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Insights on the role of boundary and internal conditions on the spreading of rock falls and avalanches: field and model data compared across the scales

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The strong dependence of the spread of rock falls and avalanches on their volume has driven attempts to capture the physics of this behaviour experimentally. However such studies are considered to be fraught with difficulties that are associated with this “size effect”. To examine these questions, this study combines field and laboratory data from a number of studies – including field-mapped naturally occurring and artificially generated rock avalanches, lahars and cliff collapses; large scale physical model tests on rockfalls; small scale centrifuge experiments; and 1g model tests on rock avalanche travel and emplacement. In this way, the data covers volumes from 10^{-4} to 10^{10} cubic metres, i.e. 15 orders of magnitude.

We find that all data display a clear volumetric dependence, irrespective of scale. Specifically, the areal spread of deposits is strongly correlated via a power law to the potential energy of the events and the gradient of this correlation is seen to be consistent, as noted previously for large scale events. Offsets of the correlation are found, however, to depend somewhat on the type of event or the boundary conditions of the experiment. Specifically, small scale experimental flows conducted on glass produce the greatest deposit spread for a given potential energy input (“mobility”), followed closely by small scale tests conducted over a rubber, sand paper or PVC base, centrifuge tests on sandpaper, and large scale rockfall experiments on concrete. Based on the same relationship, in decreasing order of mobility are then large scale rock avalanches of volcanic origin (lahars), followed closely by naturally occurring chalk cliff collapses. Rock avalanches of non-volcanic origin – whether generated artificially or occurring naturally – in fact are found to have the least mobility in terms of deposit spread versus potential energy. This may be due to their travel over tortuous terrain (in effect, a very large scale of roughness) resulting in a greater loss of energy in comparison with experiments and events from, say, chalk cliffs that usually run out onto open ledges.

It is notable that artificial rock avalanches generated in the same massif (i.e. the Russian archipelago of Novaya Zemlya) give particularly strong correlations within their own dataset, suggestive that differences in material strength is a major factor in the scatter of data collected from different sources. This is further supported by analysis of chalk collapses from France that shows that the scatter within the potential energy – areal spread relationship appears to be due to the initial strength of the chalk, with weaker chalk producing greater areal spread.

The results highlight that, while the internal shearing mechanisms that are generated within different mass movement types may be not be the identical, the external boundary conditions have the most fundamental role to play as to how the potential energy is translated into kinetic energy and hence, deposit spread. The energy needed to fragment a material also has a role to play however, with failure in relatively weaker materials leading to greater flow mobility and hence, spreading.