LANDSLIDE RECOGNITION

Identification, Movement and Courses

Edited by
Richard Dikau, Denys Brunsden,
Lothar Schrott and Maïa-Laura Ibsen

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Richard Dikau
Universität Bonn, Germany

Denys Brunsden
King's College London, UK

Lothar Schrott
Universität Bonn, Germany

Maïa-Laura Ibsen
King's College London, UK

Every year a landslide disaster occurs somewhere in Europe. Destructive events are fortunately infrequent but when they do occur they are often tragic in their effects. Europe is heavily populated and development is expanding into areas where natural events are more likely to happen. *Landslide Recognition* is written by specialists from several European institutions and is designed to portray the diagnostic features of landslides as they would appear in the field, on maps or in photographs. Brief descriptions are provided and some guidance is given in the area in which different landslide types might be expected. This book will assist planners, developers, engineers and earth scientists to recognise where a problem may exist and to diagnose what type of failure may occur. The correct investigations and remedial measures may then be applied.

The front cover photograph is taken in the Randa valley, Switzerland.

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8

Complex

8.1 INTRODUCTION

It is common for mass movement processes to combine together and complex landslides occur where the initial failure type changes into another as it moves downslope. Compound landslides are two types of movement which occur concurrently within the same failure. It is necessary, here, to describe two complex slides, the rock avalanche and the flow slide, because these represent specific problems of classification and behaviour. In addition, pictorial examples are given of these two compound forms to illustrate how the single forms can be combined.

Landslide Recognition: Identification, Movement and Causes. Edited by R. Dikau, D. Brunsden, L. Schrott and M.-L. Ibsen

8.2 ROCK AVALANCHE

M. G. ANGELI
IRPI-CNR, Perugia
P. GASPARETTO
IRPI-CNR, Padova
R. M. MENOTTI
IROE-CNR, Firenze
A. PASUTO, S. SILVANO
IRPI-CNR, Padova
AND
M. SOLDATI
Dip. Scienze della Terra, Università di Modena

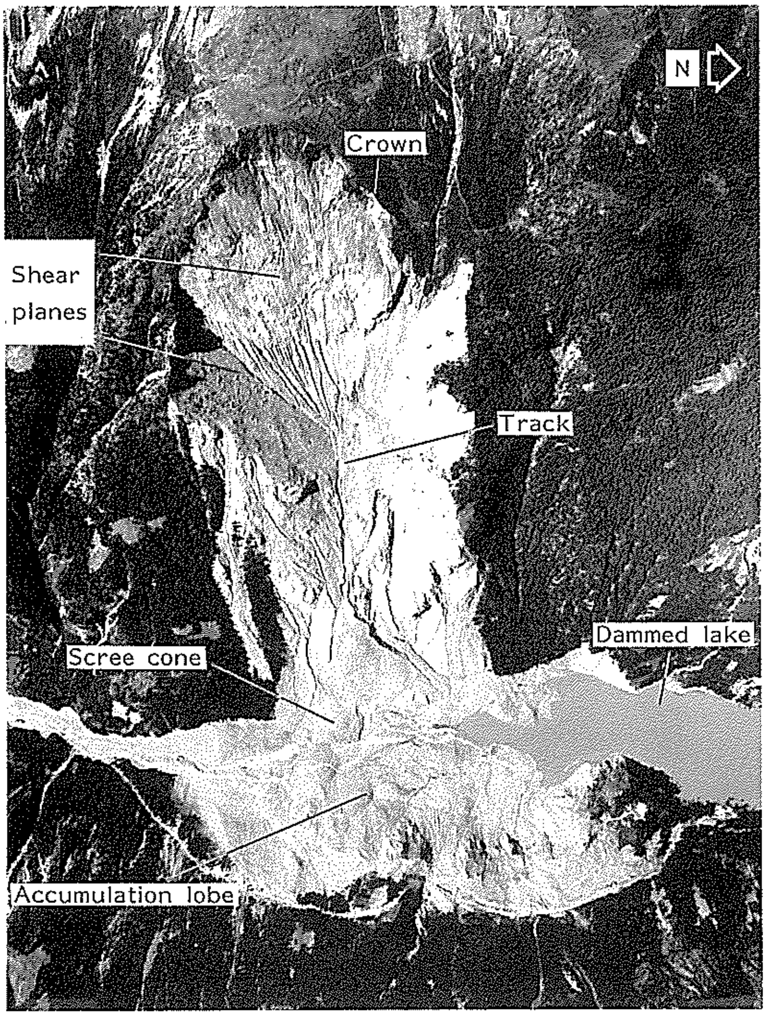

FIGURE 8.1.1 The Valpola rock avalanche occurred on 28 July 1987 in the Italian Central Alps (Authors. S.M.A n 994, 16/9/1987)

8.2.1 Alternative terms and translations

- rockfall avalanche, rock-slide avalanche, rockfall-debris avalanche (*English*)
- eboulement, écroulement de grande ampleur (d'extension catastrophique) (*French*)
- valanga di roccia, crollo-scorrimento di roccia, valanga di detrito (*Italian*)
- alud de rocas (*Spanish*)
- avalanche de rocha (*Portuguese*)
- steenlawine (*Dutch*)
- Sturzstrom, Bergsturz, Steinlawine (*German*)

8.2.2 Description and morphological detail

A rock avalanche is a large bulk of mostly dry rock debris deriving from the collapse of a slope or cliff and moving at a high velocity and for a long distance, even on a gentle slope (Hsü, 1975). Its speed can be in the order of tens of metres per second, the travel distance in the order of kilometres. In the area of accumulation, its volume can exceed 1×10^6 m^3, covering a total surface of over 0.1 km^2. Owing to its velocity and dimensions, this kind of landslide can be extremely costly in terms of human lives.

The rock avalanche can develop in two ways: first, by the fall or slide of a rock body which during movement progressively looses its cohesion by turning into dry debris and thus continues its advancement as a debris avalanche; secondly, by the sudden mobilisation of a debris deposit by means of debris avalanche, debris flow, either because of the fall of an overhanging rock mass or because of a seismic shock. For the latter it is important to describe the phases that occurred on 28 July 1987 which led to the sliding of a portion of Mt. Zandila in Valtellina (Italian Central Alps) (Govi and Turitto, 1992). At 7:25 a.m., after a preliminary phase lasting less than four days and without any sign of preceding seismic events, the

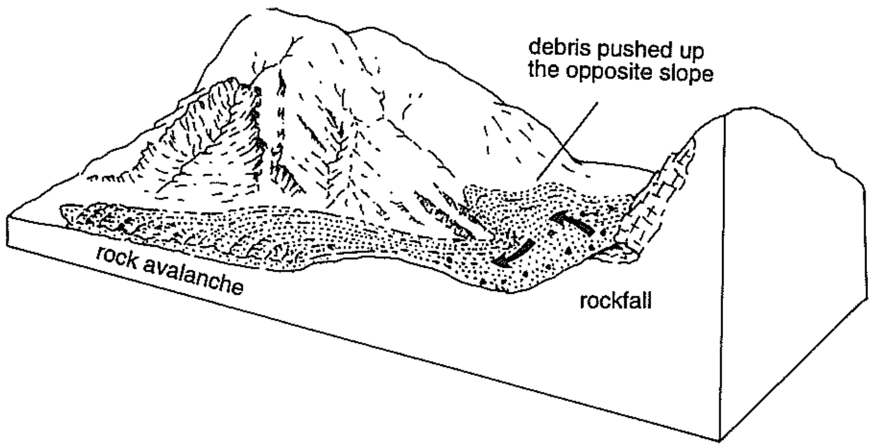

FIGURE 8.2.1 Schematic block diagram of a rockfall avalanche

detachment of a large rock volume of about 34 million cubic metres suddenly occurred. Although the collapse took place at a great velocity, its main phases of development can nevertheless be reconstructed thanks to direct witnesses and morphological evidence recorded after the event:

- the first displacements, which were relatively limited in volume, happened because of a progressive uphill widening of the crown generated by the falls occurring an hour earlier;
- after a few seconds, the entire rock mass started to slide along two main shear planes: the first was known to have a 45 ° dip to the east, the second was a neo-formation plane dipping 35 ° to the north;
- along the latter plane, the translational movements to the north, that is, toward the deep valley-floor of Valpola, took place initially with a series of short successive impulses and progressively increasing accelerations until it eventually came to a stop after the impact with a rock bluff which bordered the unstable slope. The thickness of the rock body that came into collision was estimated to be in excess of 70 m;
- following the impact, the displaced rock, which up to that moment had remained fairly compact, was subdivided into several fragments of various dimensions, falling to the valley-floor in an easterly direction from altitudes ranging from 600 to 850 m. Therefore during this phase the gravitational event which had started as a slide, rapidly turned into a rock avalanche, involving in its movement also the wood cover and the debris deposits distributed along the underlying slope. The fragmented collapsed rocks, after having obstructed a large area of the valley-floor, went up the opposite slope to a height of about 300 m, preceded by a cloud of dust which rose to an altitude of 2000 m.

A portion of the collapsed material fell into a previously formed barrier-lake, causing a mud wave which destroyed the village of Aquilone, located a few kilometres upstream, and claimed several lives. The volume of the accumulation deposit was estimated as 40 million m^3, with a maximum thickness of 90 m. On the surface of the landslide deposit the finer fraction was composed of millimetre to decimetre fragments, whilst the coarser material was concentrated along the flanks of the mass movement route.

The highest concentration of these phenomena is found in the Northern and Southern Calcareous Alps (Abele, 1974). Such a distribution is derived mainly from the widespread presence of outcrops which contain several fracture systems, as well as faults and bedding planes along which rock bodies become detached and slide. Relief, lithological characteristics and structure of the mountain chains determine not only the distribution and dimensions of rock avalanches, but also the pattern of their movement and, in particular, their aspect.

One of the distinctive features of rock avalanches is linked to the type of deposit normally made up of detrital material with a unit volume much lower than the original rock body. One should also consider that the volume of a rock mass displaced by a slope movement or completely reduced to detritus is larger in the zone of accumulation than in the zone of depletion. The volume of the deposit can be increased not only by the shattering caused by the fall, but also by the incorporation of loose materials encountered along the movement course.

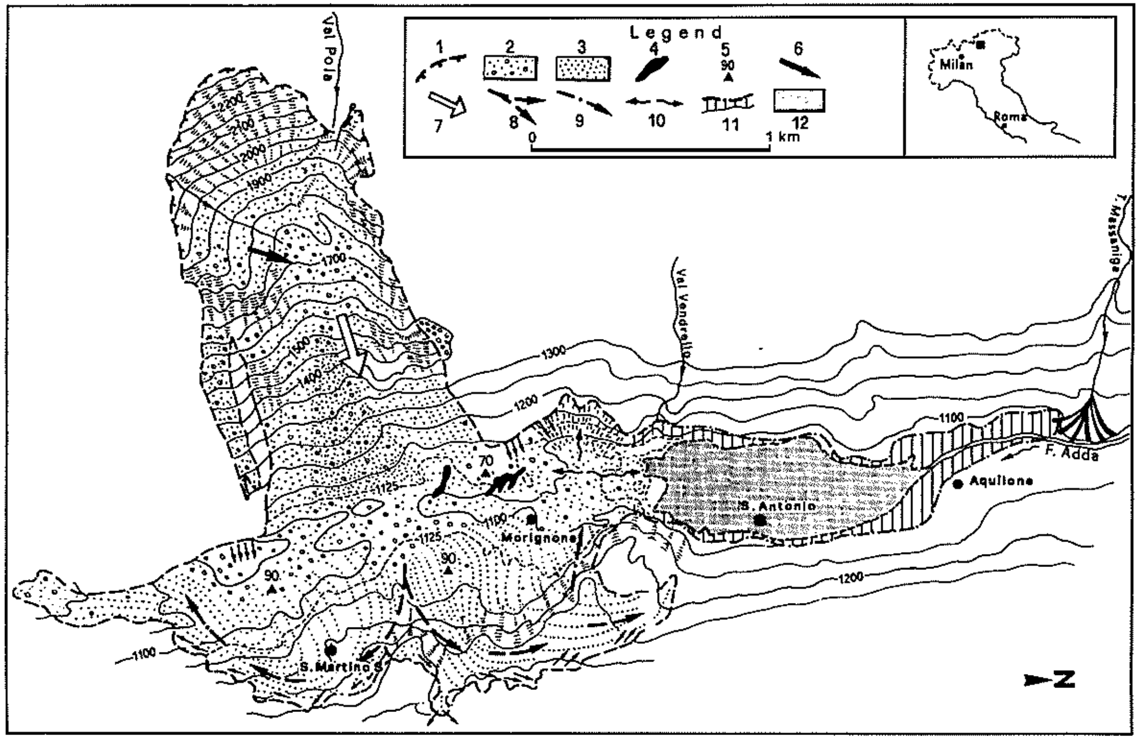

FIGURE 8.2.2 Morphological sketch map of the Valpola rock avalanche. Legend: 1, landslide scarp; 2, landslide debris with prevailing coarse grains; 3, landslide debris with prevailing fine grains; 4, lacustrine deposits mixed with landslide debris; 5, maximal thickness of accumulation; 6, slide direction; 7, rock avalanche direction; 8, movement direction on the opposite slope; 9, backward movement directions; 10, mud wave direction; 11, mud wave tracks at the foot of the slopes; 12, dammed lake (after Govi and Turitto, 1992)

From a textural viewpoint these deposits are characterised by uniform texture and a marked aerial delimitation. Also the 'small-hill' relief, which is shaped during the deposition of the debris mass or together with its successive deformations, is a typical feature of this kind of movement. Several characteristics of rock avalanches have been identified and any hypothesis for their dynamics must be consistent with them. According to Davies (1982), they include the following:

- the 'size effect', i.e. the fact that with increasing volumes of rock involved in the event, the ratio of the fall height H to the travel distance L decreases;
- the presence in rock avalanche deposits of shattered boulders consisting of fragments which, after transportation, may retain their original spatial pattern;
- the existence of lateral ridges in the distal parts of the accumulations which show that the rock avalanche motion suddenly stopped;
- the strong general similarity between rock avalanche deposits on Earth and those surveyed on the Moon and on Mars, where atmospheric and gravitational conditions are very different. Therefore it seems that the effect of gravity and air plays a minor role on the development of such movements. A comparison between terrestrial and Martian landslides is provided by Shaller and Komatsu (1994).

8.2.3 Movement

Despite the several investigations carried out, no satisfactory or universally accepted explanation has yet been proposed for the unexpectedly long distances travelled by

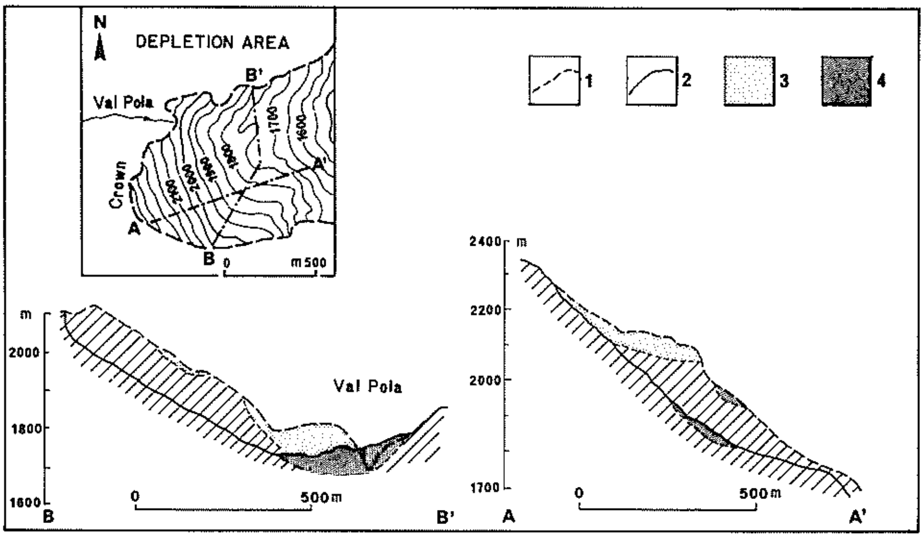

FIGURE 8.2.3 Sections through the depletion area of the Valpola rock avalanche. Legend: 1, slope profiles before the mass movement on 28 July 1987; 2, slope profiles after the mass movement of 28 July 1987; 3, relict landslide debris; 4, 1987 landslide debris (after Goui and Turito, 1992)

rock avalanches. It must be emphasised that the term 'avalanche' does not refer to any material type or transport and failure mechanism, but relates to the kinematic aspects of the movement of the loose material involved.

The mechanical analysis of rockfall avalanches includes two stages: the initial failure, which can occur by either sliding or falling, and subsequent streaming. Cruden and Varnes (1996) point out that 'The motion of Sturzstroms probably depends on turbulent grain flow with disperse stresses arising from momentum transfer between colliding grains. Such a mechanism does not require the presence of a liquid or gaseous pore fluid and can therefore explain lunar and Martian Sturzstroms'.

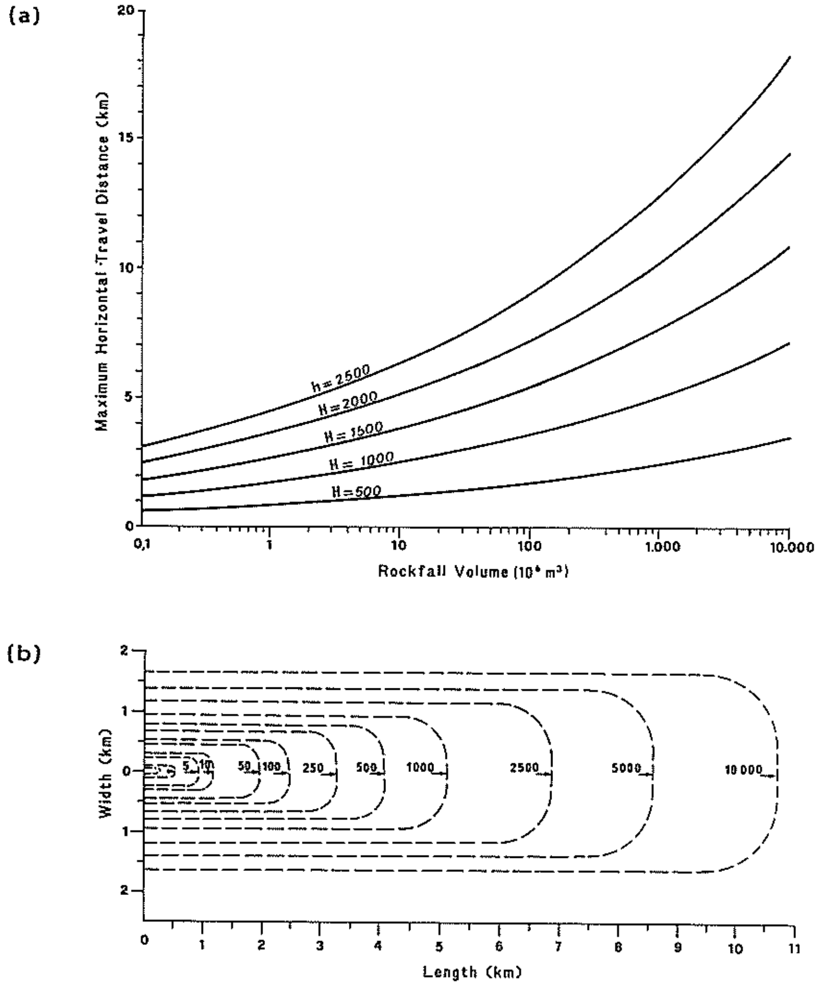

FIGURE 8.2.4 (a) The curves indicate the maximum horizontal distance reached by the debris in relationship to height (H) and volume (V) of the rockfall. H refers to the estimated height (in m) of a potential rockfall. (b) The area covered by the fallen mass. Numbers refer to the estimated volume (in 10^6 m^3) of a potential rockfall (after Li, 1983)

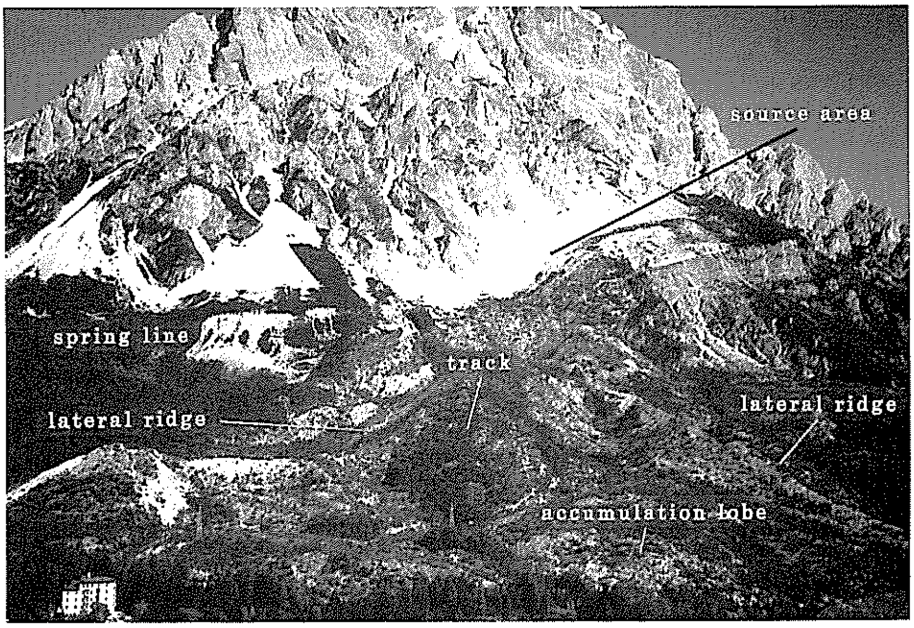

FIGURE 8.2.5 The Antelao landslide (Dolomites, north-eastern Italy), occurred in April 1841, claiming 256 lives. About 35×10^6 m^3 of debris suddenly moved probably due to the load from a rockfall which affected the overhanging walls. (Photograph by CNR-IRPI, Padova)

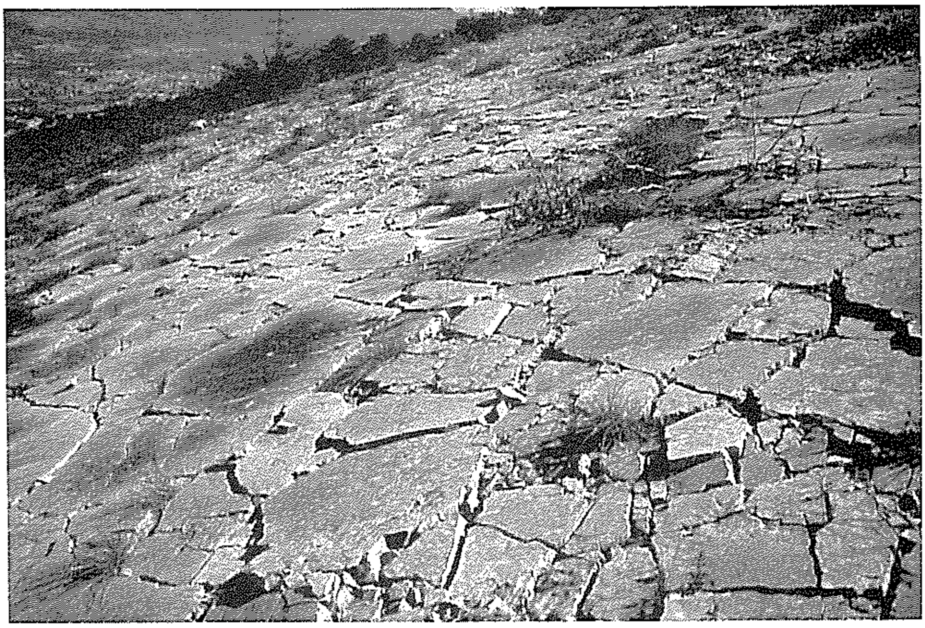

FIGURE 8.2.6 Detail of the slide surface of the Lavini di Marco rock avalanche (Adige Valley, north-eastern Italian Alps). Weathering effects on the rock surface are observable. (Photograph by U. Sauro)

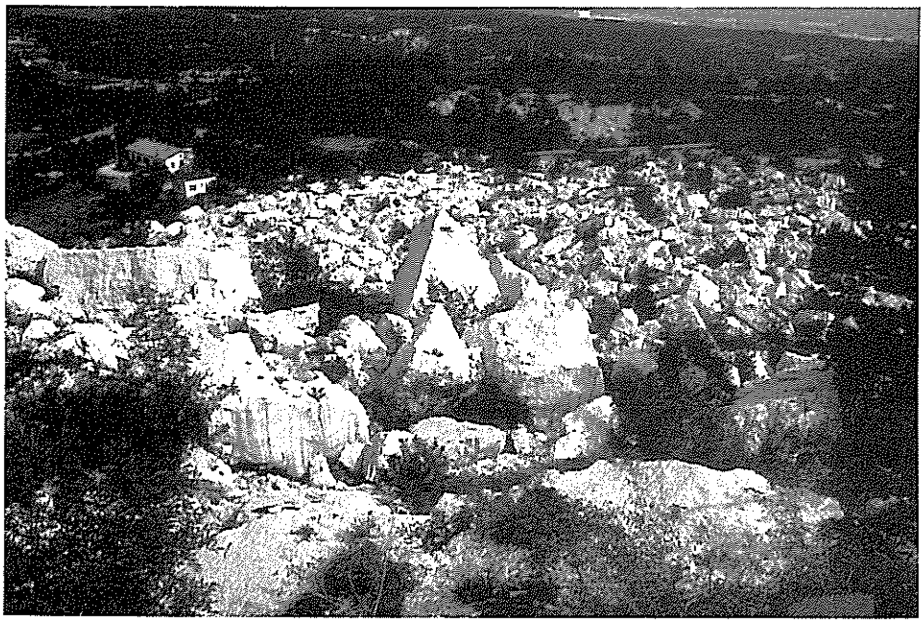

FIGURE 8.2.7 Detail of the Lavini di Marco rock avalanche accumulation zone (Adige Valley, north-eastern Italian Alps). The long inactivity has favoured karst phenomena, the evidence of which is superimposed to a previous karst micro-forms (Photograph by U. Sauro)

The velocity which characterises such phenomena is connected to the relatively low internal resistance to shear stress (Bagnold, 1954; Bjerrum et al., 1961). Thus, the main movement characteristics of a rock avalanche are as follows (Davies, 1982):

- The fall height and/or distance sliding of a rock/debris mass from a slope imparts to the moving material the possibility of reaching a high velocity.
- Once the debris mass starts moving and the velocity is sufficiently high, shearing at the base of the debris produces dilation and reduction of internal friction; therefore the debris mass may flow and spread out up to considerable distances, even on gentle slopes.
- When the velocity decreases and the basal shear is no longer sufficient to maintain the dilation, the internal friction increases and the mass stops its motion.
- The debris mass generally travels for a considerable distance owing to a particularly low effective friction coefficient between the slope and the falling rock mass. Some authors have tried to explain this phenomenon: Kent (1965) refers to the fluidisation of particles caused by incorporating air; Shreve (1968a, 1968b) postulated the existence of a cushion of trapped air on which the sliding occurs; Hsü (1975) pointed out that the low friction resistance could be reduced by the buoyant effect of dust suspensions, acting as a medium between the flowing blocks. Melosh (1980) proposed the hypothesis of acoustic fluidisation. The mechanism is described as a high-frequency vibration which may be able to

temporarily lighten the static overburden pressure in limited sectors of the moving mass, enabling sliding to occur in the unloaded parts. Other suggestions include steam generation, heating and reduction in strength due to rate of shear effects.

Because of the rapid evolution of the rockfall avalanches which last only a few minutes, the change with time consists of the rapid disruption of the material of the displaced mass and the high rate of the movement. The change over a longer period of time consists of either partial remobilisation or erosive and weathering effects of surficial waters.

8.2.4 Causes

Though several different hypotheses on the nature of the movement mechanisms have been proposed, no completely satisfactory explanations have been presented so far and the exact triggering causes which may enable realistic prediction of the extent of a threatening rock avalanche require urgent attention (Brunsden, 1979; Erismann, 1979). An attempt to forecast the elongation of a rock avalanche was carried out by Nicoletti and Sorriso-Valvo (1987) in the area of Platì (Calabria, southern Italy). The authors took into account the relationships between distance travelled, volume of accumulation, area of the deposit and vertical drop, emphasising, however, that all the models applied had weaknesses.

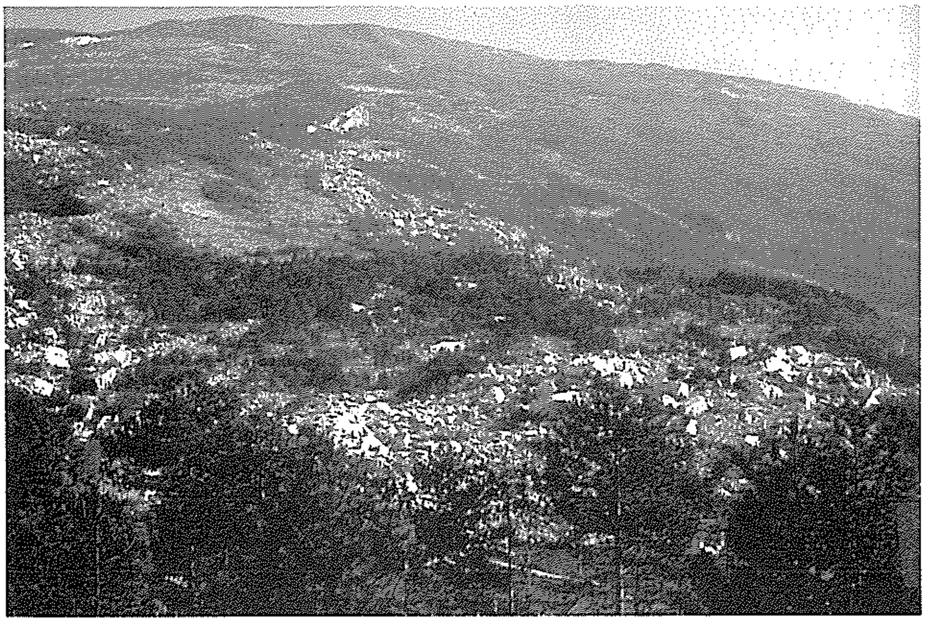

FIGURE 8.2.8 The Lavini di Marco rock avalanche occurred in the 13th century (Adige Valley, north-eastern Italian Alps). Depletion area, lateral ridges and accumulation lobes are clearly visible. Vegetation is quite developed on the landslide deposits thus demonstrating its long inactivity. (Photograph by U. Sauro) (For further detail see Orombelli and Sauro, 1988)

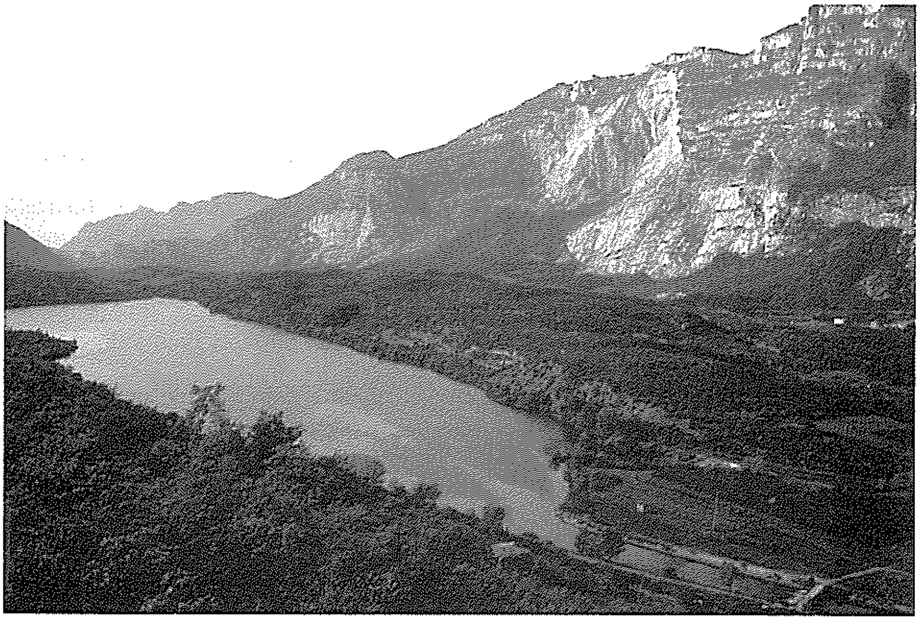

FIGURE 8.2.9 Accumulation zone of an ancient rock avalanche which partially filled the Sarca Valley (Italian Eastern Alps). The extensive vegetation cover and the gentle morphology indicate a long period of inactivity. (Photograph by U. Sauro)

Another important cause for rock avalanches has been found in alpine regions. As Panizza (1973) and Abele (1974) have stated, the ice retreat of the last alpine glaciation caused significant stress relief on mountain slopes. This unloading is one of the causes of Holocene rock avalanches. However, there is evidence that the process not only took place shortly after the ice retreat (as found between 12 000 and 10 000 BP) but that the loss of shear strength needed much more time to cause rock avalanches. The rock avalanche Eibsee (Zugspitze, German Alps) (volume: 400×10^6 m^3) has been dated at 3000 years BP which may fit this hypothesis.

Other than this the causes are those already discussed for rockfalls and rock slides. The causes for the possible elongate run-out are the volumes and the momentum conveyed by the initial failure.

8.2.5 Planning and engineering implications

Rock avalanches are incredibly destructive, they move with great rapidity and obliterate everything in their path. It is possible to identify some of the likely areas for failure and to gain some idea of the possible run-out distance for a given volume. In these areas the only planning action that can be taken is land use zoning.

Perhaps more important, once an event has occurred, is to discover whether the avalanche has dammed the valley. If it has, and a lake has formed, maximum effort must be given to take control of the breaching dam, because the resulting flow may cause a second disaster.

BIBLIOGRAPHY

Essential

Abele, G. (1974). *Bergstürze in den Alpen.* Wissenschaftl. Alpenvereinshefte, 25, München.

Davies, T. R. H. (1982). Spreading of rock avalanche debris by mechanical fluidization. *Rock Mech.*, **15**, 9–24.

Eisbacher, G. H. (1978). Cliff collapse and rock avalanches (sturzstrom) in the McKenzie Mountains, northwestern Canada. *Can. Geotech. J.*, **16**, 309–334.

Heim, A. (1932). *Bergsturz und Menschenleben.* Fretz und Wasmuth, Zürich. (English translation by Skermer, N., 1989. *Landslides and Human Lives.* BiTech Publishers Ltd., Vancouver, Canada).

Li, T. (1983). A mathematical model for predicting the extent of a major rockfall. *Z. Geomorph. N.F.*, **27**, 473–482.

Voight, B. (Ed.) (1978). *Rockslides and Avalanches.* Elsevier, Amsterdam.

Further

Azzoni, A., Chiesa, S., Frassoni, A. and Govi, M. (1992). The Valpola landslide. *Eng. Geol.*, **33**, 59–70.

Bagnold, R. A. (1954). Experiments on the gravity-free dispersion of large solid spheres in a Newton fluid under shear. *Proc. Royal Soc. London*, **225A**, 49–63.

Bjerrum, L., Kringstad, S. and Kummeneje, O. (1961). The shear strength of a fine sand. *Proc. 5th I.C.S.M.F.E.*, **1**, 29–37.

Brunsden, D. (1979). Mass Movements. In *Process in Geomorphology* (Eds C. Embleton and J. Thornes). Butler & Tanner, London, pp. 130–186.

Cruden, D. M. and Hungr, O. (1986). The debris of the Franck slide and theories of rockslide-avalanche mobility. *Can. J. Earth Sci.*, **23**, 425–432.

Cruden, D. M. and Varnes, D. J. (1996). Landslide Types and Processes. In *Landslides: Investigation and Mitigation, Special Report.* Transp. Res. Board (Eds A.T. Turner and R. L. Schuster), National Academy of Sciences, Washington, D.C.

Eisbacher, G. H. and Clague, J. J. (1984). Destructive mass movements in high mountains: hazard and management. *Geol. Surv. of Canada*, Paper 84.

Erismann, T. (1979). Mechanism of large landslides. *Rock Mech.*, **12**, 15–46.

Evans, S. G. and Clague, J. J. (1988). Catastrophic rock avalanches in glacial environments. In *Landslides*, Proc. 5th I. S. L. (Ed. C. Bonnard), Vol. 2, pp. 1153–1158.

Evans, S. G., Clague, J. J., Woodsworth, G. J. and Hungr, O. (1989). The Pandemonium Creek rock avalanche, British Columbia. *Can. Geotech. J.*, **26**(3), 427–446.

Govi, M. and Turitto, O. (1992). La frana di Valpola del 1987 in Alta Valtellina. In *Frane e Territorio* (Ed. A. Vallario). Liguori Editore, Napoli, pp. 392–414.

Howard, K. A. (1973). Avalanche mode of motion: implication from lunar examples. *Science*, **180**, 1052–1055.

Howell, J. V. (Ed.) (1960). *Glossary of Geology and Related Sciences*, 2nd edition. American Geological Institute, Washington, DC.

Hsü, K. J. (1975). Catastrophic debris streams (Sturzstroms) generated by rockfall. *Geol. Soc. Am. Bull.*, **86**, 129–140.

Keefer, D. K. (1984). Rock avalanches caused by earthquakes: source characteristics. *Science*, **223**, 1288–1290.

Kent, P. E. (1965). The transport mechanism in catastrophic rock fall. *J. Geol.*, **74**, 79–83.

Krumdiek, M. A. (1984). On the mechanism of large landslides. *Proc. 4th I.S.L.*, Toronto, Vol. 1, pp. 539–544.

McLellan, P. J. and Kaiser, P. K. (1984). Application of a two-parameter model to rock avalanches of the Mackenzie Mountains. *Proc. 4th I.S.L.*, Toronto, Vol. 1, pp. 559–565.

McSaveney, M. J. 1978. Sherman glacier rock avalanche, Alaska, USA. In *Rockslide and Avalanches* (Ed. B. Voight), Vol. 1. Elsevier, Amsterdam, pp. 197–258.

Melosh, H. J. (1980). Acoustic fluidization: a new geological process? *J. Geophys. Res.*, **84**, 7513–7520.

Melosh, H. J. (1987). The mechanism of large rock avalanches. *Geol. Soc. of America Rev. Eng. Geol.*, **3**, 41–49.

Menotti, R. M., Pasuto, A., Silvano, S., Siorpaes, C. and Soldati, M. (1990). *Guida alle escursioni del IV seminario DGPV, Cortina d'Ampezzo (BL), 25–28 September 1990.* Gruppo Informale Deformazioni Gravitative Profonde di Versante – Istituto di Geologia Applicata del CNR, Padova.

Moriwaki, H., Yazaki, S. and Oyagi, N. (1985). A gigantic debris avalanche and its dynamics at Mount Ontake caused by the Nagonoken–Seibu earthquake, 1984. *Proc. 4th I.C.F.L.*, Tokio, pp. 359–364.

Mudge, M. R. (1965). Rockfall-avalanche and rockslide-avalanche deposits at Sawtooth Ridge, Montana. *Geol. Soc. Am. Bull.*, **76**, 1003–1014.

Nicoletti, P. G. (1989). On the mobility of sturzstroms (rock avalanches): a comparison between probabilistic prediction models. *Boll. Soc. Geol. It.*, **108**, 419–429.

Nicoletti, P. G. and Sorriso-Valvo, M. (1987). Stima della pericolosità di un possibile rockslide-debris flow incombente su Platì (RC). *Geog. Fis. Dinam. Quat.*, **10**, 313–320.

Nicoletti, P. G. and Sorriso-Valvo, M. (1991). Geomorphic controls of the shape and mobility of rock avalanches. *Geol. Soc. Am. Bull.*, **103**(10), 1365–1373.

Orombelli, G. and Sauro, U. (1988). The Lavini di Marco: a complex of Holocene landslides in the morphoneotectonic context of high Val Lagarina (Val d'Adige, Southern Alps, Italy). *Suppl. Geogr. Fis. Dinam. Quat.*, **1**, 107–116.

Panizza, M. (1973). Glacio pressure implications in the production of landslides in the Dolomitic area. *Geol. Appl. e Idrogeol.*, **8**(1), pp. 289–297.

Scheidegger, A. (1973). On the prediction of the reach and velocity of catastrophic landslides. *Rock Mech.*, **5**, 231–236.

Shaller, P. J. and Komatsu, G. (1994). Landslides on Mars. *Landslide News*, **8**, 18–22.

Shreve, R. L. (1966). Sherman Landslide, Alaska. *Science*, **154**, 1639–1643.

Shreve, R. L. (1968a). The Blackhawk Landslide. *Geol. Soc. Am., Spec. Paper*, **108**.

Shreve, R. L. (1968b). Leakage and fluidization in air-layer lubricated avalanches. *Geol. Soc. Am. Bull.*, **79**, 653–658.

Varnes, D. J. (1978). Slope Movements Types and Processes. In *Landslides: Analysis and Control* (Eds R. L. Schuster and R. J. Krizek). Spec. Report 176, Transp. Res. Board, National Academy of Sciences, Washington, DC, pp. 11–33.

Záruba, Q. and Mencl, V. (1982). *Landslides and Their Control*, Elsevier, Amsterdam.

Zischinsky, U. (1966). On the deformation of high slope. *Proc 1st I.C.S.R.M.* Lisbon, pp. 179–185.

Zischinsky, U. (1969). Über Sackungen. *Rock Mech.*, **1**, 30–52.