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Guest editorial

Recent advances in landslide investigation: Issues and perspectives

1. Introduction

This special issue of Geomorphology includes 14 papers dealing with landslides selected from two conferences of the International Association of Geomorphologists (IAG): the Regional Conference held in Brasov, Romania, in September 2008 and the Seventh International Conference celebrated in Melbourne, Australia, in July 2009. The Regional Conference, under the theme “Landslides, floods and global environmental change in mountain regions”, was organized by Prof. Dan Bălteanu (Institute of Geography of the Romanian Academy) and his collaborators in a classic landslide area, the Carpathian Mountains. The participation reached 150 delegates from 30 countries. The programme of this meeting included 12 sessions with 116 contributions, 49 of which are related to landslides. This issue includes 8 papers out of the 11 selected presentations. The rest of the articles are derived from the “Hillslopes and Mass Movements” session of the Seventh International Conference on Geomorphology, organized by the Australian and New Zealand Geomorphology Group (ANZGG) under the leadership of Prof. Brian Finlayson (Monash University, Australia). Participation in this major event reached 648 delegates from 50 countries and the programme included 37 theme sessions. A total of 6 papers were selected from the 46 contributions presented at the “Hillslopes and Mass Movements” session convened by professors Mike Crozier (Victoria University, New Zealand) and Mauro Soldati (University of Modena and Reggio Emilia, Italy).

This compilation of articles covers a wide geographical and thematic canvas, with a special flavour from Eastern Europe derived from the IAG Regional Conference held in Romania. The study areas include all the major continents with the exception of North America. Eight papers from Europe (Andorra, Czech Republic, Estonia, Poland, Romania, Spain and Switzerland) deal with a wide diversity of topics; magnitude and frequency relationships in the Pyrenees, paleoenvironmental record of landslide activity in the Carpathians, slope instability in glacialacustrine clays in the Estonian coastal plain, landslide characterization in the Bohemian Massif, susceptibility mapping in Romania, mapping and assessment of debris-flow sediment sources in the Swiss Alps, and shallow slides and trenching applied to large landslides in a reservoir in the Pyrenees. Two papers deal with a catastrophic rock slide-avalanche in Japan. There is a paper on the interaction between large dam-forming landslides and fluvial activity in the deepest valley in the world located in Nepal. An article from Venezuela documents very large landslides associated with the Boconó Fault in the Andes. A paper reviews blanket peat landslides in subantartic islands. Finally, one paper discusses the relative role played by climate change and human activity on landslide activity, with numerous examples from New Zealand.

2. Landslide research and risk mitigation

Landslides, the downward and outward gravitational displacement of slope-forming materials, may damage any human structure and may even cause the loss of lives when they occur in a catastrophic way. Two relevant peculiarities of this hazardous geomorphic process are its widespread spatial distribution; there are landslide-prone slopes almost everywhere, and its high sensitivity to human- and natural-induced changes in the slopes and controlling factors. During the second half of the 20th Century there has been a rapid increase worldwide in the economic losses due to natural disasters (Munich; Re, 2005) and in the number of damaging landslide events (EM-DAT, 2010) (Fig. 1). Similar trends have been observed for the number of landslide events at national and regional scales (Guzzetti and Tonelli, 2004; Remondo et al., 2005; Bonachea, 2006; Cendrero et al., 2006). According to the database created by the Centre for Research on the Epidemiology of Disasters, landslides and related processes killed approximately 61,000 people in the world over the period 1900–2009 (EM-DAT, 2010). This high toll must be considered as a minimum estimate given the incompleteness of the database. The records become limited as we go back in time and the damage caused by landslides associated with storms, floods, earthquakes and volcanic eruptions are frequently ascribed to these other hazards. The impact of geomorphological hazards, and particularly landslides, is highly dependent on the economic development of the countries. A great part of the landslide-related casualties occur in less-favoured countries, whereas more-developed countries account for the vast proportion of the economic losses. Commonly, in natural disasters, the poor losses his life, whereas the rich losses his property. Moreover, it should be emphasized that the high number of small- to medium-scale landslides, which are widespread in many parts of the world, normally cause much higher costs to human society than high-magnitude catastrophic events, which tend to occur quite rarely. The losses due to these low-magnitude and high-frequency events are also generally increasing because of human activities, which tend to enhance both landslide hazard and vulnerability (Pasuto and Soldati, 1996). On the other hand, economic losses in less-favoured countries, although lower in absolute terms, have a much greater impact than in wealthy countries because they represent a much higher proportion of the gross domestic product (Burton et al., 1978; Smith, 1996; EM-DAT, 2010).

A significant step forward in landslide investigation has been promoted by the International Decade of Natural Disaster Reduction (IDNDR, 1990–2000) proclaimed by the United Nations, during which working groups on landslides were established, such as the International Landslide Research Group (ILRG) and the International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory (WP/WLI), which contributed to the definition of international standards in landslide investigation and stimulated research

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and publications related to this issue (Brabb, 1991; Cruden and Varnes, 1996; Dikau et al., 1996). During the previously mentioned decade an international newsletter, "Landslide News", started by The Japan Landslide Society and published in the form of a journal, became popular within the landslide scientific and technical community. This journal collected a series of interesting papers on case studies throughout the world between 1987 and 1999. A selection of the most relevant articles of Landslide News, related to either catastrophic or spectacular landslides that had occurred all over the world, was edited by Sassa (1999). In the following decade, IDNDR was replaced by the International Strategy for Disaster Reduction (ISDR) and an important stimulus to landslide studies was provided by the International Consortium on Landslides (ICL) established in 2002. This Consortium has promoted the international journal "Landslides" and managed it since 2004.

As a result of the aforementioned activities, and probably because of the increased awareness of the relevance of landslides, the number of studies on the topic has substantially increased in recent years. This is witnessed by a recent paper by Gokceoglu and Sezer (2009), who carried out a bibliometric analysis of the landslide literature published in international journals for the period 1945–2008, using the Science Citation Index Expanded database (WOS; Web Of Science). This study is based on 3468 publications collected by using in the searching process the keywords "landslide" and the terms proposed by Varnes (1978) in his classification of slope movements. Some of the most relevant findings of that study include:

- The publication of landslide papers in international journals has experienced an exponential increase since the end of the 1980s (Fig. 1). In the period 1975–1986 the average annual number of publications was 11. In contrast, from 2000 to 2008 the yearly number of landslide papers has increased from 150 to more than 340.
- The journals that have published the largest number of landslide articles are Geomorphology (367) and Engineering Geology (299), followed by Landslides (132), Earth Surface Processes and Landforms (131), Canadian Geotechnical Journal (125), Environmental Geology (104), Natural Hazards (92) and Natural Hazards and Earth Systems Science (87). It is important to note that Landslides, the journal of the International Consortium on Landslides, started in 2004. The amount of articles on landslides published in other geomorphology journals is significantly lower; Catena (29) and Zeitschrif für Geomorphologie (34). Moreover, the highest number of citations corresponds to the journals Geomorphology (3338), Engineering Geology (2620) and Earth Surface Processes and Landforms (1742). The average number of citations per paper reaches the highest values for Geology (24), Journal of Geophysical Research (22.87) and Quaternary Science Reviews (20.5).
- The country of the most productive authors indicates that landslide research and scientific divulgation in international platforms is particularly intense in some nations like Italy, Japan and Canada.
- The topics that receive great attention in the landslide literature are susceptibility and hazard assessment. In fact, landslide hazard and landslide susceptibility are among the most frequently used keywords.

The journal Geomorphology, which takes the lead in the number of papers published on landslides, has devoted a series of special issues to geomorphological hazards (for a recent review see Borgatti and Soldati, 2005a). Actually, most of these issues deal with landslides, and the frequency of their publication has recently become surprisingly high (four issues in the last three years). These issues include "Landslides in the European Union" edited by M. Soldati (1996), "Mass movement in the Himalayas" edited by J.F. Shroder (1998), "The Temporal Stability and Activity of Landslides in Europe with respect to Climatic Change" edited by A. Pasuto and L. Schrott (1999), "Studies on Large Volume Landslides" edited by A. Pasuto and R.J. Kilburn (2003), "Hazards of Mass Movements" edited by H. Suwa, P. Wassmer and K. Okunishi (2004), "Geomorphological hazard and human impact in mountain environments" (mainly dealing with landslides) edited by L. Borgatti and M. Soldati (2005b), "GIS technology and models for assessing landslide hazard and risk" edited by A. Carrara and R. Pike (2008), "Debris flows initiated by runoff, erosion, and sediment entrainment in western North America" edited by J. Coe, S. Cannon and P. Santi (2008), "Dating, triggering, modelling, and hazard assessment of large landslides" edited by G.B. Crosta and J.J. Clague (2009), "Landslide geomorphology in a changing environment" edited by T. Glade and M.J. Crozier (2010). In addition to the papers

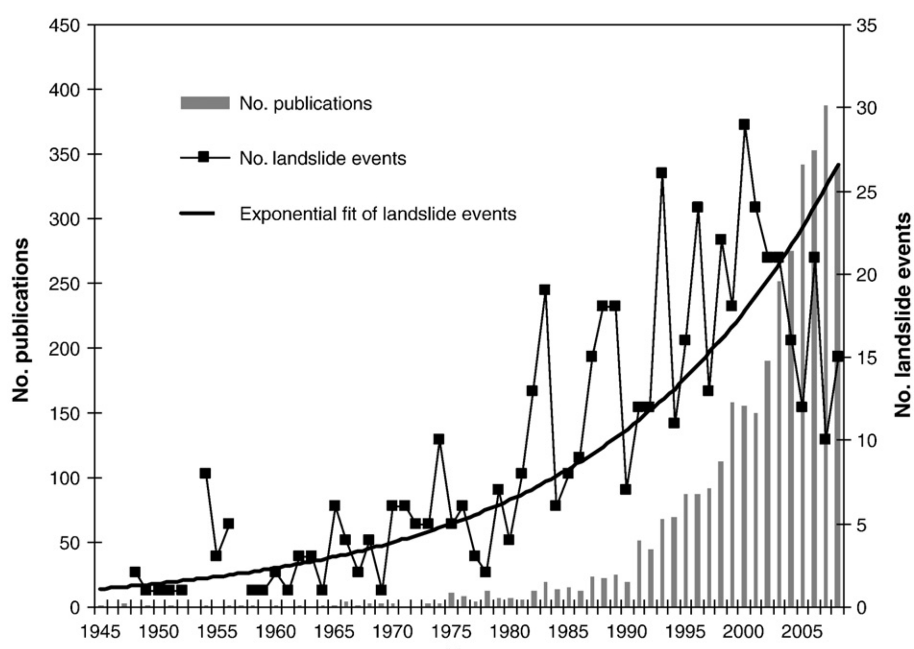

Fig. 1. Annual number of landslide papers published in international journals from 1945 to 2008 (Gokceoglu and Sezer, 2009) and number of damaging landslide events in the world and their exponential fit for the same period (EM-DAT, 2010).

published in international journals, in the last decade a large amount of scientific literature dealing with landslides has been published as compilations of articles in books (i.e.: Evans and DeGraff, 2002; Glade et al., 2005; Hungr et al., 2005; Sassa et al., 2005a,b; McInnes et al., 2007; Malet et al., 2009; Sassa and Canuti, 2009). The titles of all these publications reveal that landslide risk and the potential impact of climate change on landslide activity are among the topics that receive the greatest attention at the present time.

The dramatic increase in the production of international landslide literature that occurred over the last decades is related to the significant increase in economic and human resources devoted to landslide research. This investment has been largely aimed at increasing our capability to reduce the damage caused by landslides. However, the data presented previously reveal that there is a paradoxical parallelism between the increase in the scientific production on landslides and the amount of damage caused by this geomorphic process (Fig. 1). Apparently, the increase of knowledge in the field of landslides, and particularly in those aspects related to landslide risk mitigation, is not being to the desirable advantage for society. This situation might be related to the combination of multiple factors and circumstances:

- The exposure of population and property to landslides has increased through time. During the second half of the 20th Century the world population and the gross domestic product increased by 2.4 and 6.8 times, respectively.
- There has been an intensification of landslide activity. This could be related to the increasing human impact on the environment (i.e. Glade, 2003; Sidle et al., 2004) and climate change (i.e. Geertsema et al., 2006). Cendrero et al. (2006) suggest that there is some kind of coupling between the economic development and the increase in losses caused by natural disasters and landslides, the former having a multiplying effect over the latter. For instance, according to Evans (1999), 570 people were killed in Canada over the period 1840–1999 by 43 landslide events, of which 23% were directly or indirectly induced by human activity. Concerning climate change, intuitively we may foresee that the predicted warming of the climate and the increase in the frequency and intensity of precipitation events may result in more landslide activity (higher pore water pressure, thawing of ground ice, retreat of glaciers, …). However, at the present time there is no scientific basis for asserting unequivocally that climate change will result in general increased landsliding (i.e. Collison et al., 2000; Schmidt and Glade, 2003; Sidle and Ochiai, 2006; Briceño et al., 2007; Borgatti and Soldati, 2010; Crozier, this issue).
- There should be a sound awareness that understanding the relationship between landslides and climate change is crucial in planning effective approaches to hazard and risk management and mitigation in a changing environment. Recent advances in landslide real-time monitoring and landslide hazard modelling and prediction would in principle enable communities and end-users to be better prepared to face increasing slope instability. However, in a series of regions that are particularly sensitive to global change (Goudie, 1996), there is still an urgent need for effective risk management and informed planning policy to improve the safety and sustainability of communities at risk (Borgatti and Soldati, 2010; Goudie, 2010).
- There is not an effective transference of knowledge, including the tools applicable to landslide risk analysis and mitigation, from the scientific community to the people involved in land-use planning and risk management. The "time to market" is probably too long. Perhaps, more efforts should be devoted to improve the synergy between those that generate knowledge and innovate and those that have the responsibility of mitigating landslide risk. Additionally, correct diagnoses and prognoses may be useless in terms of risk mitigation if they are not followed by adequate decisions and actions, as illustrate the dramatic cases of the 1985 Nevado del Ruiz mud flow in Armero, Colombia, where 22,000 people died (Mercado, 2002), and the 1963 Vaiont landslide in Italy, that led to the loss of more than 2000 lives (Kilburn and Petley, 2003).
- The effective application of landslide risk mitigation strategies in less-favoured countries is highly difficult for economic, political, cultural and geographical reasons. This makes especially difficult to plan and implement early warning systems, which are globally recognised as an essential tool in disaster reduction (Basher, 2006).

Regardless of the actual reasons behind the apparently limited efficiency of landslide risk mitigation, more efforts should be devoted to landslide research and the divulgation and application of its outcomes. The papers of this special issue provide insight into multiple aspects that may contribute to improve our capability to reduce landslide-related human and financial losses: (1) Where are the different types of landslides and their precise limits? (2) How old is the landslide and what is its kinematical history? (3) Is the landslide active or what is the age of the latest displacement event? (4) What is the relative contribution of the factors that influence landslide development? (5) How will each particular landslide behave in the future? May an inactive or creeping landslide turn into a catastrophic mass movement? (6) What is the probability of occurrence of landslides in each area and what are the expectable magnitude and frequency relationships? (7) What will be the impact of future human activity and climate change on landslide activity (typology, frequency, magnitude and intensity)? (8) How should landslide-related emergency situations be managed during the pre- and post-disaster stages?

3. The papers of the special issue

The fourteen papers of this special issue can be grouped into four categories. The main contribution of six of them is the illustration, through case studies, of methodologies applicable at different stages in the landslide risk analysis and management process.

Bălteanu, Chendeş, Sima and Enciu present a heuristic landslide susceptibility model of Romania, a mountainous country in which slope instability has a particularly high incidence. This country-wide susceptibility model has been developed weighting by expert judgement a set of controlling factors (lithology, topographic gradient, maximum rainfall in 24 h, land-use, seismicity and local relief) and ranking the obtained values into 5 susceptibility classes. The prediction capability of the model has been evaluated in a particular sector with a landslide inventory obtaining reasonably good results. Perhaps, one of the main limitations of this map is that it does not discriminate different types of slope movements. This model also illustrates that geological factors, which in turn condition topography and climate, are the main controls on the distribution of general domains with different susceptibilities to landsliding. The most landslide-prone region according to the map is the Bend Subcarpathians, dominated by intrinsically unstable molasse and flysch Tertiary formations affected by neotectonic uplift and fluvial downcutting. In this sector a great part of the modern slope failures corresponds to partial reactivation of old landslides, largely induced by land-use changes. The susceptibility map, with a pixel size of $100\ m \times 100\ m$, provides a general picture of the most susceptible areas of the country, where the construction of landslide inventories and the development of more detailed landslide hazard and risk assessments should receive greatest attention.

Theler, Reynard, Lambiel and Bardou propose an innovative and process-based geomorphological mapping method aimed at representing the distribution and spatial relationships of sediment storages that have the potential to be mobilized by debris flows and bedload transport in small alpine catchments. The method, based on the processing of data gathered by field surveys, aerial photograph interpretation and high resolution DEMs, has been conceived to assess qualitatively sediment transfer processes, especially by channelized debris flows. The instability of the identified storages and their relative role in sediment contribution is assessed considering and crossing four factors within a GIS; slope, vegetation cover, connection to the main channels and genesis of the storage. The application of the method is illustrated with the example of the Bruchi torrential basin in the Swiss Alps. Here, denudation rate and sediment flux measurements have been obtained by several methods (colour lines, wooden markers and terrestrial LiDAR) to test the validity of the mapped units. One of the main advantages of the proposed geomorphological cartographic method with respect to the classical ones is that it allows assessing semi-quantitatively the amount of debris that can be mobilized and incorporated into the main channels during a hydrometeorological event. Thus, these maps provide highly useful information for the analysis and mitigation of debris-flow risk in torrential catchments and on alluvial fans.

Gutiérrez, Lucha and Galve map several large landslides affecting the flysch slopes situated upstream of the Yesa Dam in the Spanish Pyrenees. A new earth dam will be constructed in the near future to raise the maximum impoundment level by 23 m. Obviously, this project will have a detrimental effect on the stability of the slopes. On the basis of a detailed geomorphological map, they have excavated three trenches to better constrain the extent of the landslides and to reconstruct their geochronological evolution. The La Refaya rotational landslide (11 million m^3), situated just upstream of the spillway of the dam, was investigated by a trench excavated in the deposits filling the depression developed in the upper part of the slid mass. The retrodeformation analysis of the cumulative wedge-out structure exposed in the trench, together with six radiocarbon datings, reveal that this currently inactive slope movement is older than 12 ka and that its rotation (1.4°/ka in average) has been dominated by progressive displacement, most of it occurred before 5.8 ka. The trench excavated in the upper part of the El Vertedero translational landslide demonstrates, as is suggested by geomorphological mapping, that the 3 million m^3 slope movement induced by the accumulation of an earth heap in 2006 corresponds to the partial reactivation of a larger slide (6 million m^3). According to the geometrical relationships observed in this trench and the obtained OSL numerical ages, this landslide is older than 38 ka, has undergone at least a reactivation event subsequent to 20 ka and has remained inactive for a long time as suggests a highly degraded bedrock scarp over the master failure plane. Given the potential of translational slides to generate impulse water waves in reservoirs, corrective measures based on the results of this study, with an estimated cost of 11.5 million euros, have been designed for this slope. This work illustrates how some of the future advances in landslide investigation may arise from the application of techniques developed in other scientific and technical disciplines. The trenching technique, mainly used in paleoseismological studies (McCalpin, 2009), may be applied successfully to the investigation of hazardous gravitational deformation processes like sinkholes (Gutiérrez et al., 2009) or landslides. Slope movements commonly involve the development of shallow deformation structures similar to those associated with active tectonic structures; extensional faulting in the head, strike-slip faults along the flanks and thrust faulting and folding in the toe. The retrodeformation analysis of the structures exposed in trenches, allied with geochronological methods, may allow inferring practical information on the precise limits, failure mechanisms, age, kinematics and chronological evolution of landslides. These data may improve our capability to forecast the future behaviour of problematic landslides and to avoid/reduce potential losses derived from their activity.

Corominas and Moya provide an original contribution related to the determination of magnitude–frequency relationships in landslide hazard investigation. The authors show how dendrogeomorphological techniques may provide significant data not only related to landslide frequency, but also to landslide magnitude, an issue that has been rarely attempted so far by analysing the spatial distribution of disturbed trees. The aim of the paper is therefore to define the role of dendrogeomorphological techniques in the analysis of the spatial and temporal distribution of landslides and in the determination of their magnitude–frequency relationships. In this respect, dendrochronological analyses were combined with detailed geomorphological mapping and other relative dating techniques. The paper deals with magnitude–frequency determination for rock falls, debris flows and complex slides/flows on selected forested slopes in the Eastern Pyrenees (Spain and Andorra). The timing and extent of a series of slope movements were reconstructed by mapping their deposits using relative dating criteria and by dating damaged trees, whilst the area of damaged trees was considered as an indicator of the landslide magnitude. The lesson that we can learn from this paper is that the determination of magnitude–frequency relationships using dendrogeomorphological techniques is feasible only under certain conditions. The requirements are that (1) the landslide areal extent, which is related to its magnitude, can be estimated by the number and location of damaged trees; (2) the trees are distributed throughout the landslide otherwise some events may not be recorded; and (3) a satisfactory tree sampling strategy is adopted for each landslide type. In fact, in order to interpret the dendrochronological results, it is crucial to properly understand the type and dynamics of the landslide processes considered.

Fujisawa, Marcato, Nomura and Pasuto, as well as Suwa, Mizuno and Ishii, analyse two relevant and poorly explored aspects through the study of a translational slide-avalanche in Japan: (1) The predictability of the failure time using data on precursory creep displacement. (2) The temporal evolution of the motion of a very rapid landslide recorded by a video camera and seismographs. The landslide was triggered by the Namtheum Typhoon in August 2004, reached a peak velocity of 5.4 m/s and the collapse of the slope lasted 26 s. The authors, using the available data on creep displacement velocity measured by extensometers, evaluate two methods proposed by Saito (1965) and Fukuzono (1985) for predicting the rupture time of landslides. These approaches, based on the temporal increase in the strain rate and on the inverse of creep velocity, respectively, predict the time of rupture with an acceptable error of several hours. According to Suwa et al. (this issue) the ground shaking recorded by seismometers revealed four stages of energy radiation from the landslide. The authors attribute these stages to (1) the propagation of the sliding surface and detachment of the blocks, (2) the displacement of the blocks and their progressive disintegration, (3) the impact of major blocks on the valley bottom; this is the shortest stage but with the elastic surface waves of highest energy, and (4) subsequent minor mass movements. Fujisawa et al. present a detailed account of the management of the emergency situation created by the landslide, whose success was possible thanks to the correct prediction of the failure time based on the creep displacement recorded by an automatic monitoring system (extensometers and inclinometers) with an established alarm threshold. The national highway affected by the landslide was timely closed before the collapse of the slope and the traffic was diverted towards an alternative road constructed ad hoc on the opposite side of the valley. The adequate management of the crisis avoided potential casualties and significant economic losses related to serviceability interruption in a major communication route. This paper presents relevant considerations of landslide risk management, nicely illustrated by the Otomura landslide experience: (1) The indispensable role played by multi-proxy monitoring systems and accurate records of deformation with a high temporal resolution to anticipate the onset of catastrophic displacement in creeping landslides. (2) The need of a synergistic involvement of public administration and research institutions in the investigation and management of risk situations. (3) The cost-effectiveness of pre-disaster investigations and preparatory measures. Proper pre-disaster risk management generally leads to significant reduction in damage as well as large cost savings in the post-disaster recovery and correction phase. (4) The need to establish a culture of mid- and long-term mitigation strategies aimed at reducing vulnerability and increasing public awareness, especially in the potentially most hazardous areas. The approach presented in these two articles constitutes an innovative contribution on the kinematics of one of the landslide types responsible for the loss of a large number of human lives. Anticipating the rapid collapse of creeping landslides is a critical issue for avoiding casualties through the application of evacuation plans. It would be highly desirable to apply the same approach to other landslides to elucidate whether the findings found in these papers can be generalized.

A second group of papers is mainly focused on the characterization of landslides in highly variable geomorphic settings through the application of various methods. Audemard, Beck and Carrillo document two very large slope movements in the Mérida Andes, Venezuela, spatially associated with the seismogenic Boconó Fault. This dextral strike-slip fault, with a net slip rate in the area of around 7–10 mm/a, defines the boundary between the South American plate and the Maracaibo triangular microplate. The ca. 10 km long Mucubají landslide mobilizes thick late Pleistocene moraine deposits along the basal contact with the bedrock. Geomorphic evidence suggests long-term episodic activity for the Mucubají landslide, currently affected by creep displacement as revealed by geodetic measurements. The more than 20 km long La Camacha landslide complex is developed in crystalline basement rocks and consists of three main bodies. The two largest gravitationally displaced blocks are defined by prominent uphill- and downhill-facing sackung scarps subparallel to the active Boconó Fault. The other block corresponds to an active rotational landslide ca. 2 km across. Creep displacement has been recorded by geodetic measurements on this latter landslide, which constitutes the left abutment of the Santo Domingo Dam. Multiple factors have been invoked by the authors to explain the development of such large slope movements: (1) Hillslopes with high local relief and gradient, (2) Rapid fluvial incision in response to tectonic uplift, (3) Debutressing of the slopes caused by deglaciation, (4) Stratigraphic contacts and foliation with favourable attitude, (5) Removal of basal confinement caused by strike-slip displacement on the Bocono Fault, which runs along the foot of the slopes affected by gravitational deformation, and (6) Seismic shaking related to the on-site Boconó Fault and topographic amplification of the ground vibration. The authors propose that the kinematics of these landslides is very likely characterised by continuous creep deformation punctuated by major displacement events triggered by strong earthquakes on the Boconó Fault. The landslides with sackung scarps of the Mérida Andes, associated with a major seismogenic active fault, constitutes an excellent context for analysing the role played by strong seismic shaking on the kinematics of deep-seated mass movements. As is illustrated by the pioneering work carried out by McCalpin and Hart (2003) in southern California, demonstrating that the activity of sackung-type slope deformations is controlled by earthquake shaking events requires: (1) Identifying evidence of episodic displacement in the sackung features, (2) Obtaining tight absolute dates for those displacement events; this can be achieved by trenching, and (3) Establishing the contemporaneity of the displacement events between different sackung features, and especially with independently dated earthquakes. The sackung scarps of La Camacha slope movement, where favourable locations for trenching have been identified, might constitute an excellent case study to test this hypothesis. Numerically dated gravitational displacement events could be compared with the earthquake catalogues established for the Boconó Fault by historical and paleosimological investigations. If the displacement events on the sackung scarps were demonstrated to be coseismic, then these geomorphic features could be treated as a valuable and complementary source of paleoseismological information (McCalpin and Hart, 2003; Gutiérrez et al., 2008; McCalpin et al., in press).

Fort, Cossart and Arnaud-Fassetta deal with the relationships between slope movements and fluvial processes in the Nepal Himalayas. The paper is focused on the middle Kali Gandaki River valley, the deepest on earth, where a road linking two districts has been under construction over the last five years, either cutting the slope or crossing areas episodically affected by different types of landslides. The potential threats related to the road construction are assessed based on the geomorphic evolution observed over the last three decades. Three areas of recurrent slope instability, characteristic of the most frequent situations encountered across the Higher Himalayan valleys, were mapped and the combination of the hydro-geomorphic processes involved was analysed in detail. In particular, it was possible to reconstruct the spatial extent of (1) areas threatened by backflooding upstream of the landslide dams and (2) areas threatened by the collapse of the landslide dams. The research outputs confirm that medium-scale landslides (10^{5-6} m^3) play a major role in the overall process of denudation and sediment transfer in the High Himalaya. They highly influence the transient nature of bedload transport in the channel. Despite the fact that debris inputs from the slopes are discontinuous in time, when coupled with intense fluvial activity, they highly influence the transient nature of bedload transport in the channel, hence sediment fluxes and their discharge outside the mountain zone. The authors show how debris accumulation, related river diversion and subsequent bank erosion threaten human settlements and new road structures. From a methodological viewpoint, the paper highlights the importance of repeated observations at the same site which provide a better understanding of landform evolution itself at a very short time scale. Based on these observations continuous updating of detailed geomorphological maps becomes a crucial process in planning mitigation measures in a country like Nepal which has experienced road-building projects during the last twenty years in relation to demographic growth and subsequent development of urban centres.

Migoń, Pánek, Malik, Hradecky, Owczarek and Šilhán investigate complex landslides covered by dense forest in the Bohemian Massif, Central Europe, integrating several methods; geomorphological mapping, electrical resistivity tomography (ERT) and dendrochronology. The multi-approach applied has provided valuable information on the failure mechanisms of the landslides, the extent of the deformed slopes and the spatial and temporal evolution of the slope movements. ERT happened to be a successful technique for the identification of fissures indicative of the existence on incipient landslides. Dendrochronology was highly useful in establishing patterns of recent geomorphic activity in the head scarp zones of the landslides and distinguishing between active and inactive talus slopes. This study illustrates the great value of detailed geomorphological mapping allied with other techniques as a basis to assess the activity of landslides and forecast their future behaviour. It also implicitly introduces the problem of the difficulty in classifying landslides as active or inactive.

Dykes and Selkirk-Bell deal with the nature, extent and global significance of landslides in blanket peat on subantarctic islands. The aims of the authors are to review the global distribution of blanket peat failures, to provide a sounder knowledge of the general characteristics and failure mechanisms of peat landslides on subantarctic islands and understand whether they are comparable with those occurring in the British and Irish Isles, for which a richer literature is available. In particular, peat slides on Macquarie Island and Marion Island were analysed. The research shows that: (1) contrary to previous indications, only around 25% of known mass movements involving blanket peat have occurred in the British Isles; (2) the general characters of subantarctic blanket peats are probably different from those of Britain and Ireland; in addition, stability analyses indicate a strong control on the peat properties from its constituent vegetation that produce different stability conditions according to the slope steepness and orientation; (3) extreme meteorological events similar to those commonly associated with peat slides in the British Isles are rare on subantarctic islands, allowing blanket peat to accumulate to its natural maximum stable depth; (4) several common factors across the subantarctic islands are likely to be responsible for the apparently high susceptibility to peat landslides; and (5) unlike the British Isles, and particularly Ireland, the peat landslides on the subantarctic islands imply a low risk due to the scarcity of human activities. This paper indicates that geomorphological research on peatlands of the southern hemisphere is at an early stage of development and that further investigation would be desirable to establish a complete inventory of intact blanket bog and of existing landslides to provide the basis for the study of long-term evolution of peatlands, also in consideration of ongoing climatic change.

Kohv, Talviste, Hang and Kalm investigate from a geotechnical point of view the largest recent landslide in Estonia, developed in a very peculiar geological setting. This multiple rotational landslide formed in varved glaciolacustrine clays and temporarily blocked the Sauga River. The retrogressive enlargement of the monitored slope movement was mainly controlled by fluvial erosion of the landslide toe. Two aspects make this landslide a very peculiar case study: (1) The low mechanical strength of the glaciolacustrine clays, conditioned by their low overconsolidation ratio and high water content. (2) The glaciolacustrine clays confine a pressurized aquifer in the underlying glacial till deposits. Limit equilibrium back-analyses applying the Spencer's method have allowed the authors to elucidate which of the shear strength parameters obtained by soil testing determine the stability of the slope. According to the authors, some of the most relevant factors that have favoured the development of the landslide include: (1) The rise in the piezometric level of the underlying confined aquifer caused by a reduction in the pumping rate in recent times, with the consequent increase in the pore fluid pressure in the lower part of the clay formation. (2) Weakening of the clays due to a long-term increase in the degree of overconsolidation caused by fluvial erosion. The removal of the upper sediments involves a decrease in the normal stresses with the consequent decompression of the soil.

Two of the papers deal with landslides whose activity has been influenced to a great extent by extrinsic factors; past climatic variability and historical deforestation. Šilhán and Pánek analyse debris-flow deposits in the medium-high flysch mountains of the western Carpathians, Czech Republic, through detailed geomorphological mapping, morphometric studies, sedimentological analyses, electrical resistivity tomography and dendrogeomorphological methods. The authors differentiate two distinct chronological classes of debris-flow deposits; relict voluminous diamictons and recent deposits generated by low-magnitude events, mostly derived from the reworking of the older sediments. Based on geomorphic and stratigraphic evidence the authors infer that debris-flow activity and slope-derived sediment yield was significantly higher than at present time during cold Late Pleistocene epochs, when the timberline was situated at a lower elevation. This type of paleoenvironmental interpretations may constitute a valuable analogue for prognostic studies in similar mountain areas about the possible effects of vegetation cover changes caused by anthropogenic or natural factors. The findings of this investigation are useful for predicting qualitatively debris-flow activity in several scenarios, for example increase in forest cover due to the expectable rising of the timberline in Alpine areas caused by climate warming.

García-Ruiz, Beguería, Alatorre and Puidefábregas investigate the characteristics, spatial distribution and triggering factors of shallow soil landslides in the flysch sector of the Pyrenees. The development of these slope movements, with a significant contribution to soil erosion and landscape degradation, is related to the historical deforestation in the subalpine belt of this mountain area over Middle and Modern Ages. This anthropogenic change in the land cover, aimed at increasing the area of subalpine grasslands, created favourable conditions for the development of shallow landslides, mainly triggered by low-frequency rainfall events. Forest clearance has a particularly high impact on the development of shallow landslides by decreasing root cohesion and increasing water infiltration. García-Ruiz et al. in the Pyrenees and Šilhán and Pánek in the Western Carpathians document opposite temporal trends of landslide activity in similar geomorphological contexts; abrupt increase in the frequency of shallow landslides due to anthropogenic deforestation, in the Pyrenees, and a significant reduction in debris-flow activity due to the upward expansion of the forest as a result of a warmer climate in post-glacial times. These studies illustrate the great impact of vegetation changes on the stability of slopes, especially concerning shallow landslides.

The final paper by Crozier reviews several approaches that may be applied to assess the impact of climate change on landslide activity considering the predictions of downscaled General Circulation Models (GCM): (1) Deterministic, physically-based, slope stability models and combined hydrological-stability models, (2) Empirical rainfall threshold models that may take into account the antecedent water, and (3) Regional and local empirical relationships between climatic parameters and measurements of landslide activity. The author points out that, although these methods could yield useful prognoses on occurrence, reactivation, magnitude and frequency of landsliding under future climatic scenarios, the error margins and spatial scale of downscaled GCM are still too high to obtain reliable predictions. Other difficulties include: (1) The influence of climate change on landsliding depends on the typology and characteristics of the slope movements and on local conditions and (2) Empirical relationships can only be used with confidence in the areas for which they were derived. The author also presents the paleoenvironmental record of landslide activity as a tool of great potential to understand and predict the impact of climatic changes on slope stability. However, the applicability of this approach is limited by two main difficulties (Borgatti and Soldati, 2010); elucidating the causes of the mass movements to remove those controlled by non-climatic factors and dating accurately a representative number of events. Crozier indicates that, while the influence of the predicted climate change on slope stability remains uncertain, the impact of rapidly increasing human activity on landslide activity is unequivocal and can be discerned with much greater certainty. He sustains that human activity should be considered as a factor of comparable importance, if not greater, than climate change. This concept is supported by a large body of evidence. For example, studies carried out in Italy (Guzzetti and Tonelli, 2004) and in the lower Deva valley, Spain (Remondo et al., 2005), document exponential increasing trends in the temporal frequency of landslides over recent decades. These temporal trends show a close parallelism with those of the Gross Domestic Product (GDP), which can be considered as a quantitative indicator of the human capability to modify the Earth's surface (Cendrero et al., 2006). These correlations strongly suggest that the main driving force behind the rapid increase in landslide activity is the alterations caused by human activity on the geomorphic systems with detrimental effect on the stability of slopes. A similar correlation is found between the GDP and the number of disasters caused by floods and related processes, including landslides, in the world (Cendrero et al., 2006; EM-DAT, 2010). Unravelling the causes behind these relationships has relevant economic and political implications. Frequently the media and politicians tend to impute the rapid increase in damage caused by geomorphic processes, including landslides, to an intensification of their activity induced by climate change. Probably, this explanation is more comfortable than attributing the increase in risk to the vulnerability enhancement related to poor land-use management. Geomorphologists have the responsibility to assess the contribution of different factors (climate change, human activity and increase in exposure) to the growing trends in geomorphic hazards and risks and to build up the scientific basis for the design and implementation of efficient mitigation policies.

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