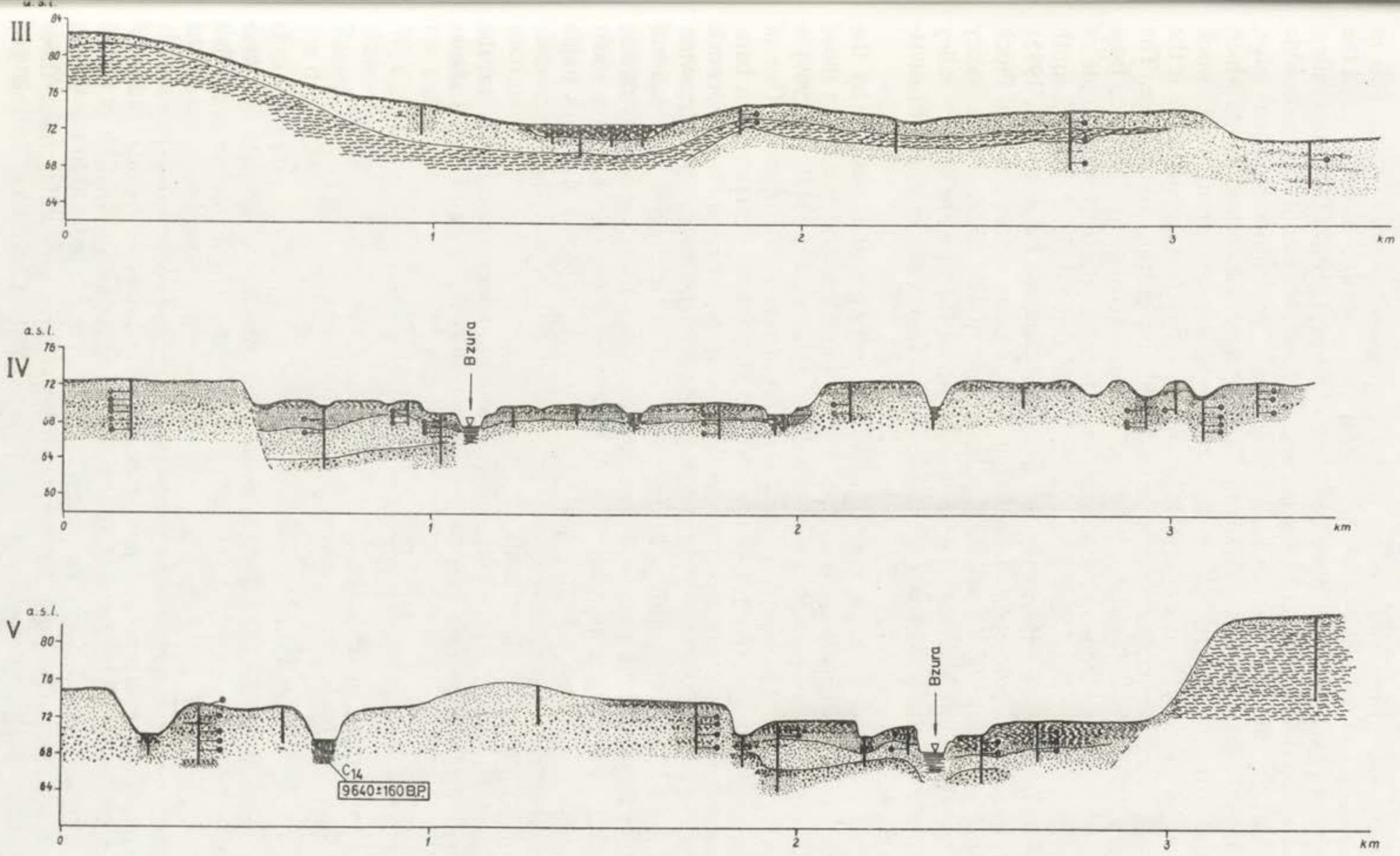

Fig. 3. Geological sections III, IV and V. Explanations as in Figure 2

this part was the result of a break in the longitudinal channel profile. This in turn caused a change from the hypercritical to a subcritical movement and the so-called hydraulic jump as well. This stage of the evolution of the Bzura valley, i.e. its age, has to be deduced from indirect evidence, because it was impossible to date the thin biogenic palaeochannel fills. The distinct erosional edge, 3 m high, in the north-eastern part of the alluvial fan passes into a bluff which separates the pro-glacial lake plain, i.e. the Błonie level from the Otwock terrace on the Vistula east of Plecewice. Thus, it may be suggested that at the Otwock terrace level the Vistula undermined the existing alluvial fan. The lower Vistula terrace, i.e. the joint Falenice-Praga level has been formed at least during the Oldest Dryas on the evidence of biogenic deposits with a date of 14 590 ± 290 years BP. These deposits are underlying a dune at Kamion south of Wyszogród but overlying the terrace plain discussed (Manikowska 1985). Such an age also is supported by datings on the same terrace south of Płock (Florek *et al.* 1987). Thus, the earliest stage of the lower Bzura valley development, during which the extensive alluvial fan and the former valley floor on its western side came into being, coincides with the upper Plenivistulian decline time, i.e. c. 15–16 ka years BP.

The successive stage of the Bzura valley development is marked by the formation of a palaeomeander system. It shows greater parameters than those of the present meanders. Based on air photointerpretation (Matusik 1969) is the identification of palaeomeanders occurring south of Mistrzewice. One of the palaeomeanders recorded to the north of Mistrzewice contains point bars. Palaeomeanders are preserved as semicircular recesses in both the Otwock terrace edge and the above mentioned alluvial fan edge south of Mistrzewice. Radiocarbon dated basal palaeomeander fills which yielded a date of 9640 ± 160 years BP here indicate that the channels were active already during the late Vistulian decline time (Fig. 3). However, this stage was of a short duration, since there is no evidence of a clearly developed valley. Both single palaeomeanders and their assemblages suggest that in part the Bzura river reworked alluvia of the Vistula.

The third stage of the Bzura valley development corresponds to the formation of the present wide and winding valley the floor of which shows variation in both morphology and lithology.

THE COURSE OF FLUVIAL PROCESSES ON THE PRESENT BZURA VALLEY FLOOR

The reconstruction of fluvial landforms occurring on the valley floor, as well as the lithofacial analysis of alluvia made it possible to define both course and characteristics of fluvial processes of the Bzura. The floodplain is divided into an upper part and lower part. The narrow part are narrow strips on the channel, the upper part is broad, especially north of Brochów. Next above the floodplain is the supra-flood terrace being represented by irregular "islands" which are encircled by palaeochannels of varying geometry. Analysis of fluvial landforms revealed that on the valley floor which developed within the Vistula terraces both course and tendency of fluvial processes differ from those occurring on the narrow valley floor upstream of Chodaków. In this gap

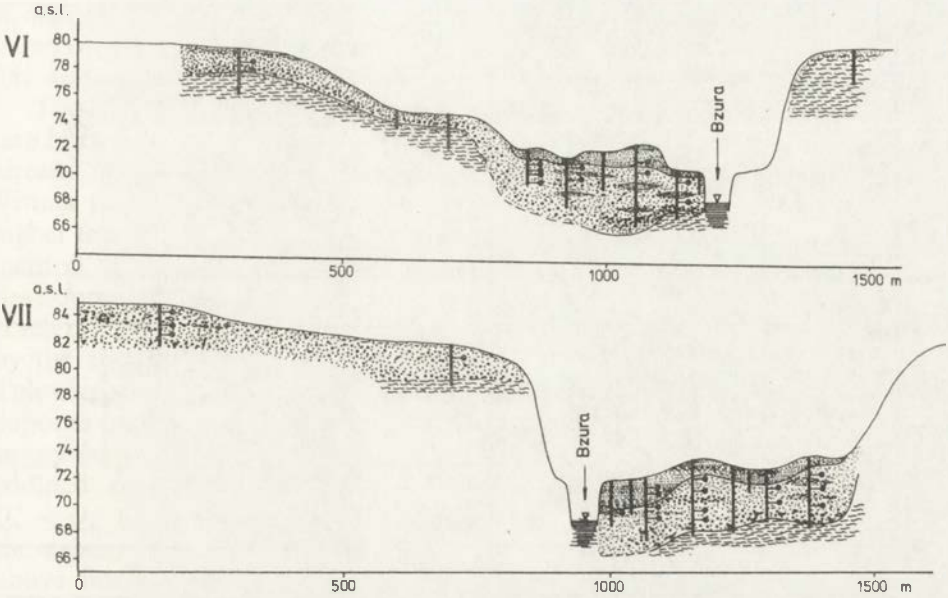

Fig. 4. Geological sections VI and VII. Explanations as in Figure 2

section, with high gradients and confined channel migrations, the valley floor has many features in common with the braided river plain. Both remnants of the supra-flood terrace and the floodplain itself here are interrupted by narrow channels which are clearly the braids through which the river strayed across this plain. Below Chodaków the river showed tendencies toward meandering. The diverse tendencies of the course of fluvial processes in the above mentioned sections of the lower Bzura valley are reflected in the structural-textural properties of alluvia. Different lithofacies have been recognized on the ground of about 150 shallow borings from which more than 200 samples were taken for sedimentological analyses. The following parameters by R. L. Folk and W. C. Ward (1957) were investigated: mean grain diameter (Mz), sorting (σ_I), skewness (Sk_I) and kurtosis (K_G). Parameter analysis, situation on the C-M Passega graphs (1964) and relations between Mz and σ_I, Mz and Sk_I allowed the dynamics of sediment transport and deposition to be relatively determined (Fig. 5). Two principal lithofacial boundaries have been established (Fig. 2, 3,4). The first boundary separates overbank facies deposits from channel facies deposits. The second one corresponds to the top of channel-lag deposits. These boundaries made it possible to recognize the tendencies toward vertical channel changes. In the Bzura valley the alluvial fills are up to 5 – 6 m thick. Underlying clayey deposits have been disclosed in a variety of places at depths of 4 – 5 m upstream of Chodaków (Fig. 4). These clays may be either pro-glacial lake deposits or detached blocks of Pliocene clays (Laskowska-Wysoczańska 1964). The fact that traces of frequent vertical changes of the Bzura channel during the last 15 000 years were nowhere explicitly stated is of

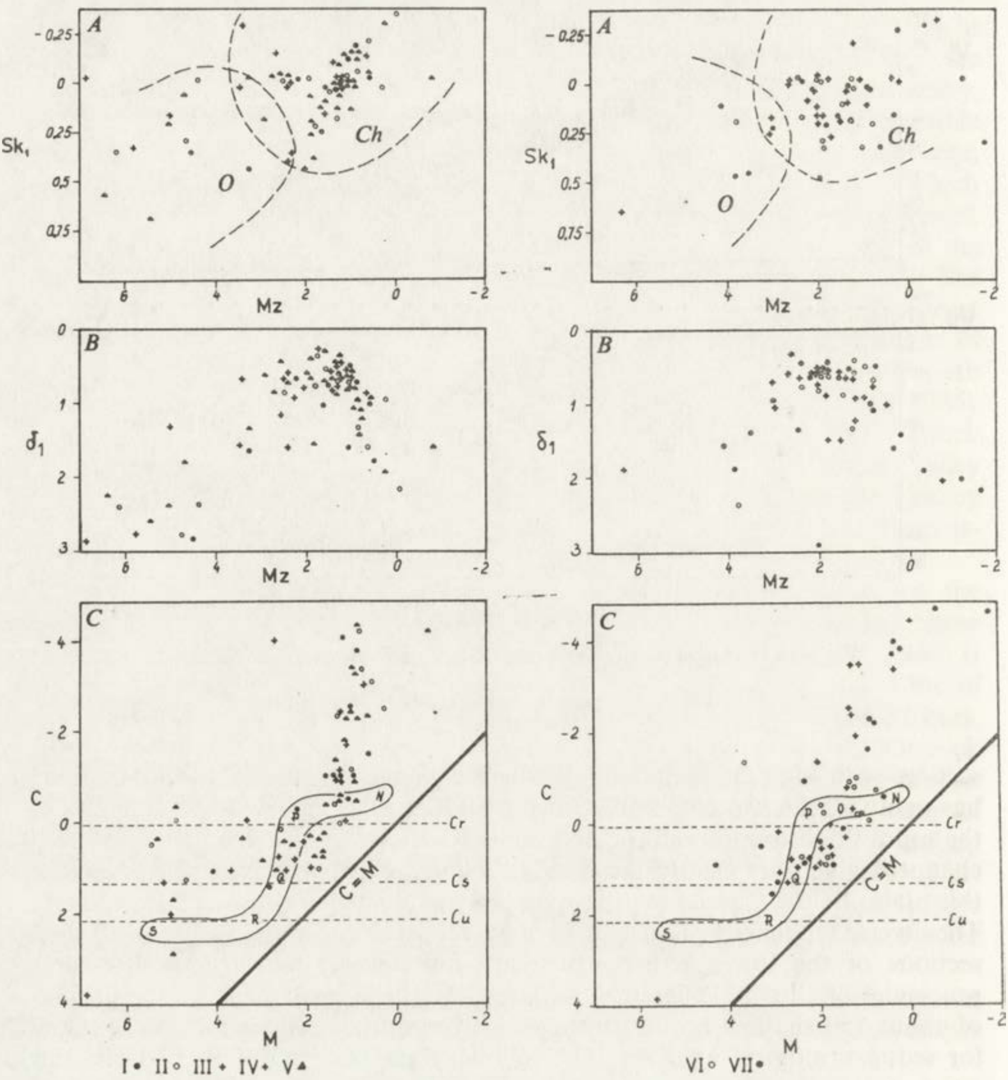

Fig. 5. Lithofacial analysis of the Bzura-formed alluvia (samples were taken from sections I–VII)

A — mean grain diameter (*Mz*) versus graphic skewness (Sk_1), *Ch* — channel deposits, *O* — overbank deposits; *B* — mean grain diameter (*Mz*) versus graphic sorting coefficient (σ_1); *C* — *C–M* Passega graph

fundamental importance for the reconstruction of fluvial events. Baraniecka's and Konecka-Betley's view (1987) on the vertical oscillations of the Vistula which caused the deposition of successive inserted alluvial series during the Bølling and the Allerød is open to question. If in fact this view were true these events would have brought about similar results in the lower reach of the Bzura tributary valley. The relative vertical stability of the Vistula channel being expressed in the decreasing tendency toward erosion in late Vistulian times and in the equilibrium of both Holocene erosion and sedimentation also is documented by datings on the biogenic palaeomeander fills which were found on the Vistula floodplain (Wiśniewski 1985; E. Florek *et al.* 1987). These fills accumulated from between 8450±104 and 990 years BP.

The lower section of the present Bzura valley below Chodaków, which cuts into both the Otwock terrace and the joint Falenice-Praga terrace, was formed already at the beginning of the Holocene. Evidence for it are datings on the Vistula floodplain and on single Bzura meanders which occur in somewhat higher terrain than the present valley floor and beyond it. Since that time slight incision of the Bzura channel took place. The anthropogenic phase of valley development (Starkel 1983) includes the last two to three millenia. In the lower reach of the Bzura valley this phase is marked by two opposite tendencies, i.e. by the slight incision of the river channel (deeper than a palaeochannel at Tułowice with a date of 2430±100 years BP) and by superposition of overbank deposits on the lowermost part of the floodplain, i.e. by aggradation. It may be suggested that both the overloading of the river with suspended load and bedload and the increased flood frequency being expressed by the relation $Q_w^+ < Q_s^+$ (Starkel 1983) may be responsible for the variable tendencies. Thus, the processes of both erosion and accumulation may be synchronous. The above findings were confirmed in the other valleys hitherto studied. This complex problem requires to take account of other factors controlling the course of fluvial processes. In the Bzura valley this is a doubtful question.

In the lower Bzura valley the course of fluvial processes reflects mainly climatic changes. The climatic amelioration in late Vistulian decline times was accompanied by decreasing stream discharges ($Q_{\overline{w}}$) of the Bzura. At the same time, the expansion of forests brought about a decrease in the transport rate of sediment ($Q_{\overline{s}}$). In the model proposed for fluvial system changes this phase is expressed by the relation $Q_{\overline{w}} < Q_{\overline{s}}$ (Starkel 1983). The multilimbed Bzura which built up an extensive alluvial fan changed to a meandering river.

From the last 15 000 years onward until the present time a tendency toward the westward shift of the Bzura river channel is dominant. This phenomenon may be due to the westward slope of the Vistula terraces and to local neotectonic movements. However, this problem requires further studies.

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