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EXPERIMENTAL GEOMORPHOLOGY AND THE INTERPRETATION OF STONE-LINES

BY

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Summary. – This paper summarizes recent insights into a series of pluvial processes which might have contributed to the formation or destruction of a stone-line profile : i.e. sheetwash, splash creep, runoff creep, rill erosion and colluviation.

Résumé. – *Géomorphologie expérimentale et interprétation des stone-lines.* – Cet article résume de récentes observations sur une série de processus pluviaux qui peuvent avoir contribué à la formation ou à la destruction d'un profil à stone-line : l'enlèvement de particules fines par le ruissellement diffus, le splash, la reptation sous l'effet du ruissellement, l'érosion en rigoles et le dépôt des produits érodés par le ruissellement.

Samenvatting. – *Experimentele geomorfologie en interpretatie van de stone-lines.* – Deze studie vat recente bevindingen samen over een reeks pluviale processen die kunnen bijgedragen hebben tot de vorming of de vernietiging van een stone-line profiel : het meevoeren van fijne deeltjes door diffuse waterafvloei, de kruipbewegingen door splash en afvloei, de geultjeserosie en de vorming van colluvium.

Introduction

It is generally accepted that the discussion of most stone-line profiles belongs to the domain of hillslope processes and slope morphology. Summarizing a complex literature one may recognize several fundamental fluxes of sediment governing the genesis of stone-lines :

a. Dominantly vertical fluxes either bringing material down by creep movements or moving it to the surface by faunal activity, e.g. by termites. It may also result from eolian deposition.

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b. Predominant lateral fluxes by mass movements or by splash erosion and running water. The transport can be grain-size selective or not.
c. Selective erosion, both in a horizontal or in a vertical sense, can result in the formation of lag deposits. Prehistoric man may also have contributed to the concentration of the dispersion of (coarse) material.

With VINCENT (1966) one may identify in many stone-line profiles 3 levels : a toplayer A which is finely textured, a gravel layer B and the underlying (weathered) bedrock C. Generally, toplayer A is poorly sorted and dominantly loamy-sandy to loamy-clayey. Therefore, it is a more or less cohesive level. Exceptional are the sites with more than 80% sandy material.

Thickness and the degree of sorting of layer B are often fairly variable. Sometimes the gravel layer is discontinuous. It can be a rectilinear level but often the stony material is concentrated in a very irregular pattern, suggesting rills or gullies. Sometimes B is multilayered. Its base generally cuts off a weathered bedrock.

Bedrock C may have been source for coarse material concentrated in the B layer and issued from veins or duricrusts, i.e. lateritic horizons.

This general description of the stone-line complex is sufficient to discuss the possible role of overland flow in its formation. Thereby various conditions, between soft sheetwash and powerful gully erosion, are taken into consideration, with emphasis on the results of process studies obtained in the laboratory and in the field.

Overland flow and the origin of stone-lines

1. SHEETWASH

DE PLOEY (1971) and later SAVAT & DE PLOEY (1982) have enlighted the role of surficial liquefaction and liquefluction on sandy material. These sediments have a very low cohesion c', inferior to 1 kPa. Raindrop impact causes in the toplayer an annihilation of shear strength by positive porewater pressures. The result is promoted sheetwash and a low probability of rill formation. Under such conditions the B layer becomes rather continuous and rectilinear. Deposition of the toplayer by sheetwash is then also possible.

Special attention may be paid to loamy subsoils which behave as pseudosands, due to strong aggregation by clays and sesqui-oxides. Such material too is prone to the same process of sheetwash with liquefaction although the grain-size composition erroneously suggests cohesive properties.

Sheetwash may have been promoted by gravel and pebbles which disperse runoff on their interspaces. This could occur at the time when layer B was corresponding to an old land surface. There seems to be an ambivalent effect of stone covers on runoff generation. On the one hand, gravel and stones intercept raindrops and dissipate their impact energy, so that surface sealing is impeded and infiltration rates increase (EPSTEIN & GRANT, 1966). YAIR & LAVEE (1976), however, found that stone covers promote runoff yield on steep talus slopes in the Sinai desert because of the delivery of water by stones to the interspaces. Downslope, this effect increases the erosivity of the flow.

Another factor influencing surface sealing, infiltration rates and runoff generation on stony soil surfaces is the position of the stones in the top layer. Maximal surface sealing will occur if the stones are well embedded *in* the top layer. On the other hand, if the stones rest *on* the soil surface, sealing will be reduced and, hence, considerable runoff volumes can infiltrate into the soil under the stones (POESEN, 1986).

2. SPLASH CREEP

Splash erosion not only means the ejection of fine particles and aggregates on interrill soil surfaces. Raindrop impact is capable to displace gravel, up to 2 cm in diameter with a resultant downslope movement which is called splash creep. In one heavy tropical rainshower the material can move, on low to medium slopes, over a distance of cm. If at the same time some runoff occurs, with a unit discharge q, then splash creep is enhanced as was shown by extensive laboratory tests of MOEYERSONS and DE PLOEY (1976).

It is evident, therefore, that the integrated effect of splash creep over geological periods is not at all negligible. For gravel the total yearly downslope movement may amount to dm or m. Experiments suggest rather a maximal displacement on sandy subsoils to which the gravel is not sticking.

3. RUNOFF CREEP

Not only gravel but also coarser material, pebbles, shows up- and downslope micromovements induced by turbulent flow and vortex erosion around the obstacles which are pebbles. This so-called runoff-creep occurs at low unit discharges, between several $cm^3/cm.s$ and several tens of $cm^3/cm.s$ (DE PLOEY & MOEYERSONS 1975, DE PLOEY *et al.* 1976). The most fundamental mechanisms of runoff-creep are still poorly understood but the effects are evident in tests. For the equivalent of one long rainstorm, the movements are of the order of mm, mainly downslope on poorly cohesive sands, like granite grus. But rill flow, on the same substratum, may cause unexpected upslope tilting due to vortex erosion at the upstream side of the pebbles, when q is of the order of tens of $cm^3/cm.s$. Thus an inversion occurs, from downslope to upslope movements, when passing from low to high overland flow discharges.

Runoff-creep seems to be less efficient on sticky, cohesive clayey loams, whereon incision produces pebbles sitting on small pedestals.

4. RILL EROSION

A first condition for the formation of rills is overland flow in more or less cohesive material, a condition often fulfilled in tropical areas. Furthermore, rill erosion supposes the following hydraulic conditions :

a. sufficient concentration of overland flow, and
b. shear velocities and shear stresses of the water should permit a dominant non-selective transport of grain-size fractions.

A first review of field data – among them some originating from tropical areas – brought SAVAT and DE PLOEY (1982) to the conclusion that most rills generate on critical slopes of 2°-3° or 4%-5%. The hydraulic explanations for this threshold condition have been recently given by GOVERS (1985) and RAUWS (1987). On slopes, inferior to 2°-3°, there is often an insufficient concentration of overland flow so that the critical shear stresses for non-selective transport are not reached.

This discussion supposes a poorly vegetated soil which is not too stony. It means that the interpretation of the stone-line complex implies some information or some assumptions about paleo-ecological conditions.

5. THE EVACUATION OF COARSE MATERIAL IN RILLS

Field measurements on a field plot in the Belgian loam region have been performed to find out which erosion processes are capable of moving stones from upland areas (POESEN 1987).

Monitoring coloured stones placed on interrills as well as in rills, revealed that during a moderate rainfall event (i.e. 6.0 mm during 12 min), rock fragments up to 9.0 cm in (intermediate) diameter travelled downslope by rill flow (Table 1). On interrills, however, the biggest rock fragments which moved during this event had intermediate diameters of 0.9 cm.

Table 1

Huldenberg field data on rill flow competence

Rill site		S_{max}	q_{max} (cm²/s)	D_{max} (cm)
Transect	Rill no.			
White	1	0.058	10.2	1.25
	2	0.074	14.0	6.2
	3	0.067	6.4	2.6
	4	0.123	27.9	5.7
Red	1	0.155	21.2	4.3
	2	0.158	21.3	> 7.8
	3	0.150	52.8	> 5.4
	4	0.176	54.6	9.0
Green	1	0.200	38.8	4.2
	2	0.188	20.5	> 6.1
	3	0.194	46.8	6.0
	4	0.222	47.0	6.3
Blue	1	0.222	40.1	5.7
	2bis	0.306	29.8	5.8
	3	0.268	78.2	7.5
	4	0.268	27.0	5.8
Yellow	1	0.087	30.8	4.65
	2bis	0.111	2.4	5.4
	3-4	0.067	99.7	7.0

S_{max} = maximum gradient of rill bed ; q_{max} = maximum rill flow unit discharge, calculated with the rational formula ; D_{max} = mean maximum intermediate diameter of rock fragments, moved by rill flow during the period of observation.

From the preceding it is clear that the competence of the rill flow, i.e. the ability of the flow to transport rock fragments as measured by the size of the largest stone it can move, exceeds almost by a factor 10 the competence of the interrill flow. Hence, rill flow and other forms of concentrated flow (e.g. ephemeral gully flow) can be held responsible as the most important processes which evacuate stones from upland areas.

Interesting to note is that the critical slope (Scr) for rill flow transport of stones, having diameters between 1 and 4 cm, varied in our study between 0.041 and 0.061. These threshold values were obtained by extrapolation of the curves, fitting the data points in a "rill bed slope – transport distance" diagram for 4 selected rills (Fig. 1). This observation indicates that incision of rills in stony soils can start during moderate rainfall events on hillslopes, having gradients above these Scr-values. These critical slopes are in agreement with reported Scr-values for starting rill and gully formation on colluvial fine gravels (i.e. 0.035, NEWSON 1980) as well as on loamy soils (i.e.

0.04-0.05, Savat & De Ploey 1982). These observations indicate that complete surface armoring due to selective erosion of the fines and the concentration of rock fragments at the surface, will essentially occur on slopes less than the Scr-values mentioned. Above these critical slopes, the probability of complete surface armoring decreases.

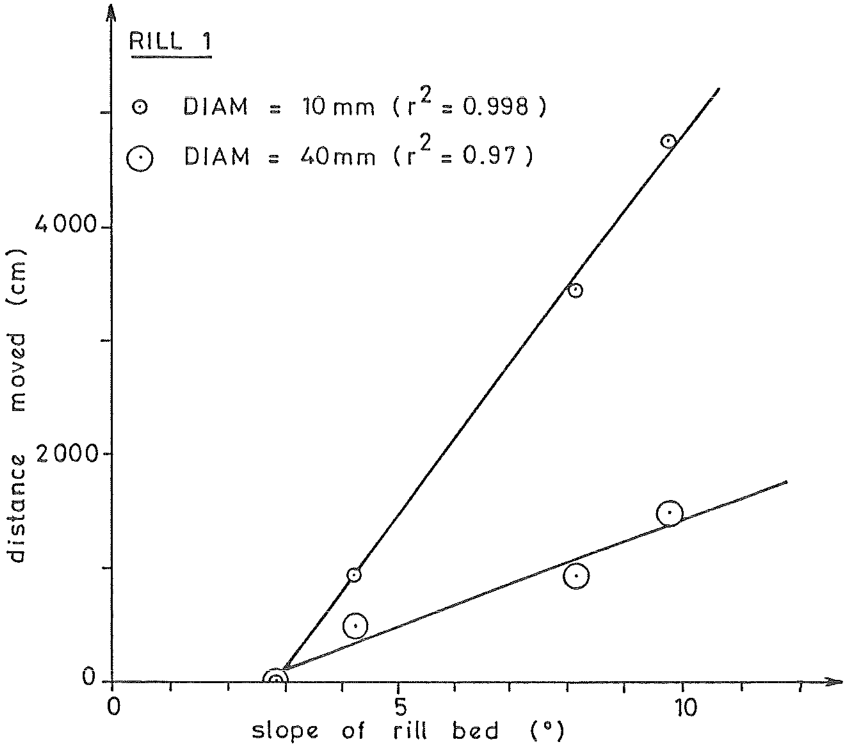

Fig. 1. – Relation between slope of rill bed and transport distance for two pebble sizes.

6. Colluviation

Experimental research on loamy material permitted the elaboration of a model which brings together :

a. the critical slope angle S_{cr} for starting sedimentation,
b. sediment concentration c,
c. unit discharge q and,
d. a grain-size factor A, proportional to D_{50} (De Ploey 1984) :

$$S_{cr} = A.c^{0.8}/q^{0.5}$$

This model predicts sedimentation of silty loams on medium slopes of 5°-10° when c amounts to several hundreds of g/l, concentrations which are realistic on highly eroded subsoils. Thereby, it has to be mentioned that q decreases during the afterflow phase, at the end of a rainstorm, a situation promoting colluviation on relatively steep slopes.

The colluviation model may be of interest to specify sedimentary conditions of layer A, e.g. on different types of pediments with a slope angle of several %.

The presence of rock fragments in colluvial deposits is an important pointer to the type of processes acting on the upland during the period of colluviation. In fact, number and maximum size of stones found in colluvial deposits reflects the competence of the overland flow which transported them downslope, provided that overland flow is the responsible process and provided that a broad range of fragment sizes was available on upslope sections at the time of upland erosion. From field observations in the Belgian loam region, characterized by slopes varying between 0 and 15°, it can be safely said that rill and/or (ephemeral) gully flows are the main processes responsible for the evacuation of rock fragments from uplands (POESEN 1987). Hence, the presence of rock fragments having diameters of several cm in colluvial deposits of such a landscape, indicate that rilling or gullying must have been active during the period of colluviation.

Conclusions

The paper enlightens recent process studies which should be taken into account when discussing the genesis of the stone-line complex.

Striking is the discovery of conditions under which coarse elements, gravel and pebbles, can be evacuated. It becomes now evident that the delivery of this coarse material to rivers, especially during periods corresponding to the formation of level B, may have been underestimated. On the other hand, the colluviation model suggests possible sedimentation of fine sediments on substantial slopes, up to 5°-10°. The latter could be useful when interpreting the sedimentary conditions of layer A.

REFERENCES

DE PLOEY, J. 1971. Liquefaction and rainwash erosion. – *Zeitschr. f. Geomorphol.*, **15** (4) : 491-496.

DE PLOEY, J. 1984. Hydraulics of runoff and loess loam deposition. – *Earth Surface Processes and Landforms*, **9** : 533-539.

DE PLOEY, J. & MOEYERSONS, J. 1975. Runoff creep of coarse debris : experimental data and some field observations. – *Catena,* **2** : 275-288.

DE PLOEY, J., SAVAT J. & MOEYERSONS, J. 1976. The differential impact on some soil loss factors on flow, runoff creep and rainwash. – *Earth Surface Processes,* **1** : 151-161.

EPSTEIN, E. & GRANT, W. 1966. – Rock and crop-management effects on runoff and erosion in a potato-producing area. – *Trans. A.S.A.E.,* **9** : 832-833.

GOVERS, G. 1985. Selectivity and transport capacity of thin flows in relation to rill erosion. – *Catena,* **12** : 35-49.

MOEYERSONS, J. & DE PLOEY, J. 1976. Quantitative data on splash erosion simulated on unvegetated slopes. *Zeitschr. für Geomorphol.,* Suppl.-Bd. **25** : 120-131.

NEWSON, M. D. 1980. The erosion of drainage ditches and its effect on bedload yield in mid-Wales : reconnaissance case studies. – *Earth Surface Processes,* **5** : 275-290.

POESEN, J. 1986. Surface sealing as influenced by slope angle and position of simulated stones in the toplayer of loose sediments. – *Earth Surface Processes and Landforms,* **11** : 1-10.

POESEN, J. 1987. Transport of rock fragments by rill flow – a field study. – *Catena,* Suppl. **8** : 35-54.

RAUWS, G. 1987. – The initiation of rills on plane beds of non-cohesive sediments. – *Catena,* Suppl. **8** : 107-118.

SAVAT, J. & DE PLOEY, J. 1982. Sheetwash and rill development by surface flow. – In : BRYAN, R. & YAIR, A. (eds.), Badland Geomorphology and Piping. Geo Books, Norwich, pp. 113-126.

VINCENT, P. 1966. – Les formations meubles superficielles au Sud du Congo et au Gabon. – *Bull. Bureau Rech. Géol. et minières,* **4** : 53-111.

YAIR, A. & LAVEE, H. 1976. – Runoff generative processes and runoff yield from talus mantled slopes. – *Earth Surface Processes,* **1** : 236-247.