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GENETIC CLASSIFICATION OF SLOPE SEDIMENTS

POSITION AND SIGNIFICANCE OF THE TOPIC

An almost indispensable prerequisite to the planning of expensive buildings and constructions is a profound knowledge of the dynamism of the relief and of the materials in which it is sculptured. It is with this purpose in mind that detailed soil mechanical, geotechnical and geomorphological special maps are drawn up and published. These maps and the texts of the explanatory notices attached to them may be fairly different according to the particular purpose in view, but they have the common denominator of representing the lithology and dynamism of the relief. Lithology is not, however, presented according to uniform principles. The above-mentioned special maps usually reflect the grain size gradation, the strength, or some other statical property of the surface or sub-surface sediments and a classification of these sediments on this basis. In the author's opinion it is, however, necessary to look beyond this practice and to set up and apply a genetic classification of sediments in order to derive from the knowledge of their origin a foreknowledge of the possible dynamic behaviour of the relief. This holds particularly for the genetic classification and the representation on maps of the slope deposits of rolling, hilly and mountainous areas and of the steep bluffs of the plains.

The classification of any slope as stable, semistable or unstable is, however, usually a time-consuming operation requiring in some cases the application of instruments; but the necessary time and the instrument or instruments are not always and not everywhere available.

The action of the various dynamic phenomena affecting the relief may be either episodic or periodic and, in the latter case, of a daily, seasonal, annual or other rhythm. The nature and efficiency of the processes acting in any particular case and the trend of relief changes to be expected can often be derived just from a systematic genetic interpretation of the slope sediments [1].

The recognition of these relationships is the fruit of a long experience in the field, of systematic research into and analysis of the connexions between the types of sediments and the processes that produce them. In the absence, up to the present time of a genetic classification of slope sediments, including a systematic attribution of their individual types to particular features and processes acting upon the slopes, the necessity has arisen to establish a comprehensive system of slope sediments with due regard to the view-points of geomorphological and geotechnical mapping.

FACTORS AFFECTING THE ORIGIN OF SLOPE DEPOSITS

The vertical structural deformations of the Earth's crust, more or less rhythmical in space and time, bring about the essential level differences of the relief, without which there would be no slopes and no slope deposits. Exogenic agencies then initiate the evolution of the slopes which in its turn gives rise to the formation of slope sediments.

The nature of the relief, and geomorphological features in general, profoundly affect and control the formation and distribution of slope sediment facies. It is mainly through the evenness or otherwise of the slope and through its climatic exposure that the morphological configuration brings about differences of facies among the layers of slope deposits. In Hungary e. g. the deposits on south-facing slopes and the fillings of derasional valleys consist of deluvial—pluvionival waste, every layers of which are well stratified, whereas in the same lithologic environment accumulation by solifluction is much more common on north-facing slopes [2].

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[1] E. g. from the correct recognition of semistable slumps or sub-recent rockslides or soil heaps.

[2] The explanation of this state of facts is presumably that the snow cover had melted, particularly in the glacial phases, prior to deep thawing of frost soil: under such circumstances, the meltwaters effected a superficial slopewash and deposited thin layers of sediment on the periodically (daily)

The role of the lithology of the deposits constituting the relief depends on the nature of the bedrock, occasionally of the weathered layer, in the area of erosion of the process depositing the slope sediment.

Differences in morpho-lithogenic factors entail differences in the sequences of various elements of the relief and thus give rise to homologous sequences. The steep rocky slopes of the mountains carry slope deposits consisting largely of coarse waste, whereas the portions of finer grain-size become increasingly frequent with increasing distances from the rock exposures and the percentage of coarse debris in the slope deposits shows consequently a regular vertical variation. On the other hand, in the rolling regions sculptured in ill-consolidated Tertiary deposits, slope sediment sequences consist of more or less homogeneous compositions of sand, loess and clay and of mixtures of these, depending on the nature of the underlying Tertiary sediment. The distribution of slope deposits outlined above is of a more or less general validity.

Climatic (hydro-meteorologic) conditions affect the slope deposits regionally (in function of the climatic zone involved) as well as locally (in function of slope exposure). They determine the intensity of weathering and comminution, the quality and quantity of the waste to be carried away, the nature of the vegetal and soil cover, the nature of precipitations, the periodicity of slopewash, the nature and intensity of the processes modelling the relief, the periodicity of downslope movement and the nature of the transporting medium. The joint influence of all these factors affects and sometimes determines the rhythmicity of transport and accumulation on the slope.

This is why the changes of the climatic conditions seasonal as well as those of longer duration affect the dynamism of the processes of transportation and hence also the nature of the sediments deposited.

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freezing and thawing soil surface. After the snowmelt, the top layer of the south-facing slopes dried out much faster than that of the north-facing ones: in other words, the conditions favourable to solifluxion existed for a much longer period of every year on the north-facing slopes than on the south-facing ones (water saturation of soil, supply of sufficient quantities of meltwater, regelation). Since the south-facing slopes were substantially degraded by Pleistocene slope evolution, the dynamism of that evolution underwent an even more substantial weakening, resulting e. g. in the cessation of slumps and slides.

In other terms the genetic types of Quaternary slope deposits and the areal distribution of these types were controlled by the joint dynamism of the structural, geomorphological and lithological features of the relief and of the climato-morphological processes acting in the region under consideration. It is consequently only by a joint evaluation of all these factors that a genetic classification of slope sediments is possible; conversely, from the knowledge of the origin of the slope deposits in a given region one may reconstruct the dynamism of ancient slopes and forecast of a slope the future behaviour.

The rhythmical changes in space and time of the factors enumerated above entail a rhythmicity of slope evolution and hence also of the accumulation of slope deposits.

In Hungary, slope deposits are almost exclusively Quaternary, as the Pliocene relief was little differentiated, and most of the country was covered by a shallow lake. The non-uniform crustal movements of the Quaternary resulted in a periodic and non-uniform emersion of the system of Carpathian basins, simultaneously with repeated climatic changes ranging from warm-temperate to periglacial. Owing to these latter circumstances, the thick and heterogeneous mantle of Quaternary, mainly Pleistocene deposits covering our mountains, hills and hummocks exhibits locally a rhythmic alternation of colluvial, delapsial, solifluxion, deluvial and proluvial slope deposits, eolian and fluvial portions of layers and buried soil horizons.

METHODOLOGICAL PROBLEMS OF THE CLASSIFICATION OF SLOPE DEPOSITS

In a comprehensive system of sediments and sedimentary rocks, slope deposits come under the heading of continental-terrestrial deposits. Their distinction from the other related types of subaerial deposits — fluvial, eolian, glacial etc. — has not, except for a few pioneering publications (Demek, 1953; Kaplina, 1965; Klatka, 1962; Lavrushin, 1965; Pécsi, 1962; Rohdenburg, 1965; Schanzer, 1962; Starkel, 1965), been systematically treated from the methodological point of view.

As a matter of fact, even a rigorous delimitation of the concept of slope deposits is lacking and, as a consequence, a definition of the content of this concept is lacking too. In scientific practice, deposits accumulated by processes of mass wasting—rockslides, slumps, mudflows, creep — have so far been unequivocally classified as slope deposits. The classification of the products of slopewash as slope deposits is not by far so unequivocal, nor is there a consensus of opinion as regards proluvial deposits. Some authors classify waste transported and deposited by torrential waters as products of slopewash whereas others range them among fluvial deposits.

There are undoubtedly some transitional types of deposits. A genetically transitional type is e. g. eolian dust deposited on a snow cover, carried away by meltwaters in the spring, which can be termed a niveo-eolian, or, if rains also played a role in its transport a pluvio-eolian deposit.

As regards such transitional types or deposits reworked by several agencies it is most expedient to consider always the last transporting agency which has deposited the sediment in its present site. The determination of the nature of this "delivering transporter" may be based upon either mineralogical and grain--size composition, or wear, stratification, texture, etc. of the sediment and the relation of its bedding to the actual relief.

The fundamental trait of slope deposits is that, as opposed to other subaerial deposits, the processes of accumulation are highly manifold both as to their dynamism and as to the nature of the transporting medium. Transportation and deposition can be due to spontaneous mass wasting by gravity (rockslides, slumps, roll, creep), to the plastic or fluid flow of wet or water-saturated sediment and to regelation (mudflows, solifluxion) and finally to slopewash.

Except for the case of slopewash, no transporting medium in the common sense of the word can be pointed out, or at best the sediment moving downslope can itself be regarded as its own transporting medium. Of course, the water effecting slopewash is itself so loaded with waste — mud, silt — that the entire slurry thus constituted can be regarded as the transporting medium. In such cases, the transporting medium and the waste transported in it constitute a single unit both as regards erosion and accumulation.

From the analysis of their geological, lithologic and geomorphic features, slope deposits can in most cases be readily distinguished from other subaerial deposits. Of course, not all types of slope sediments exhibit all the typical features of this class of deposits. The distinctive criterion may consist of a certain feature or of a group of features.

In this sense, the general properties of slope deposits are the following:

(1) The portions of layers are more or less parallel to the relief existing at the time of their deposition and exhibit consequently varying dips along various sections of the slope profile.

(2) The portions of slope deposits have a microstratified [3] texture. The layers imitate the configuration of the underlying relief. If the relief underwent a change in the course of slope sediment deposition — by smoothing, truncation etc. of the slope — the change of slope angle is reflected in the dip of the subsequently deposited strata.

(3) The grains of coarse or mixed slope deposits are almost unworn; mineralogically (or petrographically) they consist of local material. If a well-worn fluvial or eolian deposit is reworked by slope processes, there is a mixture of the otherwise well-sorted grain-size types: the exclusive presence of local material, the geometry of the deposit and the texture of the sediment are indicative of accumulation on a slope.

(4) Absence of sorting is typical of several types of slope deposits (slumps, slides, soil flows, solifluctional deposits): clay, sand and debris occur in helter-skelter, irregular mixtures.

The apparently better-sorted finer-grained slope deposits (slope loess, slope sand, reworked soil) are also ill-sorted in a relative sense, containing as they do bands of widely differing in grain size (fine detritus in slope loess, clay in sand, etc.).

(5) Detritus rolling downslope and sediment transported by slopewash may, however, form better-sorted layers whose dip is gentler than that of the underlying slope.

Both the finer and the coarser slope deposits often contain grains of reworked soil, clayey B horizons, humus or soil minerals.

Owing to the wide range of their properties a definition of slope deposits must be necessarily of a fairly general nature.

By slope deposits we mean sediments of a wide range of lithologic features, deposited in the form of a mantle by processes of mass wasting, plastic or fluid flow and slopewash either on the slope itself, or in the form of a scree or cross-stratified cone, at the foot of the slope.

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[3] Microstratification is present in all types except in the products of large-scale mass wasting such as rockslides.

The sequence of slope deposits may be interrupted both horizontally and vertically by other subaerial deposits such as eolian loess on the slope and fluvially deposited waste at its foot. In regions of glacial accumulation, a distinction between glacial and slope deposits is sometimes far from simple.

Nor is a distinction of the individual genetic types of slope deposits always simple: it requires a great deal of experience, laboratory work and a knowledge of the dynamism and conditions of deposition.

Evolution of research methodology to the required level will necessitate a great deal of painstaking analytical work. The results achieved so far will be summarized in the chapter on the genetic types of slope deposits.

GENETIC TYPES OF SLOPE DEPOSITS

ROCKSLIDES (COLLAPSIA—COLLUVIA) *

The ground mass of these deposits is formed in the protogenetic stage under peculiar lithologic, orographic and climato-morphologic conditions. (Steep or overhanging walls, rock faces from which insolation, frost, and other processes of weathering liberate a more or less coarse-grained debris.) On less steep rock surfaces, the slow creep of boulder fields and scree may exhibit a seasonal periodicity dependent upon a similar periodicity of comminution by frost and frost-pressure. Rockslides and rockfalls may further be due to earth-quakes, snow avalanches, occasional instability as the final stage of slope or shore evolution by erosion.

If the debris moving downslope is due to processes operating with a seasonal rhythm, steeply dipping stratified ill-sorted deposits of talus and scree come into existence (see Table I: types 2 and 4), which may under various conditions of diagenesis be cemented into a solid mass or be comminuted further *in situ*.

Another type of slope deposits due to mass wasting includes unstratified heaps of debris, sediments or earth whose constituent elements show no regular inner texture (see Table I: types 1 and 3). Their recognition is facilitated by their geomorphological

* Deposits of this type usually figure in the literature under the name of colluvia, but considering their origin the name *collapsia* seems to be more expressive.

setting, irregular form and unworn-unsorted material. Their frequent occurrence is restricted geographically to areas of considerable relief energy in temperate and cold regions with alternating frost and thaw and in dry hot regions with intense insolation. In the Pleistocene periglacial zone of Europe, which also included Hungary, conditions for the formation of such features were in several phases much more favourable than to-day. In the cold and dry glacial phase the frost limit lay much lower than actually and large amounts of debris were produced by frost. In function of exposure, bedrock and slope angle, these constituted a cover of varying thickness, variously interbedded with layers of finer-grained sediments.

EARTHSLIDES (DELAPSIA)

Sedimentary sequences containing clayey or loamy interbeddings may along well-lubricated slide surfaces, mostly in a state of intense saturation with water, be torn off their base by gravity and repeatedly reworked in the course of their journey downslope.

Most earthslides are local phenomena, but under a humid climate and certain favourable orographic, lithologic and hydrogeologic conditions they may be fairly frequent. Owing to the wide range of these conditions, the final products of earthslides also exhibit a wide variety of types both as to form and lithology. Certain types of earthslide (Table I: 6 and 7) may be accompanied by mudflows and evened by slopewash, but the entire water-saturated mass may itself creep until slope equilibrium is attained and the moving mass is temporarily stabilized. The links of this chain of events follow so rapidly upon each other that it is very hard to distinguish the individual stages. With regard also to engineering purposes, the following three fundamental types of earth slides can be distinguished:

(a) imbricate slide: occurring where sediments form a steep face or bluff; it takes place along a lubricated plane or curved surface at the base of the sediment complex. Length and height of displacement is small, the shorn off slices of the displaced sedimentary complex constitute a structure similar to an imbricate mountain mass.

(b) block slide: the glide plane lies significantly higher than the base of the sedimentary complex and is relatively steep;

the sediment mass is displaced as a single body — *en bloc* — to the foot of the slope. Repeated block slides may give rise to a topography of irregular mounds at the foot of the slope but the texture of the sediment is preserved within the individual mounds.

(c) mass slide: the glide surface lies also in this case high above the base of the sedimentary complex disclosed by the steep face or bluff, but the moving earth mass undergoes plastic, or — if saturated with water — fluidal deformation before reaching the foot of the slope. This is transitional towards mudflow. The result of a mass slide is an irregular scatter of debris or soil in an intensely kneaded pelitic ground mass (Table I: 7).

The formations described above can be distinguished from the results of earth- or mudflows by the morpho-lithogenetic features of the environment, by the major coherent blocks of original sediment in the material of the slide and by grain-size analysis.

ROCKFLOWS AND MUDFLOWS (SOLIFLUXIA)

This group comprises the products of reworking and accumulation by gravity of water-saturated plastic or fluid weathered masses, soils and screes on the slopes of temperate and warm humid regions. Movement and accumulation of the mass is largely seasonal but may be episodic as well, e.g. in mud-volcano eruptions, in which case the movement is fast but short-lived. On the other hand, the redeposition downslope, of thoroughly saturated clayey sediments on steeper slopes is slower but observable and seasonal in its rhythm.

Below the cover of plants and topsoil, water-saturated scree on the steeper mountainsides is in slow creep measurable with instruments only; brought about by gravity, this type of movement is promoted by freeze-and-thaw and seasonal changes in ground water movement.

The types within this group (Table I: 8, 9, 10) can be distinguished on the basis of their lithologic composition. Another typical feature is the presence of thin clayey layers separating the layers of a few dozen milimetres in thickness of other sediments. Distinction from gelisolifluxia formed under periglacial conditions is possible on the basis of pollen and grain size analysis, inspection of section and study of occasional mollusc shells. Gelisolifluxia usually exhibit syngenetic ground frost phenomena and other traces of a cold climate: in the absence of such, a distinction is fairly difficult.

SOLIFLUXION DEPOSITS ABOVE A FROZEN SUBSOIL (GELISOLIFLUXIA)

Seasonal thaw in the actual periglacial zone results in a plastic--fluidal state down to a few dozen centimetres depth of the topsoil saturated with meltwater. Gravity and daily freeze-and-thaw result in the displacement downslope of this mass or in its repeated reworking. In the foreland of the Pleistocene ice sheet, in a zone of several hundred kilometres width, this process played a very important landscape-modelling and sediment-forming role. In most places in the Carpathian basins where slopes consist of clay, clayey soils or clayey scree, the results of these processes can be observed in most sections of Pleistocene slope deposits.

As a result of research carried out on Hungarian deposits, gelisolifluxia have been subdivided on the basis of their structure, stratification and grain size distribution into four principal groups which correspond to the four principal processes of accumulation (Table I: 11, 12, 13, 14). The most readily recognisable type is the product of laminar solifluxion, a segment of more or less irregularly bedded lenses, a few centimetres in thickness, of clay, loam and other fine-grained weathering products.

These segments are presumably due to an imbrication in the plastic state of uppermost few centimetres of a thawed clayey topsoil above a frozen base, whereas in the early summer, when the thaw penetrated deeper but ground water became scarcer, laminar solifluxion was followed by a somewhat deeper-reaching amorphous ground movement. This process deposited a chaotically mixed sediment. The two above-mentioned types constitute the majority of all gelisolifluxional deposits. However, the movement of soil and sediment could take place under certain conditions also in tiny furrows and bands. The sediments thus accumulated though likewise ill-sorted and mixed, are in the profile perpendicular to the dip of the slope showing chains of crescent- or u-shaped depressions in the lenses, whose surfaces are studded by grains of debris. This is striated solifluxion (stone stripes, striated soil, *Streifenböden*: Table I: 12a, b) (Pécsi, 1961, 1963).

In garland solifluxion, debris in a clayey matrix, moving beneath a cover of grass, constitutes pillow-shaped tumours on the slope. Distinction from the foregoing types is not possible except in large sections where the texture and geometry of the layers are clearly visible.

A typical feature of gelisolifluxia is the common occurrence in a single kneaded mass of clay, sand, gravel and debris particles which never occur together in a sediment deposited by water or wind.

SLOPEWASH DEPOSITS (DELUVIA)

Rain and snowmelt give rise to a sheet of water which carries away fine particles of sediment and redeposits them in the form of finely striated sediments either on the slope itself or at its foot. These are slope deposits in a narrower sense, or still better slopewash deposits. This process is active — to some extent at least — in almost every climatic zone. Under certain conditions, however, — very humid climate, semiarid climate with sparse vegetation and occasional showers, gentle slopes made up of ill-consolidated sediments in a steppe environment, eradication of the natural plant cover, tilling of the slopes etc. it may be of particular intensity and efficacity. In hills and mountains where large areas of forest growing on a loose soil have been felled, this artificial influence may have resulted in particularly strong slopewash and deposition of slopewash sediments.

In the Danube basins, reworking of sediments by this process was particularly intense on the slopes covered with sparse grass of the cold and slightly humid or semi-arid climatic spells of the Pleistocene glacial phases. Under periglacial conditions, slopewash acted first and foremost upon the slopes consisting of loess, sand and other fine-grained clastics, while the slopes that were richer in clayey particles were mostly under the influence of gelisolifluxion.

Deposits of meltwaters and rain (cryonival and pluvial slopewash), occurring in the form of microstratified slope deposits parallel to the slope (see in more detail in Pécsi, 1962, 1965) occur interbedded in layers of 1 to 5 m thickness with sediments deposited by gelisolifluxion (type 17 in the Table I) and winds. A distinction from wind-borne sediments is possible on the basis of grain-size microscopic study of grain shapes and inspection of the geometry of the beds in the sections. Let us note that there is a number of frequent transitional types between sandy loess, loess-like eolian and deluvial deposits (niveolian, pluvioeolian types). In the classification given in Table I (types 15, 16 in part) are regarded as deluvia.

Most slope deposits in Hungary belong to the group of deluvia. As to their age, most belong to the cold, slightly humid phases of the Pleistocene glacial phases. A detailed investigation of certain key sections has proved that even within the last glacial phase, deluvia and gelisolifluxia were repeatedly formed and occur today interbedded with unstratified eolian sediments (P é c s i, 1962, 1964, 1965, 1966). As to their position in areal geography, deluvia are most abundant on gentle south-facing slopes, less so on north-facing ones.

WASTE TRANSPORTED BY INTERMITTENT STREAMS (PROLUVIA)

Sheetwash is sooner or later concentrated by the microrelief of the slope to form minute furrows at first and ravines and gullies farther downslope, in some places on the convex slope segments alone, in others — down to the foot of the slope or to the bed of an intermittent stream. The profiles of this "drainage", developed either all by itself, or under the influence of some sort of human activity, are very steep and the periodical rushers of rain may carry extremely unsorted waste in very high concentrations. Some of this waste is deposited where the slope becomes gentler or where it levels out at its foot, to be overlain by layers of finer-grained sediments as the rain abates. Hence, even at one and the same point of such a "drainage network", sediments widely differing in grain-size distribution may be deposited within a short time. The unsorted waste involved in this process forms waste cones at the foot or on the gentler sections of the slope: this is why this type of sediment is here classed under the heading of slope deposits.

In some portions of these waste cones the sediment is mixed, unsorted, but there occur also layers parallel to the slope. Mantle like waste fans consisting largely of coarse and unworn debris, more or less cemented by subsequent processes, are termed fanglomerates. However, in regions where hummocks and foothills consist of less consolidated and finer-grained sediments, most proluvia consist of sand, sandy and loessy deposits. The proluvial origin of these is proved by the texture and geometry of the layers, the presence of bands of debris and calcareous concretions at several levels.

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