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HOLOCENE ALLUVIATION IN SUBMONTANE DEPRESSIONS

ABSTRACT: STARKEL L., *Holocene alluviation in submontane depressions*. (IT ISSN 1724-4757, 2005).

The author describes the characteristic features of alluviation related to various types of depressions and tectonic tendencies in the submontane zones presenting the examples mainly from Himalayan foredeep, Carpathian foredeep, Hungarian Plain and Po Basin. He distinguishes active mountain fronts with active aggradation and mature relief of submontane depression dissected by younger valleys. Special attention is concentrated on the role of climatic fluctuations at the Pleistocene-Holocene transition and in the Holocene. During last two millennia it is observed a very distinct acceleration of deposition controlled by human activity, which in many cases turned the trend in the alluviation of submontane depressions.

KEY WORDS: Submontane depressions, Alluviation, Subsidence, Climatic fluctuations.

RIASSUNTO: STARKEL L., *L'alluvionamento olocenico nelle depressioni submontane*. (IT ISSN 1724-4757, 2005).

L'Autore illustra i lineamenti caratteristici dei processi di alluvionamento in relazione ai vari tipi di depressioni submontane e ai movimenti tettonici attraverso esempi principalmente tratti dai bacini sedimentari associati all'Himalaya, ai Carpazi, dalla Pianura Ungherese e dalla Pianura Padana. L'Autore distingue fronti montuosi attivi con attiva aggradazione e rilievi maturi delle depressioni submontane dissecati da valli più giovani. Una speciale attenzione è dedicata al ruolo delle fluttuazioni climatiche al passaggio Pleistocene-Olocene e nell'Olocene. Negli ultimi due mila anni è stata osservata una ben definita accelerazione della sedimentazione controllata dalla attività antropica che in molti casi ha modificato l'andamento del processo di alluvionamento nelle depressioni submontane.

TERMINI CHIAVE: Depressioni submontane, Alluvionamento, Subsidenza, Fluttuazioni Climatiche.

INTRODUCTION

The mechanism of aggradation in submontane depressions is on the whole fairly simple. Floods remove great volumes of solid material from steep slopes and high-gradient channels and deposit it further downstream in low-gra-

dient reaches and flat valley floors. It can be observed that the particle size of the sediment becomes markedly smaller as the gradient levels off and the river discharge is slowed down by infiltration of water in the alluvial deposits.

Over very long time sequences fluvial accumulation and erosion are conditioned by two principal factors, tectonic movements and climatic variations. The orogenic process is responsible both for the uplift of fold-mountain masses, especially young ranges like the Alps, and the complementary subsidence of the foreland. The resultant submontane depressions are characterized by a continual lowering of their base-levels and a steady decrease in the value of their river gradients.

The effect of the climatic factor on the sediment load was especially prominent in the Quaternary. The lowering of glacial and periglacial vertical belts in the mountains of the temperate zone increased the intensity of deposition in the river valleys and mountain forelands, especially during the last cold stages. Later the expansion of forest vegetation coincided with the dissection of Quaternary cold-stage deposits and gradual infilling of new alluvia during the Holocene phases of higher flood frequency and increased human activity. High subsidence and high sediment supply from the mountains resulted in a continuous building-up of the submontane plain, as e.g. in some parts of the Hungarian Plain, the Po Valley and other depressions (Somogyi, 1975; Pecsì, 1977; Castiglioni, 2001).

SHAPES OF SUBMONTANE DEPRESSIONS

Submontane depressions vary in size and shape. Generally the size of depressions in the Alpine system belt remains proportionate to the adjacent mountain chains. The process of aggradation in the depression is conditioned primarily by the direction of water courses and sediment supply. The configuration of the terrain is another factor, i.e. the submontane basin may be locked between several mountain ranges or the mountains rise up only on one side of the basin axis (fig. 1).

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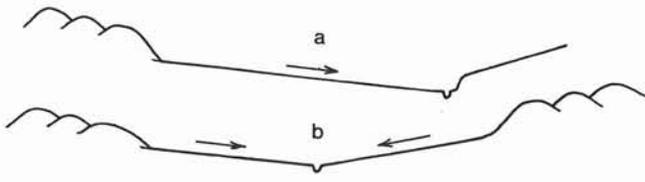


FIG. 1 - Two types of submontane depression: a) in the foredeep in front of rising mountains; b) tectonic depression locked in by mountain ranges.

Among the basins wedged between two or more mountain chains are the Po Plain and the north-eastern part of the Hungarian Basin. On its northern and western side the Po Plain is hemmed in by the Alps, which during the Pleistocene went through repeated glaciation phases, and on the southern side by the Apenines. Intensive supply of river-borne deposits by tributaries descending from both mountain ranges has resulted in the creation of two piedmont belts of alluvial fans and, in the axis of the subsiding depression at the eastern end, the raising of the river channel and the formation of a system of levees alongside the aggrading Po (Braga & Gervasoni, 1989; Castiglioni & *alii*, 1997).

In the north-eastern part of the Hungarian Basin, locked up by various mountain groups of the Carpathians, there emerged a system of coalescing alluvial fans which are drained by the main Tisza river. The Tisza underwent notable channel shifts during the Holocene (Borsy, 1995). Large areas in this part of the Hungarian Basin form a floodplain which, until regulation works began in the 18th century, had been for the most time under water (Neppel, & *alii*, 1999).

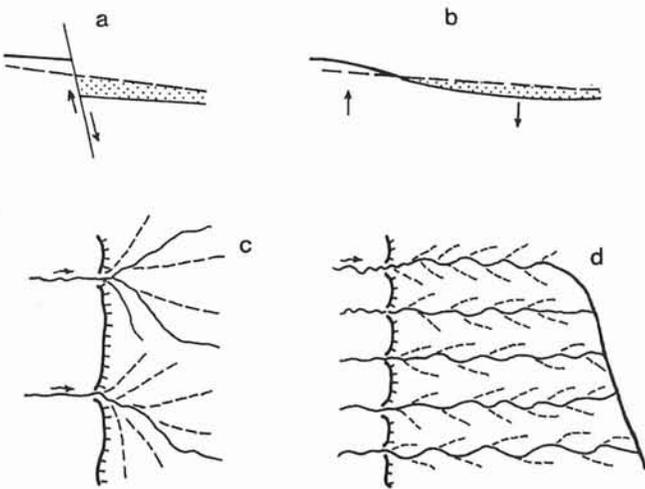


FIG. 2 - Various types of mountain front margins: a) faultline dividing rising mountains and subsiding depressions; b) gentle transition between mountains and depression; c) mountain front dissected by few large valleys with megafans; d) mountain front dissected by numerous parallel valleys with piedmont belt.

Asymmetric submontane depressions can be found mainly in typical foredeeps. This type of depression is fed by heavy sediment supply from the adjacent mountain slopes on one side, while the opposite side is usually marked by a low margin of the older platform. The main river which collects the water from extensive piedmont fans tends to shift towards the latter of the two rims. The extensive sub-Himalayan foredeep of the Ganga-Brahmaputra rivers (Goswami, 1998; Jain & Sinha, 2003), the Valachian Plain drained by the lower Danube and the Sandomierz Basin drained by the upper Vistula (Pecsi, 1977) are representative of the asymmetric submontane depression.

MOUNTAIN FRONT MARGINS

The character of the mountain front facing the depression can vary from a sharp steep escarpment to a gentle, low-angle margin extending over a broad foothill zone (fig. 2).

A steep mountain scarp usually marks a distinct tectonic faultline or an overthrust. The fact that the ground is simultaneously pushed up and drawn down on either side of the faultline (fig. 2a) results in a very clear contrast between the zone of erosion and the zone of aggradation (Joshi & *alii*, 1989). This is the case at the edge of the Eastern Himalaya (Starkel & Basu, 2000), the southern scarp of the Meghalaya Plateau (Starkel & Singh, 2004), the northern edge of San Bernardino Mts. with St Andreas fault (Crowell, 1979) and, in the Carpathians, at the northern slope of the Silesian Beskid (Starkel, 1969) and the southern rim of Vihorlat ridge (Kvitkovič & Vanko, 1972). This is also the case of the eastern part of Southern Alps (Veneto and Friuli area). A typical feature of such mountain margins is the direct contact of mountain front with flat alluvial plains.

A gentle transition from the mountains to submontane plains may be connected with a gradual tectonic activation of the upper arch of a folded mountain range, leading to the emergence of new anticlinal structures and a gradual outward shift of submontane alluvial fans (fig. 3). The Siwalik zone at the edge of the Western Himalaya is a classic example of such a margin (Kumar & *alii*, 2003; Starkel, 1978).

A slightly different gradual transition can be observed along mountain fronts with mature relief in conditions of reduced tectonic activity. This type of margin is best illustrated by the foothill zone of the Polish Carpathians, where the roots of narrow alluvial fans have crept tens of kilometres up the flat valley floors into the mountains.

Another important factor in the formation of alluvial deposits in submontane depressions is the density of mountain front dissection by a system of large river valleys (fig. 2 c-d). When the mountain massif is split by few large river valleys, vast megafans reaching the size of 100x100 km are produced at points where the rivers enter the plain. Megafans whose growth has been helped by frequent channel avulsions are especially well represented at the margin of the Himalayas (Gohain & Parkash, 1990; Jain & Sinha,

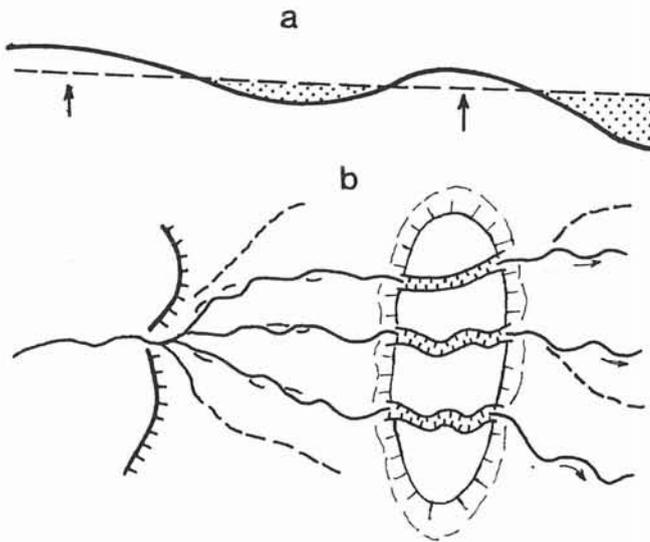


FIG. 3 - Expansion of orogenic zone with anticline rising from the submontane depression (example from the rim of the Eastern Caucasus Mts).

2003). The terrain walled in by neighbouring fan deposits develops into an interfan depression with back swamps. Alternatively, when the mountain front is dissected by a larger number of ravines, the rivers that run out of them deposit parallel narrow fans that tend to coalesce into a broad piedmont belt. This type of relief is common in the northern foreland of the Apennines (Castiglioni & alii, 1997), the western part of the Ganga catchment (Jain & Sinha, 2003), and in the foreland of the Bhutanese Himalaya in the Brahmaputra catchment (Starkel & Sarkar, 2002).

TYPES OF VALLEY FLOOR RELIEF IN THE DEPRESSIONS

As it enters a submontane depression the mountain river slows down and more or less rapidly loses its capacity to transport its load. At the constriction of the valley where it debouches the river usually forms a braided network of channels, which are capable of transporting coarse material of all sizes. It can even transport boulders, delivered by occasional debris flows or hyperconcentrated flows. In the middle reaches channel avulsions are still frequent, while its load is dominated by medium- and fine-grained sandy fractions. In its lowest reaches, where the river begins to meander it is capable of transporting only the finest load (Gohain & Parkash, 1990; Jain & Sinha, 2003; Shuckla & Bohra, 2003). The lower portions of alluvial fans can produce their own meandering rivers fed by groundwater (Sinha & Friend, 1994).

This typology of alluvial fans is best exemplified by the formations of the Himalayan foreland (fig. 4). Unfortunately, elsewhere the picture gets blurred as both the complicated Quaternary history of submontane depressions

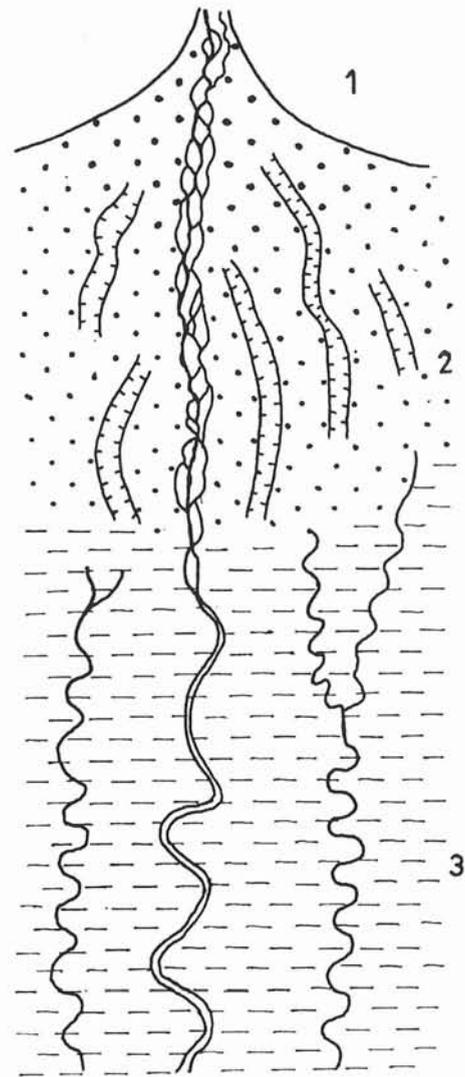


FIG. 4 - Model of alluvial fan in the Himalayan foreland (crossed by tributaries of the Brahmaputra): 1) steep root section; 2) gentle middle section with braided pattern and palaeochannels; 3) flat lower section with meandering river channel and new secondary rivers.

and the peculiarities of their internal tectonics need to be taken into account.

The block tectonics characteristic of the foredeep is not only reflected in the pattern of river channels or in the elevation of fragments of higher terraces above the floodplain (as the Nyirseg Plain in the eastern part of the Hungarian Basin) (Borsy & Felegyhazi, 1983), but also in the accelerating subsidence which sometimes occurs right in front of a mountain being lifted up (Vanko & Kvitkovič, 1980). Such differentiated subsidence caused the avulsion of the Tisza and Szamos rivers to the far NE corner of the Hungarian Basin (fig. 5). As a result the present-day Tisza collects the waters of its successive tributaries as it flows along the margin of the depression first westwards and then southwards. The operations of complicated tectonic

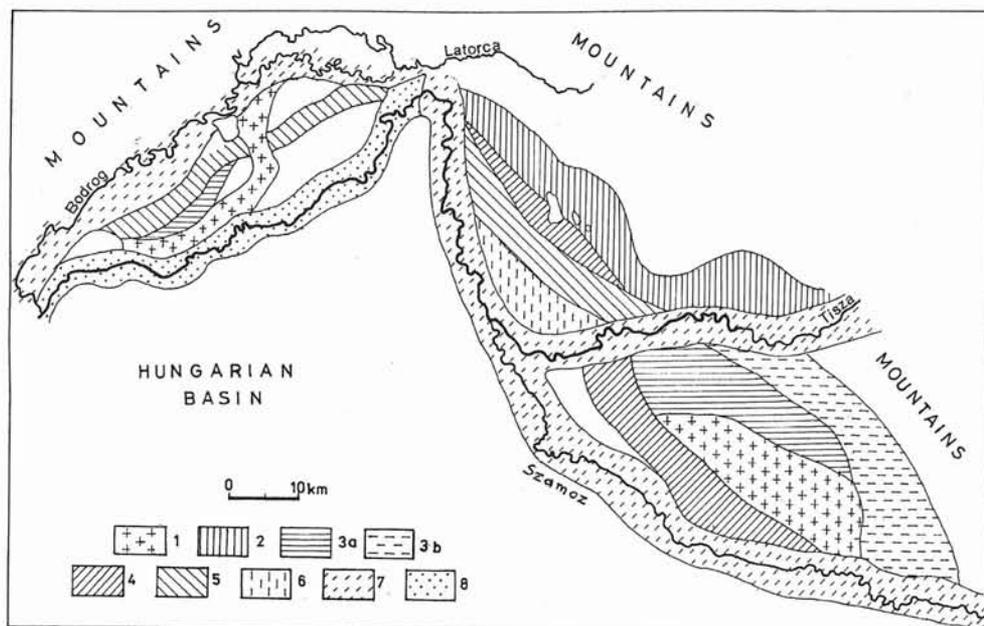


FIG. 5 - Changing routes of the Tisza in the NE corner of the Hungarian Plain during last Pleniglacial and Holocene (based on Borsy, 1995). Age of channel belts: 1. upper Pleniglacial; 2. older than Boreal; 3a. Lateglacial; 3b. Preboreal; 4. Boreal; 5. Boreal+Atlantic; 6. Atlantic; 7. Atlantic+Subboreal; 8. Subatlantic.

forces resulting in a differentiated subsidence pattern was also identified below the Po Plain (Castiglioni & alii, 1997).

Submontane depressions may be occupied by some older, inherited depositional forms, which have been cut through by present-day valley floors. In such basins the development of younger alluvial forms depends on the location of the reach and the width of the valley (fig. 6). This type of floor relief occurs in the Sandomierz Basin drained by the upper Vistula (Gębica, 1995; Kalicki, 1991; Starkel & alii, 1982; Starkel & alii, 1996). A characteristic feature of the rivers in that basin is the presence of erosional-depositional terrace steps embedded both at the constrictions of the valleys at the mountain front and in the narrow river sections cut into the alluvial plain from the last cold stage. Although bursts of extreme flooding can be correlated with a series of changes in the fill profile and in the system of cut-off meanders, the overall floodplain area was clearly shrinking. During the whole of the Holocene

seven to eight such phases were registered (Starkel, 1983; Kalicki, 1991). However, the increase of sediment load over the last 2,000 years has changed this tendency to aggradation.

A similar trend to the incision and narrowing of the active alluvial plain during the Holocene is well documented at the northern foreland of the Alps in the Danube basin (Brunnacker, 1960; Schreiber, 1985), where the terrace system is rooted in glacial-fluvial fans. Its typical formations were described by C. Troll (1957), who named them *Trompetentäler*.

The widenings of river valleys in the Sandomierz Basin (just as in parts of the Po Plain or the Hungarian Plain) leave sufficient room for avulsions of the river channel at reaches many kilometers long (fig. 7). They are indeed common in reaches with very low gradient as the meandering river builds up levees, which it occasionally overtops or breaches causing widespread flooding.

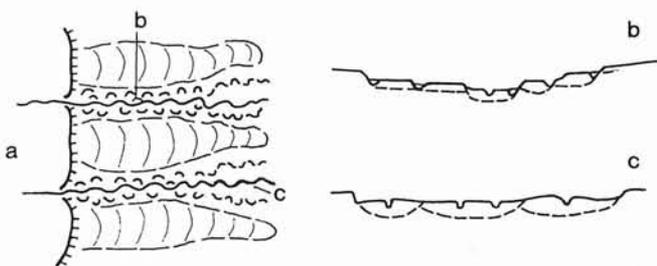
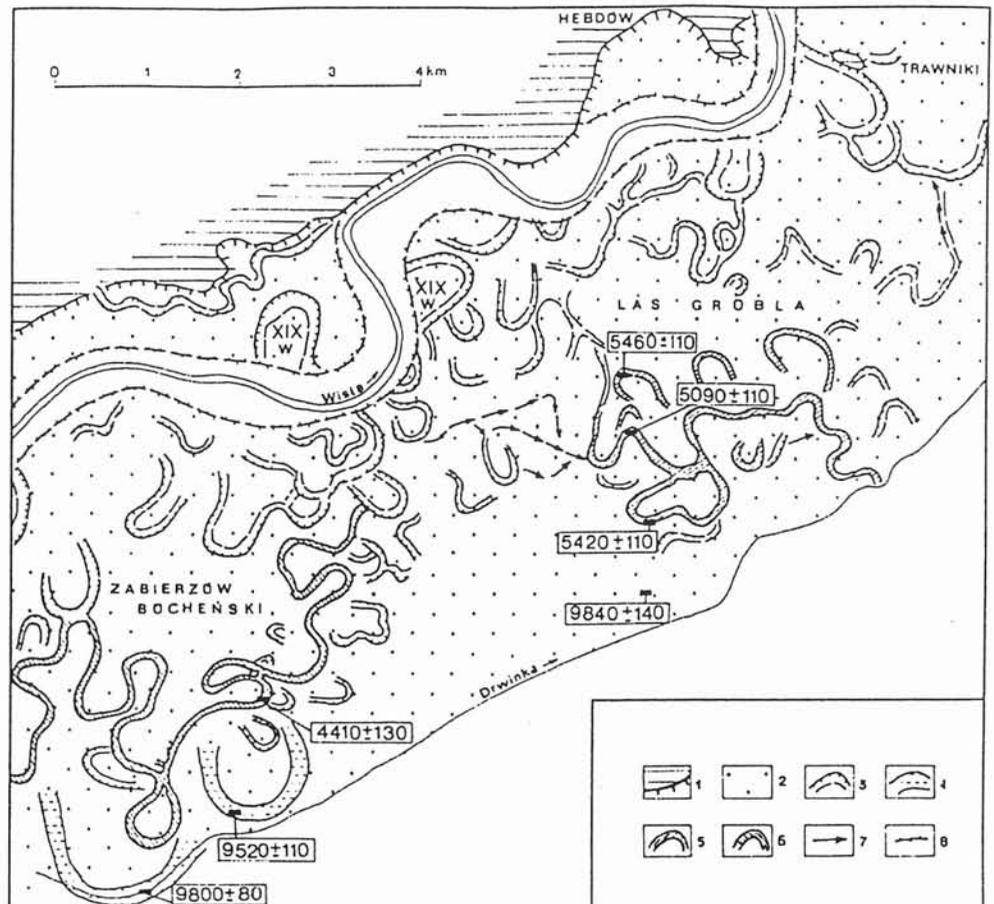


FIG. 6 - Mature relief of submontane depression and types of incised valley floors: a) mountain front and depression with valley floors and interfluvial; b) transect of valley reach with tendency to narrowing in the Holocene; c) transect of wide valley reach with tendency to channel avulsions in the Holocene.

THE LAST GLACIAL-HOLOCENE CYCLE IN SUBMONTANE DEPRESSIONS

The role of climatic change in the aggradation and valley evolution of submontane depressions is undisputed, though its impact in specific geographic locations may be subject to considerable modification due to local tectonic tendencies. In tectonically active areas such as the Hungarian Basin and the Po Valley the Quaternary deposition contains alternate beds representing cold stages and interglacials (Nador & alii, 2003; Vittori & Ventura, 1995). This aggradation is continued in the Holocene, as it can be observed in the west Slovakian corner of the Hungarian Plain (Kvitkovič, 1993).

FIG. 7 - Paleochannels of the Vistula in the western part of Sandomierz Basin (after Starkel & alii, 1991; Gębica, 1995; Kalicki & alii, 1996 and others): 1 - Pleniglacial terrace with loess cover; 2 - Holocene floodplain; 3 - paleochannels (various); 4 - paleochannels from lateglacial - early Holocene transition; 5 - paleochannels buried before 5.000 BP; 6 - paleochannels buried about 4.400 BP; 7 - crevasses; 8 - dykes.

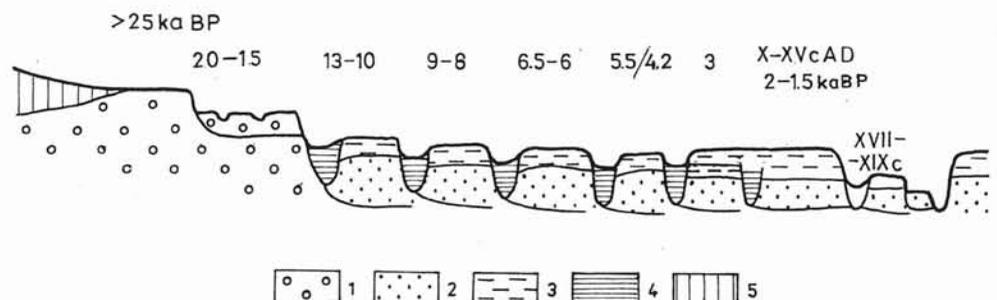


The prevailing sequence of the latest climatic cycle starts in the European submontane depression with the extensive periglacial or glaci-fluvial fans (at the Alpine rim) with braided paleochannels. This land margin was later dissected and filled in by Late-glacial systems with large paleomeanders and by several younger Holocene fills with smaller paleo-meanders. Those fills can be correlated with distinct phases of increased fluvial activity, which, in the Carpathian foreland, are dated at 8.5-8.0, 6.5-6.0, 5.4-4.9, 4.5-4.1, 3.3-3.0, 2.8-2.7, 14C ka BP and 1-2 c., 5th-6th c., 10th-11th c. and 16th-19th c. A.D (fig. 8). These phases

correspond in turn to the advances of Alpine glaciers (Kalicki, 1991; Starkel & alii, 1996).

Several deviations from that model are connected with increased human activity during the late-Roman phase (1st-3rd c. AD) and the Middle Ages (10th-15th c.) when forest clearance and farming rather than climate change played the major role in the acceleration of the hydrological processes (Starkel, in print). The building-up of floodplains and fans in submontane depressions has become more common in the course of the last millennium (Veggiani, 1974; Braga & Gervasoni, 1989; Havlicek, 1983; Starkel &

FIG. 8 - Schematic transect of late Pleistocene-Holocene alluvial fills in the Sandomierz Basin (based on Starkel & alii, 1996): 1 - late Pleistocene channel facies; 2 - late Vistulian and Holocene channel facies; 3 - overbank facies; 4 - paleochannel fill facies; 5 - loess. Age of fills in radiocarbon ka BP.



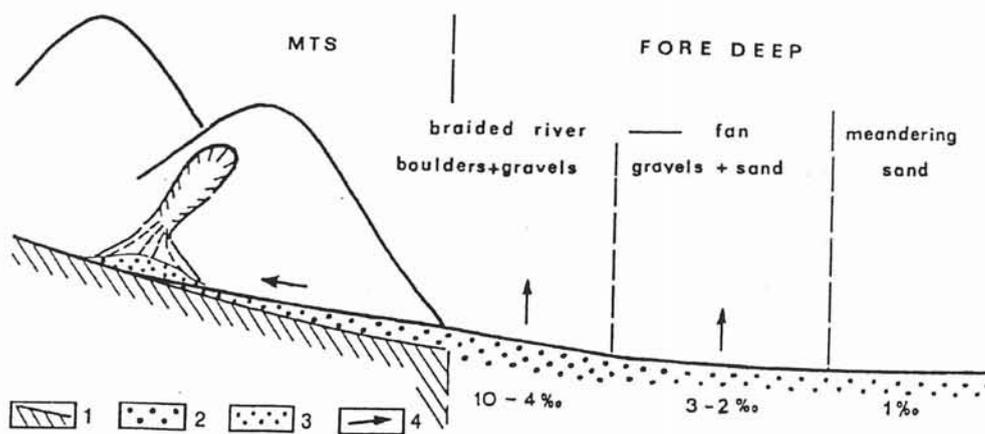


FIG. 9 - Model of longitudinal profile of alluvial fan from the margin of the Bhutanese Himalaya (after Starkel & Sarkar, 2002). 1 - bedrock; 2 - coarser alluvia; 3 - finer alluvia; 4 - trends of aggradation.

alii, 1996). The aggradation both in the channel and over-bank facies is frequently progressing upstream.

The effects of recent deforestation on the margins of the Himalaya, where the braided channels of alluvial fans are rising up to 2-3 cm in one year in conditions of frequent extreme floods, are now well documented (Starkel & Basu, 2000; Starkel & Sarkar, 2002). It has been noted that the roots of the fans are moving up the constrictions of the mountain valleys in spite of continuous tectonic uplift (fig. 9). This development is most conspicuous in the smaller deforested catchments at the foot of rising mountains.

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