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ARTYKUŁY

(ARTICLES)

LESZEK STARKEL (KRAKÓW)

EVOLUTION OF THE CARPATHIAN VALLEYS AND THE FORECARPATHIAN BASINS IN THE VISTULIAN AND HOLOCENE

1. INTRODUCTION

The purpose of this paper is to summarize the current knowledge on the evolution of the valleys at the northern slope of the Carpathians and their Foreland in the Vistula drainage basin in the last Glacial-Interglacial cycle on the background of current hypotheses. An analysis of changes in levels of river channels and flood-plains in cross-sectional and longitudinal profiles points to great complexity of erosional and accumulation processes in time which departs from the existing schemes. The analysis also indicates modification of a climatic influences by tectonic tendencies.

Excluding the Tatras and the Klippen Belt, the Polish Carpathians are built of flysch sandstones and shales which supply large suspended load and rather small bedload. The flysch Carpathians, reaching 900–1725 m a.s.l., with relative height differences of 100–400 m, are dissected by rivers whose gradients are 1–10‰ and whose catchment areas are of 2–5000 km^2. At the north, the Forecarpathian Basins, incised in the Miocene clays and lined with Quaternary deposits, border with the belt of limestone uplands, mantled with loess covers. The Vistula which flows at the northern margin of the mountain foredeep collects water of the Carpathian tributaries. These tributaries built systems of alluvial fans, sometimes dichotomous ones, into wide bottoms. At the margin of mountains the deposition is conditioned by abrupt valley widening and escapes of water into alluvia while a change in a gradient and perching of water by the Vistula are decisive factors at the outlets to the Vistula.

Main localities with investigated Vistulian and Holocene alluvial sequencies

Główne stanowiska osadów rzecznych vistulianu i holocenu

No	Locality	References	Eem	EV	PL 1	IP	PL 2	LV	10–8	8–6	6–4	4–1	1–0 ka BP
01	Drogomyśl	(Niedziałkowska et al. 1985)				=▼	=	○×▼↓	×▼↓				○=▼
02	Chybie	" " "	○▬	↓▼		=▼↓	‖						
03	Pierściec	(Niedziałkowska, Szczepanek 1994)			○	=▼↓	‖						
04	Kaniów	(Gilot et al. 1982)				○=▼↓	∨‖▼↓						
05	Góra	(Klimek, Zawilińska 1985)											=
06	Bierun Nowy	(Klimek 1992)						×▼	▬	▬▼=			
07	Bobrek	" " "						×▼					
08	Smolice	(Krąpiec 1992)							○D▼		○D	○ D	
10	Zator	(Koperowa, Środoń 1965)			‖	=▼↓	‖						
11	Wadowice	(Sobolewska et al. 1964)		○×▼↓	~	~×	~‖						
12	Ziębówka	(Środoń 1952)			○	=↓	○						
13	Myślenice	(Starkel 1968, Środoń 1968)			○	~ ↓	~						
14	Moszczenica	(Aleksandrowicz, Gerlach 1983)								#ↄ	=		
15	Łężkowice	(Aleksandrowicz, Wyżga 1992)						○	×▼ↄ	×ↄ			
16	Brzesko	(unpubl.)					○	▼		▼	=		
17	Orawka	(Środoń 1952)					=~↓						
18	Jabłonka	(Baumgart-Kotarba 1992)						○	=▼				

20	Puścizna Rękowiańska	(Obidowicz 1989)						=	—▼	—▼	—▼	—▼	
21	Na Grelu	(Klimaszewski 1961, Koperowa 1962)					○	=—▼↓	—↓	—↓	—↓	—↓	
22	Bór na Czerwonem	(Obidowicz 1989)							=	—▼	—	—	
23	Białka	(Sobolewska, Środoń 1961)			○	=↓	○						
24	Brzeziny	(Birkenmajer, Środoń 1960)			○	—↓	~						
25	Kąty k/Sromowiec	(Mamakowa et al. 1975)		○—↓▼									
26	Krościenko	(Klimaszewski 1948)					~↓						
27	Dobra	(Klimaszewski 1971, Środoń 1969)				○=↓▼	~						
28	Gruszowiec	(Starkel 1960b)					~	∨					
29	Lipowe	(Starkel 1969)					○~						
30	Sienna	(Alexandrowicz et al. 1991)		○	~								
31	Szujec	(Sokołowski 1981)				○▼	○						
32	Niwka	(Sokołowski in print)						○	×▼				
33	Zabawa	" " "							×▼				
34	Szymbark	(Dauksza et al. 1982)										○▼↓	
35	Jedlicze	(Krysowska-Iwaszkiewicz, Wójcik 1990)				○×▼↓	~						
36	Roztoki	(Wójcik 1987)					○	#▼↓	—=▼↓	=			
37	Jasło-Bryły	(Alexandrowicz et al. 1985)				○=▼↓	~						
38	Dąbrówka	(Mamakowa, Wójcik 1989)	×↓	=									
39	Klecie	(Krąpiec unpubl.)										○D	○D

No	Locality	References	Eem	EV	PL 1	IP	PL 2	LV	10–8	8–6	6–4	4–1	1–0 ka BP
40	Dęborzyn	(Klimek, Starkel 1974)								○×▼			
41	Strzegocice I	(Klimek 1992)						×▼	×▼			×▼=	
42	Strzegocice II	(Krąpiec, Starkel unpubl.)										○D	
43	Łęki Dolne	(Klimaszewski, Szafer 1945)						○↓	=↓				
44	Podgrodzie	(Niedziałkowska et al. 1977)				○~▼	○=▼	○▼	×V▼↓ↄ	V▼↓			
45	Latoszyn	(Alexandrowicz, Klimek 1985)						○=▼ↄ					
46	Grabiny	(Starkel, in Alexandrowicz et al. 1991)									○▼	○▼↓	○=▼D
47	Potok Wolicki	(Starkel, in print)						○▼	=—▼	V			
48	Dębica-Kolejowa	(Starkel, in Alexan-drowicz et al. 1981)						○	×▼↓	V			
50	Kędzierz	(Starkel, Krąpiec in print)									▼	○▼D	=
51	Wola Żyrakowska	(Starkel, Granoszewski, in print)					○=▼	×▼↓	×—▼↓				
52	Brzeźnica	(Mamakowa, Starkel 1974, in Alexandrowicz et al. 1981)			○	×▼↓	○=▼↓	○	×▼↓	×		○▼	=▼↓
53	Rzochów	(Laskowska-Wysocka, Niklewski 1969)		×↓M	○								
54	Besko-Zapowiedź	(Koperowa, Starkel 1972)						#↓	#—▼↓	=	=		
55	Rzeszów	(Jahn 1957, Starkel 1960a)			○		‖	×↓	—↓				
56	Trzebowisko	(Friedberg 1903)								○↓		○↓	
57	Łukowiec	(Starkel 1977)				×—▼							○

60	Dziurdziów	(Starkel 1965)					○~						
61	Łodynka	(Henkiel 1966)			○~	○=	~						
62	Bukowiec	(Starkel 1977)											○=▼
63	Smerek	(Ralska-Jasiewiczowa 1980)					○—▼↓						
64	Wołosate	" " "									○	—▼↓	—↓
65	Tarnawa Górna	" " "						×—▼↓	—=▼↓	—▼↓	—▼↓	—▼↓	—▼
66	Krzemienna	(Krąpiec unpubl.)										○D	
67	Podbukowina	(Mamakowa 1962)						×—↓	—↓	—↓	—↓	—↓	—↓
68	Potok Krzeczkowski	(Alexandrowicz et al. 1989)		○~△ↄ	~ↄ		‖						
69	Dybawka, Krasice	(Łanczont 1993)	○△	~‖△	‖	‖	‖						
70	Przemyśl-Ostrów	(Krąpiec unpubl.)										○D	
71	Przemyśl-Przekopowa	(Starkel 1977)						○▼	=				
72	Hurko	(Starkel 1960)						=↓		○×↓			
73	Stubno	(Klimek 1992)					○×▼	×▼	×—▼	—▼	=		
74	Barycz	(Kulczyński 1932)					=↓						
75	Walawa	(Kulczyński 1932)					=↓						
76	Radymno	(Alexandrowicz et al. 1989)		○=△	‖	‖	‖						
77	Jarosław	(Jersak et al. 1992)			○	=▼	‖						
78	Rzuchów	(Szumański 1985)						×▼					
79	Jelna	" " "						×▼	×▼				
80	Jeziorzany	(Rutkowski 1987)									×▼	○▼D	
81	Sciejowice	(Mamakowa, Rutkowski 1989a)			○	×=▼↓	‖						

No	Locality	References	Eem	EV	PL 1	IP	PL 2	LV	10–8	8–6	6–4	4–1	1–0 ka BP
82	Kryspinów	Mamakowa, Rutkowski (1989b)				○▼↓							
83	Bielany	(Rutkowski 1987)							×▼	×▼		×○▼D	
84	Ludwinów	(Sokołowski, Wasylikowa 1984)			○	○=▼↓	○			×▼	—▼	=	
85	Kraków-Rondo	(Mamakowa 1970)						○×↓	×▼↓				
86	Czyżyny-Łęg	(Kalicki 1991)						×▼		×▼		×▼	
87	Plac Centralny	(Zernickaya, Kalicki in print)						○×↓	×=▼↓				
88	Nowa Huta	(Mamakowa, Środoń 1977)			○	=▼↓	‖						
89	Pleszów	(Wasylikowa et al. 1985, Kalicki 1991)					×▼	×▼↓		○×▼↓	~▼↓ↄ		
90	Płaszów and Rybitwy	(Kalicki 1991)						○=▼		×▼		—∨	
91	Przewóz and Brzegi	(Kalicki 1991)						○—▼	○=▼			×▼	
92	Branice	(Kalicki 1991, Krąpiec 1992)						○▼↓			○×▼	○×▼D	○×▼D
93	Zabierzów Bocheński	(Kalicki et al. in print)							○×▼		○×▼↓	×▼↓	
94	Drwinka	(Gębica, Starkel 1987)							×▼↓				
95	Las Grobla	(Starkel et al. 1991)						○×▼↓	○×=▼	=▼	○=×▼	×▼	
96	Trawniki	(Gębica, in print)			○△	=△	‖△ↄ						
97	Smiłowice	" " "			○	=△	‖			~▼			
98	Niedary	" " "									○▼D	○=▼D	
100	Gróbka depression	(Gębica in print)					○	=—▼↓	==▼↓	×▼		×▼	
101	Szczurowa	" " "						○=—↓	=				

102	Włoszyn	" " "				=▼↓	○						
103	Opatowiec	(Jersak 1991)				○=▼	‖ɂ						
104	Mędrzechów	(Sokołowski 1987)									×▼		
105	Szczucin	" " "										×▼	
106	Piaseczno	(Mycielska-Dowgiałło 1977)				○▼	○	○	○×▼				
107	Machów	" " "										○▼D	○D
108	Kobylarnia	" " "						×▬▼	▬▼	▬▼			
109	Łążek	(Mamakowa 1968)				=▼↓	○						
111	Rudawa	(Rutkowski 1988)		○△						=▬▼	=▬▼		
112	Racławka Dolna	(Rutkowski 1991)							#=▼ɂ	#▼	=∨	○▼ɂ	
113	Racławka Górna	(Szulc 1986, Pazdur et al. 1988)						=▼	#▼ɂ	#▼ɂ	○▼ɂ	#▼ɂ	
114	Szklarka	(Alexandrowicz 1989)				○	‖△ɂ						
115	Maszków	(Alexandrowicz 1991)				○	=‖▼ɂ						
116	Nidzica valley	(Śnieszko 1985)					○	=▼	=ɂ	=ɂ	=ɂ	=ɂ	
117	Sancygniówka	" " "					=ɂ	=	×▼	×	=▼ɂ	=ɂ	

Fig. 1. List of main localities with investigated Vistulian and Holocene alluvial sequencies in the Polish Carpathians and their foreland (several sites closely localised were shown together)

Signs: ○ — channel facies, = — overbank facies, × — paleochannel facies, ∨ — alluvial fan facies, ‖ — loess, ~ — slope deposits, ▬ — peatbogs, # — calcareous tuffa and lacustrine chalk, ▼ — radiocarbon dating, △ — TL dating, D — dendrochronological dating, ↓ — paleobotanical investigations, ɂ — malacological investigations, ʍ — mammal bones

Ryc. 1. Lista głównych stanowisk osadów rzecznych vistulianu i holocenu w Polskich Karpatach i na ich przedpolu (blisko położone stanowiska pokazano niekiedy razem)

Znaki: ○ — facja korytowa, = — facja pozakorytowa, × — facja wypełnień starorzeczy, ∨ — facja stożków napływowych, ‖ — less, ~ — osady stokowe, ▬ — torfowiska, # — tufy węglanowe i kreda jeziorna, ▼ — datowania ^{14}C, △ — datowania TL, D — datowania dendrochronologiczne, ↓ — analizy paleobotaniczne, ɂ — analizy malakologiczne, ʍ — kości ssaków

1.1. STRATIGRAPHIC CLASSIFICATION OF THE VISTULIAN AND HOLOCENE ACCEPTED FOR SOUTHERN POLAND

Until the 1960s (Klimaszewski 1961, 1967, Środoń 1952, 1968, Starkel 1964, 1968) duration of the Last Glaciation was accepted as c. 60 000 years. Traditional division was in common usage. Initially one warming (Aurignacian?) was distinguished, then two others (Göttweig and Paudorf). Development of the ^{14}C method as well as dating of sea deposits and ice-cores allowed for discerning three fundamental units in the last cold stage: Early Vistulian, Pleniglacial and Late Glacial (Waillard and Mook 1982, Guiot *et al.* 1989, Behre 1989) (Fig. 1). In the early Vistulian (from 115 to 74 ka BP) there is an evidence of 2–3 interstadial warmings: Amersfoort-Brorup and Odderade. Out of these, the Brorup was identified in the profile of Wadowice (Sobolewska *et al.* 1964) while the no-named warmings were stated in Rzochów at the Wisłoka river (Laskowska-Wysoczańska and Niklewski 1969) and in Chybie in the Oświęcim Basin (Niedziałkowska *et al.* 1985). Of this period there are also TL datings of the fossil soils and the lowermost, younger loess (Maruszczak 1991).

The Pleniglacial comprises 3 distinct parts: the lower Pleniglacial (74–58 ka BP), interstadial warmings (58–29 ka BP), and the upper Pleniglacial (29–13 ka BP) in which an ice-sheet entered the area of Poland. While a forestless climate existed and loess was being deposed during these two cool periods, forests expanded in lower locations (to 500–700 m a.s.l.) in the Interpleniglacial and the study sites provide the evidence of 2–4 significant warmings (Środoń 1968, Starkel 1980). Investigations of ice cores (Oeschger 1991) indicate that numerous rapid climate oscillations (temperature oscillations of the order of 4–5°) of the rhythm length even of 1–3 ka took place. The interpleniglacial period is marked by fossil soils in the form of gley or sometimes humus horizons (Maruszczak 1980, Jersak *et al.* 1992) as well as by the levels of overbank and organic deposits separating two members of the solifluction-deluvial deposits and channel deposits (Starkel 1964, 1968). This period as well as the upper Pleniglacial were characterized by very large diversity of habitats which is typical of the periods of water deficit and low temperatures (Starkel 1968). The late Vistulian (13–10 ka BP) was characterized by a return of a warm period and an expansion of the boreal communities and later by a significant cooling of the Younger Dryas (Ralska-Jasiewiczowa 1980, Starkel 1991).

The Holocene, comprising the recent 10 000 years (on the dendrochronological scale its beginning is assigned to 11 000–11 300 years BP — Becker *et al.* 1991), was initially divided, according to Blytt-Sernander, into 2 phases of rather continental climate (Preboreal-Boreal and Subboreal) and into 2 phases of rather maritime climate (Atlantic and Subatlantic). The subsequent studies indicated that there were more oscillations, the longer warmer and usually drier phases alternated with the shorter moister and cooler ones, with advances of glaciers, increased

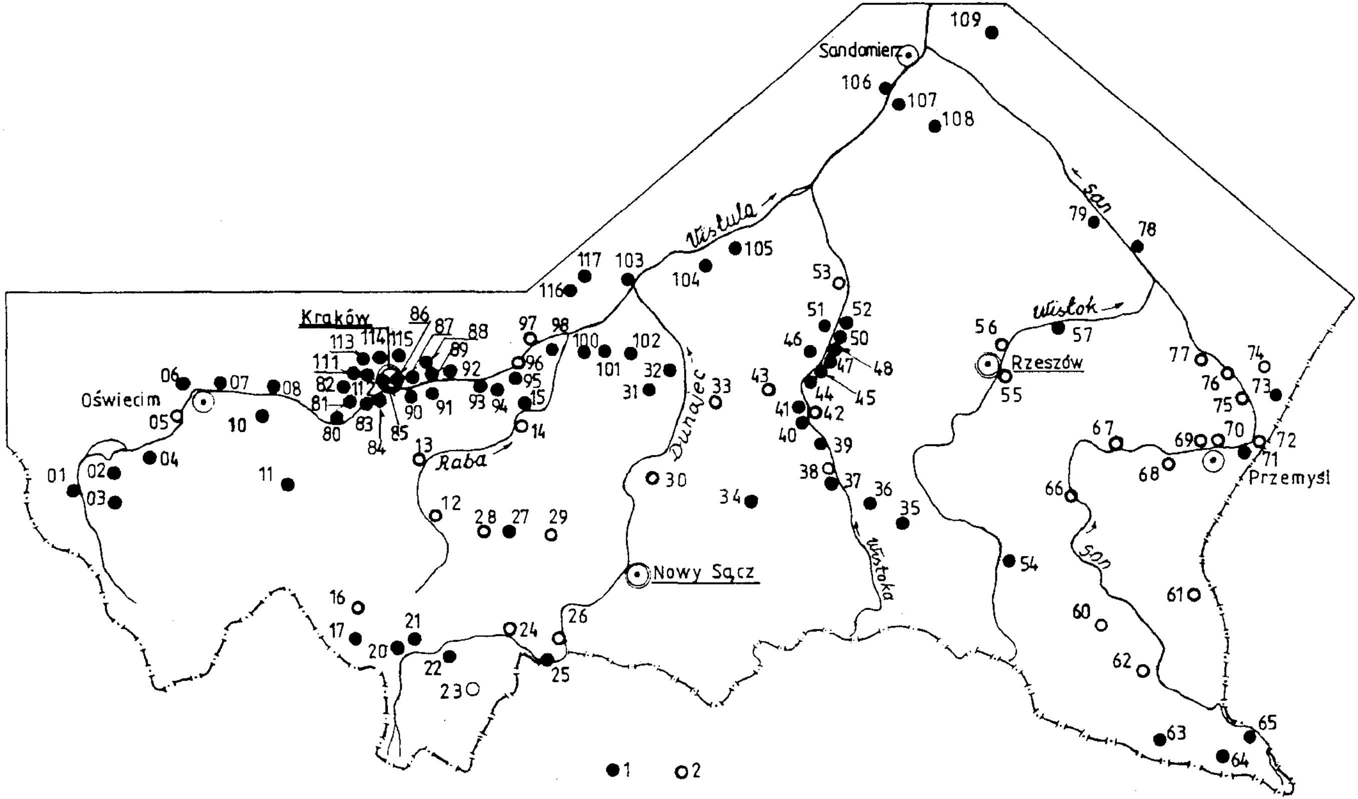


Fig. 2. Distribution of localities in the Polish Carpathians and Subcarpathian Basins presented on Fig. 1. Black rings indicate sites dated by radiocarbon method, white rings — sites dated by other methods

Ryc. 2. Rozmieszczenie stanowisk w Polskich Karpatach i Kotlinach Podkarpackich, przedstawionych na Ryc. 1. Czarne kółka pokazują stanowiska datowane metodą radiowęgla, białe — datowane innymi metodami runoff and water storage (Patzelt 1977, Starkel 1983, Magny 1993). Human impact on the environment manifested from ca 6000 BP (Wasylikowa *et al.* 1985); it reinforces in the late Neolithic and Bronze, and becomes evident since the Roman period (Ralska-Jasiewiczowa 1989).

The climatic-stratigraphic division presented in Fig. 1 has been applied in the discussion on the evolution of the upper Vistula drainage basin.

1.2. CLIMATIC CONCEPTS OF VALLEY EVOLUTION

The Alpine foreland and the periglacial Central Europe give rise to theories on erosion-accumulation cycles of valleys evolution, i.e. the theories on aggradation in cool periods and erosion in interglacials (Penck and Brückner 1909, Soergel 1921). Next, the interglacial and Holocene alluvia have been found there. Thus, the subsequent works of Trevisan (1949), Jahn (1956) and others brought modification of a former scheme of the evolutions of the valleys — accumulation phases separate the early Glacial and late Glacial phases of erosion. Schumm's contribution (1965) to the scheme was a metamorphosis of a fluvial system which, in the temperate zone, transposed braided river pattern to a meandering one in the late Glacial, i.e. the transposed rivers with predominant vertical accretion to those with predominant lateral erosion. This concept has been evidenced by the studies of the river valleys at the Carpathian foreland and in Polish Lowland (Falkowski 1975, Szumański 1983, Kozarski and Rotnicki 1977). In addition, Starkel (1960, 1977, 1983) has distinguished a number of phases of intensified river activity which are reflected in 2 inserts in the Vistulian period and in 3–5 inserts during the late Glacial and Holocene.

As for the longitudinal profile the glacial-interglacial cycle is evidenced by a reverse sequence of phases in lower river reaches which were subjected to sea fluctuations (Woldstedt 1952). When observing erosion in mountains and aggradation in areas of alluvial fans at the mountain foreland Starkel (1960) assumed flattening of the longitudinal profile of the valleys of the Carpathian rivers in the Holocene.

In the mountain areas, erosional socles of the terraces associated with glaciation (cool periods) were interpreted as the effect of upheaval, related most to the interglacial periods (Klimaszewski 1948). Then, intermingling of fluvial and solifluction deposits in the area of the terrace covers (Klimaszewski 1958) as well as of the sliding surfaces at the upper and lower faces of the terraces in the San valley was the background of the hypothesis on a terrace cycle in the areas being uplifted (Dziewański and Starkel 1962): dissection in the interglacial, accumulation in the glacial and lateral erosion joined with deepening in transitional periods.

A role of man in the evolution of the valley bottoms was perceived as acceleration of soil erosion and accretion of channel deposits of the last cold period (Mensching 1957, Klimaszewski 1948) by alluvial loams (*madas* in Polish).

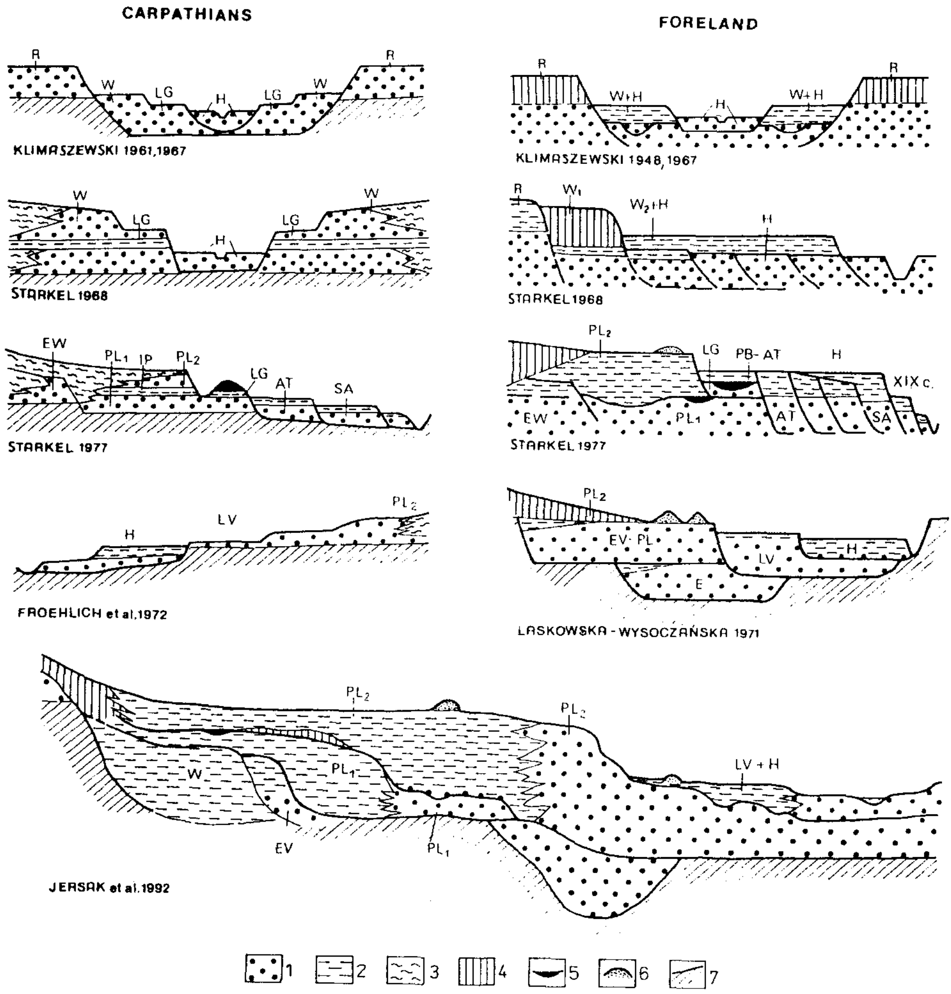


Fig. 3. Selected previous models of evolution of valley floors in the Carpathians and their Foreland after various authors. At the bottom synthetic model of valley floor evolution in the loess plateaus at the northern margin of the Subcarpathian Basins

Signs: 1 — channel facies, 2 — overbank facies, 3 — solifluction and slope wash deposits, 4 — loess, 5 — organic deposits, 6 — dunes, 7 — bedrock

Ryc. 3. Wybrane dawniejsze schematy ewolucji den dolinnych w Karpatach i na ich przedpolu wg różnych autorów. Na dole syntetyczny model ewolucji den dolin na wyżynach lessowych północnego obrzeżenia Kotlin Podkarpackich

Znaki: 1 — facja korytowa, 2 — facja pozakorytowa, 3 — osady soliflukcyjne i deluwialne, 4 — less, 5 — osady organiczne, 6 — wydmy, 7 — starsze podłoże

2. THE STATE-OF-THE-ART

The valley bottoms were studied as early as a geological atlas of Galicia was being prepared. Łomnicki (1895–1903) and Friedberg (1903) have distinguished a young diluvial terrace (with loess or dunes at the upper face) and two inserts of the Holocene alluvia building the bottom terraces at the height of 4–8 m and 2–4 m, respectively. Their age has been documented by forest flora, tree trunks and malacofauna. Presence of the Dryas florae in these terraces caused Klimaszewski (1948) to relate the age of the bottom terrace to the last Glacial. In the Holocene, only dissection by abandoned channels and accretion by *madas* could have taken place. In the upper Dunajec catchment the direct upper terrace has been associated with the marginal zone of the Tatric glaciers (Halicki 1930, Klimaszewski 1948).

The loess overtopping and presence of permafrost structures were supposed to be the evidence that the cover of the 10–20 m high terrace at the mountain foreland originates from the older cool period. Yet already Jahn (1957), Halicki (1955) as well as Birkenmajer and Środoń (1960) provided arguments for complexity of phenomena in the last Glacial: origin of alluvia from the older part while overtopping with loess or solifluction in the younger part. In 1960 Starkel has stated complexity of a structure of the bottom terrace; within the terrace there are some inserts which, based on a few pollen spectra, he has associated with the moister periods: Alleröd, Atlantic and Subatlantic. Accretion of the interlocking alluvia and slope covers during the whole Vistulian were supposed to document continuity of aggradation in a mountain interior (Klimaszewski 1958, Starkel 1964). At the foreland it has been stated meanwhile that the higher, middle terrace with loess dates back to the older Vistulian (Środoń 1968, Laskowska—Wysoczańska 1971, Mamakowa and Środoń 1977) and sandy levels with dunes hide in themselves the Vistulian inserts of various ages (Mamakowa and Starkel 1974). Dissections and inserts in valley bottoms have been related to the phases of more frequent floods (Starkel 1977, 1983) while their number and age are better documented in the Vistula valley near Cracow (Kalicki 1991, Krąpiec 1992). In addition, not only did deep troughs originate from the Eemian interglacial (Laskowska-Wysoczańska 1971) yet they can be of the interpleniglacial period (Mycielska-Dowgiałło 1977) and the last intensive deepening of these troughs took place at the turn of the Pleniglacial (Kalicki 1991, Klimek 1992).

In this century knowledge about various regions significantly increased, so did the methods. The first to have been learnt were terrace structures at the Carpathian foreland thanks to palaeobotanical and palaeozoological methods used. In the inter-war period[1] the sites with the Dryas flora on the

[1] The inter-war period is the period between 1918–1939.

San river and those with the late Glacial and Holocene flora in the Wisłoka catchment have been discovered. In the post-war period (1950–1965) the zone of loesses of the Carpathian foreland and of the alluvial fans at this foreland became the area of detailed studies. Inserts of alluvia have been distinguished, organic remnants were palynologically studied and dated by the ^{14}C method, and investigations of the fossil soils in loesses provided indirect age determination of the lower channel alluvia. The sites of interlocking alluvia and solifluction in the Beskid Wyspowy Mts contributed to information about the evolution of the valleys in the cold period while a younger history of the valleys of the upper San and upper Dunajec drainage basins has been comprehended by relating to peat-bogs.

The studies on the evolution of the valleys developed particularly intensively since 1987, i.e. after the IGCP–158 programme "Paleohydrology of the temperate zone" and the CPBP–03.13 programme were launched, when sedimentological, malacological, archaeological methods, ^{14}C-datings, dendrochronology as well as studies on heavy metals and other anthropogenic indices became used in a broad range (Starkel 1990, Kalicki 1991).

At the same time, systematic investigations of overtopping deposits (loess, deluvial deposits etc.) with the help of paleopedological methods and TL-datings (cf. Maruszczak 1991) were undertaken.

This summary is a successive one by L. Starkel as an author who dealt with paleogeographic reconstruction and stratigraphy of the Carpathians and their foreland in the younger Quaternary (Starkel 1964, 1968, 1977, 1980, 1988). Currently in the Carpathians and at their foreland there are available more than 100 sites out of which ca 80% are radiocarbon dated and several are TL-dated and possess detailed pollen diagrams. Over 400 black oaks have been studied in the alluvia of the upper Vistula (Krąpiec 1992, oral communication). The largest number of sites is concentrated in the Cracow section of the Vistula valley and numerous sites are found in the middle Wisłoka valley.

3. GRAIN SIZE PROPERTIES OF THE ALLUVIA

Grain size composition of alluvia and properties characterizing grain shapes have been recognized to a varying degree of details; the studies are limited almost exclusively to the sections of the valleys of the Vistula, Wisłoka, upper Dunajec, and San rivers (Starkel 1965, Mycielska-Dowgiałło 1978, Niedziałkowska — in: Alexandrowicz *et al.* 1981, Niedziałkowska *et al.* 1985, Rutkowski 1987, Sokołowski 1987, Niedziałkowska 1991, Kalicki 1991, Starkel *et al.* 1991, Gębica in press, and Froehlich *et al.* 1972, Baumgart-Kotarba 1983).

Based on the above the characteristics of the alluvial facies of the Vistulian and Holocene in the valleys of the Carpathians and of their foreland is possible.

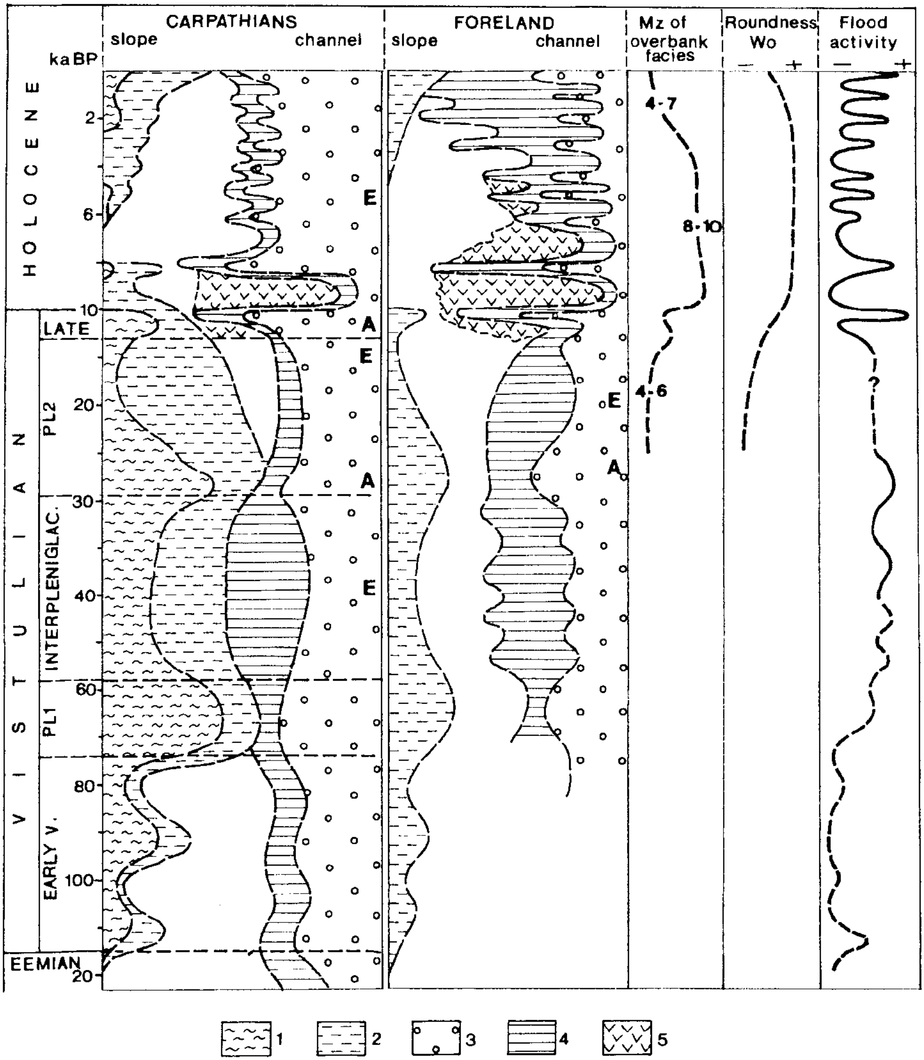


Fig. 4. Activity of various processes and participation of various sediment facies at the slopes and in the valey floors in Carpathians and their foreland during Vistulian and Holocene. Parallely are shown the curves of variations in the granulometry of overbank deposits roundness coefficient of sands and flood activity

Signs: 1 — solifluction deposits, 2 — slope wash deposits, 3 — river channel facies, 4 — overbank facies, 5 — overgrowing of floodplain by peat

Ryc. 4. Aktywność różnych procesów i udział różnych facji osadów na stokach i w dnach dolin w Karpatach i na przedpolu w vistulianie i holocenie. Równolegle pokazano krzywe zmian granulometrii osadów pozakorytowych, wskaźnika zaokrąglenia ziarn piasku i aktywności powodzi

Znaki: 1 — osady soliflukcyjne, 2 — osady deluwialne, 3 — facja korytowa, 4 — facja pozakorytowa, 5 — zarastanie równiny zalewowej przez torfowiska

Alluvia of the Carpathian rivers change their grain size composition in longitudinal profiles of rivers when the river gradient decreases and geological structure of the catchment changes. While the maximum diameters of the present-day channel deposits of the rivers of the Beskidy Mts and of Podhale reach 20–150 cm, and the overbank deposits reach from 0 to +4 phi, the rivers of the Carpathian foreland mainly transport sands (–1 to +3 phi) and deposit *madas* of the diameter of 4 to 8 phi. The rivers whose gradient is larger and where in the catchment are more resistant rocks transport coarser material. Therefore, in the upland reach and within the alluvial fans at the mountain margin the alluvia of the Soła and Dunajec rivers are by 2–4 phi coarser than deposits of the Wisłoka and San rivers, for instance. The following fundamental facies have been distinguished in the alluvia:

1. channel facies (ch), including log subfacies (ch–1) and channel bars (ch),
2. overbank facies (ob), including levee (ob–1), and flood basins (ob–fb),
3. alluvial fan facies (tf), and the most complicated,
4. facies of abandoned channels filling (cf) which include also organic deposits (peats) and lacustrine deposits (silts, gyttia and lacustrine chalks).

The characteristics given below treats separately properties of the alluvia of the cold period — when channel deposits of braided rivers prevailed, and colluvia and deluvia were supplied from the slopes, and the alluvia of the rivers of the warm period — deposits of meandering rivers in which there is a large proportion of overbank facies, especially when regarding the period after deforestation (Fig. 4).

At the mountain foreland the channel facies alluvia of the cold and warm periods do not substantially differ with respect to grain size composition and sorting. However, deposits of the cold period are characterized by a worse roundness of sand grains (Wo = 600–1 000) and poorer sorting (Mycielska-Dowgiałło 1977, Niedziałkowska 1991) and a larger proportion of gravels. The Pleniglacial channel alluvia in the mountain interior are much poorer sorted and they are less rounded. Analysis of gravels according to Cailleux method, in the case of grain size class 4–6 cm, of the valleys of the upper San basin (Starkel 1965) has indicated a very large variability in the grain roundness in the valleys of tributaries (30–60% in the class of the weakest rounded particles). These are weakly reworked out rubbles delivered from the slopes and transported over small distances. These gravels frequently interfinger with solifluction deposits (Klimaszewski 1958, Starkel 1965, 1969). Sometimes only a different imbrication of gravels allows one to distinguish between the deposits of longitudinal river transportation and lateral supply from a slope (Lipowe site — cf. Starkel 1969).

The deposits of the overbank facies of the cold period are relatively rare; these are usually laminated silts and sands, braided rivers deposits, known of the valleys of the Wisłoka and upper Vistula rivers (Niedziałkowska 1991), of mean diameters 4–7 phi, very poorly sorted (2–4) and of weakly rounded grains (Wo = 600–850). The pleniglacial deposits of the fan in Kaniów (Mz = 4.5–6 phi, σ = 2–3; cf. Gilot *et al.* 1982) are similar to the deposits described above. The grain size composition of the deposits of the interpleniglacial abandoned channel in Brzeźnica on the Wisłoka river (Niedziałkowska 1991) is also alike.

The river alluvia of the turn of the Glacial and Holocene are characterized by a larger facial diversity within particular climatic phases and by a change in a sedimentation rate and in grain size composition when deforestation was in progress.

The channel facies alluvia in the mountain interior comprise grain classes from coarse gravels to sands and are usually poorly sorted. At the mountain foreland Mz of the channel deposits varies from –2 to +4 phi (Sokołowski 1987, Kalicki 1991 and others), and the coarser armours are poorly sorted (σ = 2–4) while the sand bars are well sorted (σ = 0.4–1). The roundness of sands is better downstream: at the Carpathian margin Wo = 750–1000 (Niedziałkowska 1991) whereas in the northern part of the Basin it is 1000–1400 (Mycielska-Dowgiałło 1978). There are no changes in the channel facies of the various phases of the Holocene.

The deposits being characteristic both of the channels and the floodplains are those of small fan in Podgrodzie on the Wisłoka river. The Mz of the discussed deposits falls into the class 1.5–6.5 phi and their sorting is 0.4–3.5 (Niedziałkowska 1991).

The overbank deposits (*madas*) in the mountain sections of the valleys are sandy, e.g. in the case of point bars on the Białka flood plain in Podhale Mz = 0 to +2 phi (Baumgart-Kotarba 1983) while in the Ropa valley in the Beskid Niski Mts proportion of sand in *madas* is 15–50% (Dauksza *et al.* 1982). Roundness of sand grains is worse than in the channel deposits. The roundness of grains increases downstream the Vistula river in the Sandomierz Basin, from Wo = 600–770 (Starkel *et al.* 1991) to 800–1200 (Mycielska—Dowgiałło 1978).

The *madas* of various ages have been recognized in details in the Vistula valley, namely in the Oświęcim Basin (Niedziałkowska *et al.* 1985, Niedziałkowska 1991), and downstream of Cracow (Rutkowski 1987, Kalicki 1991, Starkel *et al.* 1991, Gębica 1994) as well as in the reach of the Wisłoka valley (Klimek 1974, Starkel *et al.* 1982, Niedziałkowska 1991). The late Glacial *madas* are usually silty-sands (Mz 3.5–7(8) phi) and their sorting varies from 1.5 to 3. The *madas* of the early Holocene and of the older part of the Atlantic are the finest (Mz 4.5–10 phi) and very poorly sorted (2–4). The *madas* dated from the Subboreal and the older part of the Subatlantic are slightly coarser (3–6.5 phi at the margin of the Carpathians, 6–7 phi in the Vistula valley) and somewhat better sorted (1.5–3). Finally, the *madas* of the historical period are characterized by larger thicknesses (aggradation), larger content of sand in a closer vicinity of the channel which is related to numerous floods (Mz from 5–8.5 phi) and by a very diversified sorting (1–3).

The youngest *madas* in the Vistula valley of the industrial period are also characterized by 10–100 times larger increase in the content of heavy metals (e.g. Pb from 6 to 400 ppm — cf. Klimek and Zawilińska 1985, Rutkowski 1987) and by the presence of lighter coal grains from Upper Silesia in the *madas* (Rutkowski 1986).

The grain size composition of the abandoned channels fills is very differentiated. The deposits register the occurrence of water bodies with lacustrine chalks and gyttias (Wójcik 1987; Gębica and Starkel 1987), overgrowing with peats (Wasylikowa *et al.* 1985, Kalicki 1991) as well as the phases of gradual filling by flood waters reaching there less and less frequently. In such a profile the lower parts are usually sandy (Mz 2–4 phi) and the top layers are silty clay (Mz 6–9 phi, Starkel *et al.* 1991).

4. STAGES OF VALLEY EVOLUTION

4.1. DEPTH OF THE VALLEYS IN THE EEMIAN INTERGLACIAL

As the datings of the lower face of alluvia are lacking it is difficult to determine precisely the age of rock socles under the Vistulian terrace in the Carpathian valleys as well as the age of the deep incisions filled with alluvia at the mountain foreland (the Eemian, early Vistulian or possibly the older Interglacial?). Therefore, it has commonly been accepted that incision reached the solid rock not in the period of the river overloading but in the interglacial period (cf. Klimaszewski 1948, Starkel 1965, Zuchiewicz 1987). Laskowska-Wysoczańska (1971) arbitrarily assumes that the being deeper towards the north fossil troughs in the Sandomierz Basin were incised in the Eemian when the river gradients were larger which is evidenced by the loess deposits of the whole Vistulian in the San valley (Jarosław, Radymno — cf. Alexandrowicz *et al.* 1989). In addition, in the marginal part of the Carpathians, on the San river, below the loess member of the early Vistulian there are the alluvia, dated by TL at 125 ± 18 ka BP, resting on the socle 4 m high above the river (Łanczont 1993). Whereas the socles in the Vistulian terrace are sporadically found in the zone of foothills, they are almost common although definitely differentiated in the Beskidy Mts; the highest, 5–10 m high, are in the axial parts of the uplifted areas (Froehlich *et al.* 1972, Zuchiewicz 1985, 1987). Frequently, as for example in the upper San drainage basin, the tributary valleys hanging above the main valley have higher socles (Starkel 1965). The only dated site in Dąbrówka near Jasło occurs on socle (Mamakowa and Wójcik 1987). In the subsiding Nowy Targ (Baumgart-Kotarba 1983) or Oświęcim Basin (Niedziałkowska *et al.* 1985) the interglacial bottoms descend below the present-day channels.

4.2. EARLY VISTULIAN (115–74 ka BP)

In the area of the Carpathians and their foreland there are some sites of the early Vistulian florae which document a stage of valley evolution in this 40 000 year long period. However, these are incomplete profiles and, therefore, their assigning to particular interstadials is ambivalent. The loess and solifluction fossilized Skawa terrace plain with the forest peat with *Picea omoricoides* (being characteristic of the Brörup) reaches 5–6 m above the present-day channel (Środoń and Starkel 1961; Sobolewska *et al.* 1964). Within the area of the Vistulian fan of the Vistula in the Oświęcim Basin the peat dated at over 45 ka BP with pollen of *Abies*, *Carpinus* and *Alnus* (Niedziałkowska *et al.* 1985) rests on older alluvia. In the Wisłoka valley near Mielec, in the Pleniglacial terrace at the depth of 10–18 m there are found forest florae containing the bones of a mammoth dated at over 50 ka BP (Laskowska-Wysoczańska and Niklewski 1969). The under-loess alluvial plain of the San river upstream of Przemyśl reaches the height of 9–10 m (Łanczont 1993) and in the tributaries the early Vistulian cover, dated by TL at 80–90 ka BP with fauna, reaches 2–3 m above streams (Alexandrowicz and Łanczont 1994). Therefore, the early glacial accumulation in the mountain foreland exceeded the height of the present-day alluvial plains and the position of the bottom in the valley cross-section was very differentiated everywhere. In the uplifted sections the florae of the early Vistulian warmings can occur on very high socles (e.g. 26 m in Kąty on the Dunajec river — Mamakowa *et al.* 1975). In the tributary valleys, being dissected with a delay (hanging mainly above the main valley) the Pleniglacial series with solifluction and deluvia descend below the present-day channels (Starkel 1965, Henkiel 1966, Alexandrowicz *et al.* 1991). Diversified position of organic horizons and different heights of the plains, especially at the mountain foreland, indicate channel oscillations in the early Vistulian, periods of prevailing accumulation or erosion. Because of that the accumulation of loesses, representing the whole Pleniglacial, was possible on the dissected fragments.

4.3. LOWER PLENIGLACIAL (74–58 ka BP)

A relatively short although a distinct cold phase, marked by dated loesses and by the under Interpleniglacial solifluction member (Starkel 1964 and Maruszczak 1980) appears in the valley bottoms as a distinct phase of river accumulation. Of this age are the occurring in low positions forestless florae in the valleys of Wisłoka (Środoń 1965), Wisłok (Jahn 1957) and Vistula near Cracow (over 43 ka BP — after Sokołowski and Wasylikowa 1984). The channel alluvia under the Vistula loess terrace have been dated in the Oświęcim Basin (Niedziałkowska and Szczepanek 1994) and in the Hebdów site on the Vistula river (TL date 69 ± 6 ka BP — Gębica 1994). Location of these alluvia at the height of 0–5 m above the present-day channel, for instance, on the Wisłoka river (Mamakowa and Starkel 1974) indicates that this is a separate fill with respect to the early Vistulian cover.

In the mountain interior gravels building the terraces covered with peats and with a younger solifluction in Brzeziny in Podhale (Birkenmajer and Środoń 1960) and in Jedlicze (Krysowska-Iwaszkiewicz and Wójcik 1990) are of this age. The height of the plains of this period did not exceed 10–11 m above the present-day channels. At the same time the older fragments of the terraces were being capped with slope covers (e.g. in Wadowice).

4.4. INTERPLENIGLACIAL (58–29 ka BP)

The period of a relative warming has been marked by intensification of fluvial activity. Formerly, only one warm episode had been discussed (the Aurignacian, Paudorf, cf. Środoń 1965, Starkel 1964), later on the 4 different had to be distinguished. The content of ^{18}O in the ice cores of Greenland have evidenced numerous abrupt changes in temperature. A few tens of dated sites are of this period.

Within the area of the Vistula fan in the Oświęcim Basin the older gravel cover is dissected, organic deposits dated from 36 to 25 ka BP (Niedziałkowska *et al.* 1985, Niedziałkowska and Szczepanek 1994) are found in troughs which do not exclude that a significant part of the fan alluvia represent the older period of the Interpleniglacial. In the Vistula valley near Cracow the peats dated 38 300 ± 3 600 BP indicate the dissection phase while the sands in Kryspinów with the date 32 400 ± 1 100 BP indicate aggradation period (Mamakowa and Rutkowski 1989). Downstream, the loess aggraded terrace covers *madas* with the Palaeolithic cultures (Kozłowski *et al.* 1970) and with the forest-tundra flora (Mamakowa and Środoń 1977). The radiocarbon date of ca 28 ka BP shows that the plain was in a range of floods in the Denekamp period. The overlaying alluvial deposits of the flood facies and the fans of tributaries, dated by TL at 51–37 ka BP (Gębica 1994), point to a significant activity of processes. Finally, erosion is evidenced by the overbank facies deposit laying on the Miocene socle under the loess in Opatowiec (31 200 ± 1 400, Jersak 1991). In the western part, on the older gravels (probably of the Interpleniglacial?), the Dunajec fan descending towards the Vistula river exposes peats covered with a thin layer of alluvia (39 100 ± 3 000 BP). The peat indicates abandonment of this part of the fan (Gębica 1994). In the eastern part the pine trunk from the Denekamp buried in gravels would point to progressing accumulation (Sokołowski 1981).

In Brzeźnica in the Wisłoka valley the older cover reaching 5 m above the river and in which the peat is dated at 36–48 BP, has been dissected at least to the level of the present-day channel (Mamakowa and Starkel 1974). In the younger fill the date over 28 ka BP would indicate large oscillations of the base in this period while in the upstream laying Podgrodzie

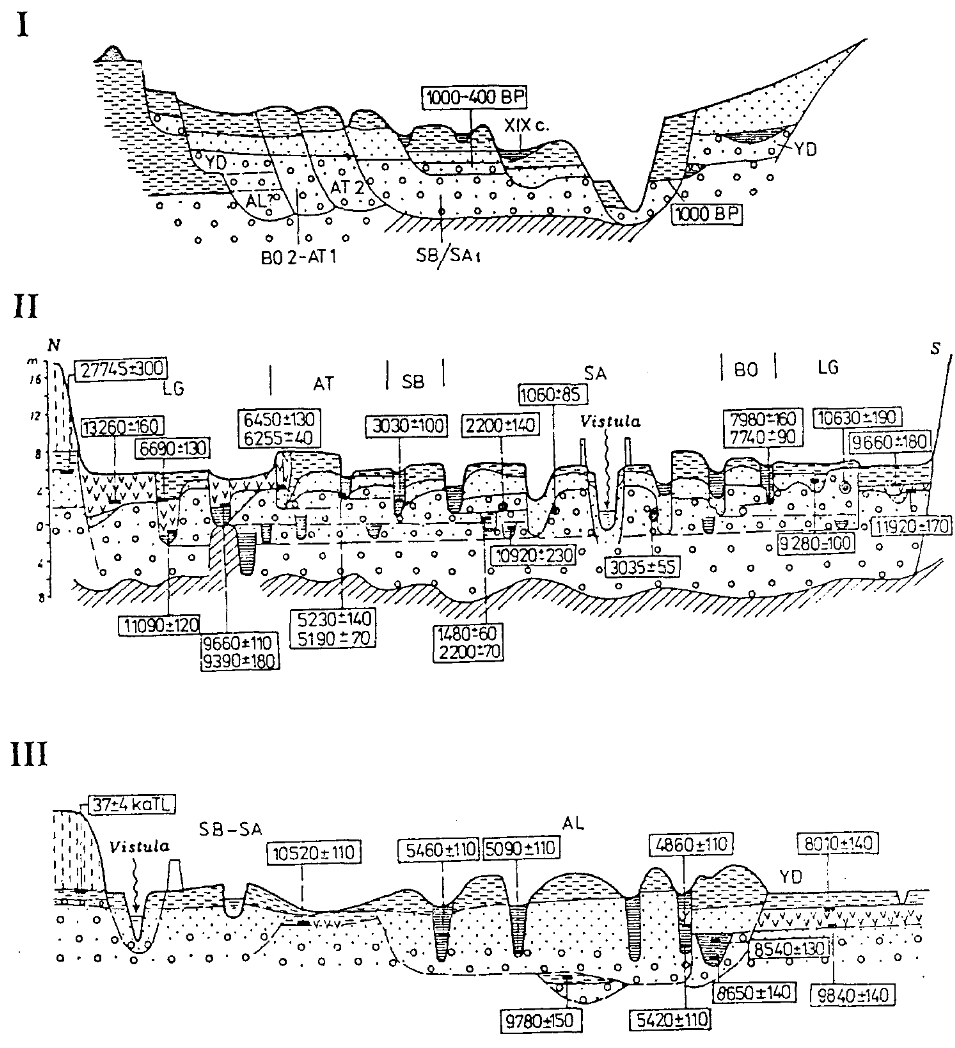
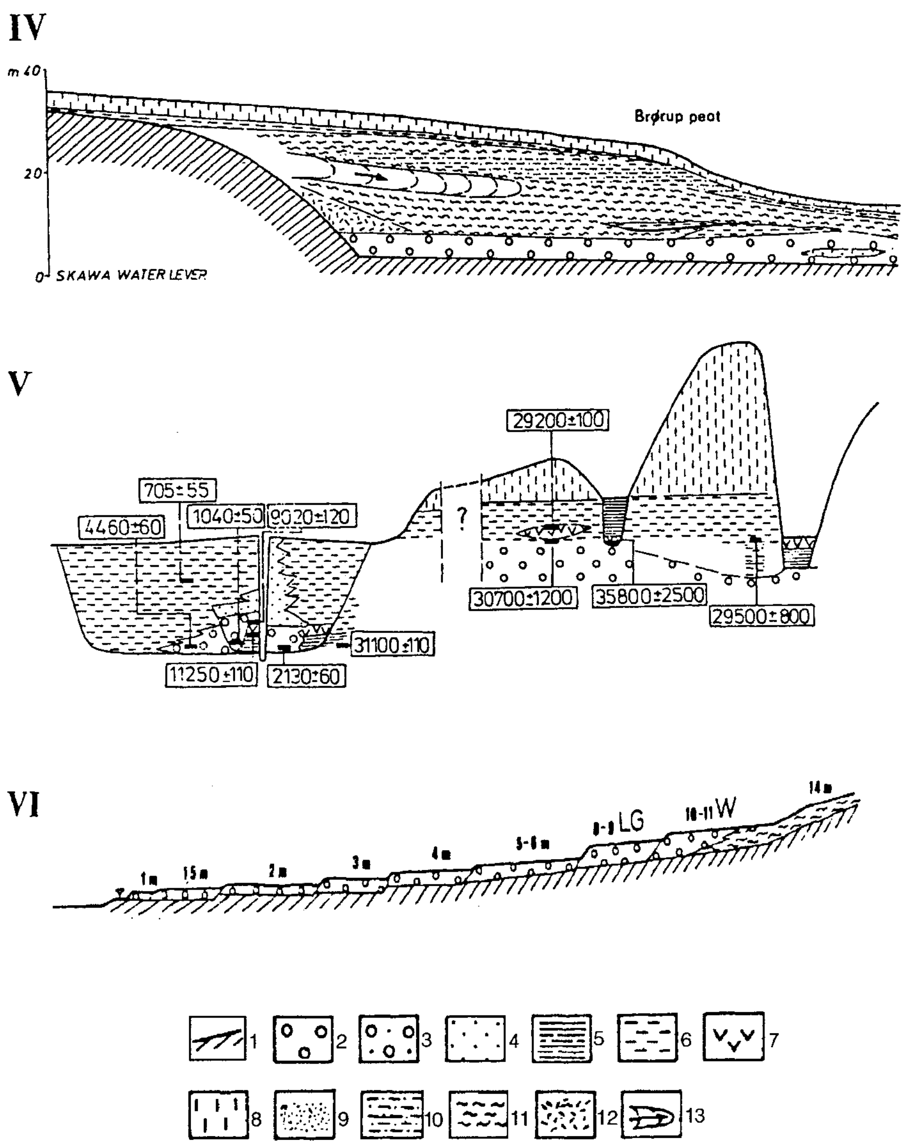


Fig. 5. Several well investigated valley cross-sections (partly simplified). I. Wisłoka river at the outlet from the Carpathians (after Starkel *et al.* 1982, changed in 1994). II. Vistula river downstream of Cracow (after Kalicki 1991). III. Vistula river at the Grobla forest — c. 20 km downstream of cross-section II (after Starkel *et al.* 1991, Gębica in print). IV. Early Vistulian burried floodplain in Wadowice, Skawa valley (after Sobolewska *et al.* 1964). V. Alluvial fan of the uppermost Vistula in the Oświęcim Basin (after Niedziałkowska *et al.* 1985, Niedziałkowska and Szczepanek 1994. VI. Erosional steps in upper Wisłok valley (after Zuchiewicz 1987) Signs: 1 — bedrock, 2 — gravels, 3 — gravels and sands, 4 — sands, 5 — paleochannel fills, 6 — overbank silts and clays, 7 — peat, 8 — loess, 9 — eolian sands, 10 — deluvial loams, 11 — solifluction loams (with debris), 12 — talus debris, 13 — landslide



Ryc. 5. Kilka dobrze rozpoznanych przekrojów dolin (częściowo uproszczonych). I. Wisłoka u wylotu z Karpat koło Dębicy (wg Starkla i in. 1982, zmienione w 1994). II. Wisłoka poniżej Krakowa (wg Kalickiego 1991). III. Wisła w rejonie Lasu Grobla — 20 km poniżej przekroju II (wg Starkla i in. 1991, Gębica w druku). IV. Wczesno-vistuliańska kopalna równina zalewowa Skawy w Wadowicach (wg Sobolewskiej i in. 1964). V. Stożek górnej Wisły w Kotlinie Oświęcimskiej (wg Niedziałkowskiej i Szczepanka 1994). VI. Stopnie erozyjne górnego Wisłoka (wg Zuchiewicza 1987)

Znaki: 1 — podłoże skalne, 2 — żwiry, 3 — żwiry z piaskami, 4 — piaski, 5 — wypełnienia paleokoryt, 6 — pozakorytowe pyły i iły, 7 — torf, 8 — less, 9 — piaski wydmowe, 10 — gliny deluwialne, 11 — gliny soliflukcyjne z rumoszem, 12 — usypiska, 13 — osuwisko the date from the series of alluvia with colluvia from the level 1.5 m above the river is 33 350 ± 750 BP (Starkel 1988). The depth of the Interpleniglacial dissection in the Vistula valley downstream of the Wisłoka mouth can be inferred from the piece of wood (dated at 40 700 ± 200 BP) originating from the trough descending 10–15 m below the channel level (Mycielska-Dowgiałło 1977). This is probably related to hanging of the young Quaternary Vistula valley above the deeper and older San valley (Pożaryski *et al.* 1994). In the Wisłoka valley, in the Subcarpathian Trough the Interpleniglacial peats have been found in the river channel (date 40 ka BP) — the channels of this period occur below (Starkel 1988a).

In the San valley near Jarosław the loess mantle covers the terrace with the typical interstadial soil (Jersak *et al.* 1992).

In the Carpathians proper the sites with florae dating the interpleniglacial warmings are numerous. In Dobra and in Myślenice (Klimaszewski 1958, Środoń 1968, Starkel 1969) they lay on the alluvia under the younger solifluction, at the level similar to the present-day channel which would indicate intensive dissection in this period. Near Jasło, in the 10 m high terrace with a socle, the interpleniglacial peat rests in an erosional channel (35 500 ± 1 500 BP, Alexandrowicz *et al.* 1985). Analogously, the covered with solifluction peats in Brzeziny and Jedlicze mentioned above, point to dissection of the older cover.

The interpleniglacial period, i.e. the period of climate oscillations, permafrost recession and intensified fluvial activity revealed likely in a few episodes of dissections and fills in the Carpathian valleys. Nowadays, however, these are difficult to identify and only in Brzeźnica on the Wisłoka river two series are noticeable (Fig. 6).

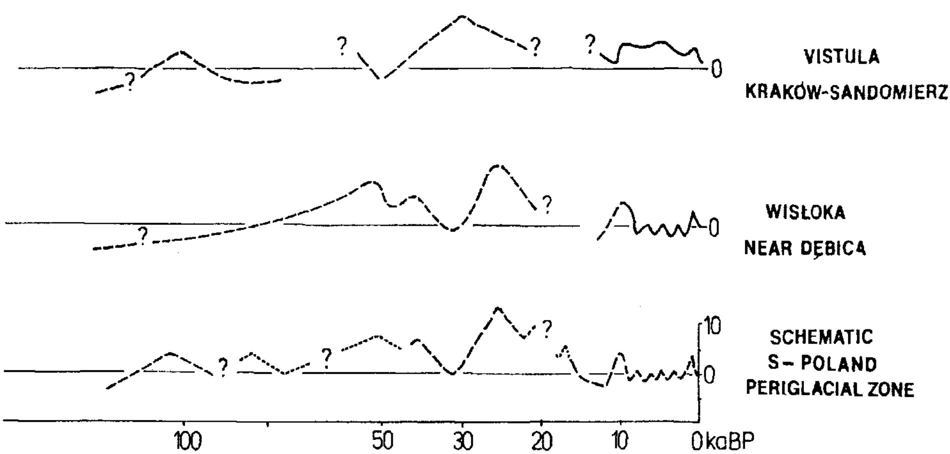


Fig. 6. Fluctuations of the vertical position of the river channels during the Vistulian and Holocene, based on records collected by various authors (after Starkel 1994b)

Ryc. 6. Wahanie pionowe koryt rzecznych w vistulianie i holocenie, w oparciu o dane zebrane przez różnych autorów (wg Starkla 1994b)

4.5. THE YOUNGER PLENIGLACIAL (29–13 ka BP)

The maximum cooling and advance of the ice sheet has traditionally been accepted as a period of formation of the Vistulian terrace and the accompanying basal accumulation plains (Klimaszewski 1948, 1967, Starkel 1968, 1969). The increasing number of sites indicates, however, that the process is much more complicated (Starkel 1994b).

In mountain areas, especially in those with long slopes susceptible to solifluction and deluviation processes, the upper Pleniglacial accumulation results in formation of the plains raising 6–15 m above the channel levels. The alluvia dated at the Denekamp are capped with the intermingled fluvial and slope deposits known from: the Beskid Wyspowy Mts (Klimaszewski 1958, Starkel 1960b, 1969), the upper San and Strwiąż valleys (Henkiel 1966). This cap in a longitudinal profile of the valley smoothes the surface of the rock socle whose height varies from 2–8 m. In the areas being uplifted the cover can be even higher although the terrace with 30 m high socle in the Wisłok gorge (according to the opinion of Zuchiewicz 1987) can hardly be included to it if in the closest vicinity the youngest solifluction deposits descend to the 12–15 m high terrace. A fan in a small basin in the Bieszczady Mts which is divided by an organic layer with the forest-tundra vegetation, the latter dated at 16 950 ± 325 BP (Ralska-Jasiewiczowa 1980) is of the Pleniglacial age.

At the Carpathian margin besides the older fragments covered with loess younger elements are registered as well. At the outlet of the Biała river in Kaniów the organic deposits of the Denekamp are covered with the 6 m thick sandy-silty deposits with the date 27 470 ± 800 BP at the lower face (Gilot *et al.* 1982). The fan of the Vistula river proper at the foreland of the Beskid Śląski has been dissected if loess sedimentation (Niedziałkowska and Szczepanek 1994) started above the level dated at 29 200 ± 100 BP. In Cracow, the Prądnik fan, uncovered with loess (Mamakowa and Środoń 1977), and formerly considered as older than Vistulian (Klimaszewski 1952) due to periglacial structures, is probably of this age. In the neighbouring Dłubnia valley, the 3 m thick cover of alluvia has been dissected which facilitated accumulation of loess from 23 900 ± 850 BP (Alexandrowicz 1991). The young pleniglacial fans of the Raba and Dunajec rivers with dunes at the top submerge under the Holocene alluvia of the Vistula river (Gębica 1994, Sokołowski 1987) evidencing the dissection prior to the end of the Pleniglacial.

In the Wisłoka valley, at the mountain foreland the 15 m high terrace in Brzeźnica is built of the overbank, rhythmically laminated sands and silts. The Dryas flora in the middle of the terrace height has been dated at 28 500 ± 430 BP (Starkel — in: Alexandrowicz *et al.* 1981). The lower plain with the traces of braided channels (known from other valleys) is lacking the overbank cover but organic inserts have been dated at 21 300 ± 1 200 BP. In Podgrodzie M. Geyh dated the wood in the level 2.5 m above the channel as 26 980 ± 345 BP and peaty silts laying 1 m above as 22 450 ± 340 BP (Mamakowa and Starkel 1977). At the similar level upstream of Pilzno Pazdur (1985) has dated organic deposits at 24–25 ka BP. The simultaneous occurrence of outliers built of silts with the Dryas flora in the 6–8 m high terrace (Klimaszewski 1948) provides evidence of dissection of this cover at the decline of the Pleniglacial.

A common occurrence of dunes on the sandy terrace in the lower San valley (Buraczyński and Wojtanowicz 1966) also indicates the dissection before the late Vistulian. In the San valley Klimek (1992) actually discovered the troughs, descending below the present-day channel, which had been filled from 15 ka BP.

Irregular aggradation and later dissections suggest similar evolution as in the belt of Uplands where a significant aggradation has also been registered. The latter in the gap reach of the Vistula river is described by Pożaryski (1955). In the Wieprz valley, consisting of narrowed and broaden sections, aggradation reached, for instance, to c. 20 m above the river level in Latyczów at c. 25 ka BP, and then dissection took place (Harasimiuk 1991). Downstream, near Tarzymiechy, the 15 m high terrace is built of silts with the date 19 320 ± 320 BP at the lower face (Jersak *et al.* 1992). In the Silesian Upland, in the Sztoła valley (the tributary to the Przemsza river) the organic deposits on the dissected surface have been dated at 26 700 ± 600 BP (Jersak and Sendobry 1991). Thus, depending on a nature of a valley section, lateral supply and presence of permafrost there were conditions suitable for significant aggradation also during the maximum cooling.

4.6. LATE VISTULIAN (13–10 ka BP)

The period of the late Vistulian was traditionally presumed the period of erosion and dissection of the Pleniglacial cover. However, these processes started earlier as it is known nowadays. In the Nowy Targ Basin the terraces — 12–15 m high fans were dissected before the Bölling, when peat started to form on the erosional terrace (Klimaszewski 1967).

In the valleys of Jasiołka and San rivers filling of the deep abandoned channels with lacustrine chalks or peat started from the Allerød (Wójcik 1987; Ralska-Jasiewiczowa and Starkel 1975). An increased supply in the Younger Dryas has been marked by the horizons of the flood deposits. Likely of this period are the alluvial fans imposed on the solifluction plains at the foot of the ridges in the Beskid Wyspowy Mts (Starkel 1960b).

In the 1950s in the Carpathians foreland, on the Wisłoka valley the author stated buried deposits with flora of the forest-tundra or of the open boreal forest, which without dating were preliminarily related to the Late Glacial (Starkel 1960a). The sediments of the Younger Dryas which were ^{14}C dated found later 4–6 m above the channel level, deposited on the erosional plain caused the author to reject the former concept and to assume a shallower, late-glacial dissection (Starkel 1977).

More recent studies of the Vistula valley near Cracow (Kalicki and Starkel 1987; Kalicki 1991, Starkel *et al.* 1991) proved that the Allerød troughs and older ones were deep, that was the period of river network transformation; the oldest meanders have been cut off at the beginning of the Allerød or at its decline (Szumański 1983, Rutkowski 1987, Kalicki 1991, Klimek 1992).

In the period of the Younger Dryas there was a significant aggradation with a return to a braiding tendency. In the Bolling and Allerød the peaty, low located wide plains at the Raba mouth (Gębica 1994) and in smaller valleys (Nalepka 1991) were also alluviated in the Younger Dryas. Downstream of the Wisłoka outlet to the Vistula river there extends the parallel depression with the traces of multi-branch channels. One of this branches has the Allerød fill — this is likely an older plain of the Wisłoka river (Mycielska-Dowgiałło 1977).

4.7. HOLOCENE (10–0 ka BP)

The Holocene evolution of the valleys in the area of the Carpathian Upland and the Forecarpathian Basins is currently best although non-uniformly studied.

Findings of sediments with tree trunks and with forest florae (Friedberg 1903, Łomnicki 1895–1903) as well as of the sediments with the Dryas florae (Klimaszewski 1948) gave raise to various interpretations of an origin and age of the plains in the valley bottoms. In the 1950s the fill of a several series of the meandering river deposits at the outlets of the Wisłoka, Wisłok and San rivers (Starkel 1960a) from the Carpathians was documented by singular analyses of pollen and macro-remnants to "moister" periods of the Allerød, Atlantic and Subatlantic. A tendency to aggradation of *madas* was stated as well. Then, it has been evidenced that the phases of dissection and fills are related to the moist periods of more frequent floods, synchronous with advances of the Alpine glaciers (Ralska-Jasiewiczowa and Starkel 1975, Starkel 1977, 1983, Starkel — in: Alexandrowicz *et al.* 1981) per analogy to the Little Ice Age, straightening of the channel and formation of the lower floodplain (Klimek and Starkel 1974, Szumański 1977). In the period of total forestation these phases lead to deepening of the channels while from the Roman period — to aggradation. The further studies in the Vistula valley have confirmed the concept of climatic fills — the number of distinguished phases increased — the equivalents of all the Holocene moisturization known in Central Europe have been found (Kalicki 1991, Starkel 1991, 1994a). The phases are dated at: 8.5–7.5, 6.5–6.0, 5.2–4.8, 4.5–4.2, 3.2–2.8, 2.2–1.8 and 1.1–0.9 ka BP. Documentation of the phases has also been expanded due to findings of avulsions of the whole channel systems downstream of Cracow (Gębica and Starkel 1987, Gębica 1994) and due to identification of numerous black oaks (Krąpiec 1992).

Simultaneously, at the mountain foreland an accelerated accretion of *madas* was stated in the period starting from ca 3 ka BP (Klimek 1987), then in the late Roman period (Kalicki and Starkel 1987, Alexandrowicz 1988) and commonly in the Medieval (Radwański 1972, Starkel — in: Alexandrowicz *et al.* 1981, Niedziałkowska *et al.* 1985). In some valley sections these madas cover and mask the older fills and paleochannels. Yet, in the case of wider bottoms, the madas usually do not cover them totally. In the marginal zones the paleochannel relief or even the old soils are noticeable (Kalicki 1991).

The younger fills of the recent 200 years reach the thickness of 3–4 m as well (Klimek 1987). They fill up the zones of braided channels dissected after channelization (cf. Szumański 1977).

In the area of the Carpathians proper the number of dated sites is smaller although the valley bottoms are lined with channel alluvia with tree trunks covered with *madas*. In the Ropa valley near Szymbark, on the socle, at the lower face of the 5 m high terrace the organic layer dated at 2 675 ± 60 BP has been stated (Dauksza *et al.* 1982). Deforestation of various ages triggered accretion with *madas*. For example, in Bukowiec in the Bieszczady Mts which was colonized at the turn of the 15th century the beginning of *madas* accumulation was dated at 460 ± 85 BP (Starkel 1988).

In the being uplifted Beskidy Mts a larger number of terrace steps, unfortunately non-dated ones, accompany the channels deepening in rock. In the Dunajec gorge through the Beskid Sądecki Mts there have been stated 5 steps lower than the 12–14 m high Pleniglacial terrace with the 5 m socle (Froehlich *et al.* 1972). In the upper Wisłok and Jasiołka valleys the number of terrace steps is 5–7 (Zuchiewicz 1987). In Podhale the sections of the braided Białka river which are dissected have steps as well (Baumgart-Kotarba 1983).

5. THE REGULARITY OF THE YOUNG QUATERNARY EVOLUTION OF THE VALLEYS — THE ROLE OF CLIMATIC AND TECTONIC FACTORS

On the background of the tendency to deepening of valleys in mountains and to slight aggradation or stabilization at a foreland the magnitude of dissections and fills is best noticeable in the last Glacial-Interglacial cycle. Not all of these dissections and fills did manifest as separate steps. From the cold period not only the Pleniglacial series but also the early Vistulian and Younger Dryas ones form separate levels (Starkel 1977, 1994b; Jersak *et al.* 1992, Fig. 3, 6, 7).

On this background tendencies to aggradation or erosion, differentiated in longitudinal profiles of the valleys do show up. The Interglacial period, on which our knowledge is limited, favoured deepening as much in the mountains where the early Vistulian deposits rest on the socles (Środoń and Starkel 1961, Łanczont 1991) as in the mountain foreland where the base of the early Vistulian members descend below the present-day channels and lay on gravels filling the deep troughs in the Miocene clays (Laskowska-Wysoczańska 1971).

The younger loesses on the early Vistulian alluvia are the evidence of dissection at the foreland which has preceded accumulation in the older Pleniglacial. In the mountain interior progressing aggradation is observed, especially in the side valleys. The Interpleniglacial period is marked by general intensification of erosion and smaller supply from the overgrown slopes. This period in the mountains is represented by the deposits of the overbank facies. In the Carpathian foreland there are evidences of at least 2 separate fills (Starkel 1994b).

The younger Pleniglacial manifests in the mountains as progressing aggradation, especially in the side valleys, accompanied by significant solifluction (Starkel 1968) or by loess delluvia (Łanczont 1991). On the other hand, dissection of the alluvial cover at the mountain foreland together with climate aridization lead to capping with the youngest loess or to blowing out of sands (cf. Starkel 1994b). In the period of 15–13 ka BP the river bottoms descended a few meters below the present flood plain (Klimek 1992, Kalicki 1991). In the mountains dissection was delayed but in the low elevated Jasło–Sanok Depression it descended below the present-day channels (Wójcik 1987) while in the Nowy Targ Basin an erosional bench was formed before the Bolling (Klimaszewski 1961). If the late-glacial meandering rivers can be explained by advancement of forests and decrease in supply, then the earlier erosion can be attributed to limited denudation in a cold continental climate. Large aggradation in the zone of Uplands 25–15 ka BP and an abrupt dissection reaching down to 20 m at the decline of the Pleniglacial 15–13 ka BP (Jersak *et al.* 1992) are not confirmed. This aggradation was likely a local phenomenon, characteristic of sandy areas which could have been degraded under permafrost conditions (Jersak and Sendobry 1991).

A cool episode of the Younger Dryas is manifested in larger frequency of floods, in aggradation and in return to braided channels in some sections (Kalicki 1991, Starkel *et al.* 1991).

The Holocene is commonly characterized by a sequence of several dissections and fills (Starkel 1990). If several terrace steps and tendency to deepening (Starkel 1977, Zuchiewicz 1987) are observed in the upper reaches, then parallel fills building the segments of the alluvial plain (Starkel *et al.* 1982, Kalicki 1991) are observed in the Forecarpathian Basins. The tendency to aggradation which started from the Roman period intensifies from the 10th–11th centuries (Klimek and Starkel 1974) and changes to deepening with frequent floods from the 17th century onward and as a result of channelization from the mid 19th century.

The old scheme (Starkel 1960) of the prevailing accumulation in the mountain interior in the glacial and carrying away to the mountain foreland in the interglacial requires modification. The number and thicknesses of subsequent fills imply the lack of simple relations. Yet aggradation undoubtedly took place in the upper reaches and an erosional impulse appeared at latest. Simultaneously, in the deposition zone at the foreland the series

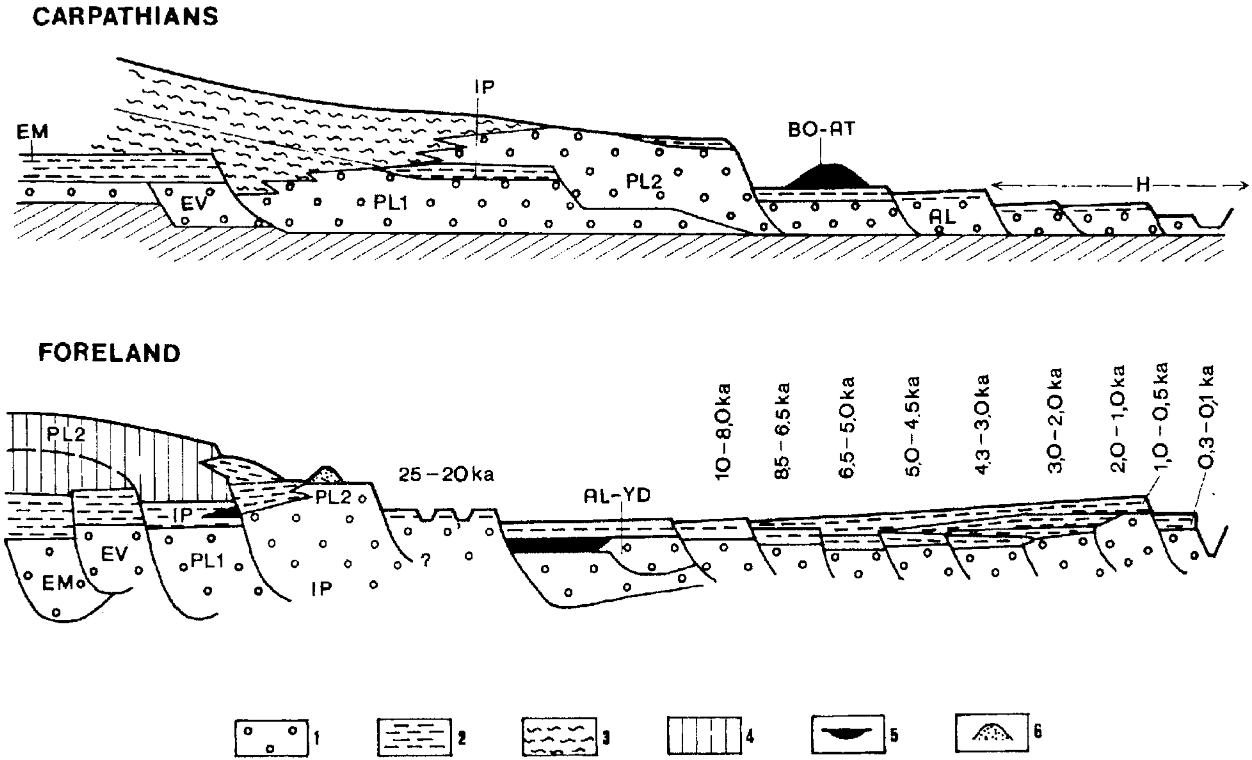


Fig. 7. Synthetic models of evolution of the valley floors in the Carpathians and Subcarpatian Basin, showing great number of fills (based on records being for disposal in 1994)

Signs: 1 — channel facies, 2 — overbank facies, 3 — slope sediments, 4 — loess, 5 — organic deposits, 6 — dunes

Ryc. 7. Syntetyczne modele ewolucji den dolinnych w Karpatach i Kotlinach Podkarpackich, ukazujące wielką ilość włożeń (oparte na danych będących do dyspozycji w 1994 roku)

Znaki: 1 — facja korytowa, 2 — facja pozakorytowa, 3 — osady stokowe, 4 — less, 5 — osady organiczne, 6 — wydmy of alluvia were deposited when the rivers were overloaded with the material supplied from the deforested slopes (periglacial periods, periods of deforestation and agricultural practices) as well as in the periods of more frequent floods, dissection and reworking of the alluvia. Therefore, many fills of the cold, warm as well as from the transitional periods are observed at the mountain margin.

The picture presented above is modified by local conditions, e.g. frequently the younger fans lay exceedingly on the older alluvia (Starkel — in: Alexandrowicz *et al.* 1981), as well as by tectonic factors. In the areas being uplifted, there is a permanent tendency to deepening in the narrowings of the valleys (and lack of terraces) interrupted by aggradation in the Pleniglacial (Starkel 1990) or in the wider parts of the valleys by the series of low terraces with the lower and lower rocky socles (Zuchiewicz 1987). In opposite, in the subsiding areas the alluvia of the Vistulian plains are buried under the younger deposits. That is characteristic of the Vistula fan (Niedziałkowska *et al.* 1985) and of the Orawa — Nowy Targ Basins (Baumgart-Kotarba 1983) and of the northern part of the Sandomierz Basin (the mouths of the Dunajec and San rivers — Starkel 1990).

Yet even in these sections the presence of terrace benches and separateness of the fills show that climatic changes are fundamental factors controlling the supply of the sediment load and frequency of floods. Climatic changes undergo faster than slow tectonic movements, finally shaping the separateness of the terrace steps.

The second modifying factor is the increase in river load transportation due to deforestation by man, facilitating wildening of the channels, accretion of the plains with *madas* and aggradation entering the mountain interior.

Department of Geomorphology and Hydrology
Institute of Geography and Spatial Organisation
Polish Academy of Sciences
31-018 Kraków, ul. Św. Jana 22, Poland

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STRESZCZENIE

Ł. Starkel

EWOLUCJA DOLIN KARPAT I KOTLIN PODKARPACKICH W VISTULIANIE I HOLOCENIE

Celem artykułu jest podsumowanie ewolucji poglądów i aktualnej wiedzy o młodoczwartorzędowej historii dolin Polskich Karpat i przedpola.

Na tle ogólnej tendencji do pogłębiania w górach i do słabej agradacji lub stabilizacji na przedpolu, najbardziej widoczna jest wielość rozcięć i włożeń w ostatnim cyklu glacjalno-interglacjalnym, z których nie wszystkie manifestują się jako oddzielne stopnie terasowe. Włożenia te są charakterystyczne zarówno dla piętra ciepłego i rzeki meandrowej, jak i dla okresu zimnego, w którym nie tylko pleniglacjalne serie, ale i wczesnovistuliańskie i młododriasowe wykazują odrębność (Ryc. 3, 5, 6, 7).

Na tym tle rysują się tendencje ku agradacji lub erozji, zróżnicowane w profilach podłużnych dolin. Okres interglacjału stwarzał warunki dla pogłębiania tak w górach, gdzie wczesnovistuliańskie osady leżą na cokołach, jak i na przedpolu, gdzie spągi ogniw wczesnovistuliańskich schodzą niżej dzisiejszych koryt.

Młodsze lessy na wczesnovistuliańskich aluwiach świadczą o rozcięciu na przedpolu, poprzedzającym akumulację w starszym pleniglacjale. W głębi gór obserwujemy kontynuację agradacji. Okres interpleniglacjału zaznaczył się ożywieniem erozji. Na przedpolu Karpat mamy co najmniej 2 oddzielne włożenia.

Młodszy pleniglacjał to w górach postępująca agradacja przy udziale soliflukcji lub deluwiów lessowych. Natomiast na przedpolu gór wraz z aridyzacją klimatu (od c. 25 ka BP) rozcinanie pokrywy aluwialnej doprowadziło do przykrycia najmłodszym lessem lub przewiania piasków. Tą wcześniejszą erozję można tłumaczyć ograniczoną denudacją w klimacie zimnym kontynentalnym. Nie znajduje potwierdzenia wielka agradacja opisana w strefie wyżyn w okresie 25–15 ka BP. W okresie 15–13 ka BP dna koryt rzek zeszły nawet poniżej poziomu współczesnych. W górach rozcinanie rozpoczęło się z opóźnieniem. Późnoglacjalną zmianę na rzeki meandrowe uzasadnia wkraczanie lasów i zamieranie dostawy.

Młodszy dryas zaznaczył się agradacją, a w niektórych odcinkach powrotem do koryt roztokowych.

Okres holocenu cechuje powszechna sekwencja kilku rozcięć i włożeń. O ile w górnych biegach obserwujemy kilka stopni terasowych i tendencję do pogłębiania, to w Kotlinach Podkarpackich równoległe włożenia, budujące kolejne segmenty równiny aluwialnej. Tendencja do agradacji znana od okresu rzymskiego, nasila się od X–XI stulecia.

Ilość i miąższość kolejnych włożeń mówi o braku prostych związków z wahaniami klimatu. Niewątpliwie w górnych biegach agradacja glacjalna była faktem, a impuls erozyjny doszedł najpóźniej. Równocześnie w strefie depozycji na przedpolu serie aluwiów składane były zarówno w czasie przeciążania rzek dostawą z odlesionych stoków (okresy peryglacjalne, wylesienia i uprawy), jak i w okresach częstszych wezbrań, rozcinania i przerabiania aluwiów.

Obraz ten jest modyfikowany przez lokalne warunki (np. młodsze stożki dopływów), przez czynniki tektoniczne i wylesianie.