Article

Edifice of fluvial terrace flights, stacks and rows

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Abstract: The paper is a kind of a small guide book through the textures and structures of river deposits in valleys. It presents principles of the flument systems with morphological river terraces and fluments (terrace bodies), different stages of the morphological terraces, structure of the flument, texture of terrace flights, terrace stacks and terrace rows. Special topics deal with flument overlaps and insight into the valley ground.

Keywords: river terrace; flument (terrace body), terrace flight; terrace row; flument stack; flument overlap; valley ground

1. Introduction

This paper points to frequent as well as rare problems that arise by constructing terrace flights, terrace rows and flument stacks. River terrace flights, stacks and rows are well known and described in details, e.g. [1–15]. The following explanations separate morphological river terraces and fluments as terrace bodies, highlight texture of terrace flights, terrace stacks and terrace rows and problems of flument overlap and of the study of the valley ground. In the later part of the paper selected examples besides the general explanations relate to the Upper Main region in south-eastern Germany.

2. Principles of flument systems
2.1 Flument and terrace

Concerning river deposits a distinction is drawn between the sedimentary body and its morphological terrace. The river deposit is called flument [14] (p. 135). As shown in Fig. 1, the flument consists of: basal lag layer, channel deposit, floodplain deposit and floodplain soil. The flument is topped morphologically by the river terrace that is a mere surface feature.

In case the flument rests upon the bedrock the contact between the flument and the bedrock is called pelma [15] (p. 70) (Fig. 2). The basal bedrock contact is the ground pelma, the lateral bedrock contact is the wall pelma.
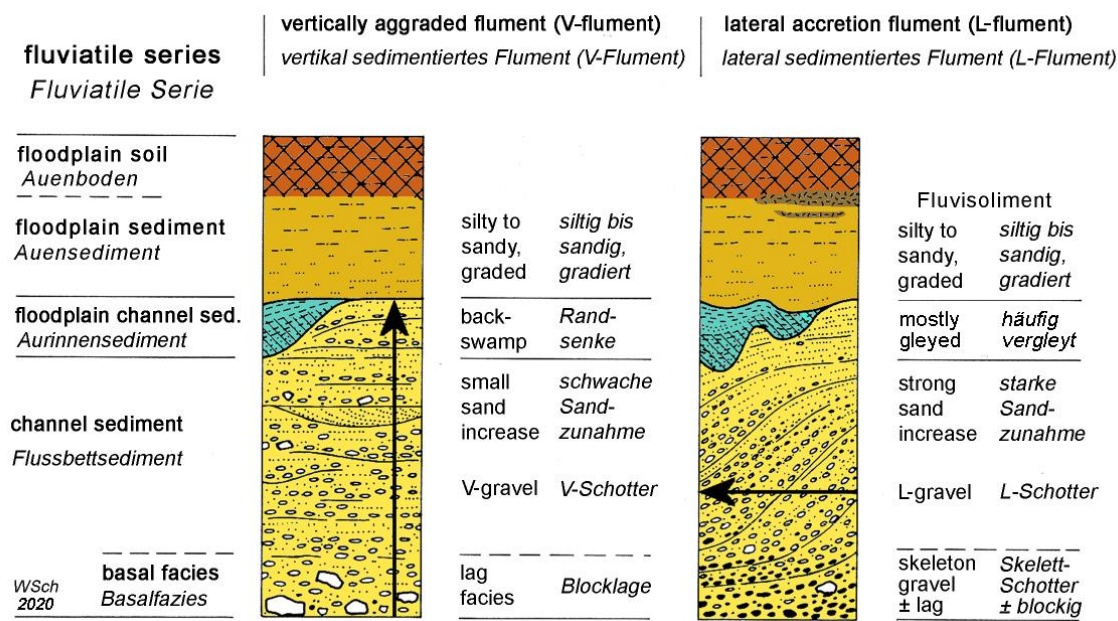
Figure 1. A complete flument is composed of all members of the fluviatile series. From [9] (p. 25, modified). The skeleton gravel is marked by black pebbles in all figures of this paper.

2.2 Types of fluments

The inner structure of the flument simplified shows two main sedimentary types, the vertical aggradation type and the lateral accretion type (Fig. 1). The first results from the braided river, the latter from the meandering river. A flument of the lateral accretion type is called L-flument (according to Lateral), that of the vertical aggradation type V-flument (according to Vertical) [9] (p. 25). The L-flument at its base is characterized by skeleton gravel (respectively open work gravel).
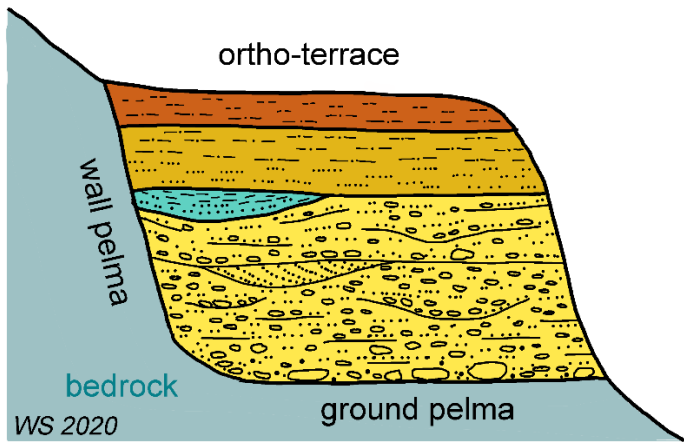

Figure 2. Ortho-terrace and pelma: A complete flument is bounded on top by the ortho-terrace, at the basal bedrock contact by the ground pelma, at the lateral bedrock contact by the wall pelma.

2.3 Stages of river terraces

The surface of a flument is called terrace. In case the flument reaches its mature stage or has already fulfilled its mature stage the topping terrace is called **ortho-terrace** (Fig. 2). The ortho-terrace is as old as the last river deposits upon the flument. Soil formation may continue upon the ortho-terrace.
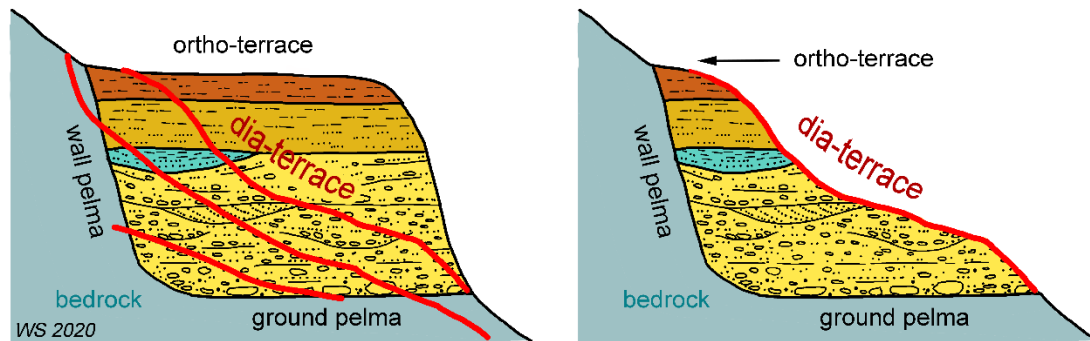

Figure 3. Dia-terrace: A complete flument diagonally cut (red lines) by the dia-terrace. Shown are three random stages of the dia-terrace leaving behind more or less volume of the previous flument.

Upon older fluments the ortho-terrace slowly gets eroded. The erosional surface still may appear as terrace, but is a plane that cuts the flument diagonally (Fig. 3). This terrace is younger than the ortho-terrace and becomes younger and younger through the time. It is called **dia-terrace** — from the diagonal erosional cut through the flument.

In Fig. 3 the dia-terrace shows different stages of erosion, drawn in red color. The upper stage allows to determine the position of the ortho-terrace by the terrace remnant preserved at the outer edge of the previous terrace. Also, all members of the flument are preserved. The middle stage leaves behind remnants of the floodplain edge channel. By this, experiences of floodplain thicknesses of the investigation area should allow to calculate the former level of the ortho-terrace. The lower stage can only indicate the terrace pelma. Compare 3.1.

If the erosion has reached the pelma leaving only a lag layer above the bedrock it is called **pelmi-terrace** (Fig. 4).
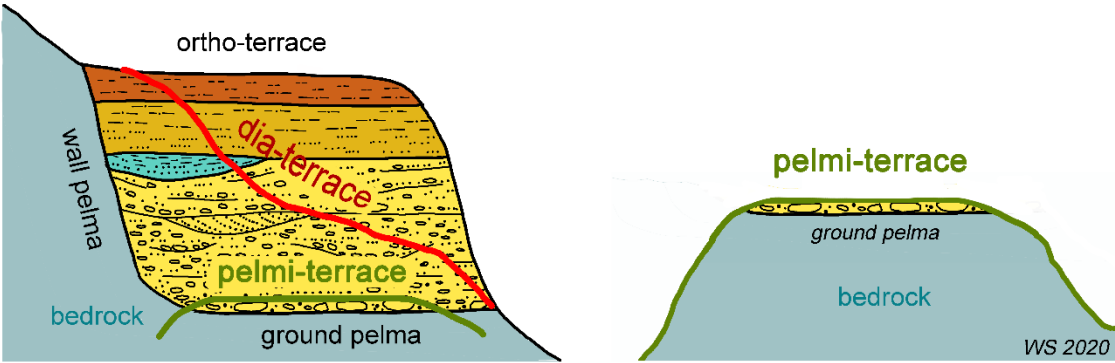
Figure 4. Pelmi-terrace: A complete flument eroded down (green line) to the basal facies leaving only the lag layer and the ground pelma (contact of the basal facies with the bedrock).

As a result, in an incised valley younger fluments can be followed and compared by the elevation of their ortho-terraces. Older fluments can be parallelized mostly by their pelma.

2.4 Flument flights respectively terrace flights

They are the result of rhythmical cut-and-fill processes of fluvial incision and fluvial deposition. The highest situated terrace of a flight is the oldest, the lowest is the youngest terrace. This is the normal expectation. However, it needs not to be so, as shown later. Examples for terrace/flument flights are given from the River Rhein (Fig. 5; compare also fine changes in [4] Fig. 4),Scheme and from the River Main (Fig. 6).
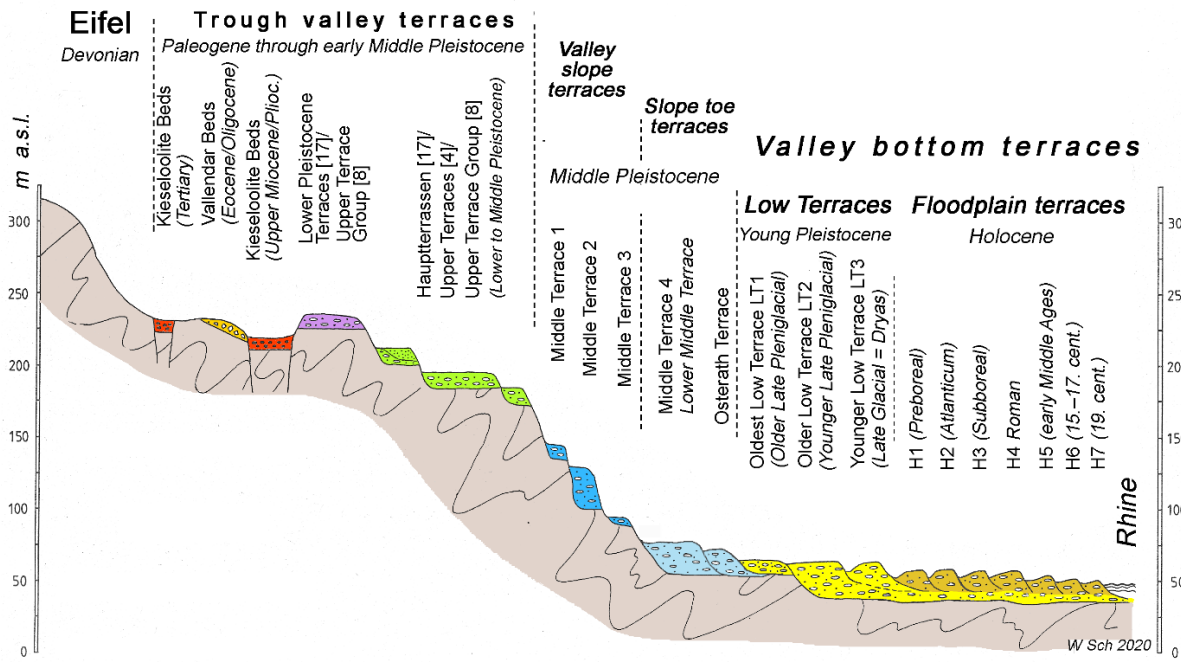

Figure 5. Flument/terrace flight of the River Rhein [17] (modified).

2.5 Flument stacks

Flument stacks are the result of superposition of fluments. Herein, in contrast to the terrace flight, the lowest flument is the oldest, the highest flument is the youngest (Fig. 7 and Main Formation in Fig. 6).

Remarkable is the fact that several fluments tends to overlap laterally owing to the upward widening of the preformed valley that is used by the stack formation.

The fluvial stack of the River Main (Fig. 7) dating to roughly 1–0,5 Ma [18] seems to grow up rather continuously. However, each break between the fluments shows a hiatus indicating standstill with soil formation and certain
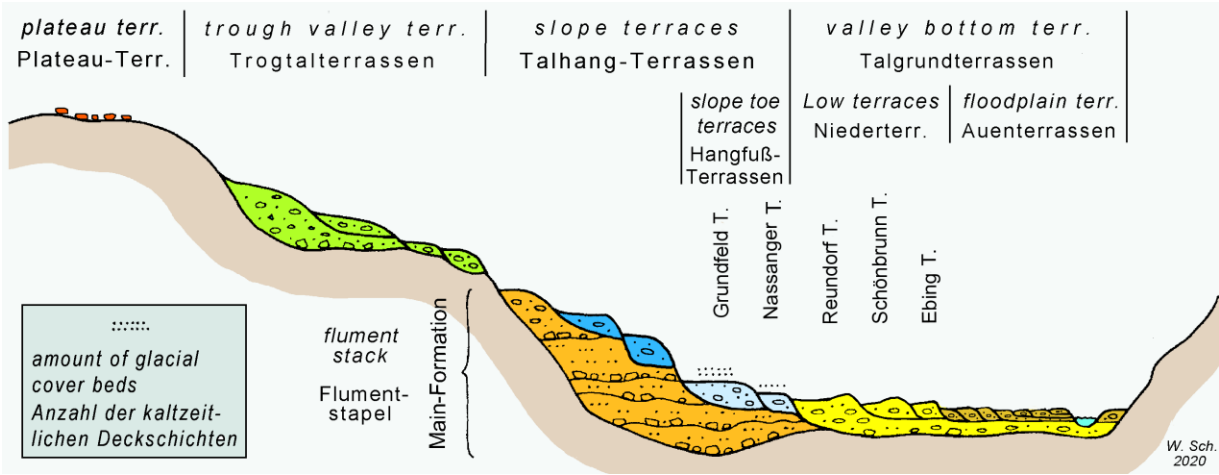

Figure 6. Flument/terrace flight of the River Main and many other rivers in Central Europe [16] (modified).

erosion. Concerning the glacial history these hiatuses indicate the climatic change between glacial an interglacial periods including the transitional period between both.

On the other hand, there are often cases where fluvial stacks contain long-term hiatuses involving several glacial periods as demonstrated later in item 3.3.
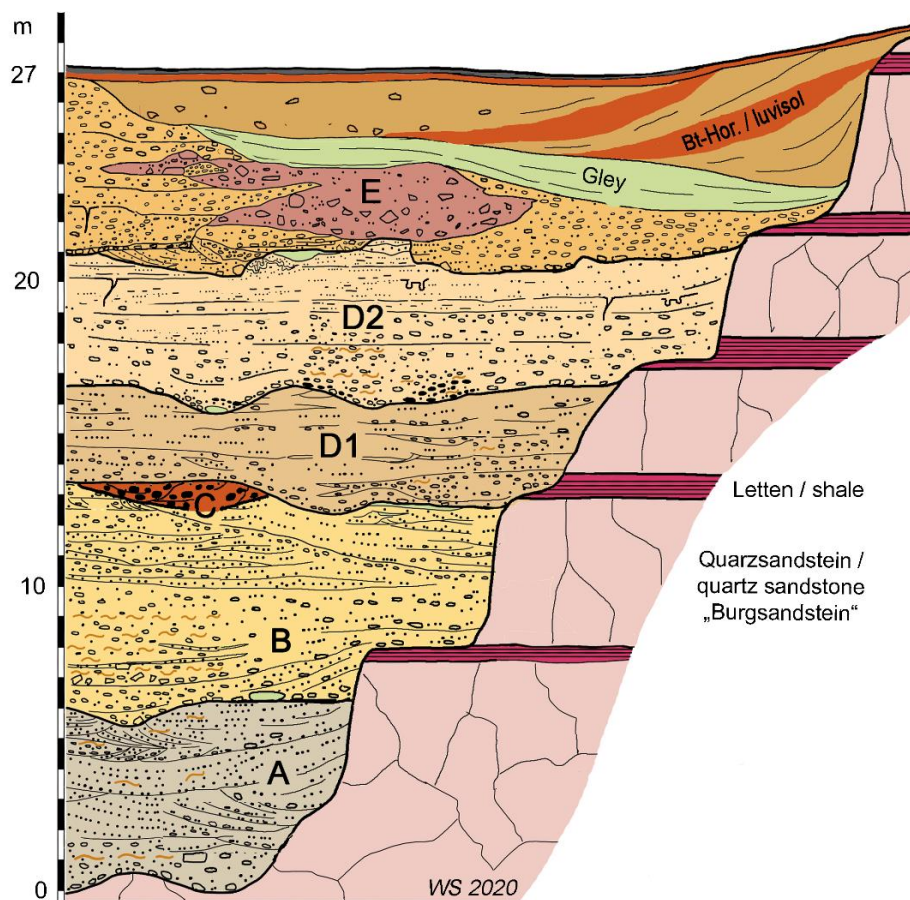
Figure 7. Scheme of the fluvial stack in the River Main area, called Main Formation. It consists of maximal six fluments: A, B, C, D1, D2 and E. Flument A, B, D1, D2 and E are fluments of vertically aggrading rivers. The small flument C presents a lateral accretional river weathered by a Luvisol (red brown). Flument E embraces much slope debris supplied by a gully. Each flument shows at least remnants of floodplain channel fills (green): A (reworked in B); B; D1 (reworked in D2); D2 and E (largely preserved). Above the back swamp of E (green) silty-sandy coverbeds with two paleo-Luvisols (red brown) and the Luvisol at the surface. – The Upper Triassic Burgsandstein is a quartz sandstone interfered with red shale. These shales, softer than the quartz sandstone, provide the possibility for lateral overlapping of the river deposits. (The overlapping extent is drawn here only small owing to the page size.)
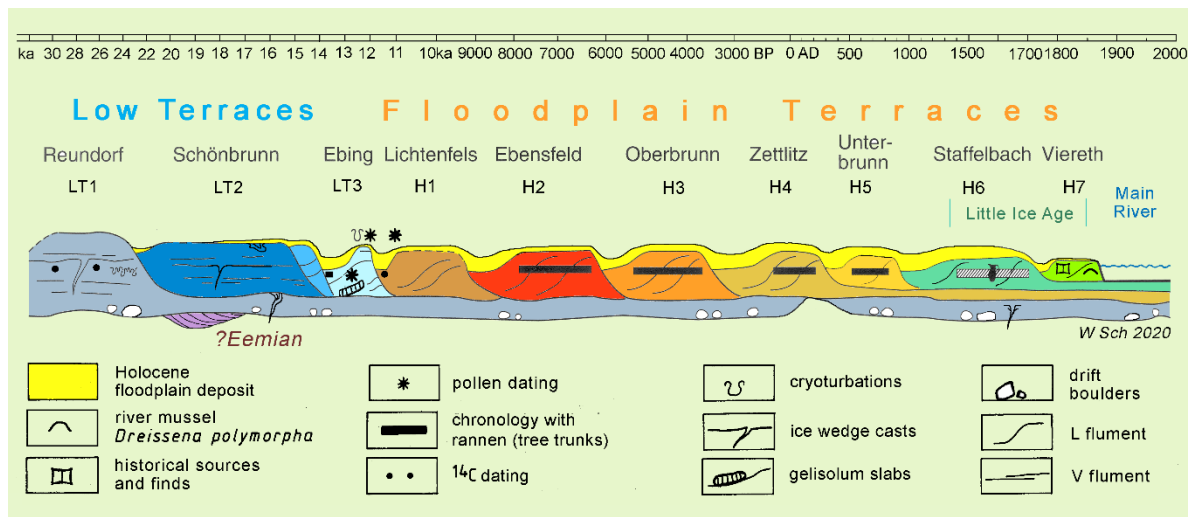
Figure 8. Terrace row. At the Main River from Low Terrace 2 (LT 2) on, the river terraces of the valley ground form a terrace row. Occasionally they get flooded (yellow), and therefore were called floodplain terraces. H = Holocene, [19] (slightly modified).

2.6 Flument rows respectively terrace rows

In case of missing incision of a river and continuing rhythmical formation of fluvial deposits, fluments and terraces can form a lateral row, called row fluments resp. row terraces [9] (pp. 12, 28). Here the terraces lie side by side at least with its surfaces in the same level. But mostly also the flument bases hold a similar level, which is the case among the Holocene floodplain fluments (Fig. 8). Separation of the individual fluments is possible by their age, but also by their floodplain soils. The amount of Holocene fluments within the terrace row at the valley bottom is rather constant in Central Europe [11, 6].

3. Application of the principles, and special problems
Fluvial overlap and stratigraphical consequences

Where flument flights, flument rows and flument stacks occur together in one and the same fluvial edifice, the building of a stratigraphical system may get difficult. In the following, some examples are presented showing interaction of flument staircases, stacks and rows:

3.1 Lateral overlap confusing the assignment of terraces or fluments

A normal river deposit, called flument, is limited on top with a more or less even morphological terrace plain, an ortho-terrace (Fig. 2). The way becoming a terrace involves that the river plain and flument was again cut by the river to form a deeper lying next younger river plain leaving aside parts of the older plain.

If a river aggradation rises higher than the preceding river incision the aggradation can overlap the incision form, provided that there is lateral space enough for overlapping (Fig. 9a).
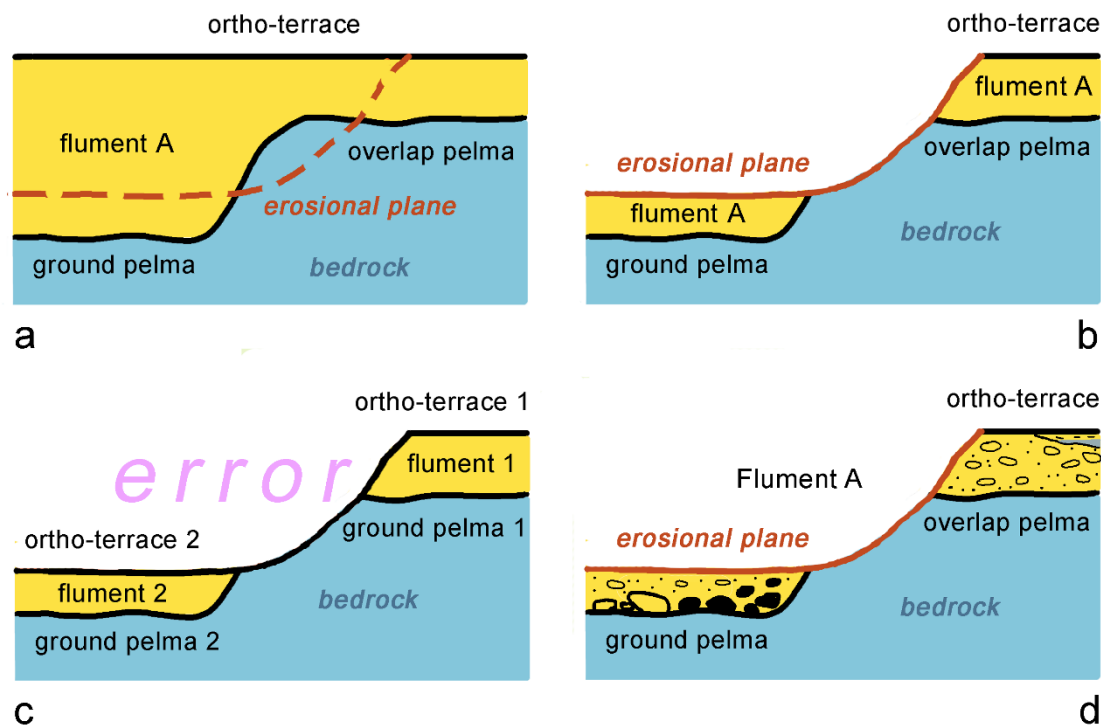
Figure 9. Flument overlap. a. An overlapping flument causes two pelmas, ground pelma and overlap pelma. b. An erosional plane separates the two pelmas and the deeper part of the flument from its higher part. c. Wrong interpretation of the separated fluments actually presenting one flument. d. Easier interpretation in case both flument proportions show the typical basal respectively upper facies of a flument.

The lateral overlap results in formation of two different base levels (pelmas) — a lower pelma starting with the first emplacement of the flument — a second and higher pelma starting with the lateral overlap of the river. Thus, one and the same flument has two base levels, the true ground pelma and the overlap pelma (Fig. 9a). The overlap pelma lies higher than the true ground pelma of the river aggradation. This constellation may cause geological misinterpretation in case of partly erosion (Fig. 9b). The erosional plane cuts the flument A in a way, that both flument relics of Flument A appear to represent two different fluments of a stair case – an apparent older flument 1 and an apparent younger flument 2 (Fig. 9c). Consequently, the overlap flument A may give rise to count the overlapping flument as two fluments, respectively to consider the overlap pelma as an own ground pelma (Fig. 9c). That means, constructing a flument flight of a valley may consider two pelmas belonging to two fluments consciousless of the fact that the two pelmas could represent one flument only. Studying the case of Fig. 9b the fact that both fluments belong together could be underlined by the development of the deeper lying flument with basal facies (block layer, skeleton gravel), and the development of the higher lying flument with finer grained clastics and/or initial floodplain facies (Fig. 9d).

3.2 Lateral overlap confusing the assignment of individual single fluments

The fluvial stack of the River Main, the Main Formation (Fig. 6), comes up 30 to 60 m thickness, 30 m upriver, 60 m downriver. It consists of at least six fluments. All fluments of the stack tend to overlap laterally. The overlap is shown as scheme in Fig. 7, and as drawing true to life in Fig. 10.
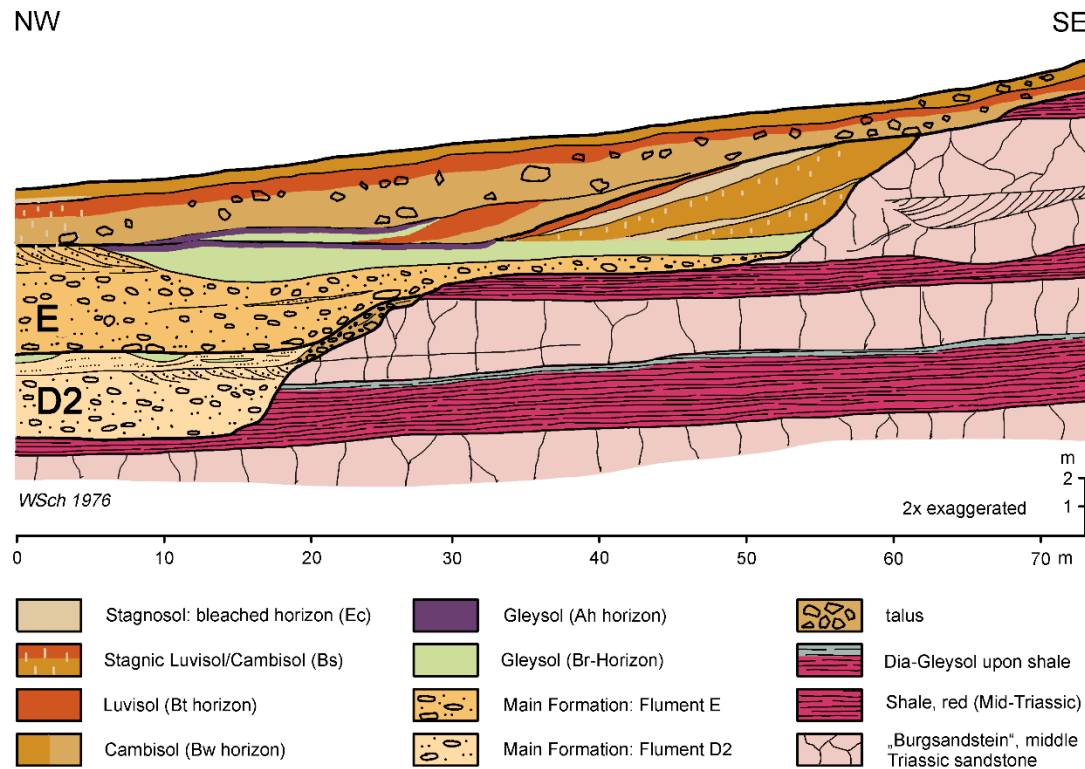
Figure 10. Flument overlap in the Main-Formation. Flument D2 overlaps laterally more than 18 meters, Flument E overlaps 37 m.

Fig. 10 shows two overlaps. The lower overlap of flument D2, and the upper one of flument E. Both overlaps developed from lateral erosion by the river Main against hard Triassic sandstone, however, using there a weaker shale interlayer for prograding. If the river of this level would cross mere claystone the progress of overlap would be easier and perhaps much more extended (Fig. 11). Fig. 11a is a theoretical figure demonstrating that the upper fluments of a flument stack may be able to deposit widely separated flument portions. Thus, as shown in Fig. 11b, it is hardly possible to assign some fluments as overlapping flument of the stack (violet) or as an incision flument of the terrace flight (green) that follows after the pile-up of the fluments. The best possibility to assign such isolated fluments (red in Fig. 11b) would be to date them directly. Dating by their lithological composition (e. g. pebble analysis, heavy mineral analysis) is useless, because the fluments of the flument flight (green) involve mostly reworked material from the flument stack (violet).
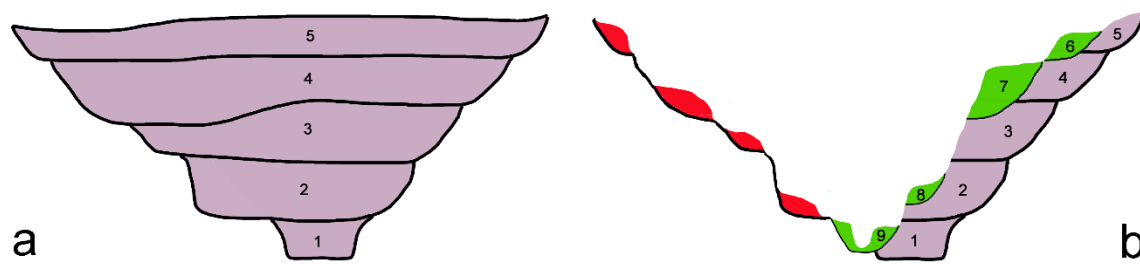
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Figure 11. a: shows a flument stack, 1 the oldest, 5 the youngest flument of the stack. b: The stack has been eroded forming a flument flight (green) with four cut-in terraces (6-9) and leaving behind only remnants of the stack 1-5 (dark violet). On the left side of the valley occur isolated, so-called lost fluments (red), the assignment of which is not clear, whether they belong to the stack (violet) or to the cut-in terrace flight (green).
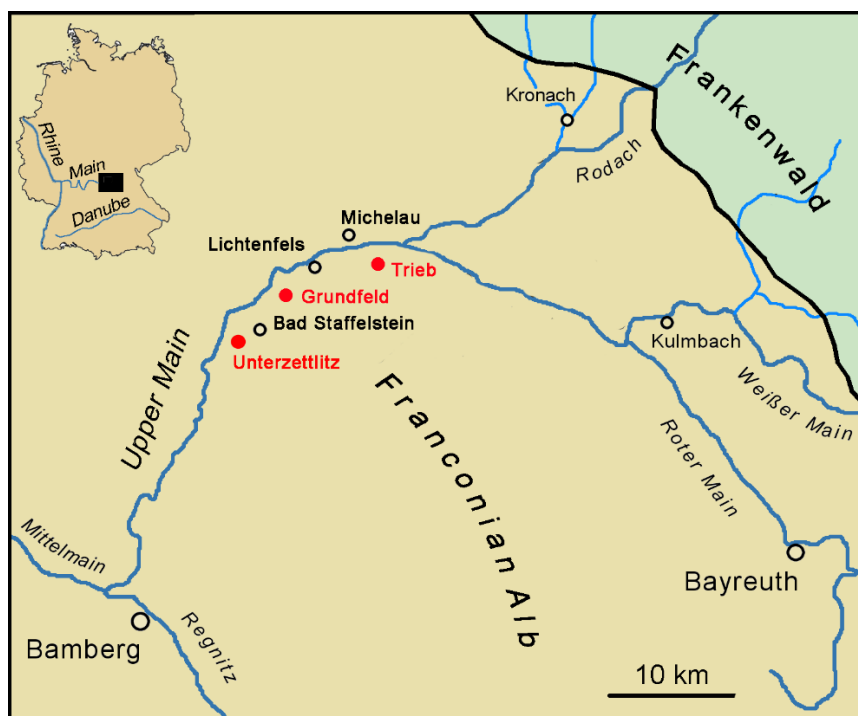

Figure 12. Location map of the Upper Main area/Bavaria

3.3 Lateral overlap owing to shift of the thalweg

During its river story the River Main changed its thalweg from east towards west. The reason for this was triggered by the onset of enhanced periglacial slope activity during the Middle Pleistocene. At
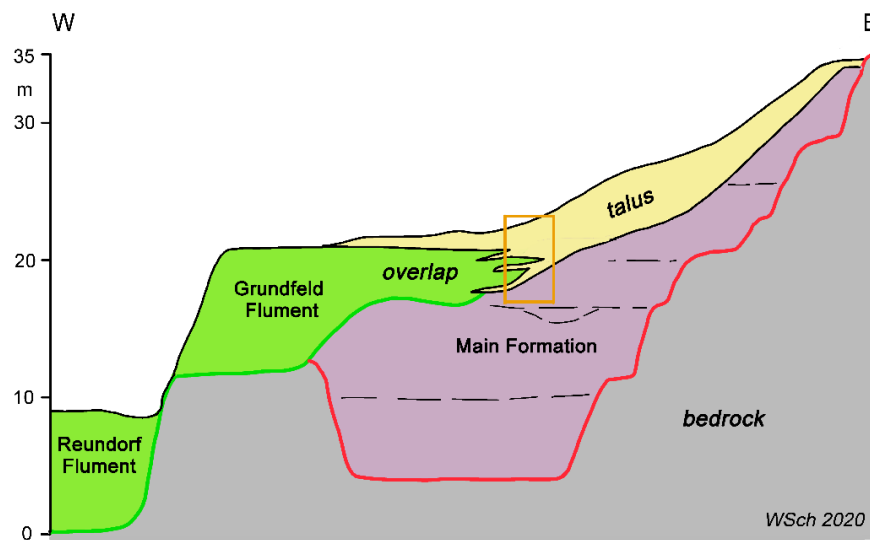
Figure 13. Scheme of the valley shift from east to west: Red line: Pelma of the eastern valley filled by the Main Formation. Green: Fluments of the western valley with overlap of the Grundfeld Flument over the truncated eastern valley respectively the Main Formation. Brown quadrangle: Detail of the overlap situation in the Grundfeld gravel pit in Fig. 14.

first, the river was running along the foot of the steep Jurassic escarpment of the Franconian Alb (Fig. 12) for some hundred thousand years (Fig. 13, right flank of the valley). Then, external feeding with supply of periglacial debris from slopes and tributaries of the escarpment increased so eminently that the river was gradually pushed to the western side. This side was bound by Lower Jurassic clayey deposits. Thus, the River Main easily undermined the western side by gradual shifting of its thalweg toward west.

By the shift of the thalweg, the river ceased downworking into the loose gravel of the Main Formation leaving a socle of the Main Formation of 2 km in width and more than 10 m in thickness. In its new thalweg it cut vertically deeper into the new clayey bedrock. Now, nestled in its new valley bed, the river in places filled up its aggradation somewhat higher than the truncated Main Formation, now overlapping the truncated surface of its old thalweg. Fig.13 as scheme, and Fig. 14 as drawing true to life, show the overlapping Grundfeld Flument over the socle parts of the Main Formation prior to being covered by slope debris. Thus, two morphological terraces lie in tight superposition in the eastern river bed: the truncation terrace of the Main Formation and the Grundfeld Terrace upon it as a thin overlap flument. Coming back to item 2.5, the Grundfeld flument here forms a stack together with the Main Formation below presenting an unconformity of roughly 300 ka years between them.
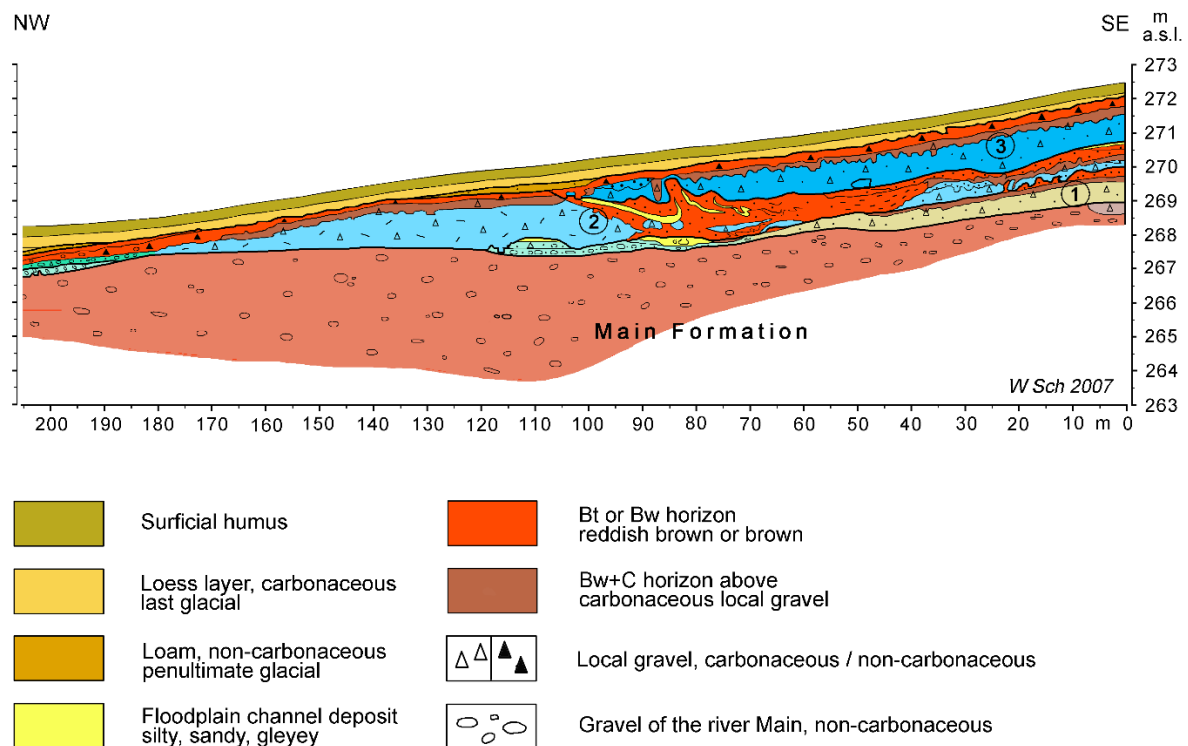
Figure 14. Grundfeld gravel pit. Location: see quadrangle in Fig. 13. Overlap of the Grundfeld Flument, with subunits 1–3, upon the truncated Main Formation.

4. Flument inventory of the valley ground

4.1 Terrace patterns of the valley bottom

The terrace pattern (Fig. 15) is the configuration of the nowadays preserved fluments of the valley bottom. The four main terrace patterns of Fig. 15 are recognized in Central Europe. Naturally, those patterns existed during all former interglacials. However, these former periods are represented by their fluments only and not by their terraces.

4.2 Terrace textures of the valley ground

The valley ground is a treasure full of secrets. Unravelling them is difficult because of its frequent position under groundwater. In rare cases construction pits allow full insight. On the Upper Main River sometimes the gravel pits were pumped out to gain the gravel nearly completely in contrast to exploitation of gravel and sand from those pits filled with ground water.

Figure 15. Terrace patterns in the valley bottom [11] (p. 32).
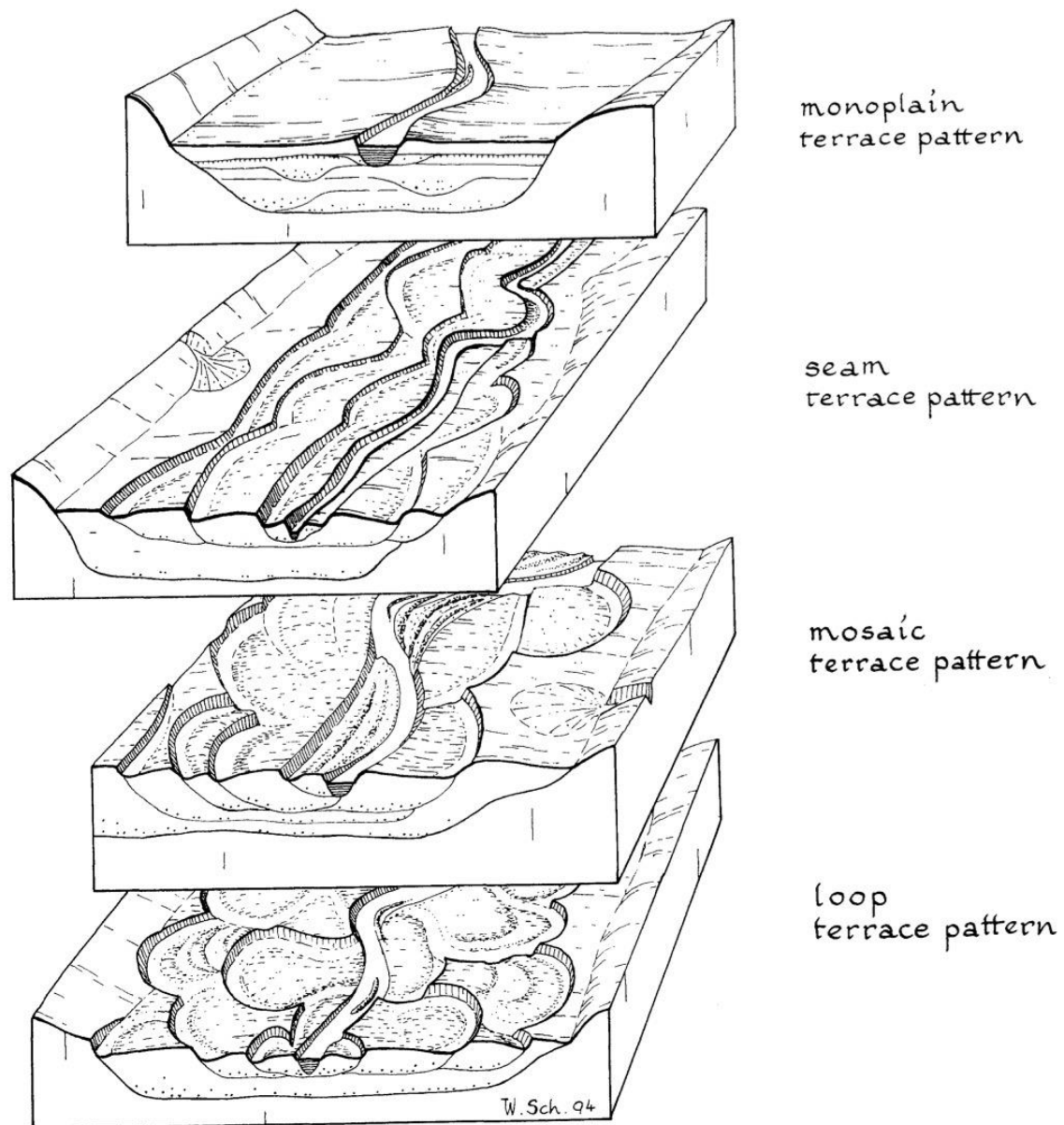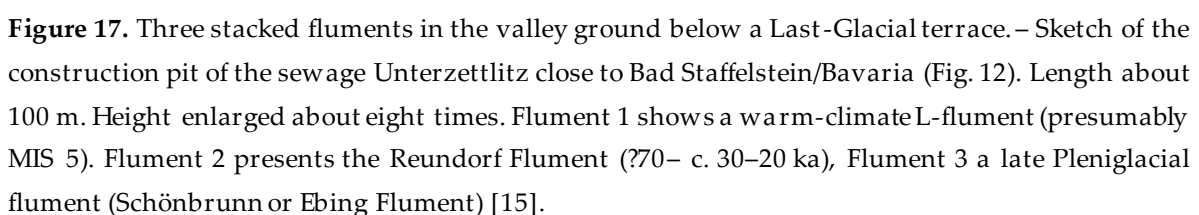
Within areas of minor tectonical uplift, the valley ground consists of the following units (Figs. 8 and 16):

Holocene fluments presented as row terraces

Young Pleistocene fluments

Pelma on bedrock

They can be (Fig. 16) incised as step terraces, form row terraces, form stack terraces with overlap or present fill-in-fill terraces. Mostly a mixture of all occurs.

In areas of stronger uplift, the fluments form step terraces, where the Holocene terraces form the pelma of the valley fill, e.g. on the Danube River [6] (p. 46). In contrast, areas of subsidence, as in graben structures, present textures much more differentiated and richer in the amount of fluments above the pelma, e.g. in the Upper Rhine Graben [20, 21].

Figure 16. Principal flument textures of the valley bottom in Central Europe [11] (p. 32).

4.2.1 Varied relief sculpture of the pelma in the valley ground

Normally, the sculpture of the pelma is even to wavy. Sometimes there occur scours from locally older erosional events as shown in Fig. 17 by the Flument 1 there; it is a presumably Eemian erosion.

Figure 17. Three stacked fluments in the valley ground below a Last-Glacial terrace. – Sketch of the construction pit of the sewage Unterzettlitz close to Bad Staffelstein/Bavaria (Fig. 12). Length about 100 m. Height enlarged about eight times. Flument 1 shows a warm-climate L-flument (presumably MIS 5). Flument 2 presents the Reundorf Flument (?70– c. 30–20 ka), Flument 3 a late Pleniglacial flument (Schönbrunn or Ebing Flument) [15].

Moreover, there occur hillocks of the pelma as shown in Fig. 8 below the Zettlitz Terrace. The hillock rises so high that the basal erosion of the Zettlitz Flument could completely scour away the socle of the Reundorf Flument. In rare cases — if harder rocks adjoin much weaker ones — such hillocks tower above the valley terraces forming islands in the valley bottom.

4.2.2 Scouring out the valley ground

In the Upper Main area for excavation of gravel in places the water is pumped out. Thus, the whole structure of the valley ground can be studied.

Normally, the pelma of the valley ground is formed by the Upper Pleniglacial, in Fig. 8 the Reundorf Flument. Where the Reundorf Terrace itself is cut by younger fluments, these younger fluments show
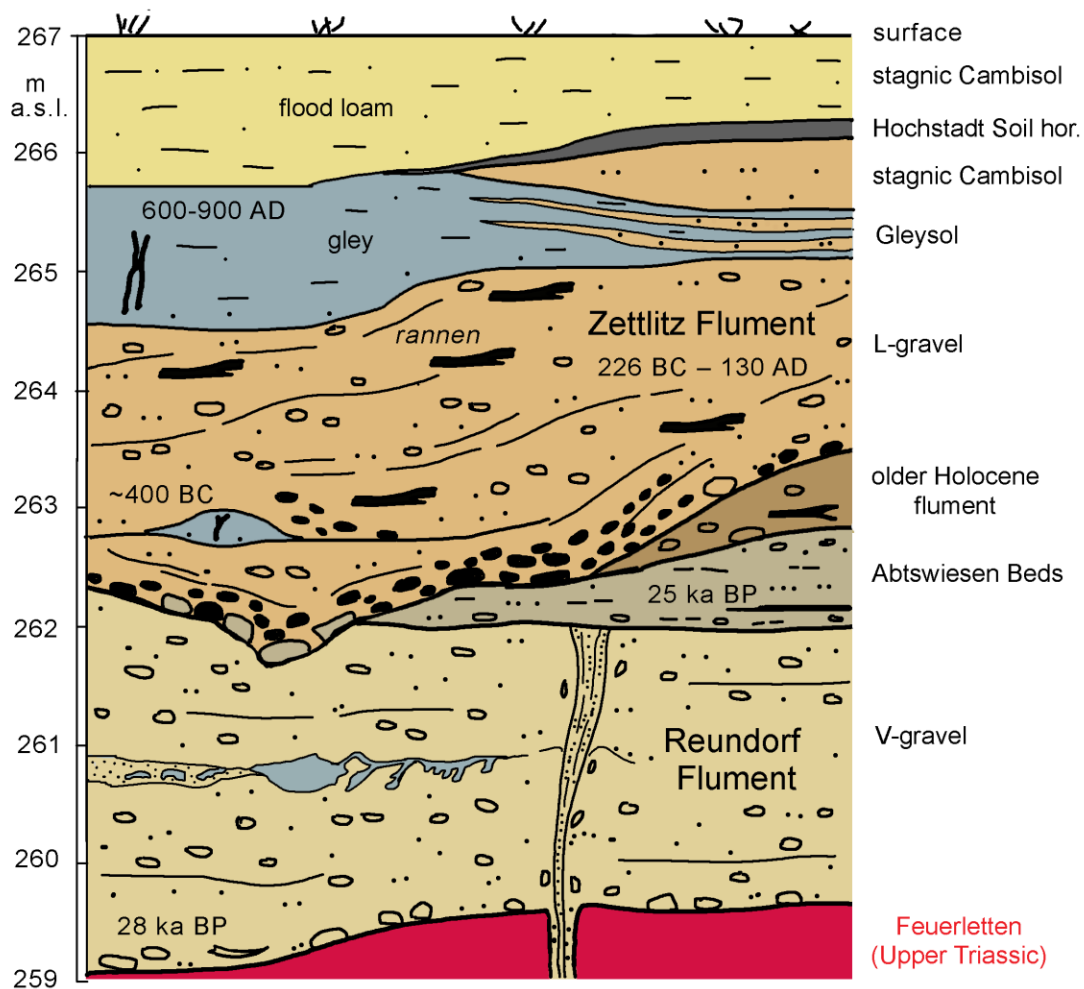

Figure 18. Stacked fluments in the valley ground below a Holocene terrace. – Sketch of an area of several gravel pits in the Zettlitz Terrace in Lichtenfels-Trieb/Bavaria. The Reundorf Flument is preserved by its socle containing the interstadial Abtswiesen Beds. These Pleniglacial deposits are unconformably overlain by the roughly 2000 years old Zettlitz Flument that is completed by the early Medieval Hochstadt Soil horizon [22] (p. 52), since then overlain by younger flood deposits.

cut-and-fill texture (Fig. 8) in a way that the Reundorf flument remains always as socle below the younger fluments. Such an example is shown by the Zettlitz Flument that overlies the socle of the Reundorf Flument . In case of Fig. 18 the Reundorf flument encompasses at its base remnants of mammoth tusks with a ^{14}C age of 23.415±475 a BP, roughly calibrated to 28 ka BP. Above occurs a layer of fines with drop soils, and even higher follow the fine grained interstadial Abtswiesen Beds [23] (p. 51) with a thin peat layer dated to 20.525±410 a BP, roughly calibrated to 25 ka BP. These Abtswiesen Beds cut unconformably ice wedge casts (Fig. 19) that extend down through the pelma into the bedrock — here Upper Triassic red shales called Feuerletten (fire shale). In places, between the basal Reundorf Flument and the Zettlitz Flument there may be left flument remnants of older Holocene age dated by wood.

Figure 19. The lateral accretion gravel (L-gravel) of the Holocene Zettlitz Flument overlies unconformably the vertical aggradation gravel (V-gravel) of the Younger Pleistocene Reundorf Flument that includes an ice wedge cast (Photo: W. Schirmer 12.10.1972).

4.2.3 Holocene fluments and terrace row

The differentiation of the Holocene terrace fill [9,11] is possible by:

1. mapping the morphological terrace row (see Fig. 15), starting with mapping from aerial photos, followed by field mapping and (hand)coring at particular points.

2. identification of their surface soils, best to do by small pits, less good by corings: These soils vary from older to younger terraces from strongly or mature soils to the incipient soil of the youngest terrace. In the temperate climate the soil catena ranges from Luvisol over Cambisol to Leptosol. This soil development passes off the quicker the lower the carbonate content of the floodplain deposits is.

Thus, in river areas with high carbonate content (e.g. Alpine-connected rivers) the differentiation of floodplain soils allows optimal differentiation of the individual floodplain terraces [11] (p. 37).

3. gathering datable material within the fluments: wood remnants, especially rannen (tree trunks), pollen etc. Remarkable are rannen (Fig. 20) that give exact dendrochronological death times for their imbedding moment (Fig. 21). These death times testify the regularly flooding that destroys the riverine forest and accumulates the Zettlitz flument (H4 in Fig. 8). As all seven Holocene fluments and terraces, this Zettlitz flument is distributed in all valleys of Central Europe indicating enhanced fluvial activity. On the River Main it dates from 226 BC to 130 AD [24].

Figure 20. Rannen (fossil tree trunks) in the Zettlitz Flument (226 BC–130 AD) in a gravel pit at Lichtenfels-Trieb/Bavaria. Stratigraphical position see Fig. 18 (Photo: W. Schirmer 19.09.1971).
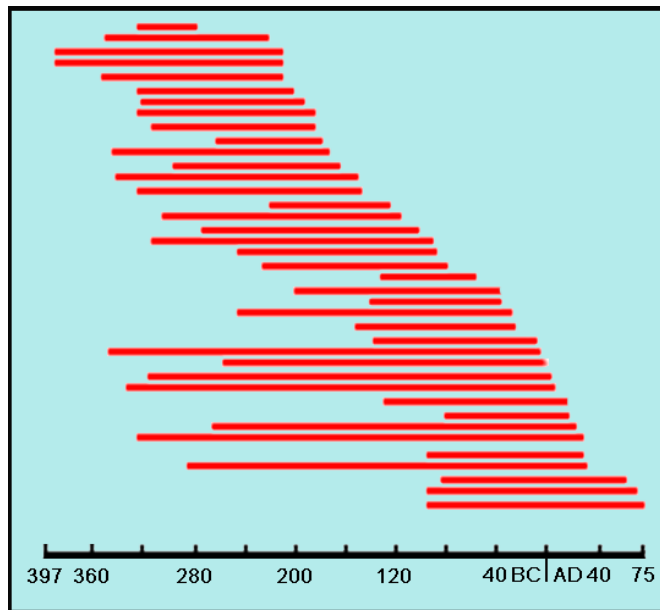
Figure 21. Oak rannen from the Trieb gravel pit collected by Becker and Schirmer and chronologically dated by Becker showing continuous death sequence as result of enhanced fluvial activity during the Zettlitz Phase.

5. Conclusion

The edifice of fluvial deposits exhibits a large variety of forms and textures, in addition a large variety of preservation conditions. The older the fluments are the more relictic is their texture.

It is essential for the differentiation of fluments within the valley fill to study good outcrops and to follow their excavation progress over long periods of time.

The principles mentioned first in item 2 should be applicable to all fluvial investigations. The given case of overlap is certainly a frequent case. The occurrence of a flument flight side by side to an earlier fluvial stack is surely a rare case. However, in smaller sections or during shorter periods it may happen in many valleys. The flument texture of the valley ground varies depending on the local tectonical situation. The cases presented here, including some variations, are frequent in many valley grounds all over the world.

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