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THE MORPHOGENETICS OF THE KARREN MEANDER AND ITS MAIN TYPES

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Abstract: Applying observations taken in a couple of karren terrain in the Totes Gebirge (Austria) the forms of karren meanders and their development were studied and karren meander types were specified. In the knowledge of the conditions of development of the meander types not only the types of karren troughs can be specified but the development of specific karren troughs can be explained too.

The properties of the bends (arc-length, meander wavelength, state of development and slip-down intensity) of four karren troughs were studied in order to know the laws of meander development and to know the factors that influence slipping. Data hint at the slipping depending on the gradient while to the lateral swing of the channel line that determines the development and rate of development of the bend the gradient has little and indirect effect.

I. Introduction

Scientists studying karren development specify a special meandering (bending) type of karren troughs (*FRIDJOF, B.* 1954, *BÖGLI, A.* 1976, *BALÁZS, D.* 1990). According to the observations meandering can be characteristic to simple or composite troughs or even to rillen (*DUNKERLEY, D. L.*, 1979). This statement is well documented and represented by surveys illustrating karren forms (*SZUNYOGH G.-LAKOTÁR K.-SZIGETI I.* 1998, *VERESS M.-BARNA J.* 1998, *BARNA J.* 1998). *VERESS M.* (1995) specifies meanders as true meanders when the channel line bent before the development of the karren trough or false meanders when the channel line started to bend only after the trough had developed. In composite troughs according to the position to one another of type I and III troughs forced-, similar-, slipped-, confined-, and free meanders were specified. (Though the author describes the slipping of the bend but at the specification of the meanders the lateral shifting of the channel line has not been considered.) The listed meanders can either be false or true meanders. The type of the meander can be identified only considering if a *slip of bends* occur after the entrenchment of the master trough or not.

During the swinging of the channel line channel bends (meanders) develop. The lateral extension of the meander can be measured by the width of the meander zone (the area enveloped by the enveloping curves of the outer fringes of the meander arcs), its size with the wavelength of the meander (the shortest distance between two neighboring points of inflection or along the axis of the channel), the arc of the meander with the length of the meander (the distance between the points of inflection measured on the channel line) (*BALOGH, K.* 1991, *BORSY, Z.* 1992). Because during the development of karren troughs entrenchment occurs in the first place the development of karren troughs is not identical with the lateral development of middle course type water courses but with the bend development of rivers of forced meandering. In the valleys of rivers of forced meandering meander slippage occurs (*PÉCSI, M.* 1975).

For the study of meander slippage observations were made in the Totes Gebirge at the No. 201 hiking trail to the Widerkar Peak and at the No. 230 trail to the Gr. Scheibling Peak. Meandering troughs were surveyed in the letter location.

II. Bend (Meander) slippage and its forms

1. The Swinging of the Channel Line

Solvent flowing on carbonate ground surface can progress straight or bending (*Fig. 1*). Any particular point of the channel line can be positioned in the central line of the flowing solvent or anywhere else.

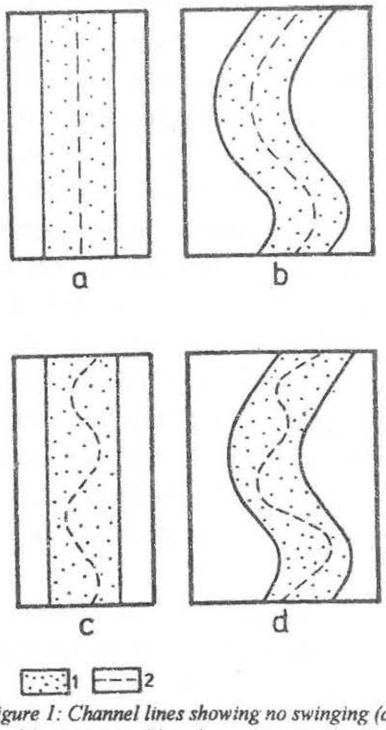

Figure 1: Channel lines showing no swinging (a), false swinging (b) and true swinging (c, d)
Legend: 1. solvent, 2. channel line

If it is positioned on the central line but the solvent is bending, false swinging occurs (*Fig. 1b*) because the lining of the edge of the flow and its channel line is the same. If the channel line does not follow the central line, true swinging occurs (*Figures 1c, d*). The swinging of the channel line can be temporary (functional) and steady.

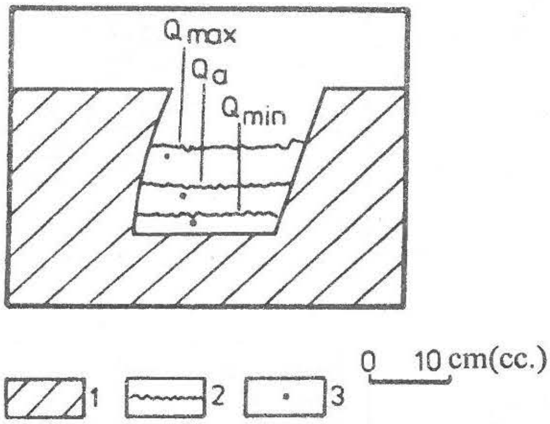

Figure 2: Channel lines of asymmetrical trough at various flow rates
Legend: 1. karren development on the rock, 2. water level, 3. channel line, Q_{min} low water level, Q_a medium water level, Q_{max} high water level

Functional swinging of the channel line is caused by the changing discharge of the solvent in the trough (*Fig. 2*). To higher discharge higher flow velocity belongs that increases the length of the channel line. Functional swinging can occur either at false or true swinging.

During steady channel line swinging slippage occurs. This letter is not restricted to one single function. The causes of steady channel line swinging can be as follows:

a/ In case of channel line swinging caused by external effect the channel line is not positioned there where it should during normal flow. The swinging does not occur because of the flow of the solvent but because water particles moving along the channel line hit obstacles. Swinging can be caused by the below listed causes:

- false meander in the trough (*Fig 3a*) or the bending of the flow,
- asymmetric trough (*Fig 3b*),
- flow from tributary trough (*Fig 3c*),
- trough-side (*Fig 3d*),
- unevenness of the surface (crack, calcite filling, eventually existing karren forms).

In false meanders due to the inertia of the flow the channel line can not precisely follow the changes of direction of the trough. The channel line section

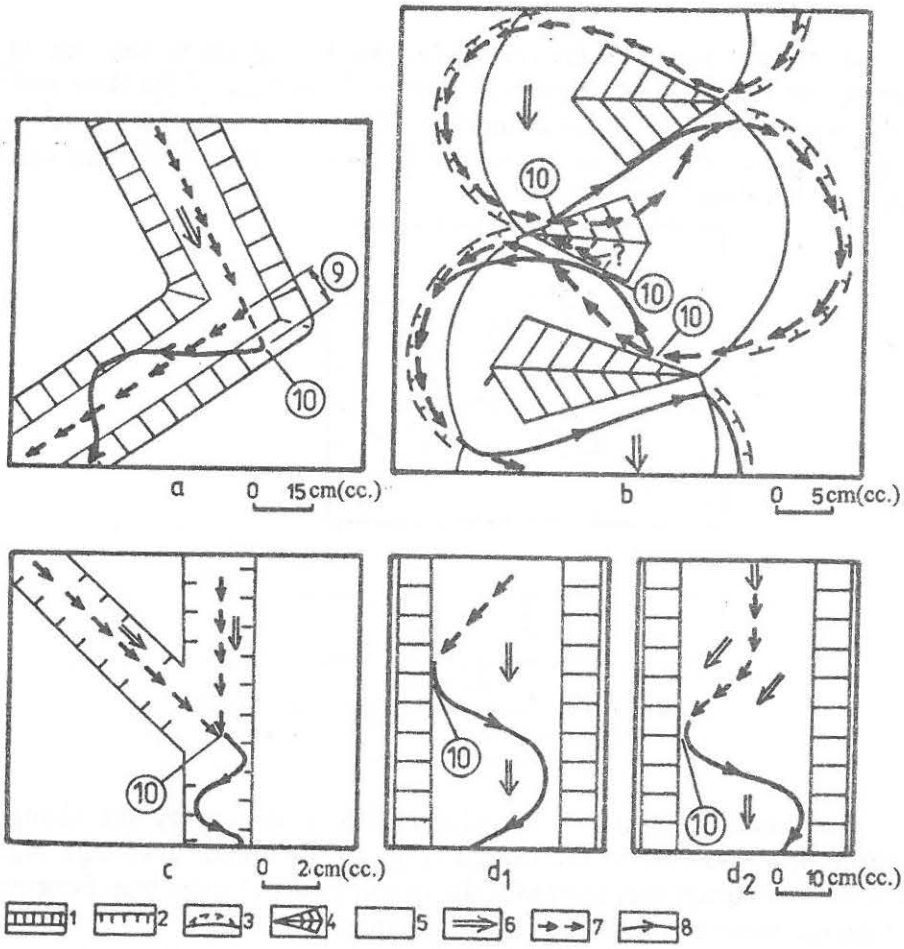

Figure 3: Swinging of channel line caused by external causes
Legend: 1. gently sloping trough side, 2. vertical trough side (type III trough), 3. overhanging trough side, 4. skirt, 5. trough bottom, 6. slope of trough bottom, 7. channel line, 8. swinging of channel line caused by external causes, 9. lengthening of channel line caused by flow inertia, 10. location of obstacle hit by the channel line, a. false meander, b. asymmetric trough, c. flowing water from tributary trough, d. there is an angle between channel line and trough side (d_1 the channel line has already swung, d_2 the channel line is swung by the slope of the trough bottom)

of the upstream trough section elongates towards the downstream rim of the trough and hits the side of the trough.

On ground surface without troughs the channel line of increasing flow can not follow the bending of the solvent. The series of functional swings can lead to the development of skirts. As a conclusion the steady swing of the channel line can occur if the laterally ever elongating skirt reaches the channel line at the entrenching trough bottom.

In the case of a symmetric trough the collision is caused by different influence. In such troughs arcing niches (overhangs) vary with variously shaped convex trough wall sections (skirts). Consequently water particles that move along a channel line parallel with the arced section arrive to a section with a different arc where the channel line will not be parallel with the new arced section will collide with the trough wall.

The role of the skirt and trough sides in the deviation of the channel line is secondary. They can only cause swinging if it had occurred caused by some other effect. It shall be noted that the channel line can hit the trough side even if its swinging had not yet occurred. E.g. in a case when the trough bottom is of such gradient that the solvent does not run parallel with the trough side but at an angle with it (*Fig.* $3d_2$).

The swinging of the channel line if it is caused by external forces will subside if the forces cease to act. The channel line "smoothes out", the subsequent meanders of the trough become ever smaller, the meander zone decreases. The local swings of the channel line make the meanders themselves of local development. It may occur that an individual swing causes a series of swings as the swinging channel line hits one and the other trough side. Finally it can be mentioned that self generation is frequent. This shall be understood that caused by some form (e.g. skirt) the channel line swings this causing the further growth of this form that influences the magnitude of the swinging.

b/ Channel line swing due to inherent causes is generated by the flow of the solvent. It can develop on homogenous, smooth rock surface where the movement of water particles is not hindered by any obstacle. (The cause of development is unknown, it can be caused by the saturation of the solvent.) The bending of the solvent can occur even before the development of the trough.

2. The Slippage

Dissolution is more intensive where the flow velocity of the solvent is higher. At higher velocity the transportation of the Ca^{++} ions and this way the adequate difference of concentration is maintained between rock and solvent. Thus the dissolution of the trough bottom is of the biggest magnitude at the neighborhood of the water level (laminar flow) or at the water level (turbulent flow) and in the letter case at the channel line.

While at the swinging of a functional channel line its position changes only in plane, at slippage it changes in space, because in the letter case due to the entrenching of the trough in the course of the channel line swing it gets ever deeper too. This process is irreversible. The cause of this is that the development symmetric trough form, the development of which can be linked with the swinging of the channel line "preserves" (bigger swings than the functional channel line swinging are not allowed by the trough sides) the lining of the channel line in a certain time. (It shall be noted that the functional shift of the channel line does not wholly happen in a plane because the water level changes in the function of the flow rate.)

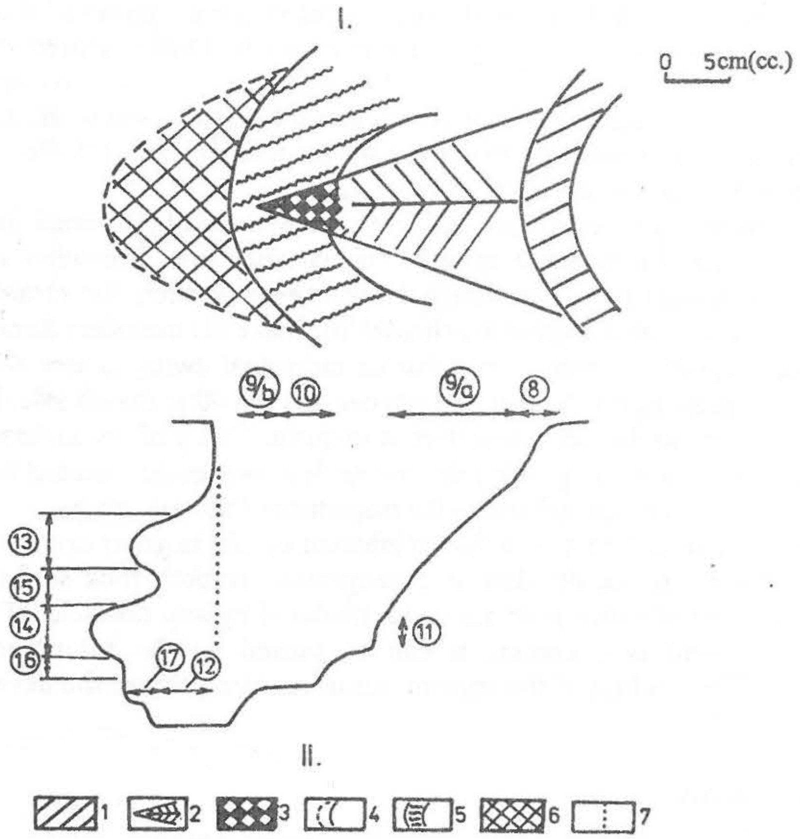

Figure 4: Morphological forms of a karren meander

Legend: I. plan, II. cross-section on the plan: 1. gently sloping trough side, 2. skirt, 3. skirt terrace, 4. overhanging side wall, 5. trough bottom, 6. meander terrace on the concave side, on the cross-section: 7. projection of the rim of the overhanging wall, 8. convex trough side, 9a. skirt remnant at the top, 9b. skirt remnant at the bottom, 10. meander terrace (on skirt), 11. skirt terrace groove, 12. meander terrace (on overhanging wall), 13. asymmetric terrace groove, 14. symmetric terrace groove, 15. crest between terrace grooves, 16. eroded crest between terrace grooves, 17. terrace groove remnant

Linked to the development of the trough the original channel line, the channel line at the initial slippage and the present channel line can be specified. The original channel line characterizes the flow of the solvent until the true swinging occurs. A channel line at the initial slippage on the ground surface - thus at the beginning of the entrenchment - is an already swinging channel line. This channel line is documented by the rim of the trough. The present channel line is the one that can be traced at the plane of the present trough bottom.

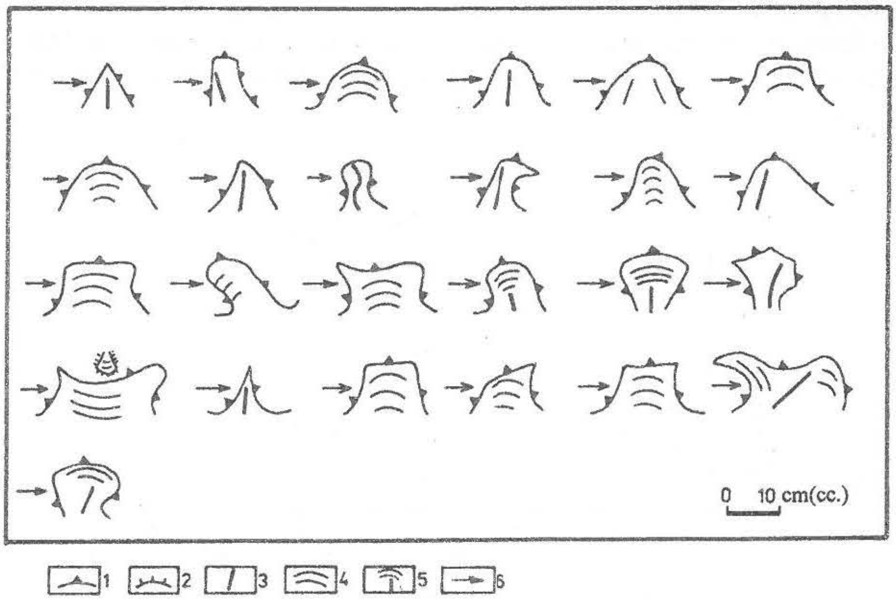

Figure 5: Skirt forms in ground-plan (on observation)
Legend: skirt of type I trough, 2. skirt of type III trough, 3. skirt ending in edge (half pyramid), 4. round (half cone) skirt, 5. skirt ending in edge at top and rounded at bottom, 6. direction of flow

The difference of the initial and original channel line is the channel line swing before the development of the trough, while the initial difference of the present channel line and the slippage is the swinging at trough development, the slippage. The total swing of the channel line can be measured on the perpendicular drawn to the tangent at any point of the trough rim and with the sum of the horizontal projections of the channel line swing prior to trough development. (It can be noted that caused by the slippage two kinds of bed zones can be specified. The original one that can be traced at the trough rims and the present one that is at the level of the trough bottom.)

In such trough bottoms where the channel line is positioned in the middle of the trough at all times (false swing may only occur), the dissolution and entrenchment is the biggest in this location. Resulting from this symmetric troughs develop in the bends (false meander, *Picture 1*).

If the channel line is not positioned in the middle of the trough (true swing) the trough does not entrench most intensively in the middle of the bottom. In these cases troughs of asymmetric cross section develop (true meander). As channel line swinging may occur at false swinging as well (functional channel line swinging) the trough can assume an asymmetric cross section. In a plan view the concave side of the trough becomes overhanging the convex side of it becomes sloping (*Fig. 4*). Skirts develop in these letter locations, skirts that are of various form in plan view (*Fig. 5*) mostly of convex rimmed, widening down from the top, sloping trough sides in profile (*Picture 2*).

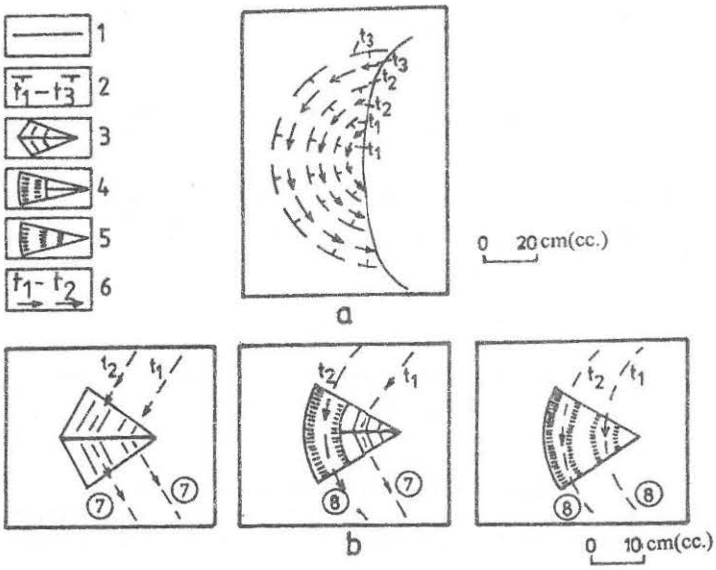

Figure 6: Connection of channel line slippage with development of the overhanging wall (a) and different skirt shapes (b)
Legend: 1. upper edge of overhanging side wall, 2. lower edge of overhanging side wall at actual trough bottom, 3. half pyramid shaped skirt, 4. half cone shaped skirt at top above, half cone shaped skirt at bottom, 5. half cone shaped skirt, 6. channel line at actual trough bottom, 7. broken channel line, 8. arced channel line

3. The Morphogenetics of the True Meander

3a. The Morphology of the Overhanging Wall and the Skirt

Overhanging wall parts can develop in such trough sections too where the upper trough rims are straight. This hints that the swung channel line touches the trough rim only in a point (or in a short section) at the beginning of the entrenchment. (There where the upper trough rim is of arced lining itself it is possible that the channel line followed the rim in a longer section at the beginning of the slippage.) At the same time it is characteristic to the three dimensional development of the overhanging wall that the length of the overhanging wall increases towards the present trough bottom. This can be explained by the steady slippage of the channel line. That is, in this case an ever longer section of the channel line adheres to the trough side resulting that lateral solution becomes more intensive at ever longer sections developing overhanging walls (*Fig. 6a*).

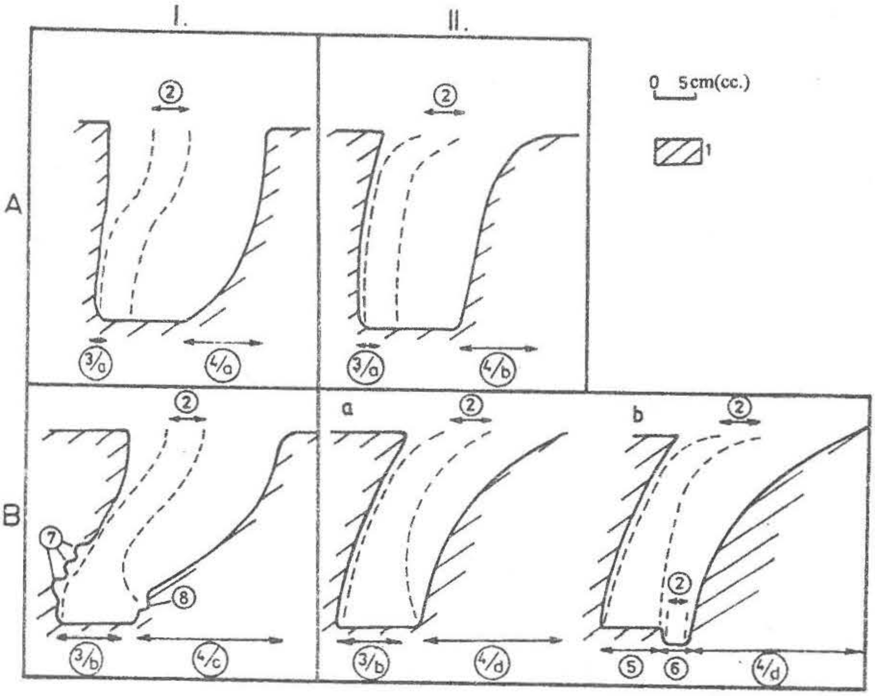

Figure 7: Morphogenetic specification of asymmetric meanders
Legend: A. small size slippage, B. large size slippage, I. initially slow slippage, II. initially quick slippage, 1. fresh rock, 2. change of the channel line zone between maximum and minimum flow rate (the measure of swinging increases during the progress of time in BI. And BII. cases, due to the asymmetric form of the trough), 3. concave side and terraces, 3a. narrow meander terrace, 3b. wide meander terrace, 4. skirt, 4a. small cross section, concave skirt, half cone at top and half pyramid at the bottom, 4b. small cross section, convex skirt, half pyramid at the top and rather a half cone at the bottom, 4c. large section concave half pyramid skirt, 4d. large section convex skirt large half pyramid at the top but rather half cone at the bottom, 5. hanging terrace, 6. type III trough, 7. terrace groove, 8. skirt terrace groove

Skirts develop at locations where the actual channel line is positioned further on from the half width of the actual trough bottom, because here the solution is less intensive as it is at the opposite wall of the trough. According to slippage the surface of the skirt is mostly cut off. A certain trough section can develop bends with or without skirts. The area bordered by the bend can shift gradually to the surface of the skirt but it may develop a sharp border with it.

Because of the different development of the channel line skirts of varying forms develop (*Figures 5, 6*). If the change of direction of the channel line is sharp, the skirt protrudes from the trough side as a half-pyramid. If it is rounded the skirt will be a rounded half-cone. If it becomes ever more arced during entrenchment the upper part of the skirt will be half-pyramid, the lower part half-cone shaped.

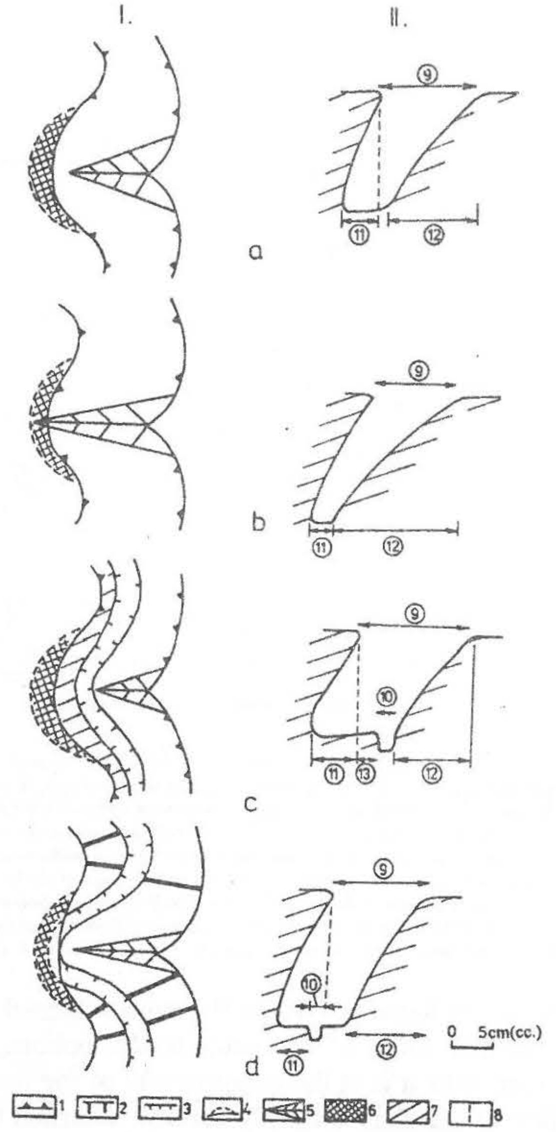

Figure 8: Meander terrace types

Legend: a. full terrace, b. damaged terrace, c. composite terrace, d. hanging terrace, I. ground-plan, II. cross-section on top-view (sections near the skirts), 1. edge of type I vertical side trough, 2. gently sloping side of type I trough, 3. edge of type III trough, 4. overhanging side wall, 5. skirt, 6. meander terrace, 7. trough bottom terrace in cross-section, 8. projection of edge of overhanging wall, 9. type I trough, 10. type III trough, 11. meander terrace, 12. skirt, 13. trough bottom terrace

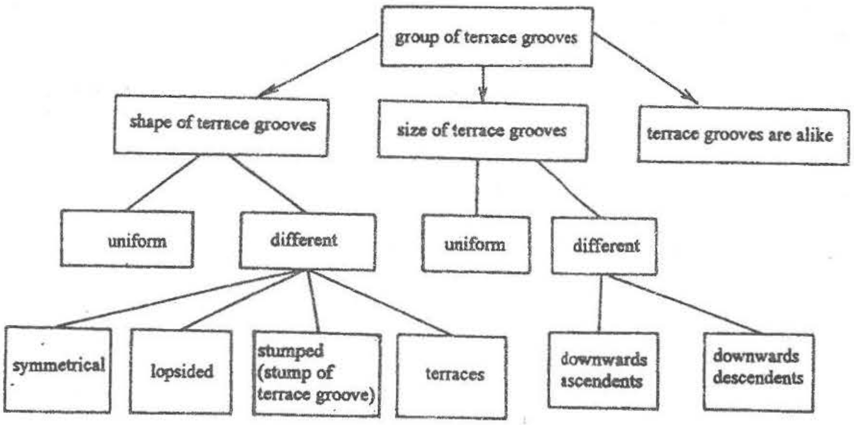

Figure 9: Variations of the observed terraces in asymmetric trough sides

The shape of the skirt is not only developed by the geometry of the channel line but by the measure of the slippage too. At quick entrenchment and big channel line swing or when the functional swing is small the skirts will be half pyramids while at slow entrenchment and small channel line swing and at big functional swing, half-cone shaped skirt develop. That is, in the first case the channel line is positioned farther in the letter cases nearer to the skirt. If the two processes are consequent at the same skirt it will be half-pyramid shaped at the top and half-cone shaped at the bottom.

The morphology of the bend is shaped by the measure and pace of the slippage of the channel line. If the entrenchment is quick or if in the course of one function the flow rate does not or only slightly changes, only small slippage will belong to a unit entrenchment (*Fig. 7.A*). In this case the skirt is short in profile. If the measure of the swing gradually increases the section of the skirt will be concave (the point of inflection closer to the trough bottom) but if the swing is considerable at the beginning of the entrenchment and than it gradually decreases, a convex skirt develops (the point of inflection closer to the trough-rim). The opposite side of the trough is less overhanging or vertical.

To slower entrenchment bigger bend slippage may belong, the section of the skirt will be long (*Fig. 7.B*). The opposite side of the trough is overhanging. It may occur in this case too that the section of the skirt is concave (the measure of the swing gradually increases) or convex (the measure of the swing decreases during the slippage).

The slippage can be gradual or intermittent. At gradual slippage the flow rate does not vary or not much, the channel line does not shift during the same function. The surface of the skirt and the opposite overhanging walls are smooth.

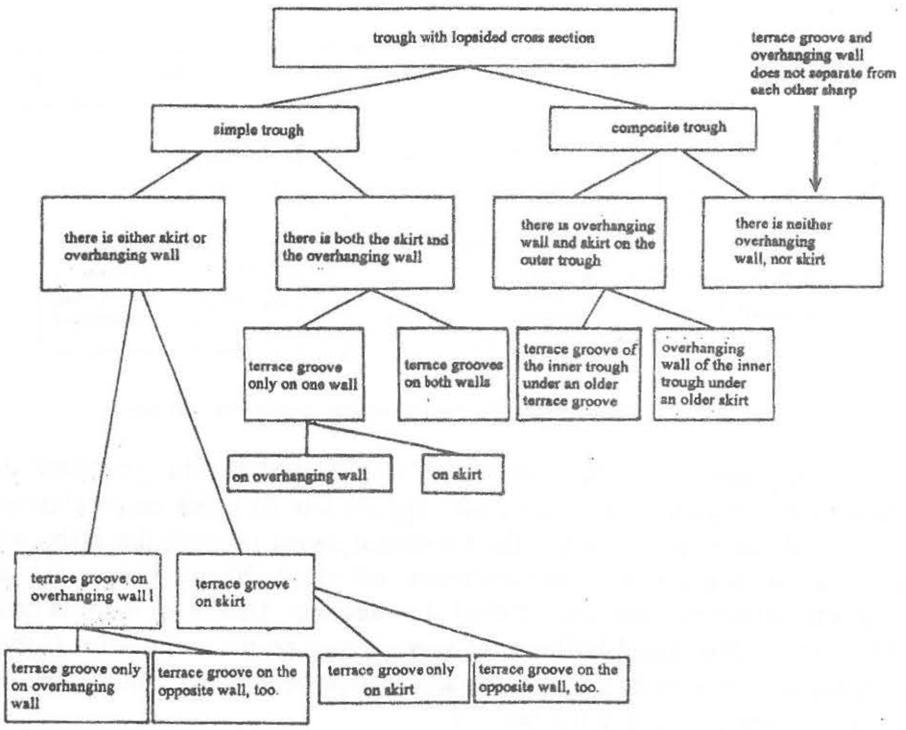

Figure 10: Terraces and terrace groups observed on features of asymmetric troughs

The skirts are often damaged. Active developing skirts can be damaged by the flow in the trough bottom. This can happen longitudinally (lopsided skirt) or laterally at right angle to the skirt. In the letter case a bend-beheading occurs. The remnant of the skirt turns into an inselberg. Older inactive skirts are damaged by frost (damaged skirt).

3b. Meander Terraces

True meanders can be terraced or without terraces.

Meander terraces can be well differentiated from karren terraces (*VERESS, M.* 1995). The letter can be traced continually on the trough bottoms at considerable length while the other can be found only locally in the meanders (*Picture 3*). The meander terraces are such plane surfaces of small extension that can be located in the concave side of the bend or in the skirts of the convex side (*Figures 4, 8*). Terraces can be located at the trough bottoms (trough bottom meander terraces) or above the bottom in the trough sides (hanging terraces). The trough bottom terraces can be full terraces (the skirt does not extend beyond the rim of the concave side) incomplete terraces (the skirt extends beyond the rim of the concave side) and composite terraces (the meander terrace transforms to karren terrace).

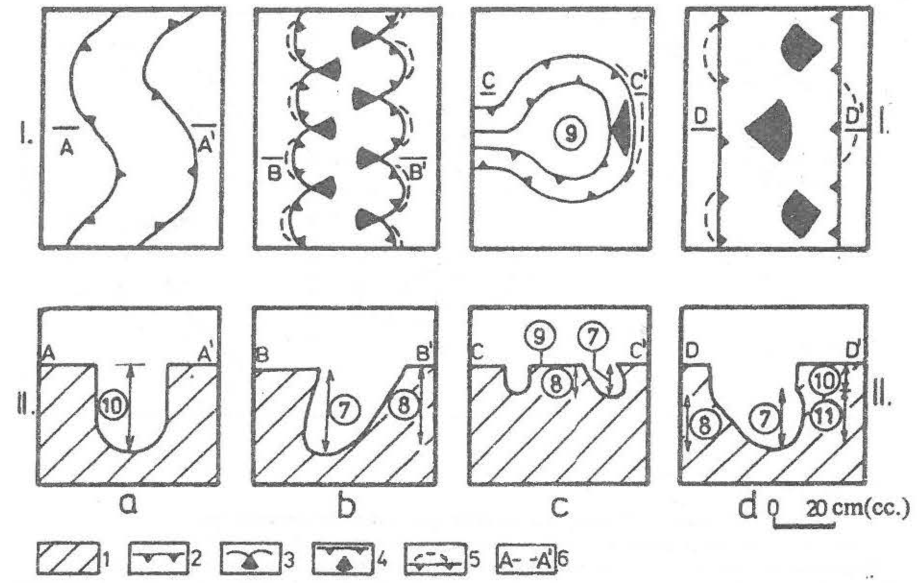

Figure 11: Meander types
Legend: on ground-plan: 1. karren development on the rock, 2. type I trough, 3. skirt starting at the trough rim, 4. skirt on the lower part of the trough side, 5. overhanging wall, 6. place of section, on cross-section: 7. overhanging side wall, 8. skirt, 9. recess, 10. symmetric cross-section trough and part of trough, 11. asymmetric cross-section trough, a. false meander, b. meander remnant, c. loop meander, d. developing meander, I. vertical-view, II. side view.

While the development of karren terraces can be explained by the development of inner troughs (the remnants of the older trough bed make the terrace), the development of the meander terraces of the concave side are due to the slippage. The slippage is not enough as an explanation for the development of these forms. The following hint at this:
- the niche (overhanging wall) is not located opposite to the skirt,
- the plan view of the skirt and the shape and size of the terraces are not identical,
- terraces don't always develop in the true meander at the concave trough side,
- terraces can develop on skirts.

The terraces of the concave trough side develop if the channel line stays at this side for extended periods of time (not only at maximal discharge). The following causes may have a role in this phenomenon:

- Due to the trough morphology resulted by the slippage (the developing skirts have a decisive role in this respect) the channel line will be such as in the maximal discharge for ever extending periods of time.

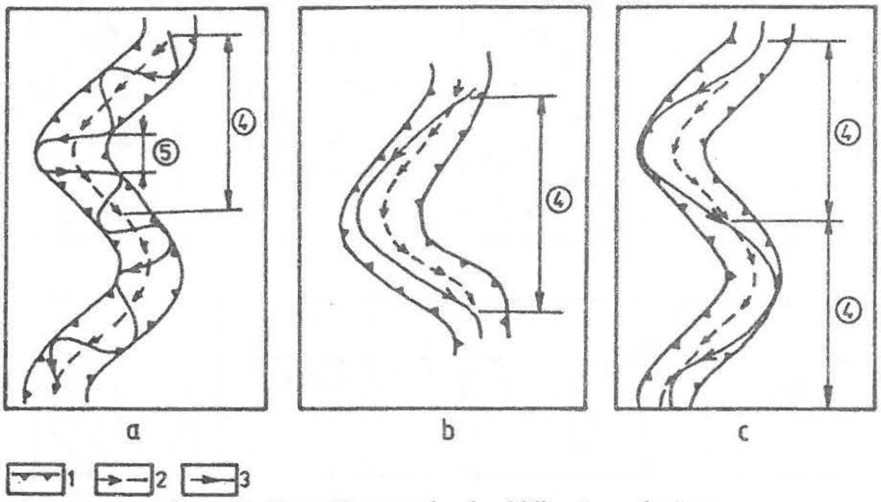

Figure 12: Channel line wave-lengths of different meander types
Legend: a. on falsely meandering trough with meander remnants, b. false meandering on trough with loop meander with simple direction change, c. false meandering on trough with loop meander with double direction change, 1. solvent, or the edge of developing trough, 2. original channel line, 3. swung channel line, 4. wave-length of original channel line, 5. wave-length of swung channel line

- During entrenchment the trough narrows. Therefore the filling of the trough will be higher even at smaller discharges. This results that the channel line will adhere to the concave trough side.
- During entrenchment some troughs are recharged by more water. This results durably higher water level resulting the described situation.

Skirt terraces possibly develop when the lining of the channel line completely changes in a part of the trough. This is made possible by the change of the morphology of the trough.

Hanging terraces may develop if the lining of the channel line changes (it does not reach the concave trough side even at maximal discharge). In this case an inner trough develops at the edge of the existing terrace. The terrace gets into hanging position.

Meander terrace-grooves are half channels (on the concave side) or step-like some cm deep and some dm long grooves (on the skirt of the convex side) in the trough sides in the meanders (*Fig. 4*). Sometimes their width may be so large that the whole overhanging of the trough wall will be nothing but one of them (giant groove). The giant grooves can be easily said from the meander terraces as their lower plane is not horizontal but tilted (*Picture 4*). Giant grooves can be observed on the overhanging walls most frequently. They seldom occur singly. Most of the time two or three grooves occur one above the other (*Figures 9, 10*). They characterize not only one bend of a certain trough or section of a trough but don't necessarily occur in each and every bend. It seems that the similarly positioned solitary terrace grooves or the groups of them in subsequent meanders are situated along a plane tilted toward the lower end. Grooves can be so close to each other that the side of the trough is nothing but an inter-groove ridge. (This ridge may be sharp or rounded.) The grooves can be symmetric or asymmetric in cross section. The upper or lower face of the groove may be missing (groove remnant). Regarding the occurrence of terrace grooves they can appear on one or on both sides of asymmetric troughs and in only the main trough or the inner trough or in both in a composite trough (*Figures 9, 10*).

The terrace grooves possibly develop at or near to the level of the

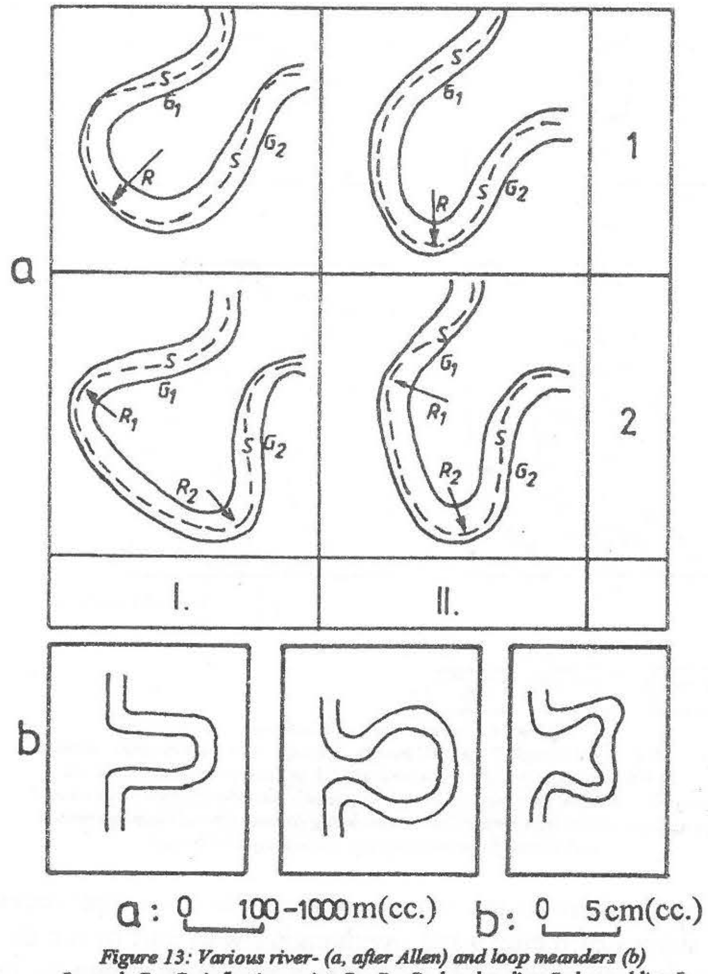

Figure 13: Various river- (a, after Allen) and loop meanders (b)
Legend: G_1, G_2 inflection point, R_1, R_2, R_3 bend radius, S channel line I. symmetric, II. asymmetric, 1. simple, 2. composite

maximal flow (*Fig. 7*). For the development of terrace grooves the lateral solution in one particular level shall persist for an extended period of time. The condition of this occurrence is that the levels of the maximal flows persist to be the at the same level in the trough. (In the case of giant grooves the maximal flow characterizes the trough for a long time than it gradually drops during entrenchment.) The vertical sequence of grooves can be explained by the entrenchment of the trough bottom because the level of the maximal flow drops.

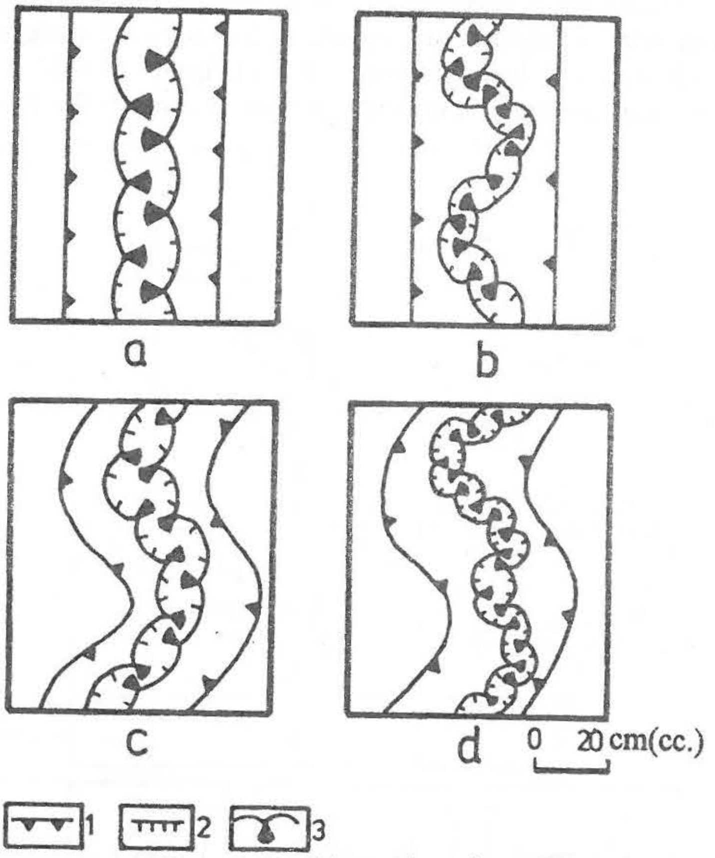

Figure 14: Joined rinnen with meander remains
Legend: 1. type I trough, 2. type III trough, 3. trough edge with meander remnant, with skirt; straight type I trough, straight (a), or falsely meandering strained meander remnant with type III trough (b), falsely meandering type I trough and meander remnant with forced false meandering (c) and slipped meander remnant with forced false meandering, (d) with type III trough..

The development of the terrace grooves near the water level explains the different shapes of them in the overhanging wall and in the skirt. While in the steep or overhanging wall the terrace grooves develop an upper face too, those in the skirt will have only lower faces (the skirt is subdivided into steps of different inclination).It may happen that the inclination of the skirt is not much and it is not divided into terraces at all.

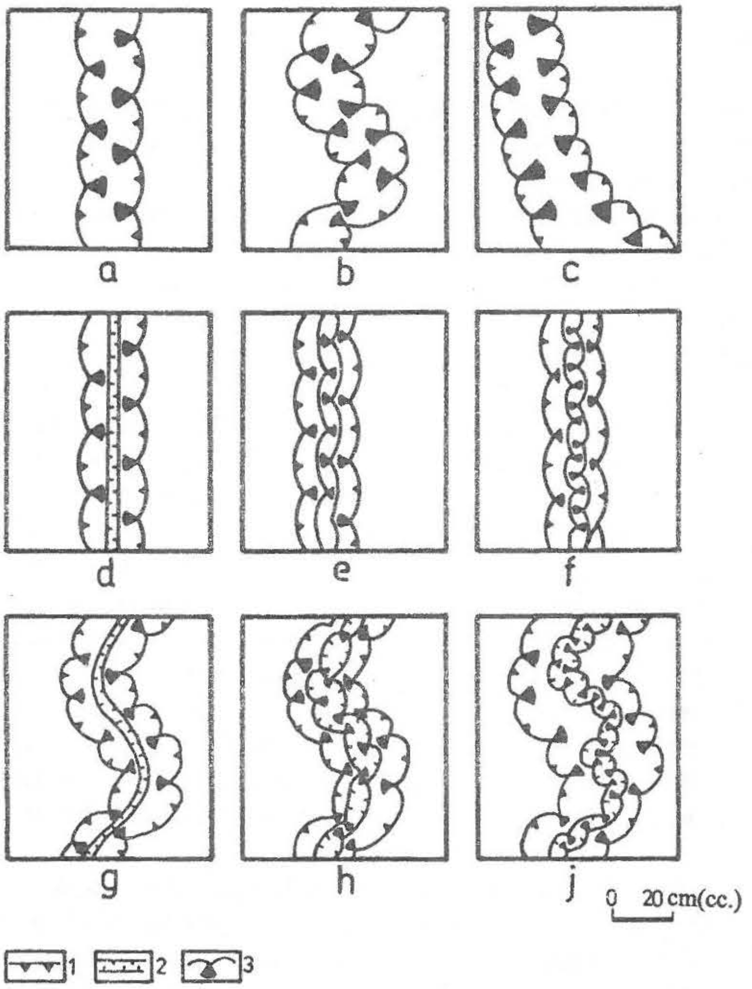

Figure 15: Simple (a, b, c) and composite (d, e, f, g, h, j) troughs with meander remnants Legend: 1. type I trough, 2. type III trough, 3. damaged rimmed trough with skirt, simple troughs: straight (a), with false meander (b), arced (c) composite straight troughs with meander remnants: type I trough with meander remnant, type III trough without meander (d), type III trough with true meander remnants with forced meandering (e), type III trough with truly slipped and forced meander remnants (f) composite false meandering trough: with false meandering type III trough (g), with true meander remnant of forced meandering type III trough (h), with true meander remnant slipped and forced meandering type III trough (j)

The terrace grooves are not of identical height at the two sides. One of the causes of this may be that the solvent surges to the concave side (higher water level) and the other cause may be that the intensity of the solution increases on the skirt when the channel line is near to it. This can happen at decreasing, thus low water level.

III. Meander Types

Karren meanders can be specified in more than one aspects, e.g. by their age or size (*HUTCHINSON, D. W.* 1996). The specification in this paper regards morphogenetic aspects.

Different meanders develop during the development of different karren troughs.

Troughs meander when they are not very frequent or when solitary. If the number of occurrences is large, meandering is less characteristic. There must be a strong relation between the number of troughs and the type of flow of the solvent (it can be a sheet flow or it can be divided to strips). This suggests that the meandering (the swing of the channel line) develops when the solvent flows in strips on the surface. The type of the flow depends on the gradient of the slope as the density of troughs increases with the increasing gradient (*ZENTAI, Z. - HORVÁTH, E. T.* 1995). Thus strip type flow and meandering can be expected on slopes of moderate gradient. The troughs can develop as rainwater runnels or in the regressive way.

The trough (or part of it) will be a rainwater runnel if it entrenches all along its length thus the age of the development is the same at any of its sections. This trough development can occur if the solvent does not move in a sheet flow but in individual strips. The solvent flowing is strips can flow straight down the slope (the direction of the dip of the slope is uniform) on a changing course with false meandering (the direction of the dip of the slope is changing).

In the case of retreating (regressive) troughs the end of the trough shifts in the opposite direction of the slope. Troughs of this type not only entrench but their length increases as well thus their lower sections are younger than the upper ones. The increase of the length occurs because solvent joins the trough-end from surfaces yet free of troughs. As the flow of the water is most intensive parallel to the slope direction, the lengthening of the trough will be opposite to the slope direction. Straight troughs develop if the slope direction is uniform and bending (falsely meandering) troughs develop if the slope direction is changing. The time of the separation to strips of the solvent is earlier than trough development on the same location.

1. False Meander

In false meanders - though the trough is bending - the trough is symmetrical in cross section and neither skirt, nor overhanging wall can not be observed in the bends (*Fig 11a and Picture 1*). This can be explained that the channel line only produced only false swings following the changes of direction of the solvent. This letter followed the changes of direction of the trough. This is possible if the trough develops backwards. (The false meanders are such trough sections that developed along slope parts of different directions.)

In the bends of the false meanders the recess does not separate excessively from the neighborhood (the neck part is missing). In falsely meandering troughs the meander-zone and meander-length is small, the wavelength is long.

2. True Meanders

True meanders develop at the true (factual) swing of the channel line.

2.1. Meander Remnants

The rims of troughs containing meander remnants are arced. Neighboring arcs connecting to each other make characteristic points. The individual points on one rim are located at the half distance of two points on the opposite side. Skirts developed from rim to bottom are located at the points. (The skirts do not continue in such recess parts that are parts of the original ground surface circumvented by the bend.) The side wall is overhanging in the sections between the points (*Fig. 11b, Picture 5*).

The length of the meander arcs of the bend remnants can be very varying compared to the wavelength of the meander regarding that the swing of the channel line can be very varying as well because of the lack of trough walls. The width of the meander zone is relatively small at the same time. This can be explained that the arc of the bends can not increase substantially during entrenchment. The original swing of the channel line is inherited. At the same time the growth of the bends towards their ends is limited by the returning channel line and by the opposite trough rim.

The arced lining of the skirts in the whole extension of each particular trough side but particularly the arced lining of the opposite trough rim proves that the channel line swinging happened on the surface prior to the trough development (channel line swinging prior to trough development). The channel line swings responsible for the development of meander remnants were triggered by internal causes in the case of such troughs that are straight and not inner troughs. The meander remnant morphology suggests the channel line swing of the solvent flowing on the surface that is possible only if the developing trough is not regressive but rainwater runnel type.

It can be observed that the meander remains troughs can not only be of straight lining. As a fact the trough rims don't show dual (composite) arcing. This can be explained only if it is suggested that the solvent causing the uniformly entrenching trough developed false meanders on the surface of varying slope direction. At the same time channel line swing occurred in the falsely meandering solvent. By this effect meander remnants developed on the trough of false meanders. In these cases the wavelength of the bend with meander remnants are always smaller than the wavelength of the false meanders consequently there is a series of bends with meander remnants on a bend of a false meander (*Fig. 12a*).

2.2. Looping meander

The trough turns back on itself in a loop. The slopes and elevation of the recesses surrounded by the loops are identical with that of the original surface. Consequently bend shifting did not occur on the area of the recesses. The trough is asymmetrical, its morphology is similar to that of troughs with meander remnants (*Fig. 11, Picture 6*). The width of the meander zone as well as the length of the meander arc is large, the wavelength of the meander is small or shows a big variety.

Looping meanders develop where the trough changes direction, thus they occur in false meanders (*Fig. 12*). When the difference between the direction of two trough sections is about 90° than the wavelength of the loop will be the same as the wavelength of the false meander. It may occur that the direction of two trough sections are similar (longitudinal trough sections) but these are connected by a transverse section. The transverse section connects to the longitudinal trough sections by false meanders. The wavelength of the two loops is identical with the wavelength of the corresponding false meander. These properties hint that at this meander type the swing of the channel line is caused by the false meandering. Consequently the swing of the channel line can be traced back to an external cause.

If the looping meander is asymmetrical from its rims down means that the channel line swung right at the beginning of the entrenchment of the false meander. In this case the trough development is of the rainwater runnel type.

Looping meanders are most similar to river meanders. These letter can be simple or composite that may have symmetric and asymmetric varieties (*Fig. 13a*). These varieties can be observed at looping meanders as well (*Fig. 13b*).

It is not likely though that looping meanders of varying arcs represent the phases of a development sequence but rather represent the pattern of meandering of the solvent before the development of the trough. Exceptions may be the multiply composite meanders. It is frequently observable here that the multiple composition is caused by the skirt development in the concave arc (counter-skirt). It develops in a way that the swung channel line can not follow the arc of the concave trough wall. It hits the wall at a point and this way a smaller opposite swing occurs. (Caused by this effect the bend becomes one of developing meanders as well.)

The looping meander is a meander type that develops mostly in type III troughs. Especially at locations where the master type I or II trough is wide.

It is possible that the looping meanders develop at the changes of direction of the solvent flow, at functional channel line swings and deviations effected by the developing skirts. According to the above said looping meanders can develop with greater chance at the locations of the direction change of the solvent flow if the change of the quantity of the solvent is the bigger as well as the differences of the parts of the slope are the bigger.

2.3. Developing Meander

The trough rim is straight or if not, the trough is falsely meandering. The upper part of the master trough is symmetric that transforms to an asymmetric trough bottom downwards without a sharp change. The skirts do not develop on the whole side slope of the trough but only at the lower part of it, the overhanging walls don't develop (*Fig. 11d, Picture 7*). There is no recess but if the recess is specified as the area surrounded by the trough rim, it is situated on the skirt.

The described change of the character of the trough cross section indicates that the channel line swing commences at the beginning of the trough entrenchment.

The developing meandering troughs can be either rainwater runnels or retreating ones as the channel line swing is younger than the beginning of the development of the trough. It hints at the regressive origin of troughs of such morphology if the true meanders are missing in the upper stretch them.

Morphological observations indicate - more studies shall be conducted in this respect - that either internal or external causes may contribute to the swing of the channel line.

2.4. Perishing Meander

Asymmetry is restricted to the upper part of the trough. At concave trough rims and above vertical walls giant terrace grooves and hanging terraces develop, skirts of small size develop at the convex side that they gradually merge into the trough sides.

Perishing meanders develop when the channel line does not swing below a certain trough depth. Perishing meanders can be arced rimmed (like the rims of the troughs with meander remnants), or without these. If the trough is arced rimmed, the channel line swing had happened before the commencement of the trough development (rainwater runnel trough development). If the rim of the trough is not arced, the swinging of the channel line occurred during the entrenchment of the trough. In this case the trough can be of either rainwater runnel, or regressive origin. (It hints on regression origin if true meanders are missing in certain parts of the trough.)

The various types of bends occur in the type I, III (*Table 1*) but in type II either.

Table I. Meanders on one of karren ground surface part in Totes Gebirge

	Type I trough		Type III trough	
Sketches of meanders	true meander	false meander	true meander	false meander
 0 5cm(cc.)		+	+	+
 0 5cm(cc.)			+	
 0 5cm(cc.)			+	
 0 5-20cm(cc.)	+	x	+	
 0 5cm(cc.)			+	
 0 5-20cm(cc.)	+	x	+	
 0 5-20cm(cc.)	+			

x special case

IV. The Meandering of Composite Troughs

The meandering of the inner troughs may be false or true. The inner trough contains false forced meanders if its false meanders follow the lining of the false meanders of the master trough. If true meanders develop in the inner trough, true forced meandering develops. True forced meandering can develop either by the false or true meandering of the master trough. Both the false and the true meandering may be similar or shifted forced meandering. In the first case the wavelength and number of bends is identical with that of the master trough (either false- or true meanders), but not in the letter case.

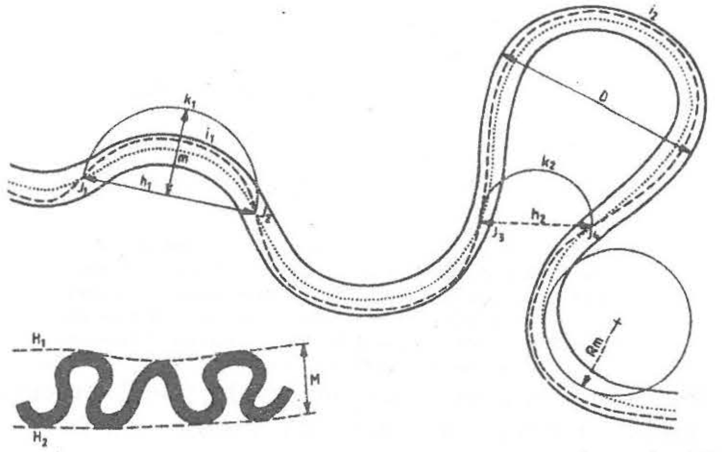

Figure 16a: Main parts of river bends after Z. Borsy (1992)

Legend: J_1-J_4 the inflection points of bends, h_1, h_2 the chords of bends, H_1, H_2 the bounding lines of bends, M the distance of bounding lines of bends (the width of bend), i_1, i_2 the length of the arcs of bends (between the inflection points, along the channel line), k_1, k_2 the circumference of the half circle drawn on the chord of the bend, R_m radius of bend (radius of the circle drawn into the bend), D diameter, m the height of arc measured at right angle to the chord. The middle line of the river is shown with a dotted line, the channel line with dashed line.

If the bending of the inner trough totally differs from that of the master trough (or this is straight) the meandering of the inner trough is false or restricted (*Picture 3*) as well as it can be falsely or truly meandering (*Picture 7*). In the first case the width of the inner meander zone is determined by the bottom width of the master trough, in the letter case the meander zone of the inner trough is less wide than the bottom width of the master trough.

Type I troughs can develop and entrench along their whole length (rainwater runnel type entrenchment) or regressively.

Regressive troughs may be straight or meandering. Straight troughs may be meander-less or with developing meanders. (In the letter case the swing of the channel line commences during the entrenchment.) The falsely meandering troughs may be looping meandering or meander-less as well. Regressive troughs may be simple or composite.

The type II and III troughs in the type I trough of the composite trough are most frequently meander remnants (*Fig. 14a*), or falsely meandering with meander remnants (*Fig. 14b*). In both cases the type III trough is of rainwater runnel origin but in the letter cases it is freely false meandering or restricted true meandering. In a falsely meandering type I trough the type III can be false-meandering or containing meander remnants. The false meandering can be similar forced meandering (*Fig. 14c*) and shifted forced meandering (*Fig. 14d*).

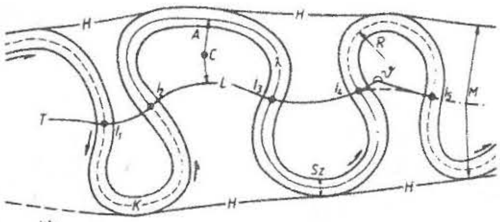

Figure 16b. Main parts of river bends after K. Balogh (1991)
Legend: H the edge of meander zone, I_1 I_2 I_3 ... I_5 inflection points, SZ width of the channel, K the middle line of the channel, J the central angle of the meander, T the line of the meander axis, M the width of meander zone, L wave-length of the meander, l length of the meander, C center of river recess, A width of river recess, R radius of the bend

If the channel line had swung before the trough developed, most of the times rainwater runnels develop with meander remnants. The troughs with meander remnants may be straight (*Fig. 15a*), or containing false meanders (*Fig. 15b*) eventually changing their direction (*Fig. 15c*).

The rainwater runnel type troughs may be simple (*Figures 15a, b, c*) or composite (*Figures 15d - j*). In the letter case mostly type III troughs occur in type I troughs. Inside the straight composite troughs the type III troughs are mostly meander-less (*Fig. 15d*) or it may be a morphology made of meander remnants (*Fig. 15e*). *Fig. 15d* shows a case where the type III trough is regressive while in the cases shown *Figures 15e* and *f* it is a gradually entrenching rainwater runnel type development.

The *Figures 15e* and *f* show true forced meandering. That is, the true meanders in the type III trough are determined by the true meanders of the type I trough. On *Fig. 15e* a true and similar type, on *Fig. 15f* a true shifted forced meander is shown.

Type III trough can develop in falsely meandering type III troughs falsely meandering themselves with regression (*Fig. 15g*) or with a morphology made of meander remnants, that is with rainwater runnel type development. In this case both the false- and true meandering may be similar (*Figures 15g, h*) or shifted (*Fig. 15j*) forced meandering.

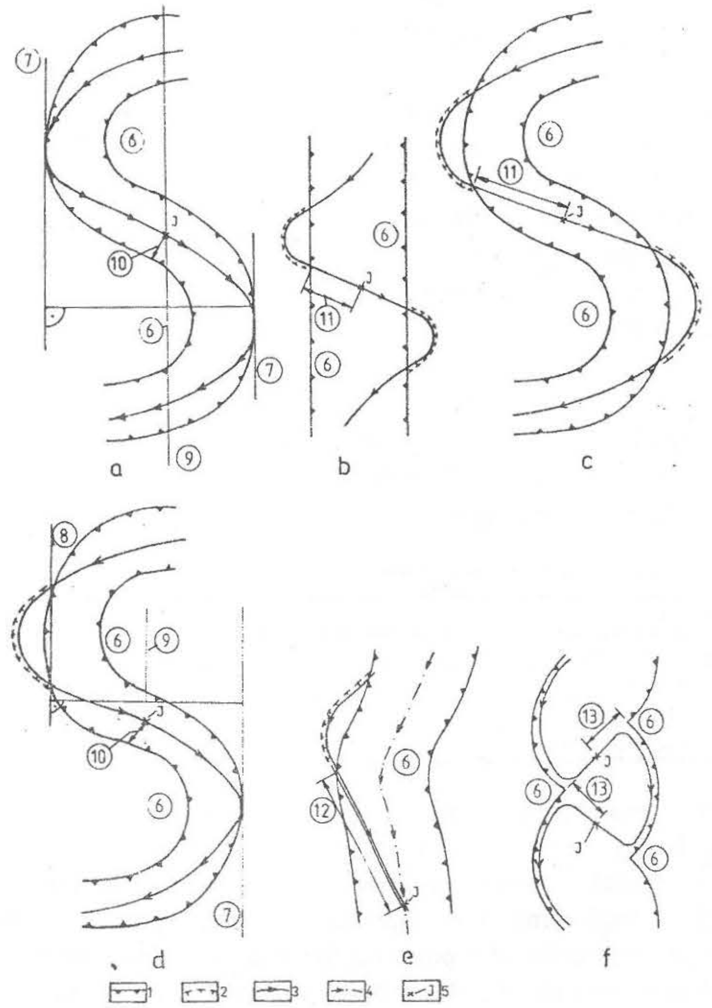

Figure 17: Plotting of inflection points of troughs with various morphology
Legend: a. plotting of inflection points of a meandering river (after J. Cholnoky), and of a trough that has no overhanging wall, b. in the case of straight or almost straight trough, where there are overhanging walls at both sides (developing meander), c. at meandering trough, where the overhanging wall developed at both loops (loop or meander remnant), d. at meandering trough, where the overhanging wall developed only at one loop, e. at falsely meandering trough (the trough sections are at about right angle), where there is only one overhanging wall, f. at trough with meander remnants and without overhanging wall, 1. trough edge, 2. end of overhanging wall at the plain of trough bottom, 3. present channel line, 4. previous channel line, 5. inflection point, 6. skirt, 7. bounding line, 8. The straight passing through the end of overhanging wall, which is parallel with the bounding line of the next loop, 9. middle line, 10. half width of the trough at the middle line, 11. shortest half width between the ends of opposite overhanging walls, 12. The straight line received as the extension of the original channel line at the end of the overhanging wall where it crosses the original channel line, 13. the shortest half width between opposite neighboring skirt tips

V. The Correlation of the Causes of Meandering and the Sizes of Meander Components

1. The Components of Karren Meanders

Besides the component that have been described (meander wavelength, meander arc length and meander zone width) the following are specified (*BALOGH, K.* 1991, *BORSY, Z.* 1992, *Fig. 16a, b*). The sinuosity of the meander is the ratio of the channel line and the axis length of the meander between two inflection points.

The rate of development (β) of the bend is determined with the equation (*LACZAY, I.* 1982):

$$\beta = \frac{i}{h}$$

where i is the length of arc along the channel line,

h is the wavelength of the meander or the chord of the bend,

LACZAY, I. (1982) specifies river bends with the values of β (*Table II*):

Table II: River bend types specified by their development (LACZAY, L. 1982)

type of river bend	value of β
undeveloped bend	< 1,1
developed bend	1,1-1,4
well developed bend	1,4-3,5
fully developed bend	> 3,5

The measurement of the various components of the trough bends is made possible by the drawing of the various channel lines on the survey map.

The initial channel line can be determined as the central curve between the trough rims. The opposite trough rim points can be staked out where the perpendicular of a point on the trough axis intersects the rims. The present channel line can be described with such a curve that merges to the bottom of the overhanging walls and passes through the inflection points. (Where there is no overhanging wall the channel line can be determined by the connecting of the inflection points with those points of the rim that are touched by the envelope curves.) Inflection points between neighboring bends of different morphology can be plotted using the methods shown on *Fig. 17.* (The lining of the channel line is varying during any single function. Thus it is possible that the channel line that can be plotted will approximate the channel line that occurs at high water.) The plotted channel lines of a surveyed trough (No. 7) are shown on *Fig. 18.* The validity of the plotting can be checked. The present channel line is of acceptable precision if the inflection points are situated on the original channel line. (It can be seen that this hasn't been achieved in all cases.)

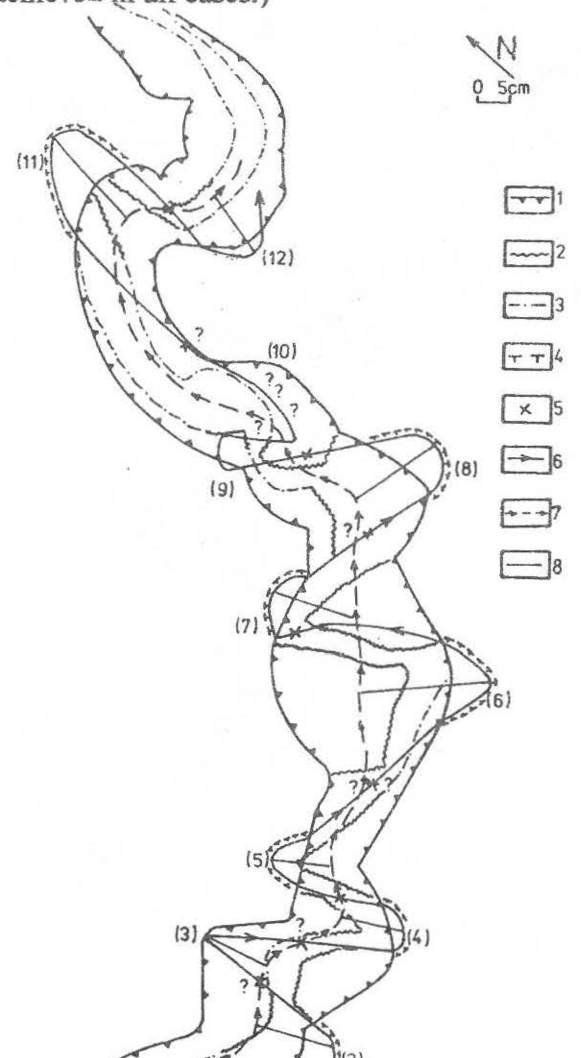

Figure 18: Constructed channel lines of trough No 7 (number in parenthesis identifies the loop)
Legend: 1. edge of type I trough, 2. lower edge of skirt, 3. end of gently sloping trough, 4. bottom of overhanging wall at the plane of the trough bottom, 5. inflection point, 6. present channel line, 7. previous channel line, 8. accessory straight along which the Sk_k and Sk_j values can be measured

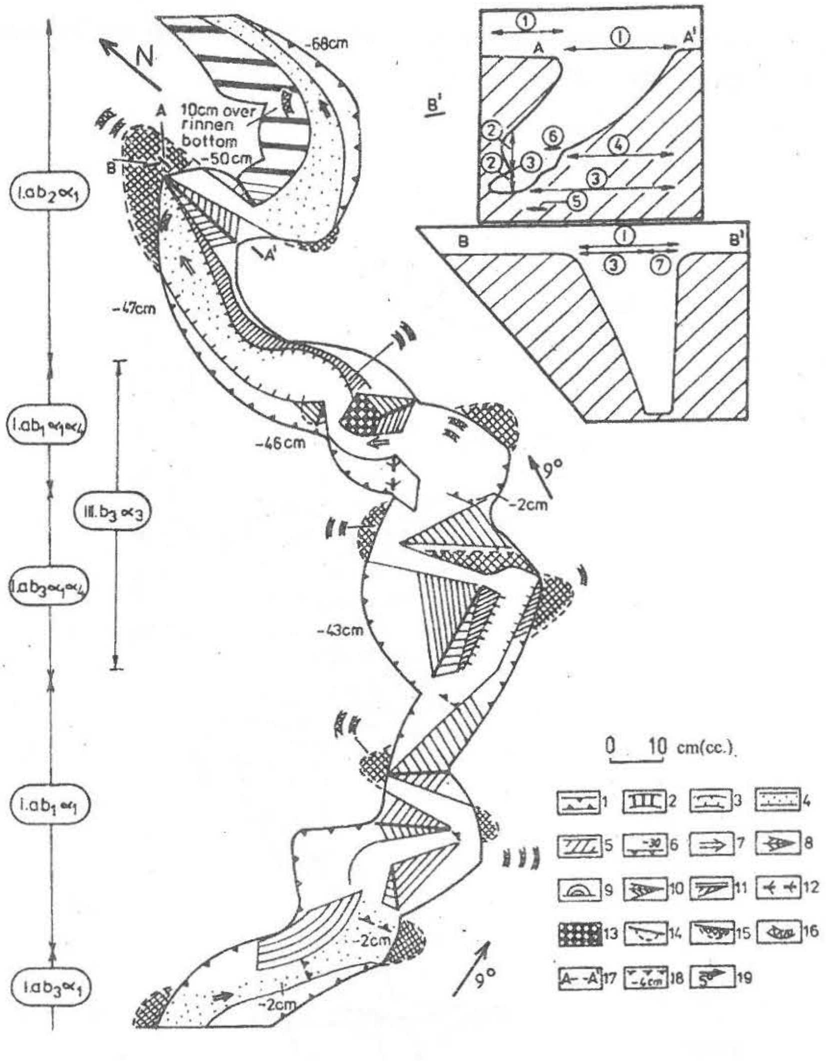

Figure 19: Morphological map of trough 7

Legend: 1. vertical side wall of type I trough, 2. gently sloping trough side of type I trough,, 3. vertical side wall of type III trough, 4. plane trough bottom, 5. trough bottom terrace, 6. depth of trough (in centimeters), 7. slope direction of trough bottom, 8. half pyramid skirt, 9. half cone skirt, 10. asymmetric skirt, 11. half skirt, 12. skirt remnant with sharp pectination, 13. meander terrace on skirt, 14. overhanging wall, 15. meander terrace at overhanging wall, 16. terrace groove and major terrace groove (the position and size of the small terrace groove in the bend is not drawn to scale), 17. position of section, , 18. solution threshold, step with depth (in centimeters), 19. The gradient and slope direction of the surrounding rock surface, a. falsely meandering trough section, b. truly meandering trough part (b_1 with meander remnants, b_2 loop meandering, b_3 developing meandering, b_4 ceasing meandering), the swinging of the channel line is due to internal (α) reason (α_1 false meandering of trough, α_2 flowing water of tributary trough, α_3 the bend or its skirt, α_4 edge of trough), section: 1. overhanging wall of concave trough rim, 2. terrace on concave trough side, 3. skirt, 4. upper skirt remnant, 5. lower skirt remnant, 6. terrace groove on the skirt, 7. trough bottom

In the knowledge of the present channel line and the inflection points the length of the meander arc and the wavelength of the meander can be measured and from these results the stage of development of the meander can be calculated.

The maximum of the slippage can be determined at a bend determining the difference between the present and original channel line (Sk_j) and the difference between the initial slippage and the original channel line (Sk_k) in the plane of the map (*Fig. 20*). This is nothing else but the biggest measure of the overhanging of the concave trough rim that can be measured in the plane of the trough bottom with a few exceptions (not detailed here). The slippage intensity (L_i) belonging to a certain trough depth can be determined:

$$L_i = \frac{Sk_j - Sk_k}{m}$$

where (Sk_j) is the difference between the present and original channel lines measured on the map.

(Sk_k) is the difference between the initial slippage and the original channel lines measured on the map.

m is the depth of the trough in the bend.

The number expressing the intensity of the slippage determines the measure of the swing (lateral shift) of the channel line at unit entrenchment. The number expressing the intensity of the slippage is negative at opposite slippage because $Sk_k > Sk_j$.

2. The Analysis of the Meander Components of Surveyed Troughs

Correlation between the slope gradient and the components of meanders (slippage intensity, channel line swing) is sought for in the following. *HUTCHINSON, D. W.* (1996) found correlation between the sinuosity of meandering troughs and the slope gradient. He found that the smaller is the slope gradient, the bigger is the sinuosity. It is not clear in the quoted communication from which measures of the trough has been the channel line calculated. This has an importance because using the length of the bending trough rim the sinuosity of the trough before the entrenchment can be determined.

Nine meandering troughs were surveyed and the scale 1:5 and 1:10 contour (*BARNA, J.* 1998) and morphological (*VERESS, M.* 1998) maps were drawn. On four of the contour maps the channel lines were successfully drawn and from one of the other maps data for the calculation of the slippage intensity were measured (*VERESS, M.* 1998). The topographic map (showing the channel lines) and the morphological map of trough No. 7 of the mentioned troughs is presented in the paper (*Figures 18, 19, Picture 8*).

The values of the slippage intensity were studied in relation with the gradient of the host surface. The numeric data of the various troughs were grouped by meander type considering if the development of the meander was resulted by internal or external causes.

Data of average slippage intensity calculated for the four troughs shows (*Fig. 21*) that the slippage intensity depends on the slope gradient in a reverse linear way. From the function produced by the usage of the data it can be determined that the slippage is 0 at 15.49° slope gradient while it is the biggest, 0.3501 at 0 °. This letter value can not actually occur as at 0 ° slope there is no flow and so there is no channel line swinging. At the producing of the function the No. 6 trough has been disregarded because of a reversed slippage. Quite naturally more data would be needed for the more accurate determination of the relation of the slippage intensity and slope gradient.

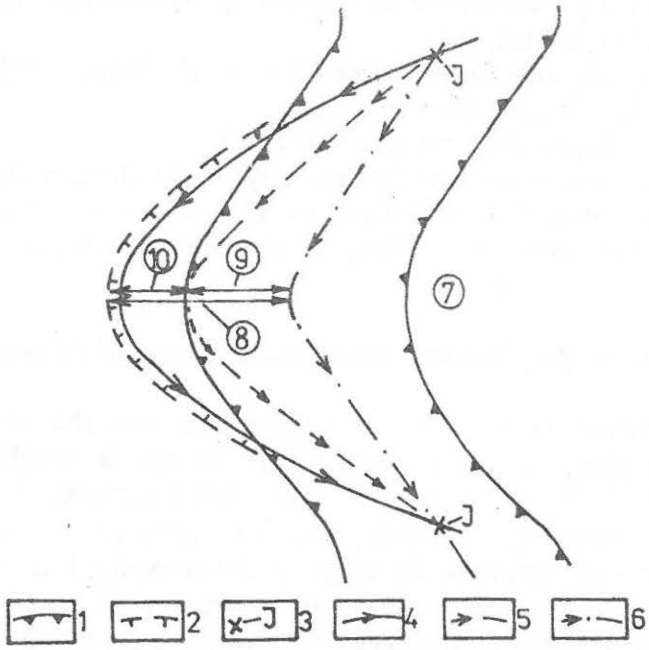

Figure 20: Swinging of channel line and its components
Legend: 1. trough rim, 2. end of overhanging wall at the trough bottom plane, 3. inflection point, 4. present channel line, 5. channel line at the start of slippage, 6. previous channel line, 7. skirt, 8. Sk_j, *9.* Sk_k, *10.* $Sk_j - Sk_k$

The dependence of the slippage intensity on slope gradient can be probably explained with the fact that at large gradients there is no sufficient time for the swinging of the channel line. (Intensive trough entrenchment is explained by the quick flow of the solvent.) Consequently at larger slope gradient less swing occurs at unit entrenchment. The quick entrenchment of the trough can factually cause the swing as the existing trough wall decreases the measure of the channel line swing. When the trough wall develops quickly the swing is hindered right at the beginning thus the process of self generation is hindered as well. (In self generation it is understood that because of the channel line swing an asymmetrical trough shape is resulted that just promotes later swinging.) The fact that the ever accelerating flow does not result lateral but vertical dissolution hints that the slope gradient has a greater role in the shaping of flow properties than those effects responsible for the channel line swing (internal and external causes). It hints to the relative independence of swinging from the slope gradient that the slippage intensity varies with the internal and external causes. In the case of an internal cause the average of the slippage intensity is 0.0928, while 0.2439 or 0.2966 at external causes (*Table III*). The fact that the slippage intensity is bigger at an external cause may signal that the external cause effects the swinging in a greater degree than the internal one. It seems that at some such troughs where the swinging of the channel line is caused by false meandering the increase of the slope gradient increases the magnitude of the swinging. (The swinging of the channel line is 1.85 cm in the No. 3 trough on a 3.29° slope and it is 4.45 cm in No. 7 at a 8.1° gradient slope.) This might be explained that the quicker is the flow of the solvent it has the more chance that the channel line hits the entrenching trough rim. For this reason the lateral solution is not slowed down during entrenchment. In the No. 1 trough however the channel line swing is large at small slope gradient, therefore for the analysis of the relation between the slope gradient and the swinging of the channel line of false meandering in origin further survey is needed. In any case the listed data indicate that the swinging of the channel line can occur on land surfaces of various gradients.

According to the data shown in Table III the stage of development of the meander depends on what caused the swinging of the channel line (internal or external cause), because the meanders made by external causes are more developed than those made by internal causes (2.5135 and 1.8724).

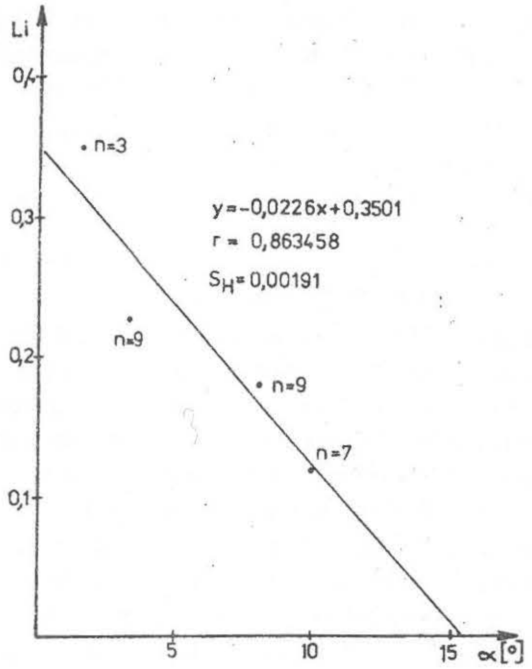

Figure 21: Relation of the slope angle and slippage intensity

4. Conclusions

a. The classification of the forms of karren meanders and the explanation of the development of the forms offer information to the understanding of the processes of solution on the trough bottom and to the knowledge about one variant of meandering that is connected with the process of karren development.

b. The development of the karren meanders and their forms have been deduced from the swinging of the channel lines of linearly flowing solvent.

c. With the classification of the meanders of the karren troughs two main types of trough development were recognized - the rainwater runnels and the regressive troughs. Those troughs that contain meander remnants, perishing meanders or looping meanders (these letter are asymmetric from their rims), are probably rainwater runnels. Falsely meandering troughs and those containing developing meanders (if their upper end is falsely meandering) are of regressive development.

d. The qualification of the simple but mainly the composite karren trough meanders offers data for the development of individual troughs. With the explanation of the troughs occurring on any particular part of a karren ground surface the explanation of the development of a major karren ground surface becomes possible.
e. The slippage intensity (L_i), that is, the lateral shift of the channel line at unit entrenchment depends on the gradient of the host ground slope. The occurrence of the swinging of the channel line and thus the development of a meander does not depend on the slope of the host surface if it has any.
f. The development of the bend (that is expressed mostly in the growth of the arc of the channel line) is big if the solvent swings in the shallow trough at the beginning of the entrenchment and the swinging persists during the entrenchment. Thus the development of bends (and the stage of development) is influenced by two effects: the effect of the channel line swinging and the slope gradient. The letter has an indirect influence such as the swinging of the channel line slows down in a smaller or bigger degree. It is suggested that the slope gradient influences the swinging of the channel line directly too if it is caused by false meandering.

Table III: The averages of components (using the data measured in the Nos. 3, 4, 6, 7 troughs)

meander type	loop	developing			remnant			all types	
cause of the swinging	external n=3	internal n=7	external n=13	all n=20	internal n=2	external n=6	all n=8	internal n=10	external 21
length of the bend	45,75	23,5	18,6153	21,0576	27,5 (66,71)*	33,5833	30,54	25,5	32,6495
wave length	15,125	12,0	10,38	11,19	16,0 (16,87)*	13,8333	14,9166	14,0	13,1128
stage of development	3,0233	2,0210	1,8992	1,9601	1,7239 (4,08)*	2,6181	2,171	1,8724	2,5135
intensity of slippage	0,3336	0,1056	0,2300	0,1678	0,08 (-3,32)*	0,1608	0,1204	0,0928	0,2439 0,2966**

* the number in parenthesis belongs to trough No. 6 (n=7)
** with the data of trough No. 3 (n=3)

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PICTURES

1. False meander (Asiago Plateau, Italy)

2. True meander (Totes Gebirge)
Legend: 1. skirt, 2. overhanging wall

3. Meander terraces (Totes Gebirge)
Legend: 1. type I trough, 2. type II trough, 3. skirt terrace, 4. terrace at overhanging wall, 5. giant terrace groove

4. True meander developed at false meander (a meander of the trough shown on picture 3)
Legend: 1. skirt, 2. overhanging wall, 3. giant terrace groove, 4. skirt terrace, 5. terrace on skirt, 6. type III trough

5. Meander remnant (Totes Gebirge)

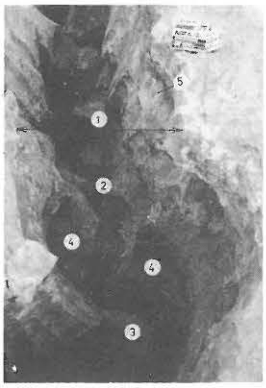
6. Loop meander (Julian Alps, Slovenia)

7. Meanders of a composite trough (Totes Gebirge)
Legend: 1. falsely meandering type I trough, 2. freely meandering type III trough, 3. loop meander, 4. developing meander, 5. skirt, demolished by type III trough

8. Trough No. 7 and its meanders (Totes Gebirge, see the qualification of the meanders on Fig 19,)

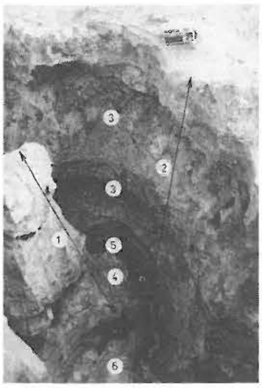
1.

2.



3.

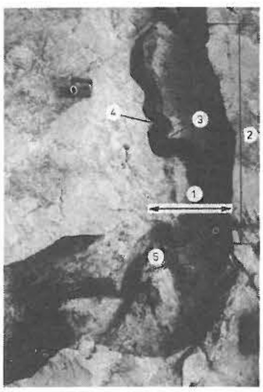
4.



5.

6.

7.



8.