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Multidisciplinary determination of Lahar Erosion Dynamics at the Colima Volcano (Mexico)

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Volcán de Colima (10º 30′44′′N, 103º 37′02′′ W) is currently the most active volcano in Mexico and the North American plate. Associated to its frequent volcanic activity, renovated in 1998 and later in 2010, secondary processes like lahars, triggered by rain mixing with the loose pyroclastic debris produced, are common. Colima lahars channelled through the main water drainages (ravines), and reach large distances along their path (from 7 to 15 km long) burying farmland and all kind of human infrastructures at the surrounding area.
The inner part of the ravines is greatly affected by lahars, especially by the bulking processes, so establish an appropriate method to determine its affection rate seems to be needed.
In order to analyze 1-year lahar erosion dynamics inside one of the most active ravine (Montegrande 2011-2012 period), our team proposed a multidisciplinary perspective that combines numerical modeling (ArcGeoWEPP), fieldwork recognition and free satellite imagery, in the assessment of the related hazards.
On the one hand, ArcGeoWEPP model allowed simulation of watersheds and hillslope profiles within ravines, taking into account climate parameters, land and vegetation covers. This tool was especially useful in areas where the terrain complexity prevented access. The results of this model were combined with 16 real cross-section topographies observed inside the Montegrande ravine and the floodplain delineation of lahars created from satellite imagery.
The total 1-year volume of debris at Montegrande was finally reached, but also the erosive, sedimentary and balanced areas were identified, so as the lahar and its deposit dimensions. 750,000 tons per year were eroded inside the Montegrande ravine during 2011-2012 lahars, 805,000 tons if the hillslopes of the surrounding area were considered, and 580,000 tons were deposited along the path. The flood plain area was 1,100,000 m2.
Numerical models combined with field data obtained from different sources seems to be a useful framework to reproduce lahar erosion dynamics at volcanic areas like Volcán de Colima.

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Lahar simulation with SPH and field calibration at the Colima Volcano (Mexico)

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As a result of the frequent effusive activity of Volcán de Colima (10º 30′44′′N, 103º 37′02′′ W), the most active volcano in Mexico, plenty of rain triggered lahars are produced, especially during the rainy season. Along the recent period of activity, particularly from 2010, many of these lahars channelled through the main ravines of the volcano and reach large distances, representing high risk for more than 10,000 people at the surroundings.
Modeling of lahars has become an important tool in the assessment of the related hazards, in order to undertake appropriate mitigation actions and reduce the associated risks. Recent lahars at the Colima Volcano are well documented, so they can be used to prove the accuracy of modelling.
In this work, we used the SPH (Smoothed Particle Hydrodynamics) method, a depth integrated coupled model created by Pastor in 2005, to replicate the propagation stage of 3 recent Colima lahars occurred on Montegrande ravine in 1992, 2011 and 2012. The studied events include hyperconcentrated, debris and a mixture of the previous flow natures.
The inputs used for the SPH simulations were the initial point, volume of each lahar and an adapted morphology of its mass. Field data used to verify the SPH results include the stopping point of the lahar, its path, velocity and height values, as the floodplain area. All this information was a result of fieldwork recognition (cross section profiles of the inner part of the ravine) and free satellite imagery analysis.
The best results were obtained using Bingham rheology. The proposed parameters to simulate Colima lahars were 20 Pa of yield strength and 30 Pa.s of viscosity for the 1992 lahar (hyperconcentrated flow), 200 Pa and 50 Pa.s in case of the 2011 debris flow, and finally 20 Pa and 24 Pa.s for the 2012 event, whose nature evolved from debris to an hyperconcentrated flow. In all cases a 1900 kg/m3 density was used.
Highly accurate results showed the relevant role played by rheological parameters and the necessity of a systematic collection of field data to calibrate the model.

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Geomorphological evolution of volcanic fluvial channels: Eighteen years of morphological monitoring of the upper strect of the Tenenepanco Gorge, Popocatépetl volcano, Mexico

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During volcanic eruptions a significant volume of material accumulates on the slopes and pre-existing gorges of the stratovolcanoes. This abundance of loose and unconsolidated material is very likely to be mobilized by rapid flows or lahars generated by sudden heavy rain or melting snow and ice. Thus, volcanic gorges are affected by complex cycles of incision, filling and widening, altering the equilibrium of river systems due to the major changes that lahars cause in channel morphology.

These geomorphological dynamics characterize the gorges located on the north flank of the Popocatépetl volcano (19°02′ N, 98°62′ W, 5424 m). This volcano, located in the centre of the Trans-Mexican Volcanic Belt, began its most recent eruptive period in December 1994, when a glacier partially covered the northern slope. Since then, the interaction of volcanic and glacier activity triggered the formation of lahars in the gorges, causing significant morphological changes in the channel (especially in April 1995, July 1997 and January 2001). The most recent major eruption at Popocatépetl took place on 19 July 2003, and since then a series of smaller eruptions has reduced the glacier to near extinction.

The aim of this study is to assess the morphological response of the Tenenepanco channel over an 18-year period, from 1995-2013, where two main scenarios can be observed: a) the period from 1995 to 2001 of volcanic activity and glacier retreat with the formation of flows and b) the period from 2002 to 2013 of relative volcanic calm, the almost complete extinction of the glacier, and the formation of secondary lahars associated with heavy rainfall.

Monitoring of the gorge has consisted in the elaboration of 14 geomorphological maps during field studies (November 14, 1995, December 5, 1997, February 7, 1998, October 6, 2001, November 14, 1995, December 5, 1997, February 7, 1998, October 6, 2001, Julio 16, 2002, February 11, 2004, September 8, 2004, February 5, 2006, November 2, 2008, February 5, 2008, November 5, 2009, November 5, 2010, November 9, 2011, November 6, 2013). An additional map (May-1989) was made based on photo-interpretation of aerial photographs taken during that period. A set of 13 morphological units were recognized in each of the maps. Subsequently, the maps were georeferenced using a 2010 orthophoto and the image of Google Earth from 2013. In a second step the 15 maps were digitized and the topology created in a CAD environment (Bentley Microstation V8i). Finally a spatial analysis was carried out in a GIS (ESRI ArcMap 10) in order to study the morphological variations of the channel gorge.

The preliminary results show that during the initial period (1995-2001) channel evolution is more variable, with episodes in which the bottom of the gorge is eroded with multiple channels alternating with others where there is only a single channel. These moments presumably coincide with volcanic activity which provides abundant material that fills the smaller gullies and concentrates the lahars in a single channel. However, the secondary flows in the 2002-2013 period tend to merge into one wide channel that drops in depth, creating pseudo-terraces.

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The presence of the Oldest Dryas in Spanish mountain landscapes

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The important advances in our understanding of the Oldest Dryas (OD) in the evolution of the continental ice caps and the oceanic basin have not yet reached the European mountains, or have only affected a small part of them. In practice, research into the impact of this period on European mountains has focused on the Alps, where the Gschnitz stadial, a glacial re-advance phase, has been clearly differentiated. This is shown in the landscape by families of moraines present in many valleys, above all in small and medium ones, with minimum age 15.9 ka, but which may represent glacial advances of at least a thousand years older. Traces of this same phase are gradually appearing in other European mountains, including some mountains in Spain.

The aim of this paper is to emphasise the importance of the Oldest Dryas in the configuration of high mountain landscape in Spain: (Sierra Nevada, Central System and Pyrenees), through the analysis of the latest studies of glacial chronology.

In Sierra Nevada, in the SE sector of the Iberian Peninsula, the definitive deglaciation occurred just at the end of the OD, between 15 and 14.5 ka, according to dates obtained from many polished thresholds. There are moraines which obtain dates between 17 and 16 ka, very close to those of the Maximum Ice Extent (MIE), although as there are still only a few of these and because of slope instability they may be morainic boulders from the MIE phase which have been destabilized, disturbed or exhumed, so that more detailed research is required. Nevertheless, it is known for certain that the end of the OD was accompanied by the massive formation of rock glaciers, resting on the polished thresholds mentioned above and with their fronts stabilized at the end of the OD, around 14.5 ka, although their roots remained active until the Holocene.

In the Central System, in both Gredos and Guadarrama, the OD was a phase of great advance after almost disappearing after the MIE. During the OD the glaciers advanced so much that at times they collided with the MIE moraines or came very close, although often this was simply a string of boulders. A rock glacier associated with the end of the OD has only been found in Guadarrama.

The presence of OD traces is evident in the Central and Eastern Pyrenees with very similar characteristics in both sectors. Here, just as in the Central System, the OD meant a great re-advance after the collapse of the glaciers which followed the MIE. The glaciers started to flow down the valleys again, although they remained several kilometres from the moraines related to the MIE. The end of the OD meant the definitive retreat of the glaciers to the valley headwalls, but before this occurred a series of rock glaciers formed in the interior of the cirques, under the most geomorphologically active walls. As also occurred in Sierra Nevada, the end of the OD meant that these glacial fronts became completely stabilized around 14.5 ka, but their roots continued active until the Holocene.

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The glaciers of Sierra Segundera (Zamora, NW Spain) during their Maximum Ice Extent: area, volume, Glacial Equilibrium Line Altitude and paleo-climatic implications

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The aim of this paper is to reconstruct the Quaternary glaciers which formed the eastern sector of the Sierra Segundera ice-cap (NW Iberian Peninsula) during its Maximum Ice Extent (MIE) local phase (33 ka) in a surface area of 165 km2, to estimate the ice volumes and Equilibrium Line Altitudes (ELAs). The study area presents a wide altimetric range of approx. 1200 m, from the Tera glacier front to the Peña Trevinca (42º14'33" N, 6º47'46" W; 2127 m) and Peña Negra (42º14'58" N, 6º47'39" W; 2121 m) horns, covering a wide plateau at an altitude of over 1700 m.

The reconstruction of the MIE paleoglaciers used a combination of various tools: a rheological numerical model which describes the ice flow, GIS and geomorphological field work to validate the results. The model used here allowed the reconstruction of the surface topography of the paleoglacial ice, even though there is no existing geomorphologic evidence to reveal the thickness of the ice at that time. The GIS enabled the creation of Digital Elevation Models (DEMs) and the estimation of thicknesses and volumes. The reconstructed topography and the delimitation of the geomorphologic features were used to estimate the ELA using the following methods: Area x Altitude Balance Ratio (AABR), Accumulation Area Ratio (AAR), Terminus Headwall Altitude Ratio (THAR) and Maximum Elevation of Lateral Moraines (MELM).

The DEM reconstructed for the surface of the paleoglaciers obtained an estimated maximum ice thickness of over 450 m during the MIE, and a total ice volume of 2.63 x 10(10)m3 for the eastern half of the ice-cap. When estimating the paleo-ELAs, the AABR and AAR methods obtain more logical values. The AABR method obtains BR=1, which questions the BR=2 assumed as representative for medium latitude glaciers with oceanic influence; the paleo-ELA AABR was 1739 m. Applying the AAR method with the ratio 0.65 gives the result 1735 m. The THAR and MELM methods give values of 1637 m and 1651 m respectively for the ELAs, which are different from the values obtained by the methods mentioned above. AABR and AAR are shown to be the most reliable methods as they do not depend on the conservation level of geomorphological features.

The estimated paleoELA in our case study is in an intermediate position between those estimated in nearby glaciers of the same type during the MIE in the Serra da Estrela and la Sierra de Béjar, at 1650 and 2010 m. The contrast is more difficult, however, with the Cordillera Cantábrica, with ELAs ranging from 1100 to 2000 m, depending on orientation.

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Static debris-covered glaciers and rock glaciers in Tröllaskagi Peninsula (northern Iceland): The cases of Hóladalur and Fremri-Grjótárdalur.

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The glacial and periglacial environment – linked to the extensive presence of permafrost- which predominates in the Tröllaskagi Peninsula (NE Iceland), has been conducive to the development of numerous glaciers, covered glaciers and rock glaciers located at most of its valley headwalls. This is the case in the Vidinesdalur valley, north of Hólar, where there is a debris-covered glacier (65º42′N-65º44′N and 18º56′W-19º00′W) at the bottom of the Hóladalur valley, one of its tributary valleys, and an extensive rock glacier at the bottom of the Fremri-Grjótárdalur, another tributary valley to the west. These two valleys have been monitored using digital photogrammetry to evaluate their activity in relation to displacement and velocity rates.
As a detailed aerial photo from 1946 and also two orthophotos dated 2000 and 2013 were available, our aim was to study the advance rate of the two glaciers from the changes observed in their morphology at these three dates. The methodological approach adopted consisted of a combination of a geomorphological field survey 2012-2014 and photogrammetric analysis of the available material from these three years. The 1946 photograms were scanned in high resolution and georeferenced in the GIS ArcMap 10.1 (ESRI ArcGIS), using the Georeferencing module, with the 2000-2013 orthophotos as support. Between 49 and 63 control points were used for each photo, located along the outer edges of the glaciers. The transformation, applying a third degree polynomial function, obtained an RMS error of 16.10480 m and 9.42038 m respectively. The geomorphological traits were then digitized and observation of the images was carried out in a CAD environment (Bentley MicroStation V8i), which also allowed us to overlay a grid and work simultaneously with various views, facilitating the detection of possible changes in the surface of the rock glacier. During the 2014 fieldwork the limits and main geomorphological units of the two glaciers were delineated with GPS.
The analysis and interpretation of the morphological characteristics clearly show the almost complete absence of changes in the superficial structure of both the Fremri-Grjótárdalur rock glacier and the Hóladalur debris-covered glacier during the time interval studied, detecting the same flow structures (transversal crests and grooves and flow lines) located in the same position. Similarly, the external limit or shape shows hardly any variations. The rock glacier may be considered to have remained practically stable from 1946 to the present. This assertion contrasts with the observations made by Wangensteen et al., 2006, who also used photogrammetric techniques and detected displacements in the interior of the rock glacier during the 9 year period from 1985 to 1994.
In conclusion, the geomorphological survey of the 1946 aerial photograph and of the 2000- 2013 orthophotos, and their comparison using photogrammetric techniques has allowed us to detect the total stability of both the rock glacier and the debris-covered glacier over the last 50 years.

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Geophysical surveys on permafrost in Coropuna and Chachani volcanoes (southern Peru)

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A network of air and ground temperature sensors installed 2004-2014 has enabled the discovery of permafrost on the Coropuna (6377 m) and Chachani (6057 m) volcanoes. However, on the Misti (5820 m) volcano there is no permafrost, which can be attributed to geothermal heat. Misti and Chachani are very close to each other, near the city of Arequipa (S. Peru). Coropuna is 150 km to the west. Various volcanic eruptions have taken place on Misti and Coropuna in the last 10 ka (Úbeda et al, 2012). The volcanic activity on the Chachani seems to be much older, although it has not been researched to date. Coropuna is covered by a glacial system of ∼40 km2 (23-11-2013) and the moraines surrounding the volcanic complex indicate a surface of >500 km2 >10 ka ago (Úbeda et al, 2011). On Chachani the evidence also suggests a great extent in the past although in this case there are no glaciers conserved at the present day. On Misti there are currently no glaciers either, nor is there any evidence conserved of their earlier presence, and this has also been related to geothermal heat. As well as other study areas, the CRYOPERU sensor network includes 4 stations in the sector Coropuna-NE; 3 stations in Coropuna-SE; 3 stations in Chachani-SE and 3 stations in Misti-NW. The stations are at different altitudes, in an interval of 4300-6000 m. Each station has a thermometer to measure the air temperature (at a height of 0.50 m) and three thermometers to measure the ground temperature (at depths of 0.15, 0.30 and 1.00 m). The sensors are synchronized in GPS time and record the temperature every 30 minutes.

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Timing of maximum glacial extent and deglaciation from HualcaHualca volcano (southern Peru), obtained with cosmogenic 36Cl.

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Andean glacial deposits are key records of climate fluctuations in the southern hemisphere. During the last decades, in situ cosmogenic nuclides have provided fresh and significant dates to determine past glacier behavior in this region. But still there are many important discrepancies such as the impact of Last Glacial Maximum or the influence of Late Glacial climatic events on glacial mass balances. Furthermore, glacial chronologies from many sites are still missing, such as HualcaHualca (15° 43′ S; 71° 52′ W; 6,025 masl), a high volcano of the Peruvian Andes located 70 km northwest of Arequipa.

The goal of this study is to establish the age of the Maximum Glacier Extent (MGE) and deglaciation at HualcaHualca volcano. To achieve this objetive, we focused in four valleys (Huayuray, Pujro Huayjo, Mollebaya and Mucurca) characterized by a well-preserved sequence of moraines and roches moutonnées. The method is based on geomorphological analysis supported by cosmogenic 36Cl surface exposure dating. 36Cl ages have been estimated with the CHLOE calculator and were compared with other central Andean glacial chronologies as well as paleoclimatological proxies.

In Huayuray valley, exposure ages indicates that MGE occurred $\sim$ 18 - 16 ka. Later, the ice mass gradually retreated but this process was interrupted by at least two readvances; the last one has been dated at $\sim$ 12 ka. In the other hand, 36Cl result reflects a MGE age of $\sim$ 13 ka in Mollebaya valley. Also, two samples obtained in Pujro-Huayjo and Mucurca valleys associated with MGE have an exposure age of 10-9 ka, but likely are moraine boulders affected by exhumation or erosion processes. Deglaciation in HualcaHualca volcano began abruptly $\sim$ 11.5 ka ago according to a 36Cl age from a polished and striated bedrock in Pujro Huayjo valley, presumably as a result of reduced precipitation as well as a global increase of temperatures.

The glacier evolution at HualcaHualca volcano presents a high correlation with precipitation cycles of the Altiplano (Tauca / Coipasa phases) and Heinrich 1 / Younger Dryas cold climatic events.
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Equilibrium Line Altitude fluctuations at HualcaHualca volcano (southern Peru).

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Interest in Andean glaciers has substantially increased during the last decades, due to its high sensitivity to climate fluctuations. In this sense, Equilibrium Line Altitude (ELA) is a reliable indicator of climate variability that has been frequently used to reconstruct palaeoenvironmental conditions at different temporal and spatial scales.
However, the number of sites with ELA reconstructions is still insufficient to determine patterns in tropical climate or estimations of atmospheric cooling since the Last Glacial Maximum. The main purpose of this study is to contribute in resolving tropical climate evolution through ELA calculations on HualcaHualca (15º 43′ S; 71º 52′ W; 6,025 masl), a large andesitic stratovolcano located in the south-western Peruvian Andes approximately 70 km north-west of Arequipa.
We applied Terminus Headwall Altitude Ratio (THAR) with 0.2; 0.4; 0.5; 0.57 ratios, Accumulation Area Ratio (AAR) and Accumulation Area Balance Ratio (AABR) methods in four valleys of HualcaHualca volcano: Huayuray (north side), Pujro Huayjo (southwest side), Mollebaya (east side) and Mucurca (west side). To estimate ELA depression, we calculated the difference between the ELA on 1955 with its position in the Maximum Glacier Extent (MGE), Tardiglacial phases, little Ice Age (LIA) and 2000. Paleotemperature reconstructions derived from vertical temperature gradient 6.5º C / 1 km, based on GODDARD global observation system considered the most appropriate model for arid Andes.
During MGE, the ELA was located between 5,005 (AABR) and 5,215 (AAR 0.67) masl. But in 1955, ELA rose to 5,685 (AABR) - 5,775 (AAR 0.67) masl. The ELA depression between those two phases is 560 - 680 m that implies a temperature decrease of 3.5º - 4.4º C.
The experimental process based in the use and contrast of different ELA reconstruction techniques applied in this study suggests that THAR (0.57), AAR (0.67) or AABR are the most consistent procedures for HualcaHualca glaciers, while THAR with ratios 0.2; 0.4 and 0.5 tend to underestimate it′s position.

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Reconstruction of glacial changes on HualcaHualca volcano (southern Peru) from the Maximum Glacier Extent to present.

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Little is known about glacial area changes in the Peruvian glaciers and how responds to climate fluctuations especially in the arid region where ice masses represent the major water supply. In this research, we present the results related to glacier area, volume and minimum glacier altitude evolution from the Maximum Glacier Extent (MGE) to 2000 on HualcaHualca volcano (15º 43′ S; 71º 52′ W; 6,025 masl), a large andesitic stratovolcano located in the south-western Peruvian Andes approximately 70 km north-west of Arequipa.

We focused the study in four valleys (Huayuray, Pujro Huayjo, Mollebaya and Mucurca) because preserved a complete and well-defined sequence of glacial deposits. Moreover, these valleys, with the exception of Mucurca, still retain ice masses relegated to active cirques on summits areas so has been possible to reconstruct glacier recent dynamics.

To reconstruct former glaciers, we used frontal and lateral moraines while delimitation of recent ice masses was based on the analysis of aerial photographs (1955) as well as Landsat satellite scene (2000). Geographical Information System (GIS) allowed map and quantify with high accuracy glacier spatial parameters.

The magnitude of glacial expansion was highest during MEG in Huayuray, where the glacier reached 22.7 km2 of extension and the front ice was situated at 3,650 masl, than in Pujro Huayjo (23.8 km2; 4,300 masl), Mollebaya (17.8 km2; 4,315 masl) and Mucurca (8.0 km2; 4,350 masl). The cause of this difference has been associated to the control exercised by topography. Glacier of Huayuray flowed by a steep slope while mass ices of Pujro Huayjo, Mollebaya and Mucurca slipped to the Altiplano. In the other hand, the data from 2000 show that the intensity of deglaciation was more drastic in Mucurca, where glacier has already disappeared, than in Huayuray (1.2 km2; 5,800 masl), Pujro Huayjo (1.8 km2; 5,430 masl) or Mollebaya (0.95 km2; 5,430 masl) as a consequence of it′s lesser glacier entity.

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Glacial and climatic evolution from the Little Ice Age last Maximum to the present in Tröllaskagi Peninsula (North Iceland): the case of Gljúlfurárjökull

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This paper presents the evolution of the Gljúlfurárjökull glacier (65º42'48" N, 18º39'13" W; 980 m), located at the headwall of the Skiðadalur valley, on the Tröllaskagi peninsula (N. Iceland). This is one of many small glaciers situated on the bottom of the Tröllaskagi valleys. This glacier is one of the few "clean" glaciers, i.e. not covered with boulders, as is the case with most of the glaciers on this peninsula. This makes the glacier especially sensitive to climate change, and it has retreated and advanced many times since its last maximum during the Little Ice Age (LIA) maximum in the mid- 19th century (Caseldine and Stötter, 1993), leaving a large number of moraine ridges. This paper analyses the change in this glacier from the LIA up to the present day, with reference to the variations in the surface, ELA and volume. Lichenometry and geomorphological field analysis were used to establish the exact limits of the glacier during the LIA last maximum. An aerial photo from 1946 and two orthophotos from 2000 and 2013 were also used. Using photointerpretation and Geographical Information Systems (GIS), the aerial photos were georeferenced to delimit the glacier in different years, analyse the surface and volume variations, and calculate the ELA for each date. The ELA analysis was carried out using the method: Accumulation Area Ratio (AAR 0.67).
The results obtained with this method are:
Little Ice Age Maximum: 945 m a.s.l. (almost the same ELA proposed by Caseldine and Stötter, 1993)
1946: 970 m a.s.l.
2000: 980 m a.s.l.
2013: 990 m a.s.l.
The ice volume lost from LIA to 2000 was: 111.68 hm3

Reference

Caseldine, C., Stötter, J., 1993. "Little Ice Age" glaciation of Tröllaskagi Peninsula, northern Iceland: Climatic implications for reconstructed equilibrium line altitudes (ELAs). Holocene 3: 357-366.

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Evaluation of Little Ice Age cooling in Western Central Andes, suggested by paleoELAs, in contrast with global warming since late 19th century deduced from instrumental records

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This paper attempts to evaluate climate cooling (ºC) during the glacial expansion phases using the product GTV•ΔELA, where GTV is the vertical air temperature gradient (ºC/m) and ΔELA (m) the difference in level observed between the Equilibrium Line Altitude (ELA) reconstructions for current and past glaciers. With this aim the Area x Altitude Balance Ratio-(AABR) method was used to produce reconstructions of present ELAs (2002-2010) and paleoELAs corresponding to the last glacier advance phase. The reconstructions were produced in three study areas located along a N-S transect of the western cordillera in the Central Andes: the south-western sector of the Nevado Hualcán (9ºS, 77ºW; Giráldez 2011); the southern slope of the Cordillera Pariaqaqa (12ºS, 76ºW; Quirós, 2013) and the NW, NE, SE and SW quadrants of the Nevado Coropuna (16ºS, 72ºW; García 2013; Úbeda 2011; Campos, 2012). The three mountains exceed 6000 m altitude, their summit areas are covered by glaciers, and on their slopes there are existing well-conserved moraines deposited by the last advances near the present front of the ice masses. Although there are no absolute dates to confirm this hypothesis, it has been assumed that the last glacial advances occurred during the Little Ice Age (LIA), which the oxygen isotopes of the Nevado Huascarán (9ºS, 77ºW) date to the period 1500-1890. For the Hualcán and Pariaqaqa the mean global value of the Earth's GTV (6.5ºC/km) was used, considered valid for the Tropics. On the Coropuna a GTV=8.4ºC/km was used, based on high resolution sensors installed in situ since 2007 (Úbeda 2011). This gradient is approaching the upper limit of the dry adiabatic gradient (9.8ºC/km), as the Coropuna region is more arid than the other case study areas. The climate cooling estimates deduced from the product GTV•ΔELA were compared with the global warming shown by the 1880-2012 series, ΔT=0.85ºC, and 1850/1900-2003/2012, ΔT=0.78ºC. The differences are small (averaging 0.05 and 0.12 ºC) suggesting that the product GTV•ΔELA may be a good indicator of climate cooling during glacial expansion phases. However, the role played by precipitation has not yet been determined, and this will be examined in future research.

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The deglaciation of the Tröllaskagi Peninsula, Northern Iceland, based on cosmogenic datings

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The Tröllaskagi Peninsula is a mountainous area in central northern Iceland. Deep valleys have dissected the Tertiary plateau basalts which form the peninsula, ranging in altitude from sea level to 1500 m.

The aim of this work is to provide an initial approach to the deglaciation process in some valleys in the Tröllaskagi Peninsula, mainly by dating polished thresholds and some moraine boulders using cosmic radiation exposure and production of isotope 36Cl.

The results obtained lead to the following conclusions:

a) In the outermost coastal areas, i.e. the peninsular capes and the mouths of the great fjords, the dating of polished thresholds situated at present around 100-150 m a.s.l obtains ages immediately after Heinrich Event 1: thus two thresholds located at the end point of the Skagi Peninsula give ages of 16.9 $\pm$ 1.5 ka and 17.1 $\pm$ 1.6 ka. At the entrance to the Eyjafjördur, fjord near the town of Dalvik, another polished threshold has been dated to 16.3 $\pm$ 1.4 ka.

b) In the intermediate areas of the fiords, deglaciation occurred just at the end of the Oldest Dryas: two thresholds, one on each side of the Skagafjördur fjord at around 150 m a.s.l. obtain minimum ages of 12.6 $\pm$ 1.2 ka on the edge of the Skagi Peninsula and 13.8 $\pm$ 1.3 ka on the island of Þórđarhöfđi, at a similar altitude.

c) The bottoms of the great valleys which originate in the central highlands of the island and which currently drain the proglacial waters from the inland ice caps were deglaciated very early in the Holocene. Dates ranging from 11.5 to 10.00 ka were obtained from 7 polished thresholds at altitudes of between 120 and 700 m a.s.l. in the valley of the Eystri and Vestrari Jökulrsár Rivers which flows into the Skagafjördur fjord, with no clear altitude-related differences observed in the chronology. Taking into account the margin of error, these results may in fact show that the deglaciation of these thresholds was practically simultaneous. A similar date of 11.6 $\pm$1.5 ka was obtained on a polished threshold in the Eyjafjafjörður valley, 3 km south of the town of Akureyri.

d) The behavior of the inland valleys in the Tröllaskagi Peninsula is very different from that of the great fjords and valleys which drain the interior of the island. The most significant feature, limiting the application of cosmogenic dating methods, is the total absence of polished thresholds, probably because they are composed of easily fragmented tertiary lavas. The summits are completely covered with block fields and periglacial pattern ground. The valley slopes are extremely unstable and affected by different types of mass movements. Cosmogenic methods can only be applied to moraine blocks located very near the Little Ice Age (LIA) moraines, on stable platforms. These dating methods have been applied in two valleys: in the Hóladalur valley, north of the Hólar farm, and in the Vatnsdalur valley, an affluent of the Svarfaðardalur valley, NW of the town of Dalvik. The results were very similar in both cases: the outermost moraines can be linked to the Oldest Dryas with minimum dates of 16.9 $\pm$ 1.4 ka, demonstrating a much more limited glaciation in the interior of this peninsula than in the rest of the island. Some fossil rock glaciers remained inactive at the end of the Oldest Dryas, with ages for the front termini of around 14 ka. There are also moraines from the Younger Dryas, dating between 12 and 11.3 ka. The only moraines completely within the Holocene are found in the Vatnsdalur valley, of 9 ka. Ablation moraines in this same valley, which appear to be much more recent, obtained ages of 1.4 and 0.8 ka. All these formations are found in a belt of 500 m wide which surrounds the snout of the present glaciers. Thus, it can be concluded that in the inner Tröllaskagi Peninsula, the glaciers had already retreated to their headwalls before the Oldest Dryas. Glacial advances have occurred since then, although these are very limited with a maximum magnitude only slightly greater than that of the maximum LIA advance.

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Time needed for first lichen colonization of terminal moraines in the Tröllaskagi peninsula (North Iceland)

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The Tröllaskagi peninsula is located in Central North Iceland. The peninsula belong to the Tertiary basaltic areas in Iceland and is characterised by numerous glacially eroded valleys and fjords. The altitude ranges from sea level to 1500 m. Around 150 glaciers, debris covered glaciers and clean glaciers exist in the cirques of the Tröllaskagi peninsula.

Lichenometric techniques were applied to date moraines formed by some of these glaciers, especially from 1970-90, establishing growth rates for some species, e.g. 0.5 mm/year for Rizocarpon geographicum. However there is no information available on how long the lichens take to colonize the boulders in a moraine once it has become detached from the retreating glacier.

The aim of this paper is to observe how long it takes for the boulders on the moraines to be colonized by lichens in the Tröllaskagi peninsula, where the separation date of a moraine from the retreating glacier tongue is known. Two case studies were used. The first was the surging glacier Búrfellsjökull, in the Búrfelllsdalur valley, an affluent of the Svarfaðardalur valley. The Búrfellsjökull glacier surged in 2001-2004 and the glacial terminus advanced 150-240 m, overrunnig a moraine formed around 1955 and formed a new moraine. About 2-3 years after the surge termination in 2004 the glacial terminus was already retreating and had left the moraine isolated (Brynjólfsson et al. 2012). The other case is the Gljúlfurárjökull glacier, in the Gljúlfurárdalur valley, an affluent of the Skíðadalur valley. It can be seen from the series of aerial photographs that the glacier terminus advanced during the 1990s until the year 2000. In 2004 the glacial terminus was already retreating and had separated from a small moraine formed during the previous advance. Thus, two different glaciers halted and formed one moraine each which they separated from almost similar time. During the detailed field work carried out in August 2014 on both moraines, lichen thalli were located and their greatest diameters measured, examining the surface, boulder by boulder, along a 100 m stretch of each moraine and counting those with existing lichen thalli and those without them.

The results from the two moraines are very similar:

a) Only 15 – 18% of the boulders presented some type of thallus.

b) There is little variety in the thallus size on one specific boulder, but great variety between different boulders, even when they are very close together.

c) The largest thalli of the moraine only appear on isolated boulders, between 3 and 0.7%.

d) In the Rizocarpon geographicum thalli, exceptional sizes were found of isolated thalli with max. diameter of up to 2,8 mm. The most frequent size observed on boulders with homogeneous thalli is 1 - 2 mm.

e) Some sectors of the two moraines still have ice under the boulders, which may explain the uneven lichen colonization in different parts of the moraine.

These observations should be taken into consideration when examining the age of the moraines using lichenometry. 8-10 years after a moraine separated from the glacial terminus, only a minimum number of its boulders are stable enough to allow lichen colonization. As time passes, the blocks gradually become stabilized and allow lichen colonization. This may explain the widely varying thalli sizes found between different blocks in the same moraine.

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