LANDSLIDES IN THE ANDES AND THE NEED TO COMMUNICATE ON AN INTERANDEAN LEVEL ON LANDSLIDE MAPPING AND RESEARCH

Reginald L. HERMANNS[1], Patricio VALDERRAMA[2], Luis FAUQUÉ[3], Ivanna M. PENNA[4,5], Sergio SEPÚLVEDA[6], Stella MOREIRAS[5,7] and Bilberto ZAVALA CARRIÓN [2]

[1]Norges geologiske undersøkelse, Leiv Eirikssons vei 39, NO 7491, Trondheim, Norway. reginald.hermanns@ngu.no
[2]Instituto Geológico Minero y Metalúrgico. Lima, Perú.
[3]Servicio Geológico Minero Argentino. Buenos Aires, Argentina.
[4]Departamento de Ciencias Geológicas. Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Buenos Aires, Argentina.
[5]Consejo Nacional de Investigaciones Científicas y Técnicas-(CONICET).
[6]Departamento de Geología, Universidad de Chile.
[7]IANIGLIA, CCT, Mendoza, Argentina.

ABSTRACT

Landslides in the Andes are some of the highest natural threats to society with single events killing up to several thousand people. Landslide mapping and landslide research became a more widely spread discipline in geosciences in the Andean countries. However efforts today by far do not match the threat and both more investigations and more mapping activities are needed to support decision makers in land use planning. In this communication we discussed five key issues that we suggest to focus on in upcoming years: Impact of climatic change on landslides occurrence, landslides susceptibility and hazard maps, prediction of megalandslides, seismically triggered landslides, and temporal spatial distribution of mud and debris flows potential.

Keywords: *Landslides, hazard, prediction, triggering mechanisms, climate change, Andes.*

RESUMEN

Deslizamientos en los Andes y la necesidad de comunicar a nivel interandino sobre el mapeo y la investigación de deslizamientos.
Los deslizamientos en los Andes son unas de las mayores amenazas naturales a la sociedad, con eventos individuales que han causado la muerte de varios miles de personas. El mapeo e investigación de deslizamientos se convirtió en una disciplina ampliamente difundida en los países andinos. Sin embargo, los esfuerzos actuales no se corresponden aún con la amenaza, y más investigaciones y mapeo son necesarios para apoyar a los tomadores de decisiones en la planificación de usos del suelo. En esta comunicación se discuten cinco temas clave en los que se sugiere poner el foco en los próximos años: el impacto del cambio climático en la ocurrencia de deslizamientos, mapas de peligro y susceptibilidad a deslizamientos, predicción de megadeslizamientos, deslizamientos disparados sísmicamente, y la potencial distribución espacio-temporal de flujos de barro y detritos.

Palabras clave. *Peligrosidad, deslizamientos, predicción, génesis, cambio climático, Andes.*

INTRODUCTION

This communication is inspired by the discussions on the 1st, 2nd, and 3rd Symposium on landslides in the Andes (respectively in 2008, 2010, and 2012 at the geological congresses of Argentina, Peru, and Chile) and is published with 8 selected full papers that were presented on the 2nd Symposium on landslide in the Andes in Peru in 2010. It reviews briefly the impact of landslides on communities and discusses five key topics that require follow up investigations and mapping activities in the Andean region that ideally also should be in future discussed on Interandean platforms. The paper also includes an overview on landslides in the Sihuas valley (Peru), that follow large scale irrigation of coastal plateaus in arid environments. This example strongly highlights the impact of human activity on nature and points out the need of improving the understanding of landslide processes.

The Andes are the world's second highest mountain belt and the inter-Andean valleys are in parts densely populated. Several cities with more than 1 million inhabitants lie in areas with high relief contrasts. Destructive landslides in those large urban centres, some of them resulting in a large number of live losses, have been reported (Salcedo 2007; Hermanns *et al.* 2012a). However, landslides with a large loss of life also occurred in more remote areas of the Andes. For example failures of Nevado

Huascarán in 1962 and 1970 in Peru resulted in the loss of live of thousand of persons (Evans *et al.* 2009). Even more persons lost their life in mudflows, following the eruption of Nevado del Ruiz in Colombia in 1985 (e.g. Montero Olarte 2007). In the Andean regions, natural conditions favouring landslides place additional strains on rural population, often affected by poverty - especially among the indigenous population - that is due to geographic isolation, high transport costs, and limited infrastructure. This leads to a situation that mortality risk due to landslides is among the highest on earth (UN Millennium Project, 2005).

Exposure of civilisation to natural hazards and especially landslides/floods is not new within the Andes. For instance, landslides have strongly impacted on settlements of the Chavin and Chimú cultures, which might have also contributed strongly to the decay of these cultural centres, Turner *et al.* (1999) and Pozorski and Pozorski (2003), respectively. Also economic growth is often hindered by landslides and entire industrial sectors can heavily be damaged. For example, due to the multiple landslides triggered by the Mw 6.2 earthquake on April 21st in 2007 that dropped into the Aisén fjord, southern Chile, and caused displacement waves with run-up heights up to 70 m, fish farming industry was nearly entirely destroyed (Naranjo *et al.* 2009).

The threat of landslides to society and economic growth is especially showcased with the largest clusters of multimillion-cubic-meter landslides that occurred within the past 12 years. One of these clusters of landslides of the Andes that occurred in the 21st century is within the La Paz valley and partly within the city of La Paz, Bolivia. (Hermanns *et al.* 2008). The latest of these landslides destroyed an urban area with around 5000 houses on February 26th in 2011 (Hermanns *et al.* 2012a). The urban centre of La Paz and the satellite town El Alto is among the densest populated area within the Andes but it lies only few km north of the rim of a gigantic landslide with a surface of 60 km² that occurred not more than 11,000 years ago (Hermanns *et al.* 2012a). The other cluster of multimillion-cubic-meter landslides of the 21st century lies in southern Peru in the Sihuas valley (Hermanns *et al.* 2008; Fig. 1). First results of a mapping activity in the Sihuas valley are summarized in this communication as an example on the human impact on the special and temporal distribution of landslides.

LANDSLIDES IN THE SIHUAS VALLEY, PERU

The Sihuas valley is incised several 100 m in a coastal plateau at an elevation of ~1200 m altitude. The plateau lies within one of South American driest regions with only rare minor precipitation events separated by dry periods lasting several years. The Sihuas valley itself is green and fertile due to the Sihuas River draining the inner Andean region towards the Pacific. In the past 25 years the coastal plateau has been progressively converted into a large oasis through South America's largest irrigation project Majes - Sihuas. The irrigation started in 1981 and water started seeping out of the valley walls below the irrigation in 1996. Since 2002 six multimillion cubic meter slides have occurred from that slope (Fig. 1).

Within the Sihuas valley there are 3 prehistoric deposits with volumes between 15 x 10^6 m³ and more than 1 km³. These deposits have not been dated yet; however their age is expected to be older than the Holocene, because their toe areas are covered by massive deposits of laharic flows from the inner part of the Andes, that are not known for the Late Pleistocene / Holocene in that region. Within the past 8 years megalandslides occurred in the valley involving volumes up to ~30 x 10^6 m³ (Fig. 1). The rockslide deposits have destroyed several km² of agricultural land within the valley. The scar areas of two of these slides lie on the southern slope and events occurred in the mid 20th century along a leaking water channel. The other six sourced from the northern slope south of the Majes irrigation project, where a large amount of water is seeping out of the valley walls (Fig. 2). Infiltration into the subsoil from the irrigation on top of the plateau is interpreted as the main factor triggering these recent rockslides. This is especially alarming as a second phase of the Majes – Sihuas irrigation project should start in a few years and also in other valleys in southern Peru (Vítor, Tambo de Cuesta) multimillion cubic meter landslides have been observed in relation with large scale irrigation projects. On human time scales the Sihuas valley has been settled and the valley walls had at least been stable in this area since the Late Moche civilization. This

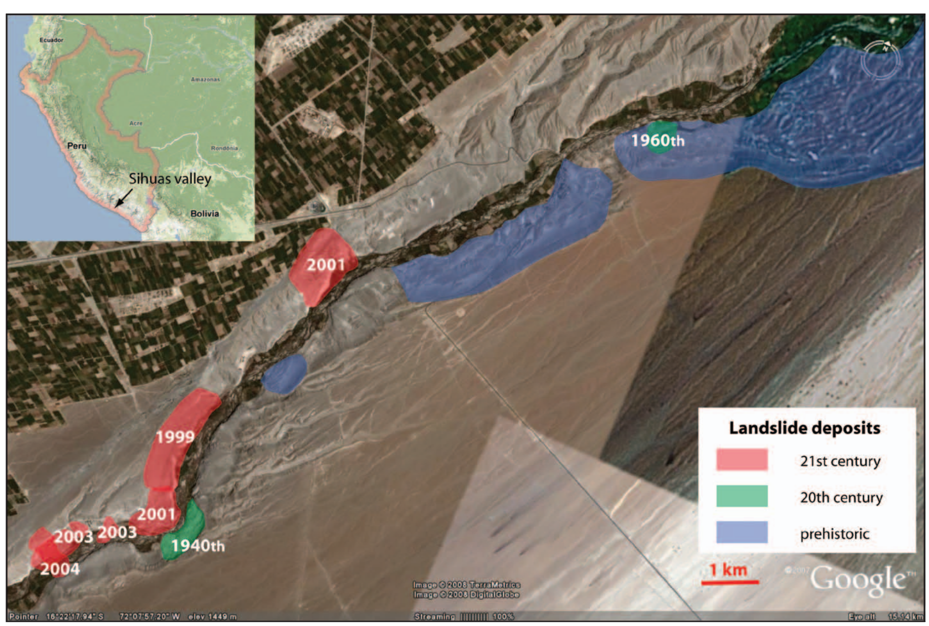

Figure 1: Satellite image showing landslide distribution of prehistoric and historic landslides in the Sihuas Valley, Southern Peru. Ages were reported by local farmers within the Sihuas valley. Note dense vegetation cover due to irrigation on the N side of the valley.

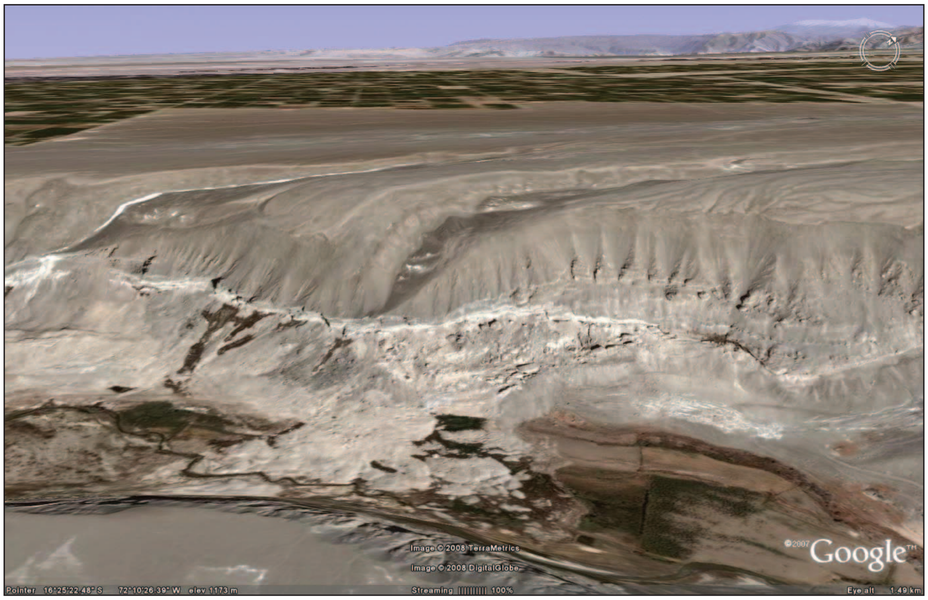

Figure 2: Oblique view of Sihuas valley with megarockslide covering cropland within the valley. Background showing coastal plateau and snow covered mountains of the high Andes. The plateau along the coastal desert is covered partially by oasis due to extensive irrigation. Note the multiple dark patches along the arid valley slopes indicating large quantities of water seeping out of the valley walls.

is evidenced by multiple graveyards that became exhumed in landslides in this valley (Fig. 3). Rests of cloth of mummies were AMS radio carbon dated to an age of 1270 ± 35 BP (TUa – 7860).

DISCUSSION

Examples given in the introduction and the case of the Sihuas valley in Peru makes evident that landslides have been a threat to civilization in the past, at present and that it will be a threat also in future. In this light the "Symposium on Landslides in the Andes" was given birth during the XVII Argentinean Geological Congress in Jujuy, Argentina in October 2008. This symposium was initiated to round up activities started within the Multi Andean Project: Geosciences for Andean Communities that brought together the Geological Surveys of the Andean countries to work in collaboration on landslides, volcanic hazard and earthquake hazard (a summary is given in Hermanns *et al.* 2011). However it was also organized to open communication among the geological surveys to a broader public mainly including research institutes and universities. The topic of landslides within the Andes was chosen as this topic was one of the three topics within the MAP:GAC project that received largest attention by the Geological surveys (PMA:GCA 2007, 2008, 2009). Selected papers from the first symposium were published one year after the symposium in the Revista de la Asociación Geológica Argentina (65/4). The second Symposium was held during the XV Peruvian Geological Congress in October 2010. During the 2nd symposium 14 talks and 1 poster were presented on landslide problematic in Argentina, Bolivia, Chile, Peru, and Norway. In this issue eight selected papers of these contributions are published as full papers. These papers resemble important issues of landslide research in the Andes that has been focus of investigation in the past but that require much more in depth study and extended mapping activities in order to give useful tools to planning institutes in order to reduce the negative impact of landslides in the Andean region: Impact of climatic change on landslides, landslides susceptibility and hazard maps, prediction of megalandslides, seismically triggered landslides, as well as mud and debris flows.

The impact of climate variability and climate change has selectively been the focus of research projects. Namely studies by Trauth and collaborators have focussed on the impact of climate change in past millennia on the distribution of rock avalanches in NW Argentina (e.g. Bookhagen *et al.* 2001, Trauth *et al.* 2002, Hermanns and Schellenberger 2008). Moreiras (2005) and Moreiras *et al.* (2012) showed the impact of climatic variability namely the effect of El Niño/ Southern Oscillation on the temporal distribution of landslides in the Mendoza valley. Clague *et al.* (2012) give a global review on the impact of climate change on hazardous processes in high mountains. Also the loss of glacial ice is understood for tropical mountain belts in the Andes (Francou *et al.* 2000; Thompson *et al.* 2006) its impact on distribution of landslides in the Andes remains poorly understood until today. The best understood processes of landslide conditioning by climate change in the Andes is the process of glacial calving into mountain lakes, that causes displacement waves overflowing and often breaching moraine dammed lakes resulting in debris flood, debris flow disasters (Reynolds 1992; Vilimek *et al.* 2005). Among those studies Valderrama and Vilca (2012) contributed to the understanding of the run-out behaviour of such processes with a paper on a recent case from April 11th, 2010 in the Cordillera Blanca.

In general, the vast amount of the scientific community has come to the conclusion that global climate will warm over the next century (IPCC 2007). This also includes the Andean region. However, different to other regions in the world (SafeLand deliverable 3.8, 2012) no research has yet been carried out in the Andes how future climatic scenarios will impact on distribution of landslides. Mapping out landslide prone areas is one essential tool for development planning. This is carried out in a stepwise approach (e.g., Lacasse and Nadim 2009). On a regional level susceptibility to form landslides are mapped based on physical conditions that change based on geology, climate and landslide type. In a second step hazard zones are mapped in areas where consequences may be severe. This is done normally on a smaller scale that gives in addition to the aerial distribution of landslide impact also information on the frequency and magnitude (volume, intensity) of events. Landslide risk maps also include consequences, which finally allow prioritising areas for mitigation measures for landslides. Except for inventory maps, systematic mapping has still been scarce in the Andean region. Well known examples are susceptibility maps that have been produced on various scales in the Mendoza river catchment (Moreiras 2006a; Rosas *et al.* 2009). Ground-breaking advancement of landslide mapping is carried out at the Geological Survey of Peru (INGEMMET) with putting landslide mapping on a national scale. Villacorta *et al.* (2012) present the first nation-wide landslide susceptibility map produced within the Andean region. The effectiveness of this tool is demonstrated by Zavala *et al.* (2012) with a subset of the national dataset. The massive landslide of Rodeopampa, Cajamarca from February 22nd, 2010, falls in the highest susceptibility class and mitigation measures might have been taken if these maps would have been available prior to the event.

A different approach is required when assessing the likelihood on a slope scale, where a single landslide (often a large landslide) can have severe consequences. At this scale frequency analyses is impossible and the likelihood of failure in future has entirely based on geologic parameters and displacement rates. Within the Andes detailed mapping of slope conditions of deforming slopes in order to assess the likelihood of failure have yet not been carried out. Differently in Norway, where mapping for future failure scenarios is carried out systematically (Hermanns *et al.* 2012b, 2013). One example is the study by Saintot *et al.* (2012) from the Romsdalen valley, Norway, where several rockslopes are mapped in detail and displacements are determined to give likelihood ranges for future failures scenarios. In the Andes deposits of large rock slope failures have been mapped systematically on different scales in order to understand conditions under which they formed (Hermanns and Strecker, 1999; Fauque and Tschilinguirian 2002; González Díaz *et al.* 2006; Moreiras 2006b, Penna *et al.* 2011). However out of those analyses no predictive tools have been developed yet.

That landslide damming is a major threat to communities in the Andes is known since 1914 when a large landslide dam breached (Groeber 1916) resulting in at least 175 casualties (González Díaz *et al.* 2001) along the 1000 km long stretch between the Andes and the Atlantic Ocean due to lack of any fast communication methods. The large impact of landslide dams and related failures on the development of entire regions became also evident by the La Josefina event, Ecuador, 1993. The direct costs due to the dam formation and failure added up to 1% of the gross domestic product of Ecuador in that year (Zevallos *et al.* 1996). Penna *et al.* (2012) focused with a study on a landslide dam with multiple phases of formation and failure in the Patagonian Andes. However, Fauque *et al.* (2005) have been so far the only ones in the Andean region to estimate the rate of formation and failure of such dams as a predictive tool for land use planning.

Earthquakes as a trigger mechanism for large landslides have been known due to the deadly consequences since the Ancash earthquake 1946 (Heim 1949) that triggered 5 rock avalanches and the Chimbote earthquake that triggered failure of Nevado Huascarán in 1970 (Evans *et al.* 2009) in the Cordillera Blanca of Peru. However earthquakes also trigger thousands of small landslides as experienced by the Chimbote earthquake (Plafker an Ericson 1978). Latest examples are the Mw 6.2 earthquake in 2007 in the Aisén fjord of southern Chile and Pisco earthquake in 2007 in Peru. Following both events systematic mapping of landslides has been carried out by Sepúlveda *et al.* (2010) and Zavala *et al.* (2009), respectively. The failure of one of the rock avalanches triggered by the 2007 Aisén fjord earthquake has been investigated in large detail by Oppikofer *et al.* (2012) using high-resolution digital surface model cre-

Figure 3: Mummy exposed by landslides from the N-slope of the Sihauas valley. Rests of cloth of the mummy was AMS radio carbon dated to an age of 1270 ± 35 BP, therefore the mummy belongs to the Late Moche civilization.

ated from terrestrial laser scanning. Such detailed studies allow separating between deposits of primary failures due to the earthquake shock and secondary failures due to toe erosion of slopes by landslides. Based on historic observations it was lately discussed that megathrust-earthquakes along the subduction zone along the Pacific rim of South America rather produce widespread landsliding while shallow crustal earthquakes although of minor magnitude produce rather regional more concentrated but more voluminous landslides (Sepúlveda *et al*. 2012; Hermanns and Longva 2012). Systematic mapping of landslides triggered by earthquake in future can test those hypotheses.
Mud flows/debris flows are further serious threats to society in most part of the Andes. Even the driest parts of the Andes with average annual precipitation below 10 mm/year can be affected by debris flows during seldom stronger precipitation events, usually related to El Niño climatic events (Sepúlveda et *al.* 2006). For example on June 18th, 1991, 91 persons lost their life in Antofagasta (Chile) in a precipitation event of 14,2 mm / 3 hr (Hauser 1997). Such precipitations in other parts of the Andes rarely would cause any mass movements. During a magnitude 7.7 earthquake with an epicentre close to that town only two persons lost their life in 1995 indicating the large threat of water-saturated landslides in this region. This is further highlighted by both the most deadly landslide events in the past century. One event is related to exceptional high rainfall along the cost of Venezuela in 1999 (Salcedo 2007) the other to the melt of the glacier covering Nevado de Ruiz in Colombia during an eruption (Montero Olarte 2007). However, such events can threat most communities within the Andean valleys as showcased with an example of a mud flow in Termas de Reyes, Province of Jujuy, Argentina from January 12th, 2010 that caused 87 injured persons and severe material damage in a recreational area by González *et al.* (2012). In this area similar events have occurred in the past as documented by historic records and deposits of previous events. Such high hazard areas could easily be recognized during systematic mapping in future and managed using appropriate land use regulations.

CONCLUSION

Landslide mapping and investigation became a more important issue for geoscientists in the past two decades in the Andean region. The Symposium on landslides in the Andes became an important platform for exchange. We hope that this Symposium can be carried out also in future during geological congresses in order to make knowledge transfer easy.
We discussed here the impact of landslides in the Andes on society and pointed to five key mapping and research areas in which we see a large potential of development that can impact on decision making processes that will allow reducing the landslide threat within the Andes.

ACKNOWLEDGEMENT

We want to thank the organizers namely Jose Macharé Ordoñez, Victor Carlotto Caillaux, and Lionel Fidel Smoll of the 15th Peruvian geological Congress to host the 2nd Symposium on landslides in the Andes. The International Centre of Geohazards supported the Symposium in Peru by providing travel allowances to invited speakers and supported editing through time for Reginald Hermanns and travel for Ivanna Penna. This is ICG contribution 410. The publication of selected papers in this volume of the Revista de la Asociación Geológica Argentina was made possible due to the support by Victor Ramos, Andres Folguera, and Pablo J. Pazos.

LIST OF BIBLIOGRAPHIC REFERENCES

Bookhagen, B., Haselton, K., and Trauth, M.H. 2001. Hydrological modelling of a Pleistocene landslide-dammed lake in the Santa Maria Basin, NW Argentina. Palaeogeography, Palaeoclimatology, Palaeoecology, 169: 113-127.

Clague, J.J., Huggel, C., Korup, O., and McGuire, B. 2012. Climate change and hazardous processes in high mountain. Revista de la Asociación Geológica Argentina 69: 328-338.

Evans, S.G., Bishop, N.F., Fidel Smoll, L., Valderrama Murillo, P., Delaney, K.B. and Oliver-Smith, A. 2009. A re-examination of the mechanism and human impact of catastrophic mass flows originating on Nevado Huascarán, Cordillera Blanca, Peru in 1962 and 1970. Engineering Geology, 108: 96-118.

Fauqué, L., Baumann, V., Rosas, M. and Hermanns, R.L. 2005. Flooding risk in Mendoza valley related to collapse of natural moraine and landslide dams, Argentina. En Hungr, O., Fell, R., Couture, R. and Eberhardt, E. (eds.) Landslides Risk management: on CD, 6 p., Balkema Publisher, Leiden.

Fauqué, L. and Tchilinguirian, P. 2002. Villavil rockslides, Catamarca Province, Argentina. En Evans, S.G. and DeGraff, J.V. (eds.) Catastrophic landslides: Effects, occurrence and mechanism: 303 - 324 p., Reviews in Engineering Geology XV, Boulder.

Francou, B., Ramirez, E., Cáceres, B. and Mendoza, J. 2000. Glacier evolution in the tropical Andes during the last decades of the 20th century: Chacaltaya, Bolivia, and Antizana, Ecuador. Ambio 29: 416-422.

González, M.A., Solis, N.G., Fracchia, D., and Barber, E. 2012. Flujo de barro del arroyo del Comedoro, Jujuy: Caracterización, causas y efectos. Revista de la Asociación Geológica Argentina 69: 382-392.

González Díaz, E.F., Folguera, A., Costa, C.H., Wright, E. and Elisondo, M. 2006. Los grandes deslizamientos de la región septentrional neuquina entre los 36° y los 38°S: Una propuesta de inducción sísmica. Revista de la Asociación Geológica Argentina 61: 197-217.

González Díaz, E.F., Giaccardi, A.D. and Costa, C.H. 2001. La avalancha de rocas del río Barrancas (Cerro Pelán), norte del Neuquén: su relación con la catástrofe del río Colorado (29/12/1914). Revista de la Asociación Geológica Argentina 56: 466-480.

Groeber, P. 1916. Informe sobre las causas que han producido las crecientes del río Colorado (Territorios del Neuquén y La Pampa) en 1914. 1-29 p.. Buenos Aires: Dirección General de Minas, Geología e Hidrogeología.

Hauser, A. 1997. Los aluviones del 18 de junio de 1991 en Antofagasta: un análisis crítico, a 5 años del desastre. Boletín No. 49, 47 p., Servicio Nacional de Geología y Minería, Santiago.

Heim, A. 1949. Observaciones geológicas en la región del terremoto de Ancash de noviembre de 1946. Sociedad Geológica del Perú, 25: 2-21.

Herd, D.G. 1986. The 1985 Ruiz volcano disaster. EOS Transaction, American Geophysical Union Transaction 67: 457-460.

Hermanns, R.L., Blikra L.H., Anda, E., Saintot, A., Dahle, H., Oppikofer, T., Fischer, L., Bunkholt, H., Böhme, M., Dehls, J., Laukens, T.R., Redfield, T., Osmundsen P.T., and Eikens, T. 2013. Systematic mapping and hazard and risk classification of unstable rock slopes with potential of forming rock avalanches in Norway. En Margottini, C., Canuti, P. and Sassa, K. (eds.) Landslide Science and Practise: in press, Springer Verlag, Berlin.

Hermanns, R.L., and Longva, O. 2012. Rapid rock slope failures. En Clague, J.J. and Stead, D., Landslides; types, mechanisms, and modelling: 59-70 p., Cambridge University Press, Cambridge.

Hermanns, R.L., Dehls, J.F., Guzmánn, M.A., Roberts, N., Clague, J.J., Cazas Saavedra, A. and Quenta Quispe, G. 2012a. Relation of recent megalandslides to prehistoric events in the city of La Paz, Bolivia. En Eberhardt, E., Froese, C., Turner, A.K. and Leroueil, S. (eds.) Landslides and engineered slopes: Protecting society through improved understanding: 265 - 271 p., Taylor and Francis Group, London.

Hermanns, R.L., Oppikofer, T., Anda, E., Berg, H., Blikra L.H., Böhme, M., Bunkholt, H., Crosta G.B., Dahle, H., Devoli, G., Eikenæs, O., Fischer, L., Jaboyedoff, M., Loew, S., Sætre, S., Yugsi Molina, F. 2012b. Susceptibility, hazard and risk classification for large unstable rock slopes in Norway. NGU rapport 2012.029, 49 p., in press.

Hermanns, R.L., Muñoz Carmona, F., Ulmi, M., and Ellerbeck, M.D. 2011. The "Multinational Andean Project: Geosciences for Andean Communities" experience – an international geoscientific project focusing on science and knowledge transfer. In: Breitkreuz, C., and Gusky H.-J., Geo-risk management – a German Latin American approach, Workshop organized by Latin American German Alumni, 2nd – 7th April 2011, Heidelberg, p. 137-144.

Hermanns, R.L., Fauqué, L., Fidel Small, L., Welkner, D., Folguera, A., Cazas, A. and Nuñez, H. 2008. Overview of catastrophic megarockslides in the Andes of Argentina, Bolivia, Chile, Ecuador and Peru. The first Landslide World Forum, Tokyo, Abstracts: 255-258.

Hermanns, R.L. and Schellenberger, A. 2008. Quaternary tephrochronology helps define conditioning and triggering mechanisms of rock avalanches in NW Argentina, Quaternary International 178: 261-275.

Hermanns, R.L. and Strecker, M.R. 1999. Structural and lithological controls on large Quaternary rock avalanches (sturzstroms) in arid northwestern Argentina: Geological Society of America Bulletin 111: 934-948.

Intergovernmental Panel of Climate Change (IPCC). 2007. Climate change 2007: Synthesis report. 73 p.

Lacasse, S., and Nadim, F. 2009. Landslide Risk Assessment and Mitigation Strategy. En Sassa, K. and Canuti, P. (eds.) Landslides – Disaster Risk Reduction: 31 - 61 p., Springer-Verlag, Berlin.

Montero Olarte, J. 2007. Flujos de detritos (Lahares) catastróficos del volcán Nevado del Ruiz, Colombia, 11 de Noviembre de 1985. En: Proyecto Multinacional Andino: Geociencias para las Comunidades Andinas: Movimientos en Masa en la Región Andina: una guía para la evaluación de amenazas. Servicio Nacional de Geología y Minería, Publicación Geológica Multinacional 4: 369-385.

Moreiras, S., Lisboa, M.S. and Mastrantonio, L. 2012. The role of snow melting upon landslides in the central Argentinean Andes. Earth Surface Processes and Landforms, 37: 1106-1119.

Moreiras, S. 2006a. Frequency of debris flow and rockfall along the Mendoza river valley (central Andes), Argentina: associated risk and future scenario. Quaternary International, 158: 110-121.

Moreiras, S. 2006b. Chronology of a probable neotectonic Pleistocene rock avalanche, Cordon de Plata (Central Andes), Mendoza, Argentina. Quaternary International 148: 138-148.

Moreiras, S. 2005. Climatic effect of ENSO associated with landslide occurrence in the Central Andes, Mendoza province, Argentina. Landslides 2: 110-121.

Naranjo, J., Arenas, M., Clavero, J. and Muñoz, O. 2009. Mass movement-induced tsunamis: main effects during the Patagonian Fjordland seismic crisis in Aisén (45°25'S), Chile. Andean Geology 36: 137-145.

Oppikofer, T., Hermanns, R.L., Redfield T.F., Sepúlveda, S.A., Duhart, P., and Basuñan, I. 2012. Morphologic description of the Punta Cola rock avalanche and associated minor rockslides caused by the 21 April 2007 Aysén earthquake (Patagonia, southern Chile). Revista de la Asociación Geológica Argentina 69:339-353.

Penna, I.M., Hermanns, R.L., and González, M.P. 2012. Endicamientos naturales en las nacientes del arroyo Lileo (Provincia del Neuquén, Argentina). Revista de la Asociación Geológica Argentina 69:372-381.

Penna, I., Hermanns, R.L., Folguera, A. and Niedermann, S. 2011. Multiple slope failures associated with neotectonic activity in the southern central Andes (37º-37º30'S). Patagonia, Argentina. Geological Society of America Bulletin 123: 1880-1895.

Plafker, G. and Ericksen, G.E. 1978. Nevados Huascaran avalanches, Peru. En Voight, B. (ed.) Rockslides and avalanches 1: Natural phenomena: 277-314 p., Elsevier, Amsterdam.

Pozorski, T. and Pozorski S. 2003. The Impact of the El Niño Phenomenon on Prehistoric Chimú Irrigation Systems of the Peruvian Coast. En Hass, J. and Dillon, M. (eds.) El Niño in Perú: Biology and Culture Over 10,000 Years: 71-89 p., Chicago: Field Museum of Natural History.

Proyecto Multinacional Andino: Geociencias para los Comunidades Andinas (PMA:GCA), 2009, Comunicación para transformar el conocimiento geocientífico en acción, 138 p.

Proyecto Multinacional Andino: Geociencias para los Comunidades Andinas (PMA:GCA), 2008, Experiencias andinas en mitigación de riesgos geológicos. Servicio Nacional de Geología y Minería Publicación Geológica Multinacional, No. 6, 107 p.

Proyecto Multinacional Andino: Geociencias para los Comunidades Andinas (PMA:GCA), 2007, Movimientos en Masa en la Región Andina: Una guía para la Evaluación de Amenaza. Servicio Nacional de Geología y Minería Publicación Geológica Multinacional, No. 4, 404 p., 1CD-ROM.

Reynolds, J.M. 1992 The identification and mitigation of glacier-related hazards: examples from the Cordillera Blanca, Peru. En McCall, G.J.H., Laming, D.J.C. and Scott, S.C. (eds.) Geohazards: 143-157 p., Chapman & Hall, London.

Rosas, M., Baumann, V., Videla, A., Gonzalez, M.A., Lo Forte, G., Fauque, L., Hermanns, R.L, Wilson, C.G.J., Lagorio, S., diTomaso, I., Hewitt, K., Coppolechia, M., Jaboyedoff, M. and Tchilinguirian, P. 2007. Estudio geoscientífico aplicado al ordenamiento territorial Puente del Inca, Provincia Mendoza, Publicación del Servicio Geológico Minero de Argentina, 73 p. and 5 maps.

SafeLand deliverable 3.8. 2012. Changing pattern in climate-driven Landslide hazard at selected sites in Europe (focus on Southern Italy, the Alps and southern Norway) in the next 50 years. Edited by the SafeLand European project by Vandromme, R., Hohmann, A., Desramaut, N., and Bails, A. Available at http://www.safeland-fp7.eu/results/Pages/wa3.aspx, 80 p.

Saintot, A., Dahle, H., Derron, M.H., Henderson, I. and Oppikofer, T. 2012. Large gravitational rock slope deformation in Romsdalen valley (Western Norway). Revista de la Asociación Geológica Argentina 69:354-371.

Salcedo, D.A. 2007. Los flujos torrenciales en el estado Vargas y área metropolitana de Caracas, Venezuela, Diciembre 1999. En: Proyecto Multinacional Andino: Geociencias para las Comunidades Andinas: Movimientos en Masa en la Región Andina: una guía para la evaluación de amenazas. Servicio Nacional de Geología y Minería, Publicación Geológica Multinacional 4: 336-368.

Sepúlveda, S.A., Fuentes, J.P., Oppikofer, T., Hermanns, R.L., Moreiras, S.M. 2012. Analysis of a large-scale, stepped planar rockslide failure in the Central Andes uplands, Chile, using roughness profiles from terrestrial laser scanning. En Eberhardt, E., Froese, C., Turner, A.K. and Leroueil, S. (eds.) Landslides and engineered slopes: Protecting society through improved understanding: 1243 - 1247 p., Taylor and Francis Group, London.

Sepúlveda, S., Serey, A., Lara, M., Pavez, A. and Rebolledo, S. 2010. Landslides induced by the April 2007 Aysén fjord earthquake, Chilean Patagonia. Landslides 7: 483-492.

Sepúlveda, S.A., Rebolledo, S. and Vargas, G., 2006. Recent catastrophic debris flows in Chile: Geological hazard, climatic relationships and human response. Quaternary International 158: 83-95.

Thompson, L.G., Mosley-Thompson, E., Brecher, H., Davis, M., Leon, B., Les, D., Lin, P-N., Mashiotta, T. and Mountain, K. 2006. Abrupt tropical climate change; past and present. Proceedings of the National Academy of Sciences 93: 10,536-10,543.

Trauth, M.H., Alonso, R.A., Haselton, K.R., Hermanns, R.L. and Strecker, M.R. 2000. Climate change and mass movements in the NW Argentine Andes: Earth and Planetary Science Letters 179: 243-256.

Turner, R.J.W., Knight, R.J. and Rick, J. 1999. Geological landscape of the pre-Inca archeological site at Chavin de Huantar, Peru. Current Research 1999-D. Geological Survey of Canada: 47-56.

UN Millenium Project. 2005. Investing in development: A practical plan to achieve the Millenium Development Goals: 329 p., New York.

Valderrama, P. and Vilca, O. 2012. Dinámica e implicancias del aluvión de Laguna 513, Cordillera Blanca, Ancash, Perú. Revista de la Asociación Geológica Argentina 69:400-406.

Vilímek, V., Zapata, M.L., Klimeš, J., Patzelt, Z. and Santillán, N. 2005. Influence of glacial retreat on natural hazards of the Palcacocha lake area, Peru. Landslides 2: 107-115.

Villacorta, S., Fidel, L., and Zavala, B. 2012. Mapa de susceptibilidad por movimientos en masa del Perú. Revista de la Asociación Geológica Argentina 69:393-399.

Zavala Carrión, B., Gómez, J., and Lu, León S. 2012. Deslizamiento de Rodeopampa, reactivación de movimiento en masa en una zona de alta susceptibilidad en la región Cajamarca, Perú. Revista de la Asociación Geológica Argentina 69:407-417.

Zavala Carrión, B., Hermanns, R.L., Valderrama, P., Costa, C., and Rosado, M. 2009 Procesos geológicos e instabilidad macrosísmica INQUA del sismo de Pisco del 15/08/2007, Perú, Revista de la Asociación Geológica Argentina 65: 760-779.

Zevallos, O., Fernández, M.A., Plaza Nieto, G., and Klinkicht Sojos, S. 1996. Sin plazo para le esperanza, reporte sobre el desastre de La Josefina - Ecuador, 1993. Escuela politécnica Nacional: 348p., Quito, Ecuador.

Recibido: 11 de febrero, 2012
Aceptado: 23 de abril, 2012