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Comment on "A random kinetic energy model for rock avalanches: Eight case studies" by T. Preuth et al.

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[1] *Preuth et al.* [2010] present an original mechanism to explain the long runout of landslides and show that this mechanism allows for the simulation of a large number of landslides without case-by-case calibration of the model. However, *Preuth et al.* [2010] present no unequivocal data to demonstrate that their key new mechanism, random kinetic energy (RKE), exists at an intensity sufficient to cause the effects they claim. In that respect their model is, in our opinion, at present in the same category as other mechanisms such as undrained loading, acoustic fluidization, and frictionite (molten rock): they are plausible ideas that lack independent verification. This opinion is based on the following considerations.

[2] 1. The justification presented for the concept is that *Preuth et al.* [2010] have previously found that *assuming* the occurrence of RKE in experimental snow avalanches allows the velocity distributions measured in these avalanches to be explained. In this paper they present no evidence that they have observed or measured RKE in reality. The obvious place to look for RKE (or reports of it), in the context of rock avalanches, is in laboratory studies of the gravity flow of sand, but they report no attempt to do this, nor do they quote existing reports of it. Even this phenomenon, though, takes place under very low confining pressure compared with that beneath several tens of meters of rock avalanche debris, so it would not demonstrate that RKE is significant in rock avalanches. RKE is assumed to be generated by random components of the motion of the grains. This requires that the grains in motion must be capable of achieving appropriate velocities in all three dimensions. This is certainly the case in shallow grain flows, and near the surface of deep ones, where the confining gravitational stress is insufficient to keep grains in continuous contact, and impact and rebound can certainly cause high time-variant velocity components. In the case of grain flows sufficiently deep to represent rock avalanches, however, the confining pressure is such that grains have little space to move and are probably always in continuous contact, sliding past each other under shear. This behavior is known as dense granular flow [*Campbell*, 2002], and in this case the only random KE that can be generated in rigid grains is that due to grains moving laterally as they shear past each other. It is essential to explain how RKE can be sufficiently energetic in these conditions to cause the effects claimed by *Preuth et al.* [2010].

[3] 2. Even if RKE does exist, it is essential to prove that it is able to play a significant role in natural flows. The influence of RKE in the *Preuth et al.* [2010] model is mainly related to the values of two parameters, α and β, which are assumed rather than being measured or calculated. The parameter α controls the genesis of RKE by shearing, while β controls the way the RKE decays, which is assumed to be exponential [*Preuth et al.*, 2010, equation (15)]. The value of β is 0.8 s^{-1} [*Preuth et al.*, 2010, paragraph 45]. This means, for example, that after 1 s, the kinetic energy is still 45% of the initial energy (9% at 3 s, 4% at 4 s). The time scale for particle vibrations to be considered as having stopped, once external inputs have ceased, is thus a few seconds, which does not appear realistic. Stainless steel beads, for example, which exhibit a coefficient of restitution of about 0.9, reach 9% of the initial kinetic energy only 40 ms after the external source has ceased [e.g., *Grasselli et al.*, 2009]. The coefficient of elasticity of rocks being lower, the energy decrease will be faster, more than 100 times faster than that given by *Preuth et al.* [2010, equation (15)]. For debris avalanches composed of a large proportion of very fine material, the mechanism is still more difficult to believe. It is necessary to explain how the vibration energy is not absorbed during the displacement of the blocks in the fine matrix, and how shocks are not damped by the matrix. A rock falling onto the surface of a matrix-rich debris avalanche will not bounce and will only produce a weak sound. By what mechanism could the rate of decay of mechanical energy be low enough at the base of debris avalanches to maintain the kinetic energy of particles for the duration of several seconds? The chosen value of α is 5 [*Preuth et al.*, 2010, paragraph 47] (although this could be a misprint since in paragraph 19 it states that $\alpha \in [0, 1]$). This would mean that the random energy generated by the friction is 5 times higher than energy lost by friction itself, which is not possible. With this choice of the parameters α and β, the friction is thereby strongly, but artificially, reduced, nor does it prove that RKE exists in natural flows.

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[4] For these reasons we remain unconvinced of the significance of RKE in large rock avalanches. *Preuth et al.*'s [2010] RKE process is very similar (in fact it appears identical) to the "acoustic fluidization" mechanism [e.g., *Collins and Melosh*, 2003]; both rely on the shear-induced vibratory motion of grains to cause variations in intergranular direct stresses that allow shearing under unusually low shear stresses. Acoustic fluidization, however, has been shown to be insufficiently energetic to be capable of causing the effects its proponents claim [*Sornette and Sornette*, 2000], and we suspect the same might apply to RKE.

[5] There are a number of assumptions and simplifications in the RKE model. The flow is assumed to follow a Voellmy law, and the RKE only modifies the two coefficients of that law. Although *Preuth et al.* [2010, paragraphs 4 and 6] admit that the Voellmy relation provides little insight into rock avalanche behavior, it is nonetheless used as the basis of their model. The laws describing the increase and the decay of the RKE are also empirical ("[o]ne method to produce random energy is to proportion it linearly with the frictional work rate" [*Preuth et al.*, 2010, paragraph 19]) although all the model results depend on these relationships [*Preuth et al.*, 2010, equation (14)]. Some parameters are derived from snow avalanches, assuming dynamically similar behavior between rock and snow/ice. For some simulations, they are modified according to particular conditions [e.g., *Preuth et al.*, 2010, paragraph 48]. The initial topographies, the failure surfaces and the way the masses initially collapsed are not accurately constrained. The effect of the (assumed) release of energy by initial fragmentation is not taken into account. These issues all make the model questionable. The use of too many unconstrained parameters gives possible but non-unique solutions.

[6] The authors' assumption, that all the fragmentation that occurs in a rock avalanche takes place at the start of the landslide motion, is energetically untenable. For a start, what is the source of the energy to cause the intense fragmentation at the beginning of the motion? Only a small quantity of potential energy has been transformed into useful kinetic energy at this stage. *McSaveney and Davies* [2007] showed that at least 90% of the debris deposit of the 10^7 m^3 1991 Mt. Cook (New Zealand) rock avalanche was composed of particles which were less than 10 microns in diameter; the power (rate of energy release) required to accomplish this generation of fines in a short period at initiation of the landslide would be similar to that of a nuclear bomb. The common presence of shattered undisaggregated clasts in the distal regions of rock avalanches [*Davies et al.*, 1999; *Davies and McSaveney*, 2002; *McSaveney*, 1978, 2002] proves that fragmentation occurs throughout the runout, not just at the start, and the energy analysis of *Preuth et al.* [2010], which does not take this into account, is therefore incomplete.

[7] We are distinctly uncomfortable with the analogy between snow avalanches and rock avalanches used to support the RKE mechanism for the latter. The substantial difference in physical properties (e.g., failure stress, elasticity, coefficient of restitution, fracture toughness, density, melting point) between rock fragments and snow or ice particles requires a formal demonstration that the analogy is quantitatively supported if it is to be credible.

[8] In some of the *Preuth et al.* [2010] simulations, basal friction was reduced to a very low value (e.g., 0.1–0.2 [*Preuth et al.*, 2010, paragraph 48]). This appears to be assuming the required result at the outset; since the whole purpose of the RKE mechanism is to *explain* the low friction needed to cause the observed deposit geometries, this assumption appears to predetermine the required outcome.

[9] Our final comment is that a much more detailed empirical test of the RKE mechanism is required. It is relatively easy to approximately match poorly constrained field data with a numerical model, which is what the authors appear to have accomplished, judging by the data presented. In our opinion a stringent test of the empirical validity of the RKE process would be its ability to accurately model a well-constrained field case in three dimensions. This comment applies in general to all studies based on numerical simulations of geophysical flows. Simulating only the runout of a given example is not enough to conclude that a model is correct. Comparing the runout and the lateral extension of deposits is not a serious test in steep-sided valleys because the flows are constrained by the steep topography: thus, all models can give good results. In steep-sided topography, the comparison of runups all along the path and not only at the front is very important to check if the model can accurately reproduce the velocities of natural flows. To state that a model accurately reproduces a natural case, we have to compare not only the runout and the runups, but also the available field data: the thickness, structures, and surface morphologies of both the natural and the numerical deposits. The resolution of the topography should be accurate enough to reproduce the first order structures. Since the initial dislocation stage of a debris avalanche, when the coherent edifice is transformed into an avalanche, is generally not simulated correctly, it is also important to choose examples whose dislocation stage was rapid enough to have only a small impact on the whole emplacement. Otherwise, without information of how the collapse occurs, some field cases are impossible to simulate. One of the best field examples we know is the Socompa deposit, which is exceptionally well preserved and whose preevent topography and deposit morphology have been described in detail [e.g., *Francis et al.*, 1985; *van Wyk de Vries et al.*, 2001; *Kelfoun et al.*, 2008]. This allows the avalanche history to be reconstructed and an accurate comparison of the runout, the extension, the thickness, and the morphological features obtained by numerical modeling with field data [*Kelfoun and Druitt*, 2005; *Davies et al.*, 2010]. For the validation of future numerical models, there is a real need for this type of unambiguous and quantified field data, which would be available to everybody. In order to genuinely advance the science of the mechanics of large landslides and debris avalanches, the whole community needs to contribute in order to be able to test future numerical models objectively and with sufficient precision.

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