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The evolution of fluvial systems in the Upper Vistulian and Holocene in the territory of Poland

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Abstract: The location of Polish territory at the junction of a shield - platform, Hercynian and Alpine Europe creates the possibility of studying a great diversity in the evolution of fluvial systems. As well as the climatic change from periglacial to temperate, an important role was played by the drainage of the whole territory towards the north and by the blocking of valleys by the advances of the Scandinavian ice sheet. Studies of the evolution of fluvial systems started at the end of the 19th century, but detailed investigations initiated in the 1970s provided a good background for stratigraphic and paleogeographic reconstructions. In the territory of Poland, several W-E oriented zones of various sequences and trends of evolution have been distinguished. In the southern and middle parts of extraglacial Poland climatic changes are registered in the erosional and depositional sequences. These are especially well expressed in the valleys of mountain rivers which show changeable flood frequency and different tectonic tendencies. In the upland and lowland zones, there is a very distinct phase of continental climate. In the zone of the last glaciation, systems of ice marginal streamways were developed in association with a new superimposed valley pattern, composed of transversal gaps and young, expanding fluvial systems. The periglacial episode was reflected in the valley floors in the zone of older ice sheet advances. During the *Litorina* transgression, a wide belt was submerged, but this sea level rise is not reflected in any obvious evolution of the valley reaches upstream.

Key words: fluvial system, Upper Vistulian, Holocene

Introduction

Poland occupies an area at the junction of three main tectonic units of the European continent: the NE part of the Fennoscandian Shield and Russian Platform, the western region of Hercynian horsts and grabens and the southern, Alpine zone of young mountains and foredeeps. The whole territory slopes to the north, so the main direction of drainage is towards the Baltic depression. This belt, less than 1000 km wide, was exposed to the Upper Quaternary climatic fluctuations and a N-S shift of the morphoclimatic zones responsible for the repeated appearance and decay of the periglacial zone as well as for advances and retreats of the Scandinavian ice sheets. There is no doubt that, on the vast European lowlands, the W-E directed fluctuations of degree in continentality were also accentuated.

Therefore, regarding the evolution of the fluvial systems on Poland's territory we may expect their diversity in a south-north transect reflecting all these external factors as well as with the internal growth of the catchments and the decline of gradient towards an unstable base level.

History of research

It is now over one century ago when Zaręczny (1894), Łomnicki (1903) and Friedberg (1903) recognised two various Upper Pleistocene and Holocene alluvial fills in the upper Vistula basin and its lower course. Jentsch (1901) and Keilhack (1904) studied the retreat of the last ice sheet and the formation of ice marginal streamways.

During the inter-war period the group of terraces in the Middle Vistula valley was related to supposed ice retreat (Lencewicz, 1927). Their number was multiplied in the gap of Lower Vistula which was formed after ice retreat from the Pomeranian marginal zone (Galon, 1934, 1953). In the upper reaches Klimaszewski (1948, 1967) assumed a Vistulian age for the alluvia filling the valley floors, where they are buried by Holocene overbank loams.

Detailed mapping in the post-war period (both geomorphological and geological) brought new evidence. The loess-covered terrace (or dune-structured sandy one in southern Poland) has been associated with the last cold stage (Jahn, 1957; Laskowska-Wysoczańska, 1971) and several fills of late Vistulian and Holocene age were discovered in the valley floors (Starkel, 1960). In the Carpathians, the interfingering of fluvial and solifluction slope deposits was used as an indicator of

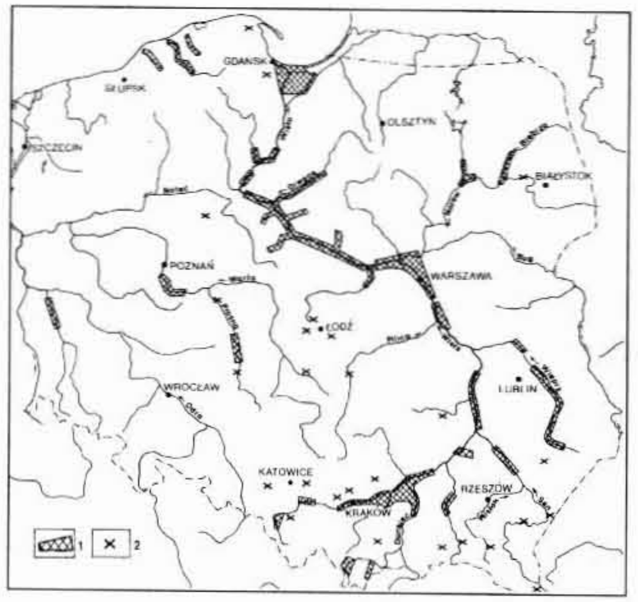

Fig. 1. Areas of detailed studies on late Pleistocene and Holocene fluvial systems.
1 - valley reaches surveyed in detail, 2 - other localities and short valley reaches mentioned in this summary.

cold stage aggradation (Klimaszewski; 1971, Starkel, 1968). In the Warsaw Basin, the sequence of terraces was associated with ice retreat phases (Różycki, 1967). Detailed surveys of ice marginal streamways and the Vistula system gave evidence on the age of the drainage evolution in Northern Poland (Galon, 1967; Kozarski, 1962; Roszko, 1968). Falkowski (1975)

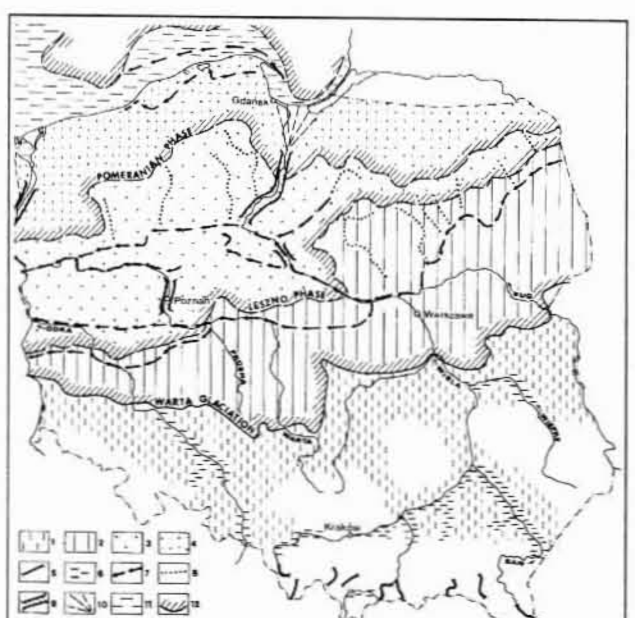

Fig. 2. Types of river valley evolution.
1 - zone of pre-penultimate glaciation with extensive periglacial features, 2 - zone of the Warta glaciation with periglacial features and remains of glacial order in the drainage pattern, 3 - zone of last glaciation, superimposed valley pattern with expressed periglacial features, 4 - zone of younger phases with superimposed young valley pattern, 5 - valley reaches with uplift tendency, 6 - valley reaches with possible subsiding tendency, 7 - ice marginal streamways (pradolinas), 8 - main sandur valleys, 9 - valley gaps across marginal zones, 10 - delta, 11 - area submerged during *Litorina* transgression, 12 - ice margins during various phases.

elaborated the concept of the transformation of river channel patterns from braided to meandering, as associated with environmental changes during the late Vistulian.

In the 1970s the number of sites dated by radiocarbon and palynological methods increased rapidly. Parallel alluvial fills of Vistulian age (Mamakowa & Starkel, 1974) as well as Holocene age (Ralska-Jasiewiczowa & Starkel, 1975) were documented. Later, several national and international projects started (among them IGCP-158) which surveyed hundreds of kilometres of valley reaches and yielded hundreds of radiocarbon and other datings which indicated that the stratigraphy was in need of revision and enabled extensive paleogeographic reconstructions to be made (Fig. 1). Among these were complex paleogeographic studies along the Vistula valley (Starkel, 1990) and detailed investigations of palaeochannels as palaeohydrological indicators in the Lower San (Szumański, 1983), Middle Warta (Kozarski, 1991; Kozarski *et al.*, 1988) and Prosna valleys (Rotnicki, 1987, 1991; Rotnicki & Młynarczyk, 1989). Starkel (1983) proposed a general model of cut and fill formation. Great importance was placed on the widespread introduction of dendrochronological (Krąpiec, 1992) and palaeomalacological dating methods (Alexandrowicz, 1987).

In the various upland regions detailed studies of the age of the terrace sequence were undertaken, emphasising the role of loess deposition (Jersak *et al.*, 1992; Śnieszko, 1985) and climatic fluctuations during the cold stage (Turkowska, 1988; Superson, 1996).

In the coastal zone the role of sea level fluctuations was investigated (Mojski, 1990; Florek, 1991). Most results relating to the Vistulian-Holocene transition are summarised in the volume related to the IGCP project 253 - Termination of Pleistocene (Starkel & Gębica, 1995; Turkowska, 1995; Kozarski, 1995; Mojski, 1995, and others).

Areal distribution of various factors in the evolution of fluvial systems

The following factors discussed below are considered in the evolution of the fluvial systems:

1) the size of catchment and the longitudinal profile of valley floors and river channels;
2) the pre-existing relief (inherited from the previous stages of the Quaternary);
3) climatic changes, reflected in variations of the hydrological regime and sediment load;
4) the last advance and retreat of the Scandinavian ice sheet;
5) differences in neotectonic movements;
6) an eustatic factor (fluctuations of the newly formed Baltic Sea);
7) anthropogenic factors, appearing in the Neolithic.

The size of catchment and the longitudinal profile of valley floors and river channels

The territory of Poland is drained by two large rivers: Vistula (194 424 km²) and Oder (118 861 km²). The remaining are small rivers which directly reach the Baltic Sea. In the great river basins there are various well developed reaches, which are controlled by various factors, but the equilibrium

profile itself regulates the dominance of erosion upstream and aggradation downstream. A great number of tributaries may also have some impact on the river regime in the section downstream of their junctions. The length of various reaches facilitates the gradual smoothing of the impact originating upstream; on the contrary, any disturbance downstream needs a long time to be transmitted upstream.

The pre-existing relief (inherited from the previous stages of the Quaternary)

The main drainage courses cross various geomorphic zones starting from the Carpathians (up to 1000-2500 m a.s.l.) and Sudeten Mts. (800-1600 m a.s.l.), a submontane depression, the South-Polish Uplands (400-600 m a.s.l.) and the vast Polish Lowland.

In the elevated part, most of the valleys were initiated in the Tertiary and rejuvenated in the Quaternary. Excluding valley heads and narrower, structure- controlled gaps or gorges, their floors are wide, with preserved fragments of older Quaternary alluvial as well as glacifluvial, eolian or other fills.

In the lowlands 3 zones may be distinguished: (1) a zone of pre-penultimate glaciation with extensive periglacial plains and a well organised drainage pattern, (2) a zone of penultimate (Warthe) glaciation with well developed periglacial features and remains of the glacial order in the drainage pattern, (3) a zone of the last glaciation with the valley pattern superimposed on the meltout - depositional relief left after ice retreat (Fig. 2).

Climatic changes, reflected in variations of the hydrological regime and sediment load

The course of climatic changes during last 30 ka is relatively well known over Polish territory (Maruszczak, 1987, Manikowska, 1995). The shift from oceanic to continental climate dated about 25-20 ka BP, later well expressed in the extension of permafrost and aeolian activity between 20 and 15 ka BP, is especially clear. Amelioration of climate towards a temperature humid type was realised in three relatively abrupt changes ca 14.5 ka, 13.0 ka and 10.0 ka BP. All these variations show some metachronous shift in time going from the S and SE towards the north. In the west-east transect some differences in continentality are detectable, expressed in two loess facies (Jersak, 1979), as well as in the Holocene vegetation history (Ralska-Jasiewiczowa, 1983).

The last advance and retreat of the Scandinavian ice sheet

About 45% of Polish territory was covered by the last ice sheet between ca 22 and 14 ka BP. River valleys were blocked by ice, rivers were diverted from their courses and, together with meltwater, were flowing to the west, following ice marginal streamways (Galon, 1968). Together with ice melting (depending on the type of deglaciation), new areas became free of ice and a new drainage pattern started to be organised still under the periglacial climate (Kozarski, 1980, 1995). Later, this pattern became reorganised during the melting of ice blocks and the progressive amelioration of the climate.

Differences in neotectonic movements

In the evolution of some regions, the tectonic factor may be important. During times of periglacial climate its role was affected by extensive slope degradation and seasonal overloading of rivers (Starkel, 1968). The tendency of mountain regions to uplift and of submontane depressions to subside may be reflected in a trend towards erosion or aggradation (Liszkowski, 1982). In the lowland areas, the existence of glacial rebound is difficult to prove, due to its superposition on other isostatic trends (Brykczyński, 1986).

An eustatic factor (fluctuations of the newly formed Baltic Sea)

The Baltic Sea was preceded by the Baltic Ice Lake, the level of which is considered to be more than 80 m below its present level. The Yoldia transgression started from ca 80 m a.s.l. (Kępińska *et al.*, 1979). At that time, the shallow Southern Baltic Basin was dry. The *Litorina* transgression from ca 7 ka BP caused a rapid rise up to the present level and vast coastal flat areas were submerged. This shortening of river courses promoted new conditions for the development of deltas (Mojski, 1990).

Anthropogenic factors, appearing in the Neolithic

Forest clearance started in the Neolithic, first on a local scale, then on a regional one (Starkel, 1990) causing changes in the rate of overbank deposition, coarsening of sediment and, finally, in the last centuries, the transformation in the channel pattern (Klimek & Starkel, 1974; Starkel, 1995c). However, this is not a main subject of this paper.

Regional differentiation in the evolution of fluvial systems

The combination of these various factors caused a regional differentiation in the evolution of fluvial systems which has been discussed several times by the Author (Starkel, 1968, 1977, 1979, 1990, 1994, 1995b, 1995d; Fig. 3).

Upper mountain reaches

In the mountains, the channel gradient (slope) depend on various factors and in the mature wide Carpathian and Sudetic valleys it fluctuates between 2 and 10‰. The tectonic tendency and lithology of bedrock are very important. The aggradation during the cold stage, reflected in the interfingering of slope and fluvial sediment with a distinct erosional break during the interpleniglacial is a common feature. This is registered by overbank sediments with dated organic intercalations (Klimaszewski, 1971; Starkel, 1968). In reaches which have a rising tendency e.g. in the transversal gaps of the Dunajec (Froehlich *et al.*, 1972) or Wisłok (Zuchiewicz, 1987), several steps were cut in alluvia and then in bedrock which reflect late-glacial and Holocene phases of incision. In the subsiding Orawa - Nowy Targ Basin, this dissection started long before the late Vistulian. Organic deposition started on an erosional step during the Bölling interstadial (Klimaszewski, 1967). Peatbogs located in the abandoned channel have been recognised in the Upper San valley at Tarnawa. Three distinct flood phases, two in the form of overbank deposits during the Younger Dryas and between 8.7-7.8 ka BP and the third one as a submergence during early Sub-boreal have also been identified (Ralska-Jasiewiczowa & Starkel, 1975).

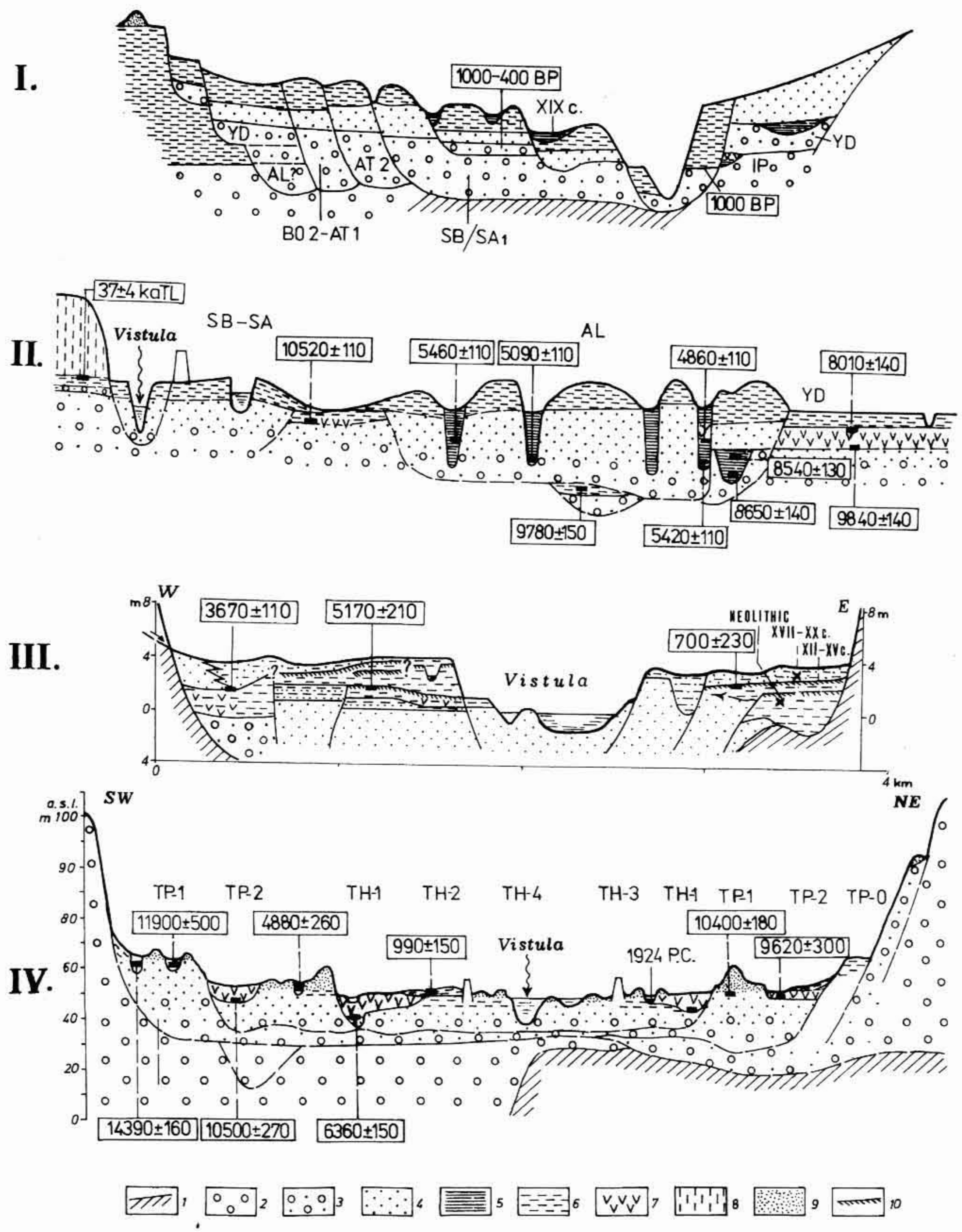

Fig. 3. Selected generalised cross-sections of river valleys in the Vistula catchment.
I - Wisłoka valley at the Carpathian foreland (after Starkel, 1995b), II - Vistula valley at the Grobla forest - the western part of Sandomierz Basin (after Starkel *et al.*, 1991), III - Vistula valley in the narrow gap across the South-Polish Uplands (after Pożaryski & Kalicki, 1995), IV - Vistula valley in the Płock Basin - upstream of maximal extend of last ice sheet (after Florek *et al.*, 1987).
1 - bedrock, 2 - gravels, 3 - sands and gravels, 4 - sands, 5 - palaeochannel fills, 6 - overbank loams, 7 - organic sediments, 8 - loess, 9 - aeolian sands, 10 - fossil soil horizons.

Foothill reaches

In the wide belt of the Carpathian Foothills the older Vistulian terrace is buried by the loess or solifluction sediments (Starkel, 1977; Łanczont, 1995) and the oldest deposits in the deeply incised abandoned palaeochannels are dated as Alleröd (Mamakowa, 1962; Wójcik, 1987; Klimek, 1992). The distinction of younger fills is relatively poor, but the presence of buried oak trunks from the last two millennia indicate a dominant role of aggradation connected with deforestation (Starkel, 1995a; Krąpiec, 1996). In the minor river catchments under several metres of loamy deposits are buried organic sediments from the Atlantic phase or even older (cf. Starkel, 1960, 1995b).

Submontane basins

Late Quaternary alluvial fills are generally recognised, but we are still searching for a depositional representative of the coldest phase 25-15 ka BP. The interpleniglacial terrace buried by loess (Mamakowa & Środoń, 1977; Gębica, 1995) has also been generally recognised, two fills being dated 30 ka BP (Starkel, 1995a) with late-glacial dunes, and then several younger fills, among them a distinct level with late-glacial large palaeomeanders and/or a braided pattern, with several generations of smaller palaeochannels and, finally, a lower floodplain with larger channels (cf. Starkel, 1983; Kalicki, 1991). The concept of phases with higher flood frequency during the Holocene responsible for the formation of several fills and channel avulsions originated in this region (Starkel, 1983, 1985); this was slightly revised after new discoveries (Kalicki, 1991; Starkel et al., 1996). The following phases (after the Younger Dryas): 8.7-7.8 ka BP, 6.6-6.0, 5.5-4.9, 4.4-4.1, 3.2-3.0, 2.7-2.6, 2.2-1.8 ka BP; V-VI century AD, X-XII and XV-XVIII century AD are distinguished there.

Due to the varying width of valley floors and distance from the mountains, sediments and forms are different and several types have been distinguished (Starkel, 1990; Starkel, 1995b; Gębica, 1995; Starkel *et al.*, 1996) (Fig. 3 I and II).

1) A sequence of alluvial fans at the mountain front, with two distinct upper pleniglacial terraces, 15 m high, younger than 28 ka BP, and 10-12 m high with a braided pattern (Mamakowa & Starkel, 1974; Starkel, 1995a), deep pre-late Vistulian incision (Klimek, 1992) and several Holocene fills (Alexandrowicz *et al.*, 1981). This reach shows a distinct tendency towards deepening and narrowing of the floodplain. The trend opposite to aggradation was recognised in the subsiding Oświęcim Basin in the foreland of the Silesian Beskid (Niedziałkowska *et al.*, 1985).

2) Wide valley floors (5-10 km) which have a well developed loess terrace, remnants of a lower sandy level with dunes and a floodplain which has several fills and a distinct tendency to avulsions. As a result, wide fragments of valley floor with abandoned systems of palaeochannels from the Younger Dryas (Kalicki, 1991), late Atlantic (Starkel *et al.*, 1991) or early Subboreal (Kalicki *et al.*, 1996) have been preserved. The avulsions were typical also in the earlier times, which is indicated by islands of higher terraces separating two younger valley (cf. Starkel, 1990). The outlet of the Raba river (Gębica, 1995) possessed similar landforms.

3) In case of narrower gaps, as for the Vistula reach in the Cracow Gate or the gap of the Middle Vistula across the South Polish Uplands, the river energy due to confined meandering was manifested in the vertical variations. Therefore, in both valley reaches, the channel deposits represent the youngest members and, on the narrow benches, overbank deposits separated by fossil soil horizons are preserved (cf. Rutkowski, 1987; Pożaryski & Kalicki, 1995; Fig. 3, I).

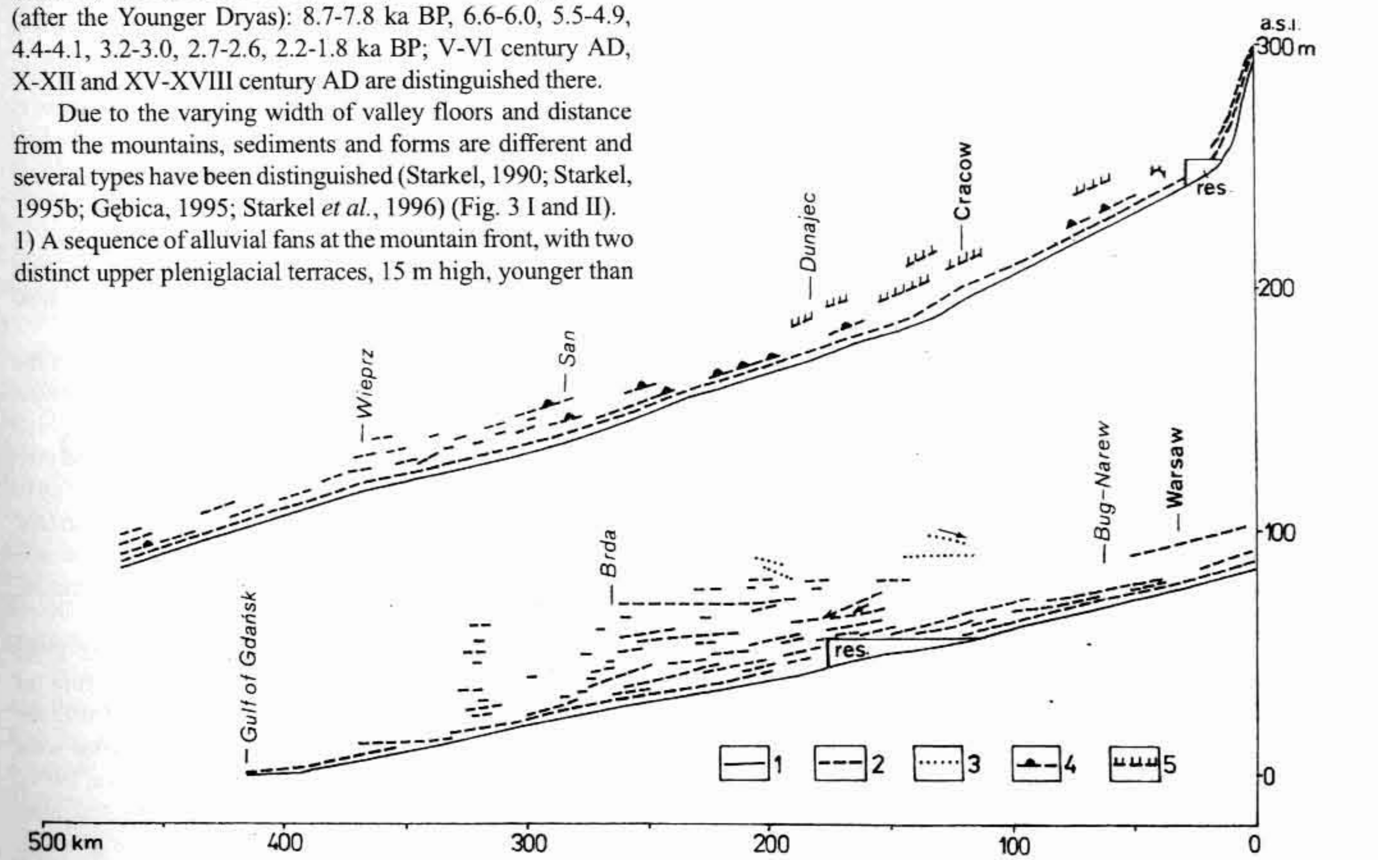

Fig. 4. Longitudinal profile of the Vistula valley (Starkel, 1990).
1 - mean river level profile, 2 - terrace levels, 3 - outwash plains from last ice sheet advance, 4 - pleniglacial terrace with late glacial dunes, 5 - interpleniglacial terrace covered by loess.

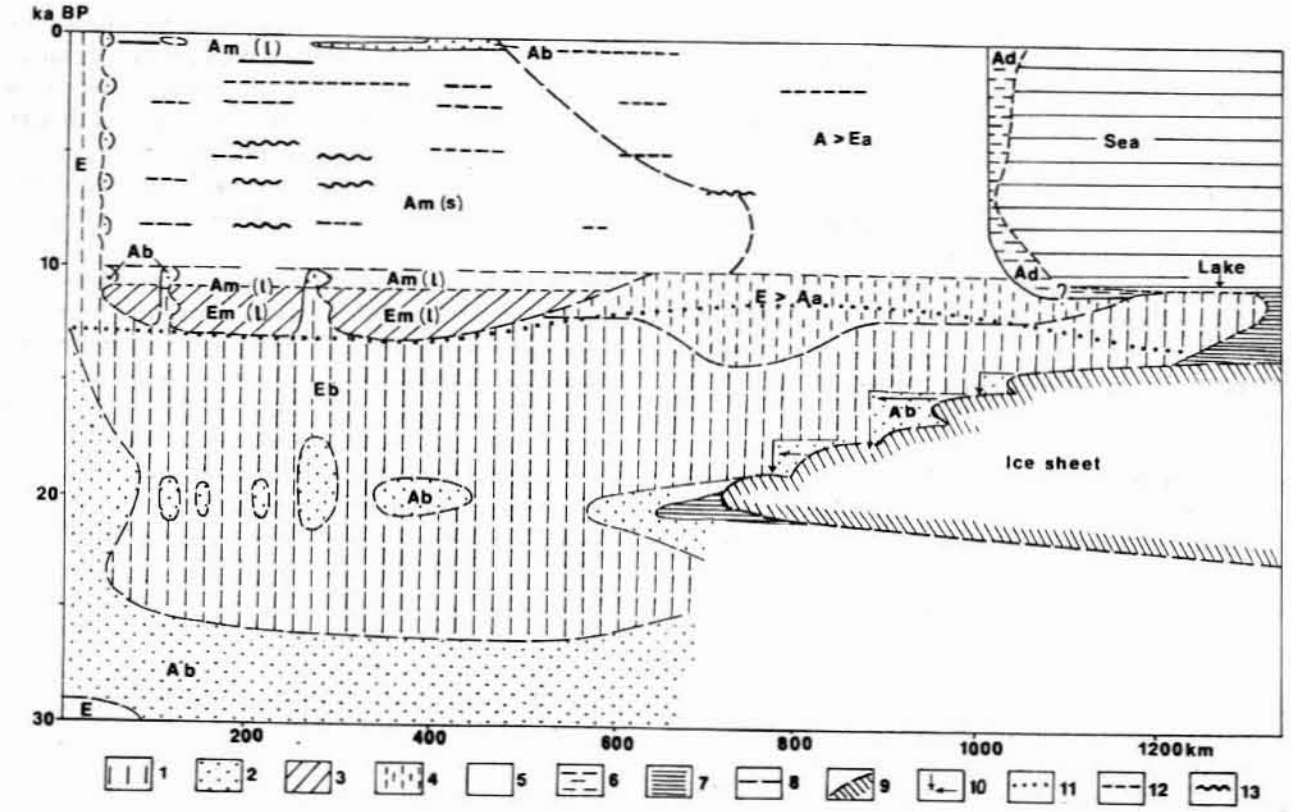

Fig. 5. Evolution of the Vistula valley in longitudinal profile during last 30 ka (after Starkel, 1990, modified).
1 - erosion by braided river (Eb), 2 - aggradation by braided river (Ab), 3 - erosion by meandering river - large meanders (Em(l)), 4 - erosion with some aggradation by anastomosing or straight river (E>Aa), 5 - accumulation either by meandering river - small meanders (Am(s)) or by an anastomosing one (A>E_a), 6 - deltaic deposits (Ad), 7 - ice dammed lake, 8 - sea, 9 - ice sheet (modified after Kozarski 1995), 10 - former outflow directions (westward along pradolinas and southward over outwash plains), 11 - retreat of permafrost, 12 - turn of deposition during flood phase, 13 - channel avulsion.

The South-Polish Uplands

Most of the upland rivers drain directly either to the Vistula or the Oder. Their width differs, according to their glacial histry and tectonic tendencies, and their preglacial floors may be buried to several decametres below the present river (Gilewska, 1972; Maruszczak, 1972). In areas built from chalk and with a thick loess mantle, complex fluvio-deluvial-colluvial bodies dated either to interpleniglacial (Harasimiuk, 1991) or to the kataglacial phase of the upper pleniglacial (Jersak, 1976; Jersak *et al.*, 1992; Superson, 1996) are very common. In the valleys with thick reservoirs of glacifluvial sands their reworking under permafrost conditions was very active and extensive sandy fills are observed in their lower reaches (Jersak & Sendobry, 1991; Buraczyński, 1994). The late Vistulian or early Holocene organic deposits in the valley floors indicate earlier intensive erosion (Śnieszko & Dwucet, 1995). This was followed by Holocene aggradation, which accelerated after forest clearances (Śnieszko, 1985).

A slightly different picture is observed in the limestone areas where, after the late Vistulian, erosion followed at many localities. The deposition of calcareous tufa was interrupted during phases with frequent flood episodes (Rutkowski, 1991; Pazdur *et al.*, 1988; Alexandrowicz, 1988).

The Lowland periglacial zone (extraglacial)

This zone, 100-250km wide, was glaciated in its northern part during the penultimate Warta advance. In this zone, large transit valleys (Vistula, Bug, Oder, Warta, Prosna) and smaller river pattern may be distinguished. The first are easily recognised in the Warsaw Basin, where the staircase of terraces was earlier associated with the retreat phases of the last Scandinavian ice sheet (Różycki, 1967), then with lateglacial climatic oscillations (Baraniecka & Konecka-Betley, 1987) and later the pre-Epe (>14.5 ka BP) erosion downstream of Warsaw was documented by overbank deposits underlying the dunes on the first overflood terrace which have been dated at 14.5 ka BP (Manikowska, 1985).

In the Prosna valley, Rotnicki (1987) recognised the dissection of the higher terrace (with radiocarbon dates between 28 and 26 ka BP) which preceded an erosional phase which coincided with the maximum of the glacial advance and then aggradation about 18.5 ka BP. During the late Vistulian up to the Younger Dryas, the Prosna created large palaeomeanders, which indicate a 5-fold increase in bankful discharge (Rotnicki & Młynarczyk, 1989). During the Holocene lateral migration, several generations of smaller meanders were created.

In the smaller valleys of the Łódź region, the role of the Vistulian valley formation depends on the nature of transformation of the previous river pattern formed after the retreat of the Warta ice sheet. Many closed depressions were incorporated into the uniform valley system (Klatkowa, 1989). Detailed studies of periglacial sediment have shown that, after the post-interpleniglacial aggradation, a phase of strong aeolian activity followed with the formation of a gravel pavement and, later, during the late Vistulian, deposition turned to erosion again (Manikowska, 1985, 1995; Turkowska, 1988, 1995).

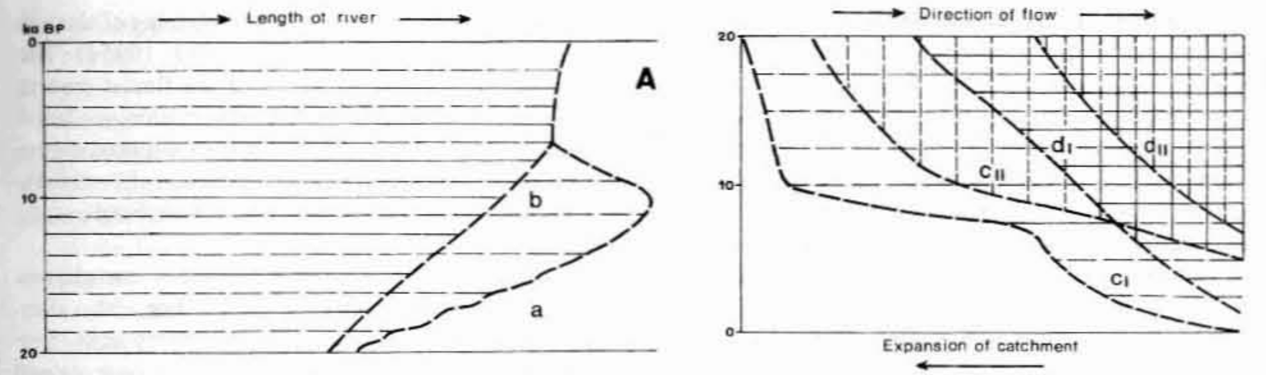

Fig. 6. Two ways of "expanding" river valleys in the zone of last deglaciation (after 20 ka BP).
A - Expanding downstream (e.g. Vistula, Oder): a - growing length in time (later transgression), b - expansion of floodplain controlled from upstream.
B - Tributary valleys expanding "upstream", controlled by low base level: c_I - backward growth of river in zone of older phases, c_{II} - backward growth in zone of Pomeranian phase, d_I - formation of uniform floodplain in zone of older phases, d_{II} - formation of floodplain in the zone of the Pomeranian phase.

After a slight aggradation during the Younger Dryas, distinct episodes of higher fluvial activity about 8.5, 5.5 - 4.5 and 3.5 - 3.0 ka BP were recorded (Turkowska, 1988; Kamiński, 1993).

Ice marginal streamways - underfit streams

In northern Poland a system of ice marginal streamways (pradolinas) develped, following the three main phases of the ice retreat (Galon, 1967, 1968). After detailed studies in West Poland several new phases were recognised (Kozarski, 1988). The existence of only one streamway in the east is a common feature; in the west, their "avulsions" developed due to fast retreat from the marginal zones of Leszno (20 ka BP), Poznań (18.5 ka), Chodzież (17.2 ka), Pomeranian (15.2 ka) and Gardno (13.2 ka) (Kozarski, 1988). Some parts of these wide floors were gradually dissected (as in the case of Toruń - Eberswalde pradolina; Kozarski, 1962) and sometimes became active up to the Bölling (like the Warta south of Poznań - Kozarski *et al.*, 1988). Thermokarst probably played a considerable role in their lateral development. This was assumed by Jahn (1975) and later supported by Kozarski (1995) and his team (Antczak, 1986) after discovery of ice wedge casts and frost cracks connected with expansion of permafrost over the deglaciated areas south of the limits of the Pomeranian phase. Later, these floors were overgrown by peat. The peat accumulation started in the Alleröd and totally fossilised the floor of the Biebrza pradolina near the interfluve between the Vistula and the Niemen Basin (Żurek, 1975). This part represents a classical underfit stream. The short-lived narrow pradolinas drained at present by the Zgłowiączka and Bachorza streams at the Vistula - Warta interfluve have a similar character (Andrzejewski, 1995; Wiśniewski, 1982).

New datings from the Baltic Sea floor (cf. Mojski, 1995) and the Gardno phase (Rotnicki & Borówka, 1994) indicate that the age of the marginal zones must be increased and Kozarski (1995), in his last paper, accepts the age of the Chodzież phase as being about 17.7 ka, older then 16 ka for the Pomeranian phase and about 14.5 ka BP for the Gardno phase. The most northern pradolina of Bölling or Alleröd age is submerged under the Baltic Sea (Mojski, 1990).

The large transit valley of the Vistula river

Following the ice retreat, the water of all rivers draining the southern periglacial zone as well as that accumulated in the ice dammed lakes (Warsaw Basin) formed the gaps across the marginal zones and, step by step extended their courses towards the Baltic depression (Fig. 2). In several transverse reaches systems of terraces are found, up to 10-12 in number, which reflect this pronounced incision (Galon, 1934). Several authors have made efforts to correlate these steps along the Lower Vistula and tributaries (Galon, 1967), but only the dating and correlation of the 3-4 lowest ones has proved possible (Roszkówna, 1968; Drozdowski & Berglund, 1976; Tomczak, 1987). As concluded by Wiśniewski (1982, 1987; also see Starkel, 1990), the correlation of higher terrace levels based on altitude is useless because these levels are all associated with transformations of different reaches during deglaciation (Fig. 4).

In the lowest course, incision probably continued until the beginning of the Holocene, when the low water level of the Yoldia Sea started to rise from - 80 metres. Fluvial deposits of early Holocene age are recorded below the Vistula delta (Mojski, 1990). The construction of the Vistula delta started from 7 ka BP jointly with the *Litorina* transgression. The Holocene evolution of the Lower Vistula valley is controlled more and more by the hydrological regime of the upper and middle part of the basin. This means that the phases of Subboreal and Subatlanic aggradation and channel abandonment are synchronous with those identified in the Subcarpathian Basins (Florek *et al.*, 1987; Tomczak, 1987; Starkel, 1990).

Detailed studies of the divergence of the Middle Warta valley (to the west of the pradolina, north of the Poznań gap) have shown that the transformation from braiding to meandering followed in the early Bölling stage, and the next change towards small meanders and a narrowing of the floodplain coincided with total reforestation at the beginning of the Holocene (Kozarski *et al.*, 1988; Kozarski, 1991). But even here in a lowland valley, the formation of abandoned meanders coincided with wet phases before 8, 4 and ca 2.5 ka BP.

The tributaries of Vistula river in northern Poland

In their evolution, tributary valleys show a close association with the main valley. Therefore, the incision during the deglaciation fluctuated between 20 and 50 metres (Galon, 1953; Niewiarowski, 1968). A detailed study of several tributaries by Andrzejewski (1994) has shown various mechanisms of evolution which relate to the previous origin of valley segments (sandur plain, ice marginal streamways, subglacial streamways), which later were incorporated in one system. In several valleys with a low gradient, even the late Vistulian transitional phase, with its large palaeomeanders, registered.

In the evolution of these valleys, their first phases of transformation just after the deglaciation are very important. Under a cold periglacial climate in the southern part of the Pomeranian marginal zone, winter freezing was combined with the formation of icings which were recorded on the outwash plain in the shape of oriented depressions (Kozarski, 1975). The melting of dead-ice blocks continued until the Alleröd period when most of the lakes were formed, especially in subglacial channels (cf. Kozarski, 1995). Many of the small lakes are still not fully incorporated into the fluvial system. The larger ones, those located in subglacial depressions and draining to the pradolinas, show a tendency to overgrowth by peat (Niewiarowski, 1994).

The river valleys in the coastal zone

In this belt, which is up to 100 km wide, and which drains to the Baltic Sea, all valley patterns are superimposed on the meltout depositional relief created during the deglaciation of the Pomeranian and Gardno phases between 16 and 14 BP. Most of the valleys are composed of fragments of different genesis including various meltout depressions, e.g. the Radunia valley near Gdańsk (Koutaniemi and Rachocki, 1981). A very low base level during the late Vistulian and early Holocene created the conditions for erosional advances upstream but various types of lithology and influence of transfluent lakes formed barriers to the small rivers. Studies of several of these rivers by Florek (1988, 1991) has shown that, in their lower courses, these river reached the stage of floodplain maturity and the first meandering patterns are recorded from ca 8 ka BP. The impact of the Baltic transgression, earlier estimated as a very important factor (Rosa, 1964), appeared to be restricted to only several kilometres.

Regularities in evolution of fluvial systems

Several regularities may be observed in the evolution of the fluvial system on the territory of Poland during last 30 ka. Most of these are connected with the climatically controlled changes in the runoff and sediment load; others are related to the specific role of the invasion of the ice sheet from the north and following deglaciation.

The aggradation usually associated with the cold stage is more related to a delivery of sediment, flood type and its frequency. Therefore, we observe a progressing downcutting during the increasing continentality about 25-20 ka BP (Starkel, 1994). During the warm stage (Holocene), there are phases with either higher or lower flood frequency. The first are the periods of both increased erosion, a straightening of channel as well as of aggradation (Starkel, 1983, 1995d). The transitional phase of reorientation of the fluvial system combined with revegetation is reflected in erosion combined with a transformation of the braided pattern to a meandering one with a transitional phase of large meanders (Szumański, 1983; Kozarski *et al.*, 1988; Starkel, 1990; Vanderberghe *et al.*, 1994 - Fig. 5).

As concluded by Falkowski (1975) the best conditions for studying the chain of changes are those in the middle valley segment which has reached a stage of maturity with free meandering. In young fluvial systems these changes are not synchronous in the whole longitudinal profile. But, to some extent, the reaction to climatic change in a uniform landscape may be synchronous in the valleys of various orders. This is probably true of the Lublin Plateau, where episodes of erosion and aggradation during the last cold stage were simultaneous (Superson, 1996).

Polish territory provides a good opportunity for studying the impact of ice sheet advances and retreats on the formation and evolution of fluvial systems (Rotnicki, 1987; Starkel, 1995d). But the relief configuration and type of substrate create condtions different from those described from Canada (Teller, 1995) or Finland (Koutaniemi, 1991; Mansikkaniemi, 1991). In the whole Poland, two types of evolution of the river valleys are present: the expanding downstream and the expanding upstream (Fig. 6). Also the underfit streams over the pradolinas and sandur plains are very typical in this area.

The Vistula and Oder are examples of the expanding downstream valleys. Their length and gradient increased with progressive deglaciation. But also with time the floodplain formed uniformly in all upstream sections. It developed like a carpet being unrolled downstream. Such a floodplain is under the control of flood waves originating in mountain headwaters and of sediment waves from the deforested foothills and loess plateau.

The converse direction of evolution may be observed in the tributary valleys draining the ice-free areas. The "backward" evolution, connected with the lowered base level, is realised by the expansion of the river catchment, incision and, of sections in between, by aggradation. The rate of adaptation depends on river discharge and the duration of incorporation into the new system. Therefore, the mature river channel, and also the floodplain, appear at first in the lower course or in the section stabilised by the local base level (cf. Koutaniemi, 1991).

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Sources of material supply and nature of fluvial transport in post-glacial agricultural-forested catchment (the upper Parsęta river, Poland)

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Abstract: Understanding the character and temporal variability of fluvial transport is of fundamental importance for the qualitative and quantitative description of contemporary fluvial systems. In the present study certain features of fluvial transport are regarded as markers which indicate the way the denudation system of a catchment operates. On the basis of mapping carried out along the upper Parsęta channel, only a small part of the catchment was found to take part in the supply of suspended material to the river channel. The occurrence and intensity of processes active in the supply of sediment for transport in the Parsęta channel depends largely on lithology, channel morphology, conditions of water flow, hydrogeological conditions, and vegetation. These factors are modified by the activity of man and animals. Variations in the transport of solutes along the upper Parsęta result from differences in lithological sources, which, in turn, are associated with other environmental factors which determine the rate of water circulation.

The figures for ionic and suspended flows obtained in this research confirm the regularity with which dissolved material is overwhelmingly predominant in the fluvial transport of Pomeranian rivers. The changing meteorological conditions in the catchment, and also the seasonal development of its plant cover, are reflected in the way the river flow is sustained and, in the fluvial regime, is expressed as the amount of material leaving the catchment system. The three periods of denudational activity which have been distinguished on the basis of differences in their fluvial transport regimes, reflect the seasonal efficiency of denudation processes in the catchment. The seasonal variations in the fluvial transport in the upper Parsęta provide an insight into the development of the present-day relief of the young-glacial area of West Pomerania.

Key words: fluvial transport, source of material, solute load, sediment load, post-glacial catchment

Introduction

In the contemporary denudation system of West Pomerania, fluvial transport plays a fundamental role by carrying away material from erosion and denudation in the catchments. A detailed analysis of fluvial transport provides a good indicator of relief evolution, including soil leaching and erosion. The character of the fluvial transport is also a good indicator of change in the landscape structure of a region. In the present study, the subject of the investigation was the upper Parsęta catchment, which is regarded as representative of the post-glacial zone of West Pomerania and the Polish Plain. Systematic investigations of modern morphogenetic processes in the upper Parsęta catchment have been carried out since 1981. Since 1 November 1985, daily measurements have been taken in the profile which closes the upper Parsęta catchment (at Storkowo); this catchment is regarded as an independent denudation system.

The programme of research in the upper Parsęta catchment is based on methodological assumptions derived from Cholley's concept of a denudation system (Tricart, 1960) and Bertallanffy's (1984) systems theory. They have provided the basis for the conception of geoecosystem operation, as formulated in Kostrzewski (1986, 1993). The following, already established regularity is the basic assumption of this investigation: the kind and amount of material flowing through the measuring point reflect current geomorphological processes taking place in the river channel and catchment (Gregory & Walling, 1973; Schumm, 1977; Richards, 1982; Froehlich, 1982; Knighton, 1984; Zwoliński, 1989).

The basic objective of the research conducted in the upper Parsęta catchment is the understanding of the operation of the geo-ecosystem of a lowland river in the conditions of climatic change and various forms of human impact. The aims of the present investigations include:

1) an evaluation of the controls, pattern and intensity of fluvial transport, which are reflections of the denudation processes occurring in the upper Parsęta catchment system, i.e. mainly soil erosion and leaching,
2) an analysis of variations in the physico-chemical properties of solutes and solids in the upper Parsęta channel as factors controlling the variability of fluvial transport and determining its role in the contemporary denudation system of the catchment;