Analysis of the Segmentation in the Profile of Alpine Talus Slopes

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ABSTRACT

A method for analysing the segmentation in the profile of talus slopes is used in an Alpine periglacial environment. Two populations of talus slope profiles are examined according to the development of their headwalls. Beneath massive rockwalls the profile appears bi-segmented: a break point situated at a constant angle (33-34 degrees) divides an extensive proximal segment with a shallow curvature from a shorter and more concave distal segment. When the headwall disappears, the segmentation is modified and a concavity extends throughout the profile. A new model for talus slope formation is proposed in which the rockfall mechanism and the removal processes are combined.

RESUME

Une méthode d’analyse de la segmentation du profil des éboulis est expérimentée dans les Alpes, en milieu periglaciaire, sur deux populations de talus d’éboulis se différenciant par le développement de leur paroi dominante. Avec une paroi massive, le profil apparaît bi-segmenté: un point de rupture (Φ) situé à une valeur de pente stable (33-34 degrés) sépare un segment proximal doté d’une concavité à grand rayon de courbure et comprenant en longueur plus de la moitié du profil d’un segment distal plus court et à concavité plus accentuée. Quand la paroi disparaît, la segmentation évolue et peut aboutir à l’extension d’une seule concavité à tout le profil. Des arguments sont avancés pour présenter un modèle nouveau pour les éboulis de gravité en matériel à faible cohésion, dans lequel le mécanisme de chute et les actions de remaniement sont combinés. Ce modèle concorde bien avec les résultats des études effectuées récemment sur ces formations de pente dans plusieurs milieux periglaciaires.

KEY WORDS: Talus  Slope evolution  French Alps  Headwall

INTRODUCTION

Numerous profiles have been measured of talus slopes in various climatic environments and for many lithological groups. The most systematic studies are those of Piwowar (1902), Rapp (1960a, 1960b), Andrews (1961), Melton (1965), Malaurie (1968), Howarth and Bones (1972), Young (1972), Chandler (1973), Carniel and Scheidegger (1974), Statham (1976), Church et al., (1979), Albjar et al., (1979), Caine (1983) and Hétu (1986). Because talus slopes have traditionally been considered as accumulations of granular material deposited by individual rockfalls, analyses of their angle distribution is of great interest for generating talus slope evolution models (e.g. Van Burkalo, 1945; Carrigy, 1970; Chandler, 1973; Kirkby and Statham, 1975; Statham, 1976; Carson, 1977).

In testing scree material in the laboratory to determine characteristic angles and to simulate
rockfalls, two antagonistic models have been developed. The older one, proposed by Ward (1945) and more recently by Carson (1977), considers the talus slope to be at the repose angle of the material. This angle approaches 35 degrees, an angle generally found on natural talus slopes and thought to reflect the constant redistribution of material from the apex to the base by slow creep or dry avalanching processes. More recently, Kirkby developed. The older one, proposed by Ward the material. This angle approaches 35 degrees, an angle generally found on natural talus slopes and surface. This dynamic friction angle concept implies that the slope angle is less than the repose angle (i.e. angle of residual shear), as measured in shear box tests, because the latter is achieved only when the rockwall is completely buried.

Relatively few studies have examined the talus slope geometry in a natural environment. In general, the majority of profiles include a straight slope in the upper part and a concave slope in the basal part (e.g. Andrews, 1961; Howarth and Bones, 1972; Young, 1972; Statham, 1976; Church et al., 1979). Kirkby and Statham (1975) infer that the straight-concave pattern is due to an exponential distribution (Poisson law) of particle travel distance on the scree slope. For others, mainly working in snow environments, the basal concavity mainly depends on processes such as snow avalanches and debris flows (e.g. Rapp, 1960a, b; Church et al., 1979; Hétu, 1986; Kotarba et al., 1987). Caine (1969) provides the only coherent model for slush avalanching as the principal process, but subsequent studies have not confirmed its validity (e.g. Gray, 1973; Whitehouse and McSaveney, 1983; Luckman, 1988).

In our study of talus slopes we have assumed that the profile is segmented. This is based upon two field observations: (1) there is a general downslope displacement of particles on the upper part of the talus, and (2) there is extensive fall sorting along the profile. If most of the material falling down the cliff were to come to rest on the upper part of the talus and if this material were to be removed by gravity-induced processes which stop before the base, a 'break' would appear, theoretically, on the profile. By contrast, a constant inclination of this break point would suggest that material has achieved an angle of stabilization. It can also be assumed that the pattern of profile segmentation changes according to the development of the headwall, because this controls (a) the quantity of material supplied to the talus and (b) the probability that certain particles will reach the basal section.

**METHODS**

Thirty-five talus slopes were examined on low-cohesion materials in the French Alps (Briançonnais, 45°00 N, 6°30 E) at elevations between 2500 m and 3000 m a.s.l. The underlying lithologies were predominantly granites, gneisses and quartzites. The 0 °C isotherm is located close to 2500 m a.s.l. At these altitudes snow covers the talus for at least seven months of the year. Profiles were measured in 10 m segments from the base to the top of each talus slope. Accuracy of the slope angle measurements was close to half a degree.

The slope profiles were divided into two groups according to the size and shape of the headwall, using two headwall parameters: (1) relative height, defined as being the height of the talus slope (H₀) divided by the height of the talus slope plus the height of the headwall (H₁), and (2) mean inclination (αᵣ). A first group consisted of 18 talus slopes with massive and steep headwalls. In this group H₀/H₁ < 0.5 and αᵣ > 45 degrees. A second group consisted of 17 talus slopes with indistinct or missing headwalls. In this group the H₀/H₁ value varied between 0.5 and 1.0 and αᵣ < 45 degrees. In total, 724 slope segments were identified, of which 369 were in the first group and 355 were in the second group.

A purely geometric data processing approach was adopted, based upon 'soft' modelization. Let P be the slope, let t be the fractional distance upslope on the scree and assume that each profile is roughly linear within each zone. Its derivative will be approximately a step function and its second derivative will be nearly zero, except in the neighbourhood of each point of rupture, where it will present a step. Cubic smoothing splines are frequently used by statisticians in order to represent a signal. A parameter, ρ, permits one to differentiate between the 'smoothing' and the 'interpolation' term (Wegman and Wright, 1983). The main point of this procedure, as applied to talus slope profiles, is to identify the coordinates of principal discontinuity points which are present throughout the profile. In the simplest case (the straight-concave pattern) only one break point (ψ) occurs and the profile is 'bi-segmented'. In more complex cases several breaks appear along the profile. Some of these are local and accidental, and may be neglected. Others, which are signalled by
the second derivative, produce durable alterations in the profile. Two have been recorded in our analyses, noted as $\psi_1$ and $\psi_2$ according to the decreasing value of the second derivative.

RESULTS

Group One

One can distinguish two general patterns: (1) an exponential curve presenting a clear and single break in the profile (Figure 1a, profile ELAa8), and (2) a more complex curve (higher value of $\rho$) with several breaks (Figure 1b, profile ETCa3). In both cases a proximal segment extends to 50-60% up the profile with a large shallow concavity. This segment precedes a shorter distal segment with a more pronounced concavity. The transition occurs at point $\psi$. Figure 2 plots the coordinates of selected break points and shows that $\psi$ has a relatively uniform value for the majority of slopes: 33-34 degrees and 0.5-0.8 $t$. On the profiles with several break points it is possible to identify one well-marked break at 33-34 degrees and another may appear near the apex at 35-37 degrees. In this case, the second break point relates to the talus slope whose upper part has penetrated the rockwall by a chute.

Group Two

Three patterns are typical: (1) a tri-segmented pattern, including a straight slope followed by others which are more curved (Figure 3a, profile ELaw2), (2) a pattern which tends to fit with a straight line (Figure 3b, profile ELAa5) and (3) a profile with a straight and extensive proximal slope followed by a short and strongly concave distal slope (Figure 3c, profile EARa1).

Synthesis

The data suggest that the segmentation of talus profile changes according to the size and inclination of the headwall. As shown in Figures 2 and 4, a high headwall (1) leads to a bi-segmented profile with a pronounced break point $\psi$ whose position is quite stable. Stability involves angle value, always being close to 33 degrees. A small or...
TALUS SLOPE EVOLUTION

The evolution of the rockwall-talus slope system may be considered as a bi-phase model.

In the beginning, owing to the height of the headwall, detached blocks fall down the talus with great energy and are spread throughout the profile. One can assume that the probability of particle deposition decreases downslope, an assumption confirmed by several authors who have measured supply rates throughout the profile (e.g. Gardner, 1983; Pérez, 1985; Hétu, 1986; Luckman, 1988; Francou, in press). It is also well known that talus deposits, especially in the proximal zone, exhibit high mobility (e.g. Rapp, 1960b; Pissart, 1964; Gardner, 1979; Pancza, 1979; Hétu, 1986; Pérez, 1988). This type of non-cohesive material displacement has various origins. These include dry avalanches, impact energy transmitted by falling blocks, changes in the stability conditions due to matrix eluviation, and thermal variations around the freezing point. The sieve effect (Carniel and Scheidegger, 1974), generated by burying small particles under larger ones, maintains a constant instability, as pointed out by Church et al. (1979).

The constant occurrence of break point \( \psi_2 \) at 33-34 degrees can be explained by the transition from a deposit-transport system in the proximal segment to a pure accumulation system in the distal segment (Figure 6). Break point \( \psi_1 \), therefore, represents a ‘dynamic’ break. This pattern is also reflected in sorting above and below the break point. The proportion of small-size particles (a-axis < 10.0 cm) rapidly decreases downslope of this point (Francou, 1988).

The second stage of evolution occurs when the rockwall tends to disappear. As the height of fall declines, chutes develop and large-size deliveries become less frequent. As a consequence, the movement of rockfall debris downslope tends to become shorter and accumulation zones are limited to the foot of the headwall. Oversteepening of the apical talus section continues to induce movement which is marked in some profiles by a break point.
Figure 3 Profiles of three talus slopes with low or missing rockwalls in Group Two. (a) ELAw2, tri-segmented profile with rockwall; (b) ELAa5, profile tending towards one concave slope; (c) EARa1, profile tending towards straight slope with extinction of the headwall.

Figure 4 Types of talus profiles according to the development of the headwall. 1. Massive headwall; 2. Declining headwall. $\psi_p$, principal break point; $\psi_p^*,$ break point in proximal position; $\psi_d,$ break point in distal position. Numbers underlined indicate slope angles of break points. Numbers not underlined indicate slope angles of segments. The dotted lines indicate different possible positions of the break point in the profile.
CONCLUSIONS

The principal inadequacy of the traditional scree-rockfall model of talus slope evolution is its inability to deduce slope evolution from the dynamic friction angle concept. Furthermore, it places the angle of repose at too high a value. Our analysis of the segmentation in the talus profile in the French Alps leads us to propose another concept of talus slope evolution. Talus is viewed as an assemblage of slopes which combine different dynamics and which work at different rates. As long as the rockwall is massive and active, the rockfall mechanism is the dominant process and talus slope development fits well with a bi-phase model. As the rockwall declines, removal activity becomes more important. In order to further refine this model, it is necessary to conduct studies upon the variability of granulometry and mobility of talus material. These may confirm the dynamic significance which we attach to the profile segmentation.
ACKNOWLEDGEMENTS

The assistance of colleagues and friends is gratefully acknowledged, especially Laurence Manté for data processing and Frank Dellion for data collection in the field. Les White corrected the English draft translation and Professor Hugh French (Ottawa) made numerous modifications and improvements to the final text. The comments of an anonymous referee are appreciated by adoption.

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Francou Bernard, Manté C. (1990)

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Permafrost and Periglacial Processes, 1, 53-60

ISSN 1045-6740