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Influence of large scale topography on gravitational rock mass movements: New insights from physical modeling

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[1] Gravitational slope failures and associated rock mass movements can be observed at various scales in the same area. It seems obvious that the different movement scales should be interrelated, but their relationships are poorly understood. We address this problem using 3-D physical modeling. Experiments were conducted with mechanically homogeneous models with two-scale topographic features. A large scale corresponds to the whole mountain (several kilometers), and a smaller one to a part of a mountain slope (~one kilometer). Results show that large scale relief induces large-scale (large volume) gravitational movements. Introduction of small-scale topographic features results not only in the generation of smaller-scale landslides, but also in considerable changes in the deformation pattern. The various-scale processes occur simultaneously and affect each other. To predict the evolution of a landslide, it is therefore necessary to take into account the topography and deformation pattern at various scales. **Citation:** Bachmann, D., S. Bouissou, and A. Chemenda (2006), Influence of large scale topography on gravitational rock mass movements: New insights from physical modeling, *Geophys. Res. Lett.*, 33, L21406, doi:10.1029/2006GL028028.

1. Introduction

[2] Gravitational rock mass movements can affect only a part of the mountain (rockslides or rockfalls [Hutchinson, 1988]), but frequently gravity driven deformation involves the whole mountain, as in the case of Deep Seated Gravitational Slope Deformation or Sagging/Sackung [Zischinsky, 1966; Beck, 1968; Savage and Varnes, 1987; Hutchinson, 1988; Crosta, 1996; Agliardi et al., 2001]. The various-scale mass movements should be interrelated [Agliardi et al., 2001] but their relationship remains generally unclear [Bisci et al., 1996; Sorriso-Valvo et al., 1999]. The main reason is that the mass movements are typically studied at the scale of the single event. Only a few field studies have been conducted at the large regional scale [Braathen et al., 2004; Jarman, 2006].

[3] Insights into this issue can be gained using mechanical modeling. However, most of the modeling studies are 2-D and consider relatively small objects [Barla and Chirioti, 1995; Brueckl and Parotidis, 2001; Eberhardt et al., 2004]. Only a few 3-D numerical models have been carried out [Ambrosi and Crosta, 2006], and to our knowl-

edge never at a larger scale than that of a single mountain flank.

[4] In this paper we investigate the gravitational destabilization of models characterized by two distinct topographic scales (wavelengths) using a 3-D physical modeling technique. The large scale corresponds to the whole mountain (several kilometers horizontal dimension), and the small scale corresponds to a part of a mountain slope (~1 km horizontal dimension). The modeling technique is based on the use of the especially created elasto-plastic material “Slope1” and an original vertical accelerator device enabling increases in “gravitational acceleration” up to 50 times [Chemenda et al., 2005].

2. Experimental Procedure

[5] The model material *Slope1* includes liquid and solid hydrocarbons and possesses low friction elasto-brittle-plastic properties with strain softening. To create the model the melt of the model material is poured into a rigid box at a temperature of 50°C. After cooling to a temperature of 20°C at which the crystallized material is strong enough and can be easily handled without being damaged, it is shaped (cut) to obtain the desired relief (Figures 1a, 2a, 3a and 4a). In this study we investigate homogeneous models representative of pervasively fractured mountains at large scale [Varnes et al., 1989; Kellogg, 2001]. Results obtained on heterogeneous (faulted, weathered) models have been reported previously [Bachmann et al., 2004; Chemenda et al., 2005].

[6] Once the model is ready it is put onto the mobile platform of the vertical acceleration device (accelerator). The platform is uplifted up to $h = 2$ m or less and then is released. During free fall it reaches a maximum velocity just before coming into contact with a shock absorber. The model is then rapidly but smoothly decelerated. During this phase, the model undergoes a strong acceleration (deceleration) up to 50 g acting in the same direction as gravity. The acceleration cycling can be repeated as many times as needed (usually ca. 100 cycles) to obtain the needed deformation. Evolution of the model deformation can be thus observed and accurately documented after each acceleration cycle. This discrete “gravity” loading technique was shown to be equivalent to a continuous (static) loading [Chemenda et al., 2005; Bachmann et al., 2006]. For more experimental details and scale analysis see Chemenda et al. [2005].

3. Results

[7] A total of about 40 experiments have been conducted under various conditions. We report here the results of four most representative experiments (experiments 1 to 4) with

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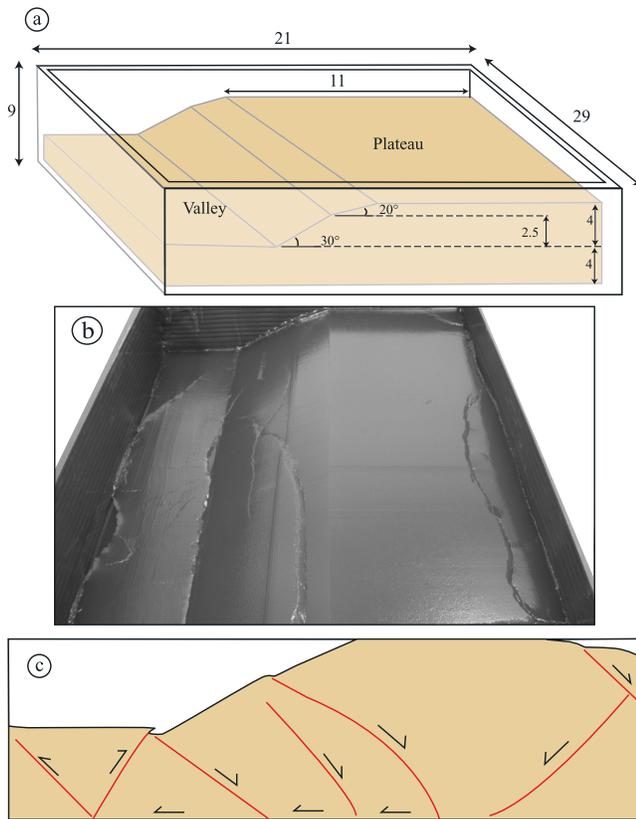


Figure 1. Experiment 1. Model with one 2-D slope (dimensions are in centimeters). (a) Scheme of the model. (b) Picture of the deformed model. (c) Schematic presentation of model deformation in cross section.

increasing complexity of the model topography (compare Figures 1a, 2a, 3a and 4a). All experiments have been conducted under the same conditions: model material cohesion is 2600 Pa, “gravity” acceleration is 50 g. The scaling factor has been chosen to be 1/50000, so that 1 cm in the model corresponds to 500 m in nature.

3.1. Experiment 1: Single 2-D Slope (Figure 1a)

[8] Figure 1b shows that the whole model has been mobilized in a 2-D manner. Its deformation has been accompanied by the formation of numerous faults and microfractures (Figure 1c).

3.2. Experiment 2: Two 2-D Opposite Slopes Forming a Valley (Figure 2a)

[9] The deformation still occurs in a 2-D manner (Figure 2b). The deformation is now more localized and the mobilized volume is considerably smaller than in the previous case. One can clearly see two principal faults including a circular master fault reaching a depth comparable to the height of the slopes, and one secondary fault within the sliding body (Figure 2c).

3.3. Experiment 3: 3-D Model of a Simple Prismatic Mountain Bordered by Valleys (Figure 3a)

[10] Only the central part of the model (a mountain itself) is affected by the gravity driven failure (Figure 3b). One can observe two master faults running to great depth that accommodate vertical subsidence and lateral spreading of

the mountain (Figure 3c). During this process a number of secondary faults has been formed within the sliding unit.

3.4. Experiment 4: Model Presented in the Previous Experiment Complicated by Introduction of Two “Small” (Second Order) Valleys (Figure 4a)

[11] As in the previous experiment, only the central mountain is involved in the deformation, but it is very different (Figure 4b). Three scales of mass movements are observed now. The larger scale corresponds to that of a whole mountain side (area A in Figures 4c, 4d and 4e). A middle scale corresponds to the size of the second order valleys (areas B in Figures 4c and 4e). The smallest scale movements are located at the toe of larger-scale sliding units (area C in Figure 4c). These latter appear when the mass movements of larger scales are still active.

4. Discussion and Conclusions

[12] The two first experiments clearly demonstrate that the destabilization of a single mountain and a mountain closely surrounded by other mountains occur in quite different manners. In the first case the deformation and faulting are distributed in a large volume (both horizontally and vertically), including both the mountain and the adjacent valley (Figures 1b and 1c). In the second case, the deformation is more localized and the sliding unit is much smaller (Figures 2b and 2c). Such a deformation is closer to that observed in nature, while the typical configuration

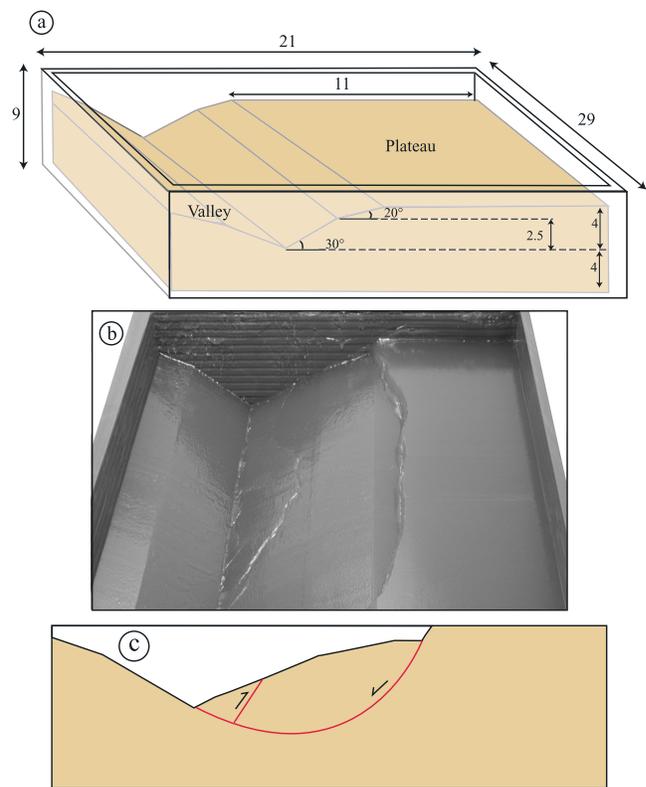


Figure 2. Experiment 2. Two 2-D slopes facing each other. (a) Scheme of the model. (b) Picture of the deformed model. (c) Schematic presentation of model deformation in cross-section.

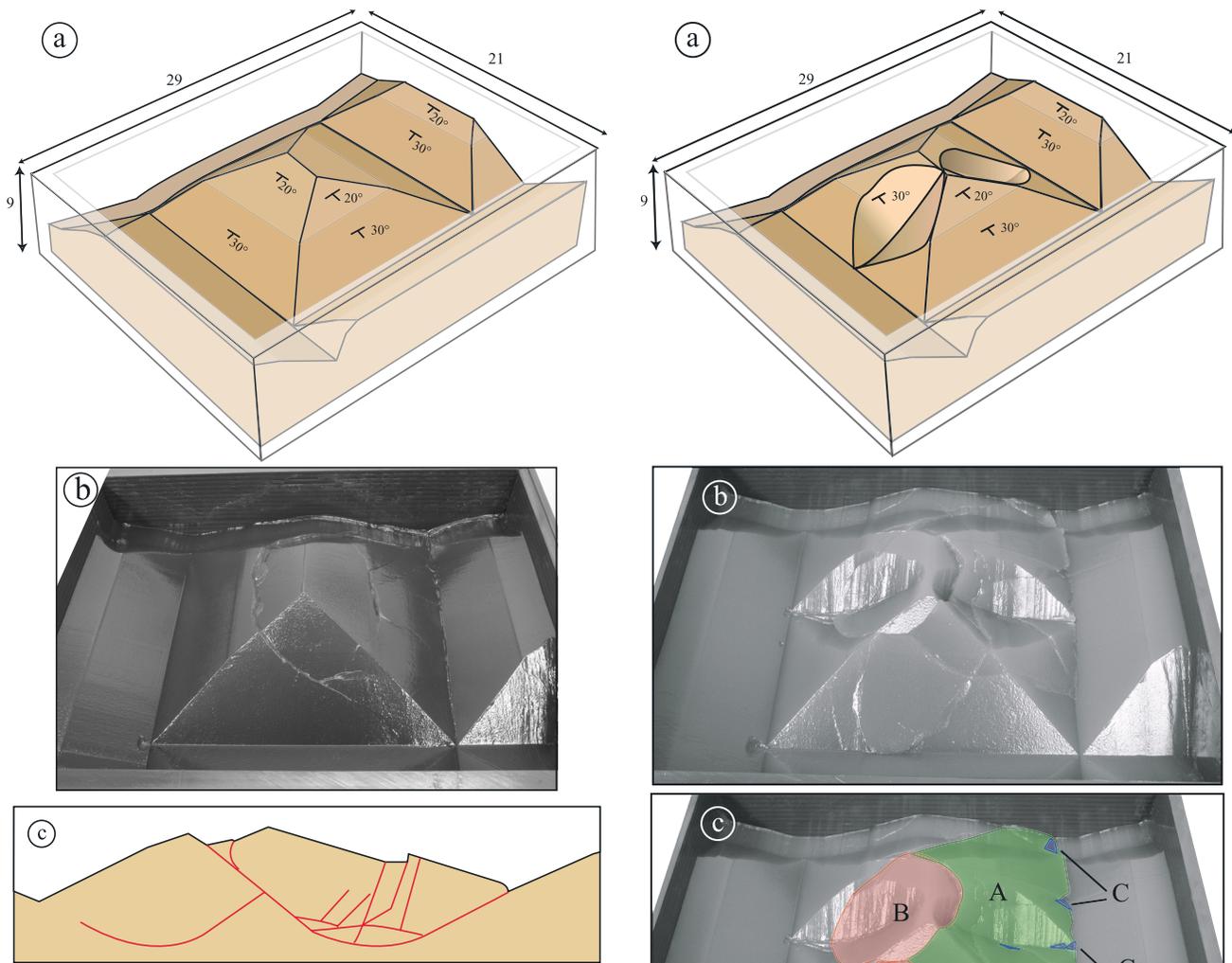


Figure 3. Experiment 3. 3-D model of a prismatic mountain bordered by valleys. (a) Scheme of the model. (b) Picture of the deformed model. (c) Schematic presentation of model deformation in cross-section.

adopted in most of modeling works corresponds to the first case (single slope). Indeed neither numerical nor analytical models considered the influence of the adjacent mountains on stress state repartition within the massif [*Savage and Varnes, 1987; Kinakin and Stead, 2005*].

[13] The third and fourth experiments demonstrate how introduction of relatively small topographic features (second order relief) complicates the deformation pattern at the whole mountain scale. In this case one can observe mass movements corresponding to both the largest relief wavelength (the whole mountain scale) and to the smallest relief wavelength introduced into the model, but one also observe the landsliding at a smaller scale. The mass movements of all scales are interrelated and affect each other: one scale movement can trigger movements at another scale. This shows that while studying a single landslide in order to predict its evolution, the area of investigation should extend well beyond this object since its evolution will depend on what is happening at larger but also at smaller scales. In the upcoming experiments along with multi-scale relief we will integrate into the model different scale faults that should also affect the deformation pattern.

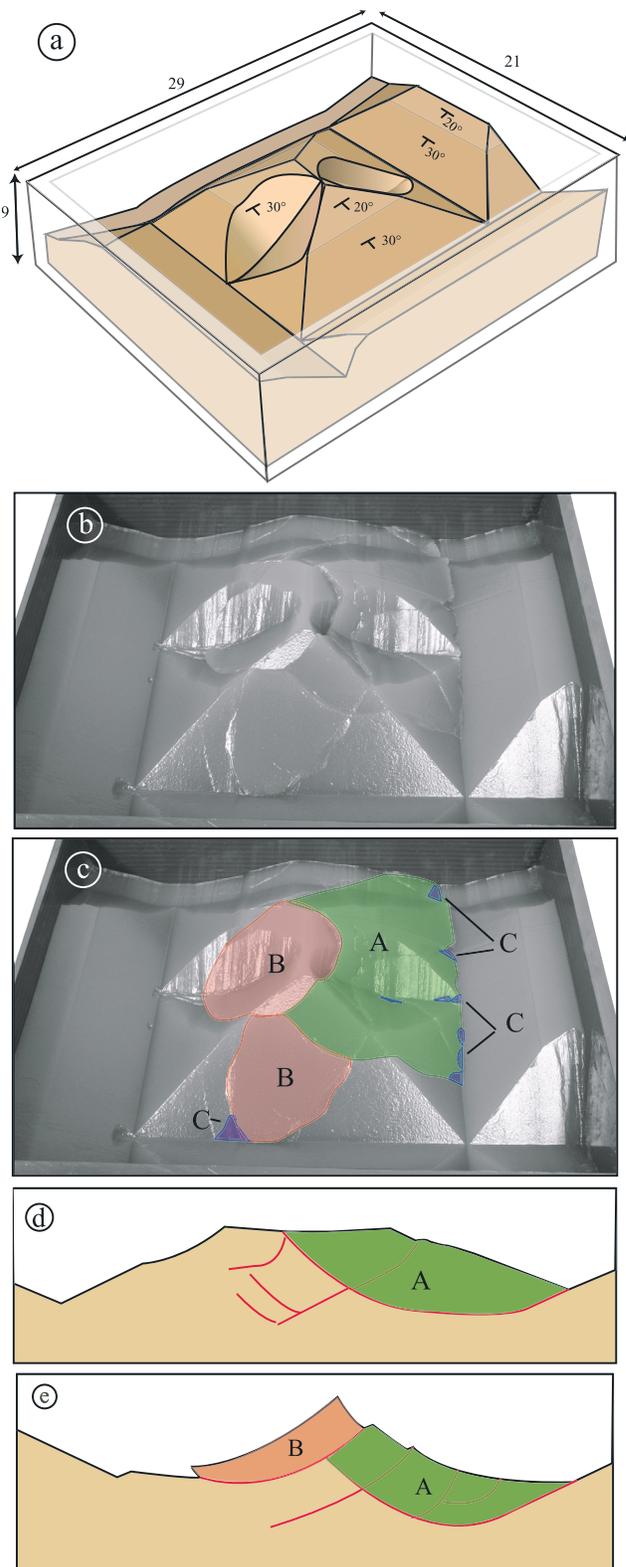


Figure 4. Experiment 4. 3-D model with two-order relief. (a) scheme of the model; **I** and **J** are the locations of the sections shown in Figures 4d and 4e respectively, (b, c) Pictures of the deformed mode. (d) Scheme of the deformation corresponding to section **I** shown in Figure 4a. (e) Scheme of the deformation corresponding to section **J** shown in Figure 4a. **A**, **B**, and **C** show landslides of different scales, large, intermediate and small, respectively.

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