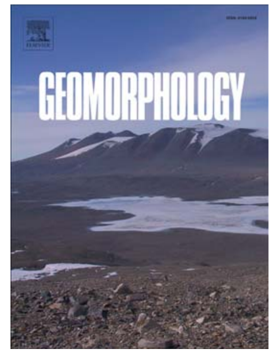

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PII: S0169-555X(12)00219-X
DOI: doi: 10.1016/j.geomorph.2012.05.001
Reference: GEOMOR 3990

To appear in: *Geomorphology*

Received date: 1 November 2011
Revised date: 30 April 2012
Accepted date: 2 May 2012

Quaternary glacial evolution in the Central Cantabrian Mountains (Northern Spain)

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Abstract:
The glacial evolution of the Cantabrian Mountains is not well known. Previous studies have focused on the extent of the glacial maximum and the presence of younger features in several massifs. Recently, efforts have been made to date glacial periods, particularly the glacial maximum. This work presents a reconstruction of the glacial evolution in the Cantabrian Mountains, providing data on the environmental characteristics and timing of the different stages from the Quaternary glacial maximum to the Little Ice Age. The study area covers 3000 km^2 between the 4º58´W and 3º34´W and includes eleven massifs of the central area of the Cantabrian Mountains. The selected sectors have an Atlantic and Atlantic-Mediterranean transitional climate and include the highest massifs (above 2600 m) and low-altitude glacierized massifs (lower than 2000 m). Glacial extent and evolution have been reconstructed on the basis of detailed geomorphological and morphostratigraphic mapping. The equilibrium line altitude (palaeo-ELA) has been estimated for the different stages of each tongue. The ELA has been assessed by the AAR and modified Kurowski methods and altitude methods have been considered. A numerical chronological framework is proposed using 17 AMS radiocarbon and one OSL data obtained in lake and bog deposits from three massifs. Four main glacial stages have been differentiated, between 38,000 BP and the Little Ice Age. They correspond to different cold environments, and the number of glacial stages varies from one to four among the different massifs. Conclusions are analysed in the context of the Quaternary glacial evolution of other Iberian mountains.
Key words: glaciation, ELA, geochronology; late Quaternary, Cantabrian Mountains

1. Introduction:

During the Quaternary, glaciers developed in almost all mountain systems over 2000 metres altitude in the Iberian Peninsula which show features of different glacial stages and different sizes from the recent Pleistocene to the nineteenth century. Only in the areas nearest to the Atlantic coasts, in the north and west of the Iberian Peninsula, did glaciers appear in low-altitude mountain systems. The extent and location of Pleistocene glaciers are well known and documented in many syntheses (p.e. Gómez-Ortiz and Pérez-Alberti, 1998; Pérez Alberti et al. 2004), which provide information from the pioneering studies of Penck (1897) and Obermaier (1914) to recent contributions and reconstruct the evolution and glacial morphostratigraphy in different peninsular massifs. Nevertheless, interest has arisen recently about the significance of glaciers in the European context and the chronology of the different glacial stages as a result of the availability of new dating techniques and growing interest in glaciers for palaeo-environmental reconstructions (Pérez Alberti et al. 2004; Hughes and Woordward, 2008; García Ruiz et al. 2010). In this sense, there are controversies depending on the dating techniques applied, and the present or past climatic context (Atlantic, Mediterranean). It is therefore of interest to increase knowledge on the Quaternary glacial chronologies of the Iberian Peninsula and their different geographical characteristics. In Southern Europe there are many indications of glacial stages prior to the Last Glacial Maximum (LGM), which could have reached greater extents in both Atlantic and Mediterranean environments (Woodward et al. 2004; Pérez Alberti et al. 2004; Hughes et al. 2006 a, b; Allen et al. 2007; Hughes and Woodward, 2008; Jalut et al. 2010; García Ruiz et al. 2010; Pérez Alberti et al. 2011). Age determinations indicate earlier glaciation respect to the Last Glacial Maximum (LGM) in northern Europe (Mardones and Jalut, 1983; Jalut et al., 1992; 2010; Vidal et al. 1999; García-Ruiz et al., 2003, 2010; Jiménez et al. 2002; González-Sampériz et al. 2006; Calvet, 2004; Moreno et al., 2010) attributed to the southernmost location of the North Atlantic Polar Front during the LGM (Ruddiman and McIntire, 1981; Florineth and Schluchter, 2000). But not all dates are in agreement and the results of other studies carried out in the Pyrenees or the Central System reveal a possible synchrony between peninsular and European LGM (Pallás, 2007; Calvet et al. 2011; Palacios et al. 2011).

In the Cantabrian mountains glacial landforms were attributed to two Quaternary glaciations, Riss and Würm (Penck, 1897; Obermaier,1914; Nussbaum and Cigax, 1953), although they were later attributed, still without numerical age determinations, to a single recent Quaternary glacial period (Alonso et al. 1982; Smart, 1986; Martínez de Pisón and Arenillas, 1979; Frochoso and Castañón, 1986, 1998; Flor and Baylon, 1989; Castañón and Frochoso, 1992, 1996; Martínez de Pisón and Alonso, 1993; Serrano and González-Trueba, 2002; González-Trueba, 2007a, b). More recent studies which include palaeoglacial reconstructions and dates (Moreno et al. 2010; Jalut et al. 2010; Serrano et al. 2011a, b), confirmed that the glacial maximum of the Cantabrian Mountains was prior to the European LGM. Although there are as yet few numerical dates for the Cantabrian Mountains, data available point to a distinct behaviour with respect to European glaciers during the end of MIS 3 and MIS 2. The aim of this contribution is to make a synthesis of studies in the different Cantabrian massifs based on morphostratigraphic reconstructions, ELA estimations and new dates, in order to improve knowledge of the chronological and environmental framework of the different glacial stages.

2. Study area:

The Cantabrian Mountains extend 700 km between the Pyrenees and the Galician mountains, with a broad diversity of landforms and landscapes (Fig. 1). The study area is in the central part of this mountain range and includes its highest massifs (Picos de Europa -2648 m- and Peña Prieta -2539 m-). This sector forms the divide between Atlantic, Cantabrian and Mediterranean basins, and spans the Asturian basement to the west (Fuentes Carrionas, Picos de Europa, Sierra de Cebolleda, 2078 m), and the Mesozoic cover to the east (Alto Campoo, 2174 m; Valdecebollas, 2143 m; Pas Mountains, 1718 m). In the basement Devonian and Carboniferous slates, quarzites, limestones, sandstones and conglomerates alternate. The relief is governed by structure, lithology and differential erosion, configuring isolated massifs and ranges individualized between elongated depressions. Limestones, quarzites and sandstones form positive relief, and slates and turbidites the depressions. The Mesozoic cover is made up of Triassic sandstones and conglomerates with dipping and folded landforms (Peña Labra, Campoo and Valdecebollas). Towards the east Jurassic and Cretaceous marls, sandstones, limestones and turbidites of variable thicknesses alternate (Campoo, Pas Mountains). River courses in the northern side cut structures and individualize massifs, whereas in the south they tend to adapt to structures. Present climate is strongly influenced by the existence of high relief near the sea that hampers the passage of fronts. Thus, there is a hyperhumid oceanic mountain environment on the northern side with rainfall over 2500 mm/year, whereas the south has an Atlantic-Mediterranean transition environment with about 600 mm/year.

The Pleistocene glaciation was limited in this range to the highest massifs (Fig.1), giving rise to separate but close glacial units. These were of small size compared to the large glaciers that developed towards the east in the Pyrenees or the

Alps, but similar in size and distribution to glaciers in other mountains of the Iberian Peninsula, both to west and the south.

3. Methodology:

A glaciomorphological map of each area studied was made to a scale of 1/25,000, based on a morphostratigraphic survey, the reconstruction of the Quatenary glaciers and their evolution (Table 1). The locations of the stepped moraine complexes were analysed and the main relative glacial morphogenetic stages established from accumulative glacial landforms in all massifs. The morphostratigraphic analysis was used to establish the temporal location of each glacier and rockglacier (Lukas, 2006, Huhges, 2010). Correlation between massifs was made including data on orientation, altitude of fronts, glacier length and type and the Equilibrium Line Altitude (ELA). Data on rock glaciers was compiled (Table 2) and used as indicators of cold phases with mountain permafrost (Barsch, 1996; Haeberli et al. 2006) related to glacier development or deglaciation phases. Thirty three rock glaciers have been inventoried including data on altitude, length, width, orientation, lithology and stage.

Estimates of ELA of former glaciers were used to correlate moraines and to explain some climate conditions from temperature-snowfall relationships. Although palaeoclimatic estimations might not be precise, and ELAs may be underestimated or overestimated if the reconstruction is made from alpine or ice field glacier land systems, the ELA is a very useful parameter for the environmental characterization of glaciated environments and regional variations of former glaciers (Porter, 1975; Seltzer, 1994; Osipov, 2004; Benn and Ballentyne, 2005; Benn and Evans, 2010). The factors influencing ELA are albedo, supraglacial debris, topography, orientation, snow overfeeding by avalanches and wind, glacier geometry, hypsometry, winter snowfalls and summer temperatures (Porter, 1975; Ohmura et al. 1992; Seltzer, 1994; Benn et al. 2005), and so climate-ELA relationships may be inexact due to avalanches, wind and supraglacial debris action (Benn and Lehmkuhl, 2000; Nesje, 2006). Winter snowfalls and spring-summer temperatures are the most interesting factors for palaeoenvironmental reconstructions at a regional scale. mELA, the medium value of palaeoELAs in a massif, indicates the theoretical glacial conditions of equilibrium and allows regional comparisons between massifs. Temperature-snowfall relationships explain the elevation of the ELA. In areas with high snowfall the summer temperature required to melt the snow cover on glaciers is greater than in areas with low snowfall. Thus, in moderate-sized regions with homogeneous thermal behaviour the ELA rises with the decrease in snowfall, following longitudinal or latitudinal snowfall gradients. Therefore mELAs may be used to deduce old snowfall gradients, the source of humidity and reconstruct atmospheric circulation patterns (Miller et al, 1975; Lehmkuhl, 1998).

Ninety-four palaeoELAS were calculated in the study area (Tables 1a, b and c). For their reconstruction the Accumulation Area Ratio Method (AAR) was applied, based on the relationship between the balance of mass and the percentage of the area of accumulation with respect to its total area, assuming a percentage of the AAR of 0,6 ± 0,05 or 60% ± 5%, which is characteristic of valley glaciers at medium latitudes (Kuhle, 1988; Porter, 2001; Nesje, 2006). ELAs from each massif were calculated from a spreadsheet with GIS software on maps to 1/25.000 and 1/10.000 scales, differentiating between northern and southern orientations and general mELA. Dissymmetry between north and south mELA distributions is a good indicator of dominant glacial land systems (alpine glacial or icefield land systems) and environmental changes between glacial stages.

Seventeen samples (Table 3) were dated in three massifs (Picos de Europa, Fuentes Carrionas, Pas Mountains), sixteen by mass spectrometry accelerator (AMS) and one by OSL on supraglacial water-supplied, fine sediments (Fuentes Carrionas). For the OSL age determination the method used was fine grain on grain size 2-10 microns, with the usual calibration methods (Aitken, 1985). AMS dating was performed on total lake sediments and peat obtained by means of a 25 m deep core from a proglacial lake in the Picos de Europa, and several cores 2-1.5 m in depth from intramoraine peat in the Pas Mountains (Trueba Valley). The ages obtained by means of conventional radiocarbon determinations were calibrated using the software 5.0.2 CALIB (Reimer et al., 2004) for the more recent ages and the software CALPAL for the older ones, beyond the limits of the previous calibration. Greater final error is recorded for samples prior to 25 ka BP (approx. 800 years) during the isotopic period MIS 3 (Bard et al., 2004; Danzeglocke et al. 2009).

4. Results on glacial morphology, climatic indicators and glacial fluctuations.

4.1. Picos de Europa:

The Picos de Europa are located to the north of the Cantabrian mountains (43º10´N-4º50´W) just 20 km from the sea (Figure 1). It is a mountain range divided in three massifs (Western, Central and Eastern, separated by deep gorges) and characterized by a marked oceanic influence with annual precipitations of over 2500 mm/year. Relief is abrupt and the range includes the highest of the Cantabrian Mountains (Torre Cerredo, 2,648 m a.s.l.). Lithology is composed of limestones alternating with slates, conglomerate and turbiditic sandstones, producing a glacio-karstic landscape. The glacial history of the massif has been studied and Pleistocene glaciers partially reconstructed since the early twentieth century (Obermaier, 1914), but all studies have been related to the glacial maximum stage in different massifs (Obermaier, 1914; Smart, 1986; Frochoso and Castañón 1998; Castañón and Frochoso, 1992; Gale and Hoare, 1997) or to specific, small complexes such as Duje or Enol (Frochoso and Castañón, 1986; Flor and Baylon-Misioné, 1989; Castañón and Frochoso, 1992, 1996; Moreno et al. 2010). Recently, different glacial stages have been established (Serrano and González-Trueba, 2002; González-Trueba, 2006, 2007a, b, c; González-Trueba and Serrano, 2010; Serrano et al. in press) and chronologies estimated (Castañón and Frochoso, 1996; Jiménez and Farias, 2002, Jiménez et al. 2002; Moreno et al. 2010; Serrano et al. in press).

The main glacial landforms of the Picos de Europa are glaciokarstic depressions, but there are short and steeply sloped glacial troughs in northern orientations. Height differences prevented the development of long glaciers, though their fronts reached very low altitudes (450 m in Dobresengros, 600 m. in Bulnes, and 800 m in Liébana). The maximum expansion of glaciers is defined by summit icefields (F-I) and there are numerous and extensive erosion and accumulative glacial landforms. Thirty nine glacial tongues covering a total of 99 km^2 in the Eastern and Central massifs have been studied. The ice was interconnected at the highest parts. Glacial diffluences and transfluences connected the main glacial tongues coming out of icefields, the longest of which were those of el Duje (7 kms), Bulnes (3,2 kms), el Deva (4 kms), Valdiezmo (4,2 kms) and El Torno (4 kms). In the Central Massif glaciers ended at 700-800 m a.s.l. to the north, and 900-1030 m a.s.l. to the south. They were higher in the Western Massif (Figure 2). The mELA of the glacial maximum (F-I) is located at a mean altitude of 1666 m in the Central and 1722 m in the Eastern massif. All massifs were completely covered by ice during this stage, although doubts still remain about the specific location and reconstructions of some glacial fronts during the maximum (González Trueba, 2007 b;

Serrano et al. in press). Chronologies for the maximum in the Picos de Europa point to an age between 90 and 17-20 ka ago in the Duje valley (Frochoso and Castañón, 1998), between 40 and 35 ka in the western massif (Moreno et al., 2010) and less than 35,700-34,850 cal a BP in the Central massif and Duje area (Serrano et al. in press). Inside the external moraine complexes, moraine arches denote a stage of retreat (F-II), characterized by a reduction in length and width of glaciers, but with proportions similar to those of the previous stage and volume increase in the frontal portions. This is visible in the Áliva moraine complex and the Eastern massif, where glaciers decreased in size by 32%. The mELA ascended only 70 m in the Central massif and 25 m in the Eastern one, and fronts were very close to those of F-I, which we have ascribed to a period of retreat, equilibrium and stabilization with a minor advance immediately after F-I.

In the interior of the massifs, above 1800-2000 m, there are well preserved moraine complexes (Figure 3A, B and C), mainly in glacial cirques oriented to the north and with walls of 200-250 m difference in height (González-Trueba, 2007a, 2007b; González-Trueba and Serrano, 2010). These landform complexes point to a period of equilibrium and minor advance once the Picos de Europa were practically deglaciated (F-III), which has been named the Stage of Cirque Glaciers (González-Trueba, 2007 a, b; González-Trueba and Serrano, 2010; Serrano et al. in press). The ice surface lost with respect to the maximum represented 88.4% in the Central massif, and 96.5% in the Eastern one, and there were only small glaciers located in shaded sites. The ELAs were located above 2,000 m in most cases, though they were lower in the Eastern Massif, where topoclimatic factors made ELAs abnormally low. In the Eastern and Central Massifs mELAs were located, respectively, 310 metres and 460 m higher than during the previous stage. This stage showed features of two advances in the Eastern massif (Stages IIIa and IIIb) and rock glaciers to the interior of moraine complexes in the Central massif. These rock glaciers are indicators of mountain permafrost during the stages indicated (Table 2). Finally, in the Central and Western massifs there are footprints of historical glaciation (F-IV) in the highest cirques, always oriented to the north (Serrano and González-Trueba, 2002; González-Trueba, 2006, 2007 c; González-Trueba et al. 2008). The Little Ice Age glaciation was marginal, below the regional climatic ELA, with very small glaciers whose fronts were located above 2,200 m, determined by location with respect to the ocean and topoclimatic effects (González Trueba, 2007a, b; González Trueba et al. 2008).

4.2. Sierra de Cebolleda

The Sierra de Cebolleda (43º6´1´´N-4º55´48´´W) is located on the Cantabrian dividing line to the south of the Picos de Europa between the Cares (Cantabrian) and Esla (Duero) basins (Figure 1). It forms an E-W range with altitudes greater than 1700 m and summits over 2000 m (Gildar, 2074 m). Its position to the south of the highest massifs of the Cantabrian Mountains shelter it from the N and NW winds, resulting in a mean annual rainfall of 1200 mm (Allende, 2008). This small range has been the subject of attention in general studies concerning the glacial maximum (Castañón, 1989; Alonso et al., 1982; Alonso Herrero, 2002; Frochoso and Castañón, 1998), in which the distribution of moraines, the maximum extent of glaciers and the presence of rock glaciers were established (Alonso Herrero, 2002; Pellitero et al. 2011).

During the glacial maximum (F-I) there were 11 cirque glaciers oriented preferentially to the N and S. To the north, tongues of over 2 km have been reconstructed, extending down to 1000 m and with a mean altitude of 1120 m. These were alpine glaciers with large cirques located above 1600 m and large, well-preserved moraine complexes (Vega de los Montañeros, La Armadiella, Ladredo and las Carricias). On the southern side there were 5 well-defined cirque glaciers housed in the highest parts, with highly deteriorated moraines. Their fronts were between 1670 and 1825 m, significantly higher than those on the northern slope, and did not have glacial tongues.

The moraine complexes suggest there were four morphogenetic glacial stages (Figures 2 and 3D). To the north the stepped moraine complexes in the valleys show two fluctuations very close together in four of the large troughs, which indicate a 95 m increase in their respective mELAs. The outer moraine defines the maximum extent of glaciers and was housed within the connection between the lateral valleys and the Valdeón valley bottom. The inner moraines (F-II) show stages of glacial retreat with tongues of 2-3 kms, which did not reach the bottom of Valdéon. On the southern side, only the cirques of Orza and Verdes de Cable present two moraine complexes, the innermost of which (F-II) is 60 m higher than the outer one (F-I). In the interior of the northern valleys there are moraine complexes (F-III) with fronts between 1425 and 1590 m. In some cases, as in the cirque of Freñana (Figure 3D), they show two fluctuations close in time (FIIIa and FIIIb). This stage presents a mELA 100 m above the previous one, and is well represented in all the cirques. Finally, moraines (F-IV) housed in the cirques permit the reconstruction of cirque glaciers of moderate dimensions with fronts between 1690 and 1860 m. The mELA of these glaciers is found to be 85 m higher than the previous one, corresponding to a period in which the mountain was practically deglaciated. During this pulsation six rock glaciers developed with lengths between 135 and 750 m, located above 1680 m and with northern orientations. Their presence indicates the existence of permafrost above this altitude during this glacial stage.

This massif is characterized by strong North-South dissymmetry. Northern glaciers had well developed tongues whereas to the south there were small cirque glaciers, which disappeared immediately after the maximum or they were so small that did not leave morphological evidence of their existence.

4.3. Fuentes Carrionas

The Fuentes Carrionas massif (43º 0´45´´N-4º43´55´´W) is located to the SE of the Picos de Europa (figure 1) on the dividing line between the Carrión (Duero) and Deva (Cantabrian) basins. It constitutes a complex orographic knot with N-S and W–E alignments in crests and valleys with summits (Fig.3 E and F) that surpass 2500 m (Peña Prieta, 2539). Its location, SE and on the southern edge of the highest part of the Cantabrian range, provides shelter from N and NW driven snowfall but exposes it to wet SW fronts during winter. It is a sub-Atlantic, transitional to Mediterranean climate, defined by cold winters and precipitation around 1000 mm/year (Allende, 2008). The maximum extent of this glacier was studied by Castañón (1989), Castañón and Frochoso, (1992), Frochoso and Castañón (1996, 1998). Further studies and detailed geomorphological mapping have recently been carried out on glacial evolution and rock glaciers (Pellitero, 2009, 2011; Pellitero et al. 2011).

An icefield existed here during the Glacial Maximum (F-I), with six glacial tongues (Figure 4) between 3.7 and 14,9 km long, fronts between 1200 and 1450 m altitude and mELAs at 1754 m. Tongues with E and N orientations were better developed, whereas the southern slopes were free of ice. The mELA and the position of the fronts indicate moderate glacial asymmetry and limited influence of topoclimatic factors. In the N area the presence of ice fields and an alpine glacier land system with frequent glacial transfluences points to cold conditions and good snow feed. On the glacial fronts two very close stages are visible, the first (F-Ia) with scarce lateral moraines and till deposits, and the second (F-Ib) with well preserved frontal moraine complexes, indicating a stage of advance and equilibrium. Both stages, with the local mELA 7 metres lower in F-Ib, show similar conditions and appear to belong to a single glacial cycle. A third set of frontal moraines (F-II) was located at 1600-1700 m. These were individual alpine glaciers, several km long and located at the cirques. The mELA was 140 m higher than in the previous stage and there was a clear trend towards glaciers originating in cirques with a northern orientation (83%). In this period rock glaciers (Table 2) developed above 1900 m, which denotes cold conditions above the glacial fronts and the likely existence of mountain permafrost. Finally, a group of moraines housed above 1875 m, with a mean altitude of 1920 m, indicate a stage (F-III) of cirque glaciers of moderate dimensions (Figure 3F), between 275 and 650 m (except the Cardaño glacier, 1200 m). The mELA of these glaciers was above 2000 m, 130 m higher than during the previous stage, and 84% of them had N and NW orientation with a topoclimatic location that favoured over-accumulation of snow by wind and avalanches. The presence of rock glaciers (Table 2) with N orientation above 1700 m and with S orientation above 2100 m, denotes a generalized periglacial layer at over 2100 m. Lastly, there were inactive protalus lobes to the interior of the moraines of stage III, which we interpret as the footprints of a last historical periglacial stage, confined to the highest cirques oriented to the north.

In the outer moraines of the Vega de Naranco an OSL date of 36,028±2350 a BP was obtained. The sample was extracted from a sandy deposit of supraglacial till over a lodgement till on the top of the moraine. In the palaeolake dammed by the frontal moraine complex of Vega de Naranco, two lacustrine silty and sandy samples were dated by AMS. Dates of 16,900-16,740 cal a BP in the lower part and 28,630-28,330 cal a BP in the upper one were obtained. The sandy nature of the latter sample indicates that its age is not very reliable. Between the first and the last moraine there would have been a retreat and a fresh advance (Pellitero, 2011) with the deglaciated valley occupied by a lake around 16,900-16,700 cal a BP (Figure 6).

The ice-walled lake plain of Cardaño, located to the South of Espigüete massif, has the same age as the lateral moraine of the Glacial Maximum. In the lower part of the lacustrine deposit an age of 15,570-15,240 cal a BP was obtained. In the upper part of the lacustrine deposit the dated age is 5,750-5,660 cal a BP (Table 3). As the bottom of the lacustrine deposits has not been dated, it is not possible to know when the lake was generated. The 15,570-15,240 cal a BP is a minimum age, and there was a period of lacustrine infill and glacial activity older than the dated sediments.

4.4. Alto Campoo-Valdecebollas

The valley of Campoo or upper Ebro valley (43º 0´N-4º22´W) is an intra-mountain valley open to the East (Figure 1), between the Sierra del Cordel (to the N; 2125 m) and the Sierra del Híjar (to the S; 2174 m), the southernmost point of which is the Valdecebollas massif (2143 m). The Sierra del Cordel forms the divide between the Ebro and Cantabrian basins and the Sierra del Híjar that of the Duero and Ebro basins (Figure 4 b). The Sierra del Cordel receives the N and NW fronts and has precipitations above 2000 mm/a as well as cloudiness throughout the year, whereas in Valdecebollas, the seasonal contrast is stronger and precipitation is lower than 1000 mm/a. Pleistocene glaciation was initially studied by Hernández Pacheco (1944) and later works analysed with more detail its extent and stages (Alonso et al. 1982; Frochoso, 1990; Frochoso and Castañón, 1998; Serrano, 2001; Serrano and Gutierrez, 2000; 2002).

During the Glacial Maximum there were 26 glaciers with highly variable dimensions, typology and orientations in the crests of Alto Campoo (Figure 4). At the maximum extent of Pleistocene glaciers the head of the valley was occupied by an alpine glacier land system of 1500 ha and a tongue glacier 6.2 km long. At the front, a frontal diffluence generated two glacial tongues whose fronts were at around 1300 m. The remaining glaciers, in both N and S slopes, were cirque glaciers, only in some cases with small tongues. All the glaciers were located below the crests, in 88% of cases above 2000 m, except to the E of the northernmost sierra, where the cirques developed under crests between 1800 and 2000 m. In this stage (F-I) there was a moderate N-S dissymmetry in the altitude of the mELAm, with glacial fronts 100 m higher to the S. The mELA for the massif was at 1700 m.

Nine of the valleys and cirques studied in Campoo and Valdecebollas show signs of a retreat stage (F-II) immediately following the maximum (F-I). In the Alto Campoo glacier, the largest with a length of 2.6 km (Figure 5a), the north oriented cirques fed ice to the main tongue. The mELA had risen 160 m with respect to its previous position and its front had retreated 3.5 km. In this stage the mELA had risen by just 75 m and the N-S dissymmetry was not significant (<20 m). Also, alpine glaciers still predominated (55%) against cirque glaciers (45%). It was, therefore, a lesser fluctuation of the previous stage, with the mountain dominantly glaciated at all orientations. A new glacial stage (F-III) formed the well-preserved moraines visible in nine of the cirques studied (Figure 5b), with a preferential orientation to the north (88%). They correspond to glaciers 130-400 m long, determined by topoclimatic factors. The ELA had risen by 120 m with respect to the previous period and glacier fronts were located 230 m higher. These glaciers behaved differently according to their position. To the south, there was a marked dissymmetry between slopes and the glaciers with southern orientations practically disappeared after stage I. In the Sierra del Híjar, the dissymmetry between northern and southern slopes was less, and glaciers on the south do not present retreat stages, whereas in the Sierra del Cordel there are remnants of retreat stages in both N and S orientations. Considering that the altitude of the three sierras is very similar, it seems that what determined the more complex glacial evolution of the Sierra del Cordel was the greater snowfall, determined by its N orientation. N-S dissymmetry was very clear in the southern massif of Valdecebollas, where glaciers to the south disappeared after stage I, whereas to the north four glacial stages (F I, IIa and IIb) can be established from the 17 moraine arches running from the cirque to the front of the glacier.

4.5. Pas Mountains

The Pas Mountains (43º11´5´´N-43º3´52´´N) form the divide between the Ebro and Cantabrian basins (Pas, Miera and Asón rivers), with an altitude between 1200 and over 1700 m. They constitute a SW-NE oriented massif that represents an important orographic barrier, 25 km from the sea (Figure 1). Present precipitation surpasses 2500 mm/a, an extreme oceanic condition that was also present during the Pleistocene. Studies on Pleistocene glaciation in the Pas Mountains initially focussed on their description as glacial landforms in low altitude mountains (Saenz, 1935; Hernández Pacheco, 1961; Lotze, 1962; Hazera, 1968; Moñino et al. 1987, 1988; Serrano, 1995, 1996) and later on the reconstruction of their evolution and chronology (Serrano and Gutiérrez, 2002; Turú et al. 2007a, b; Serrano et al. 2011b).

Two massifs can be differentiated in this mountain sector, Castro Valnera (1718 m), without cirques and with long glacial valleys to the north (Miera, 5 km) and SE (Trueba, 15 km), and Veinte-Pizarras (1472 m), north of the dividing line, with cirques and troughs of moderate size. The erosional landforms on the limestone highlands are ill-defined and do not allow precise reconstructions. The valley bottoms, on the other hand, were sculptured on shales and siltstones and present four lateral and two frontal well-preserved moraine complexes (Figure 4). The absence of cirque glaciers in the upper part of the massif indicates feeding of the tongues from a great ice field from which outlets fed the Miera, Bustalveinte and Trueba valleys (Lotze, 1962; Serrano and Gutiérrez, 2002). This ice field shows net dissymmetry, with the main accumulations of snow to the east of the dividing line on which the main outlets of the Cantabrian slope are found (with fronts at 620 m in La Brenia, 600 in Los Collados, 400 in the Asón and 620 in the Miera). On the Mediterranean slope, to the SE, there was only one large glacier, the Trueba, forming a U-shaped, 8 km long valley, with a frontal moraine complex at 760 m in Espinosa de los Monteros (Serrano, 1996; Serrano and Gutiérrez, 2002; Turu et al. 2007 b; Serrano et al. 2011 b).

The Glacial Maximum was reconstructed from frontal and lateral complexes (Trueba, Miera, Asón, La Brenia, Peña Lusa, Valdició and Porracolina). The main erosion and accumulation landforms belong to the glacial expansion stage (F-I) dominated by the large ice-cap, with the MELA at around 1190 m. Comparison of the MELA between the northern and southern slopes indicates there was hardly any dissymmetry, with just 80 m difference. Ice domes involve greater errors in ELA estimates, although the proximity of both indicates glacial development determined by over-accumulation above 1150 m. The frontal moraines of the Collados (Asón) and Espinosa (Trueba) and the lateral ones of the Trueba denote a complex glacial evolution. In the Trueba two stages were established: a maximum advance (Espinosa Polideportivo pulsation, 1), retreat, and a new advance (Espinosa-Los Cuetos pulsation, 2). In the intramoraine depression of pulsation 2, a 1 m core was extracted from a peat bog formed in a poorly drained area between two moraine arcs. The peat material, overlying a till (Figure 6) was dated by AMS at 29,149-28,572 cal a BP (Table 1), which indicates that the glacial maximum (F-I) was prior to this date. In the Trueba valley, the frontal moraine complex of Bárcena indicates there was a glacial tongue 4.5 km long at 783 m. This points to a stage of glacial advance and stabilization (Bárcena pulsation, F-II) following a less-pronounced retreat. These complexes are correlated with those of the Collados, Imunia or Lusa, which show two very close pulsations. The altitudinal proximity of fronts between Espinosa and Bárcena (20 m) and of the MELAS estimated (10 m), point to a retreat during the same glacial stage, and so we ascribe all of these to a single glacial stage dominated by the presence of an icecap of approximately 30 km^2.

Upstream, moraines were present only in smaller cirques oriented to the north, (Figure 5) Miera (Pico de la Miel, 1512 m) and Valdició (Pizarras, 1474 m). The rest of the massif would, by then, be totally deglaciated. These were very small cirque glaciers belonging to two equilibrium stages (F-III and F-IV), though they are difficult to place chronologically. After the disappearance of the ice-cap, the altitude difference between their fronts was 250 m and that of the estimated mELAs 120 m. Finally, two small pulsations determined by topoclimatic conditions can be identified, one of well fed cirques and a second, higher one.

5. Discussion. Pleistocene glacial advances, glacial environments and chronologies in the central Cantabrian Mountains:

5.1. Glacial stages and chronology in the Cantabrian Mountains

The morphostratigraphic correlation between glacial fronts and altitudes of ELAs allowed the identification of three to five main glacial stages, from the maximum to the historical glaciation, depending on the massifs (Table 4). The combination of different factors (length of glacial tongues in relation to the ELA, mean altitudes of ELAs, orientation of glaciers, types of glaciers, their altitudinal or orographic development) permits the glacial conditions of each stage to be established and to assess the relative role of humidity and temperature changes. Four main glacial stages have been identified in this part of the Cantabrian Mountains:

- Glacial Maximum Stage, S-I: This represents the maximum expansion of glaciers (Table 5), with the dominance of ice fields and ice domes in oceanic mountains and voluminous frontal moraines in all of them. Fronts are at 400-600 m on northern slopes and at 700-900 m on the southern ones, indicating a stage of rapid and brief advance.

Dates obtained by means of ^{14}C show similar chronologies. In the Picos de Europa the glacial maximum was prior to 35,700-34,850 cal a BP in el Duje (Serrano et al. in press), 40 ka ago in Enol (Moreno et al. 2010) and 40,480$\pm$820 a BP in Comeya (Jiménez and Farias, 2002). Dates in areas further east point to ages of 28,990$\pm$230 a BP in Redes, (Jiménez et al. 2002), close to 44 ka in Sil, (Jalut et al. 2010) and prior to 25.6 ka in Sanabria (Rodríguez et al., 2011). In the Trueba valley (Pas Mountains) a peat-bog locared within the external moraines was dated as prior to 29,149-28,572 cal a BP. Finally, the dating carried out using OSL in the Fuentes Carrionas massif is in accordance with the previous ones, with a minimum age of 36,028 ± 2350 a BP. All of them point to a glacial period in MIS3, older than the Last Glacial Maximum (LGM) of N and NE Europe, a fact already noted in the Pyrenees. All dates obtained on lacustrine sediments, peat bog and supraglacial till, and by AMS and OSL techniques, present similar minimum chronologies. Although they are minimum ages and some dates in Mediterranean and High Atlas mountains point to older glaciations (Hughes et al. 2006 a, b, 2011), their location at the bottom of sediment columns, the good preservation of landforms and the fact that dates were obtained using different techniques support the results. In The Pyrenees the glacial maximum may be asynchronous with respect to the European LGM (Mardones and Jalut, 1983; Hughes and Woodward, 2008; Lewis et al. 2009, García Ruiz et al., 2003, 2010), although there are also dates of the maximum advance during the LGM (Pallás et al. 2007; Delmas et al. 2008, García Ruiz et al. 2010). For the Pyrenees and the Cantabrian Mountains a maximum prior to 48-32 ka was established and a generalized advance stage between 32-18 ka characterized by surge events (Jalut et al. 2010). Other evidence of cold stages in the Iberian peninsula, Europe and North Africa indicates advances of ice sheets in the north of Europe during the Early Middle Weichselian, between 60-59 ka (Svendsen et al. 2004; Hughes et al. 2011), in accordance with the cold water stages of the Iberian margin between 60 and 65 ka, a period of intensity and duration similar to the LGM (Martrat et al. 2007). Between the 65 ka and LGM cold water stages of lesser intensity and duration than the LGM have been reported, and one of similar intensity to the LGM, although briefer, between 39-40 ka. These would be periods of cold oceanic waters that would supply cold and partially humid air masses from the N and NW, as well as masses less cold but more humid from the SW, favourable to the supply of intense snowfall prior to the LGM, making this the most extensive glacial advance of the recent Pleistocene in the Cantabrian Mountains.

- Advance and stabilization, S-II: (Stage of Retreat from the Maximum): The moraine complexes located in the interior and very close to the moraines of the maximum indicate a second glacial equilibrium stage, shorter than S-I. The valley of the Trueba and the Picos de Europa show a stage of retreat and new re-advance with multiple frontal moraine arches. In Áliva, el Deva, Vega de Naranco and Valdecebollas this advance generated shorter but better fed glaciers than those of the previous stage, and these were more sensitive to changes. In the Trueba and Campo, this stage was delayed with respect to the maximum, with smaller glaciers.

The different directions of glaciers in el Duje (Serrano et al. in press), the presence of two different infill deposits in the trough of the Trueba (Turú et al. 2007a; Serrano et al. 2011b) and the different lithology of the moraines of Vega del Naranco (Pellitero, 2011) point to a glacial retreat and re-advance to positions very close to the SI. In Picos de Europa, a minimum LOI in the lacustrine sediments of Campo Mayor permitted a stage of glacial advance to be established at between 21,500-21,390 cal a BP and 35,700-34,850 cal a BP. In the Cantabrian mountains a period of glacial equilibrium has been dated as 20,640±300 a BP in the Alto Nalón (Jiménez et al. 2002), and in Enol a second stage of deglaciation (Moreno et al. 2010) between 20-18 ka ago. These moraines are, therefore, prior to the LGM of the N and NW of Europe, but very close to it, in MIS 2 or the transition from MIS3 to MIS2. The marine sediments and echosoundings in the ice define the end of MIS3 as less cold, but with a complex climatic pattern characterized by cold, abrupt climatic changes and brief warming between 33 and 28 Ka (Jouzel et al. 1997; Zachos et al. 2001; NGRIP, 2004; Martrat et al. 2007). This complexity is reflected in the succession of short moderately intense cold stages in waters of the Iberian margin (Martrat et al. 2007). In the Pyrenees and the Cantabrian mountains a stage of generalized glacial advance has been established between 32-18 ka ago defined by surge events (Jalut et al. 2010). The S-II of the study area may be masked in this glacial expansion, although evidence of surge events has not been found, while multiple retreats and equilibriums have. This is a longer stage in time and it possibly derived from an increase in humidity following the retreat of the maximum. The differentiated behaviour between the Atlantic mountains of lower altitude and the rest may denote less cold conditions but with an increase in humidity, and therefore with the development of long but smaller glaciers than those of the previous stage. The glaciers located at greater altitude were more sensitive and unstable, with continuous advances and retreats, which denotes greater variations in the feed than in temperatures. The increase in the humidity deduced from the advance and instability of glaciers may come from the less cold conditions of the Atlantic, which permits the access of more humid air masses to the oceanic mountains during this period.

The maximum glacial expansion during the LGM coincides with a period of intense cold (Ehlers and Gibbard, 2003; Ehlers et al. 2006), and although there are no well preserved or shaped moraine complexes remaining, periods of equilibrium and advance in Redes and Enol have been documented (Jiménez et al. 2002; Moreno et al. 2010) as well as a minimum LOI circa 19 ka ago in Campo Mayor (Picos de Europa). All of these reflect the cooling of the LGM, which does not confirm a glacial advance, possibly because the intense cold was accompanied by the fall in latitude of the frozen sea that led to the access of cold but very dry air masses during the winter, and a relative decline in the snowfall from the N and NW together with the access of oceanic air masses from the SW (Ruddiman and McIntae, 1981; Florineth and Schluchter, 2000).

- High mountain advance, Stage of cirque glaciers (S-III). A period of equilibrium and lesser advance is indicated by the moraines located inside the cirque glaciers and with ELAs of 2050-2130 m a.s.l.. The ice fields and ice domes had disappeared, giving way to alpine and cirque glaciers. In the Pas Mountains there were no glaciers on the southern slope and only small alpine and cirque glaciers were preserved on northern orientations. The mean altitude of fronts, ELAs and rock glaciers denote the presence of well fed glaciers only in favourable topoclimatic conditions.

The greater continental nature and strong dissymmetry of the southern massifs where topoclimatic factors are determinant, indicate that snowfall came predominantly from the N and NW. The intense cold permitted the genesis of rock glaciers in favourable places, but there was not enough snowfall for the development of glaciers. In Picos de Europa, Cebolleda, Fuentes Carrionas and Valdecebollas there were two fluctuations close together in time (IIIa and IIIb), and also two families of rock glaciers always on northern orientations, in a well developed periglacial altitudinal area with likely mountain permafrost. They point to two cold stages close together in time and in their environmental conditions. These stages are not present in the Pas Mountains or Campoo, where only one advance is detected. The chronology of this period is based on indirect data, and so much uncertainty remains. In the lacustrine sediments of Campo Mayor-Áliva a more moderate minimum LOI is registered, from circa 13.9 ka (Serrano et al. in press), and in Enol, an equilibrium in the Ca content is interpreted as cooling between 14.5 and 13.5 ka (Moreno et al. 2010). Both approximations, though made using indirect age determinations in Picos de Europa, permit this stage to be attributed to the Tardiglacial (14-10 ka). The Tardiglacial is a period of glacial advances in Europe (Svendsen et al. 2004; Ehlers et al. 2006, Cossart et al. 2011), but there is no agreement on whether the increase in the cold resulted in a global glacial advance (Glasser et al. 2006), a regional response, or just an equilibrium during the glacial retreat of the LGM (Bennet et al. 2000). The presence of small glaciers at altitude has been confirmed in several massifs of the Cantabrian Mountains of over 2000 metres, in alto Nalón, Campoo and the Palencia Mountains (Jiménez, 1996; Serrano and Gutiérrez, 2002; Pellitero, 2008, 2011; Pellitero et al. 2011). It therefore appears to be a general feature in the highest among the Cantabrian Mountains, where a cold period at the end of the Pleistocene was capable of generating small glacial advances in favourable locations.

- Little Ice Age (S-IV). In the highest cirques, always located between vertical walls and oriented to the north, marginal glaciation developed in the Picos de Europa and cold processes in Fuentes Carrionas. The ELAs are located below the climatic ELA and determined by topoclimatic factors resulting in the over-feed and preservation of the snow. This stage is ascribed to the LIA (González Trueba, 2007 c; González Trueba et al. 2008), a relatively humid period with heavy but not very cold snowfall. The thermal fall of the LIA, estimated at 0.9ºC with respect to the present day, made possible the development of glaciers wherever topoclimatic locations were favourable, with highly oceanic characteristics. After the first testimonies of Casiano del Prado, Saint Saud and Penck about former and active glaciers in the Picos de Europa and Peña Prieta, Miotke (1968) and Clark (1981) point out the possible existence of traces of LIA glaciers in the Cantabrian Mountains. There is evidence of only one advance stage formed during the coolest times of the LIA. Historical documents describe the contact between the glaciers and frontal moraines around 1840-1850 when the LIA glaciers reached their maximum extent (González Trueba 2006, 2007 c). Between 1890 and 1895 glaciers and moraines were separated, indicating that the ice had begun to retreat several decades earlier. In the first decade of the twentieth century, glaciers lost surface, length and volume and glacial activity had probably ceased leaving only ice patches (González Trueba et al. 2008; Serrano et al. 2011a).

5.2. Pleistocene glaciers and regional glacial environments.

The ELAs show behaviour that was homogeneous among glacial stages but different among massifs. Two groups can be differentiated:

- In the northernmost massifs, with greater Atlantic influence (Pas Mountains, Picos de Europa and Sierra del Cordel), distance from the sea and orographic barriers determined the develpment of glaciers, and the fewer the barriers and the shorter the distance to the sea, the lower the ELAs.

- On the dividing line and the southern massifs (Campoo, Valdecebollas, Fuentes Carrionas), the mean altitudes of the ELAs increase as we move further away from the sea and the altitudes of the ELAs of each stage are closer together than in the previous group. Both in Cebolleda and in Fuentes Carrionas there is a sharp N-S dissymmetry from the glacial maximum, with very low ELAs to the north and marginal glaciation.

Variations in the ELAs between massifs denote the greater sensitivity of the northern massifs to environmental changes and with swifter responses. The differences in altitude between the ELAs of stages II and III (increases between 85 and 132 m) are very homogeneous for all the massifs. Although neither temperature nor humidity variations for each period can be compared, one of the variables can be derived from the other proxies (Benn and Ballantyne 2005), which are not available for the Cantabrian Mountains, and it is possible to make comparisons between different massifs in each time period.

- In Picos de Europa, Fuentes Carrionas and the the Pas Mountains stage I is Atlantic in character without preferential orientations. Stage II it is moderately oceanic and topoclimatic factors play a role, although in both stages the glaciers are distributed in highly varied orientations. In stage IIIa the glaciation type is moderately oceanic with the dominance of northern orientations and greater importance of topoclimatic factors.
- Campoo, Cebolleda and Valdecebollas evolve from Atlantic conditions in stage I to moderate Atlantic ones determined by topoclimatic factors in stage II.

In summary, the lower massifs further from the sea evolve towards marginal glaciation immediately after the glacial maximum. Given that thermal behaviour should be homogeneous in all mountain groups, with any local variations depending on altitude, changes in snowfall conditions would probably determine the behaviour differences between massifs.

Nowadays the thermal and W-E snowfall gradients are not significant for the massifs in the study area (Allende, 2008). Accepting the hypothesis that each glacial stage would be characterized by thermal homogeneity throughout the area, for such a reduced space (40 km in latitude and 100 in longitude) we consider that the thermal gradient was not significant during the Pleistocene. It would be snowfall and its variation in intensity and origin that would be the determinant factor in the types of glaciation during the Pleistocene glacial stages. During the oldest stages (I and II) in the north, ice fields and ice domes predominated, while to the south on the dividing line and the ranges of lower altitude, alpine glaciers with the moderate presence of rock glaciers and a more developed periglacial altitudinal area were more prevalent.

The most extreme cases are the Picos de Europa, to the west of the study area, and the Pas Mountains to the east. The former, with maximum altitudes above 2600 m, are 28 km from the sea, with at least three mountain barriers between the sea and the summits (from 745 m to 1317 m) which produce intense barrier effects. The threshold of glaciation is at its maximum above the summits of 1800 m. In the Pas Mountains, with a maximum altitude of 1715 m 31 km from the sea and without significant orographic barriers (hills of 400-800 m), the threshold of glaciation during the maximum was below the summits of 1400 m, 400 m lower than in the Picos de Europa, and glaciers surpassed 76 km^2. In both cases the glacial fronts reached similar altitudes, 400-600 m to the north and 800-900 m to the south, limited by the altitudinal thermal environment control. The extensive areas of accumulation and the very short tongues of the Picos de Europa are determined by local relief energy. In the Pas Mountains, snowfall and cloudiness determine the development of ice domes and outlets, particularly to the south.

In Campoo, 38 kms from the sea and with three interspersed orographic barriers, the thresholds of glaciation were similar to those of the Picos de Europa (1800 m), but the moderate altitude (2000 m) limited the feed to the glaciers. Only in Cebolleda were orientations determinant. Protected by the Picos de Europa to the north and the southern massifs to the south, snowfall was considerably less and alpine glaciers only developed to the north. Nevertheless, in Valdecebollas and Fuentes Carrionas, to the south of the dividing line, the relationships between fronts, altitudes of the ELAs and orientations point to wet conditions in spite of their position far from the sea (45 and 47 km respectively) and presence of orographic barriers. There would not be, therefore, an N-S snowfall gradient. Due to their windward position and moderate altitude, the SW airflows would explain the oceanic character of the glaciers, with the development of glacial domes in the most southern mountains, which would compensate for the N-S and NW-SE snowfall gradient.

Generally speaking, it appears that the altitude of glacial fronts increased with distance from the sea, and that the main factors for the development of glaciation, distance from the sea, barrier effects and altitude, were compensated by the airflows from the SW in the most southern massifs. This behaviour is different to the present one, with a sharp N-S rainfall gradient due to the dependence on airflows from the N and NW (Rasilla, 1996; Allende, 2008). This difference could only be explained by a more southerly circulation of the atmospheric currents that favoured the access of SW fronts, with wetter air masses reaching the south of the Cantabrian Mountains (Florineth and Schluter, 2000) and the consequent development of glaciers.

6. Conclusions

During the Pleistocene, mountain glaciers of moderate size developed around the summits of the highest massifs in the central part of the Cantabrian Mountains. Four main glacial stages can be identified in them, three Pleistocene and one historical. The former has been dated as being prior to 35,700-34,850 cal a BP in the Picos de Europa, 29,149-28,572 cal a BP in the Pas Mountains and 36,028±2350 a BP in Fuentes Carrionas. The glacial maximum (GM) of the Cantabrian Mountains is considerably earlier than that in the Alps, clearly within the MIS3 and conforms to the ensemble of age determinations that place the maximum glacial expansion of the Cantabrian Mountains prior to the European LGM (Figure 7). The chronology is consistent with other Pyrenean and Cantabrian glacial chronologies (Mardones and Jalut, 1983; Hughes and Woodward, 2008; Lewis et al. 2009, Jalut et al. 2010; García Ruiz et al., 2003, 2010). Other cases have been described in neighbouring mountains of Europe. In the Mediterranean there are dates in the Central Apennines, where the glaciers reached their maximum extent around 27 ka ago (Giraudi and Frezzotti (1997), and in the Greek mountains where the dates belong to Middle Pleistocene and 80 ka, 53 ka and 28-24 ka ago (Woodward et al. 2004, Hughes et al. 2006; Hughes and Woodward, 2008). In the Alps the last glaciation occurred between about 30 and 18 ka ago, but an open question is whether post-Eemian glaciers reached the lowlands prior to the last glaciations, so that there was a glacial advance of early to middle Late Pleistocene age (Preusser et al. 2003, Ivy-Ochs et al. 2008). There are evidences of major glaciations in the Western Alps during MIS 4, but no such evidence has been found in the Eastern Alps. Atmospheric circulation and hence sources of moisture in combination with the higher elevation could explain this fact (Ivy-Ochs et al. 2008). Also, several glacial advances have been dated to MIS 3/4 and MIS 2, but the lowlands of France and Switzerland were ice-free during all of MIS 3 (Preusser et al., 2003, Ivy-Osch et al. 2007, 2008) and glaciers reached their maximum extents during the Last Glacial Maximum (MIS 2) (Schaefer et al., 2006). In the north of the Iberian Peninsula and Mediterranean mountains, a possible fast advance of glaciers up to their maximum extent, at the same time as the continuous increase of Scandinavian ice sheet between 80 and 50 ka ago, has been pointed out (García Ruiz et al. 2010). During MIS 3, a period characterised by strong climatic oscillations including warm and extremely cold periods (Dansgaard et al., 1993), the inlandsis continued to grow until it become stable, while the Atlantic glaciers of the northern Iberian Peninsula decreased in two stages.

During stage I the massifs located to the S presented a snow feed only slightly lower than that of the northern and coastal massifs, and so the atmospheric circulation from the SW must have been very active. To the north and in the highest mountains, ice fields were dominant, whereas to the south and on lower summits small glacial domes alternated with alpine glaciers. The retreat and later advance to similar positions -stage 2- was also prior to the LGM. The morphological changes in some massifs indicate that the glacial maximum did not correspond to the largest volume of ice. The advance stage (S-I) of extensive, small-volume glaciers was followed by a new advance stage (S-II) of larger volume but smaller-extent glaciers. It is interpreted that this period had a significant change in snowfall but not in temperatures, with a more active response in the highest massifs.

The third stage OF advance is correlated to the Tardiglacial in this study. We assume a general deglaciation of the lowest massifs, from which the ice disappeared regardless of their position with respect to the sea. In the higher altitudes the importance of topoclimatic factors was greater and glaciers were small. At the end of this stage the deglaciation of the entire Cantabrian Mountains began. A new, moderate glacial advance took place in the Little Ice Age, affecting only the highest mountains, where topoclimatic conditions are determinant for the development of small glaciers.

The main factors that determined the different types of glaciation during the Pleistocene were distance to the sea, barrier effects and altitude, compensated by airflows from the SW during stage 1 in the southernmost massifs. The response is confirmed by the fact that during the glacial maximum all the massifs developed extensive glaciers regardless of their altitude and position with respect to the sea, but from stage 3 onwards only the highest massifs were capable of hosting glaciers, also regardless of their position with respect to the sea.

Acknowledgements

This research was funded by the R+D Programme of the Ministry of Science and Innovation (project CGL-2010-19729), the Ministry of the Environment (OAPN-053/2010) and the FPU Programme of the Ministry of Education. We thank P.D. Hughes and an anonymous referee for their comments which helped to improve the original manuscript. Finally, we also thank Prof. Mateo Gutiérrez-Elorza for his pioneering work and decades of dedication to Spanish Geomorphology.

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TABLE AND FIGURE CAPTIONS

Table 1a. Data on reconstructed glaciers in the Picos de Europa.

Table1b. Data on reconstructed glaciers in Fuentes Carrionas and Sierra de Cebolleda.

Table 1c. Data on reconstructed glaciers in the Campoo-Valdecebollas and Pas Mountains.

Table 2. Data on relict rock glaciers in the study area.

Table 3. Dates in the study area.

Table 4. Correlation and chronology of glacial stages in the central Cantabrian Mountains.

Table 5. Number, extent and orientations of glaciers during the Glacial maximum.

Figure 1. Location of the studied massifs in the Cantabrian Mountains. 1, Picos de Europa. 1a, Western massif (Cornión), Central Massif (Urriello), Eastern massif (Ándara) 2, Sierra de Cebolleda. 3, Fuentes Carrionas. 4, Campoo. 5, Valdecebollas. 6, Pas Mountains.

Figure 2. Location of moraine landforms, A, Picos de Europa, Cantral massifs and B, Sierra de Cebolleda.

Figure 3, Glacial landforms. A, Frontal moraine complex of Amuesa, Picos de Europa, 1360 m, Stage I. B, Moraines of Jou de los Cabrones, Picos de Europa, 1360 m, Stage III. C, Cirque and Little Ice Age moraine of Jou Negro, 2230 m. D, Glacial trough of Freñana, Sierra de Cebolleda. 1, frontal moraine (S-I); 2, frontal moraine (S-IIIa); 3, frontal moraine (S-IIIb). E. Glacial trough of Cardaño (1) and head cirque (2) in the Fuentes Carrionas massif. F, Fuentes Carrionas, 1, glacial trough of Pineda; 2, Fuentes Carrionas cirque, lake and moriane complex, stage III; 3, Pozo de Curavacas area, where moraines of stage III are located.

Figure 4. Locarion of moraine landforms, A, Fuentes Carrionas; B, Campoo; and C, Pas Mountains.

Figure 5. Glacial landforms. A, Glacial features of the Híjar valley, Campoo; m2 and m3, lateral moraines, stage II. B, Cuenca Bucer Cirque, south slope of Sierra del Cordel, with moraines of stage III. C, Miera valley and lateral moraines of stage I, Pas Mountains. D, Moraine complex of stage I (m1), stage II (m2) and stage II in the head valley of the Miera river, Pas Mountains.

Figure 6. Stratigraphical logs and profiles of sediments in the study area. A. Chrono-lithostratigraphic log and profile in the lateral moraine complex of Campo Mayor, Áliva (Picos de Europa). B, Chrono-lithostratigraphic logs and profiles of the frontal moraine complex in the Trueba Valley (Pas Mountains). C. Geomorphological sketch, chrono-lithostratigraphic logs and profile in Vega de Naranco (Fuentes Carrionas Massif). Map legend: 1, moraines. 2, lake deposits. 3, proglacial terrace, 4, alluvial fan, 5, glacial trough. 6, crests, ridge. 4. Legend of columns and profiles: t, till; ts, supraglacial till; L, lake deposits; p, peat bog; F, fluvial, torrential and foreset deposits; Ds, debris slope; S, bedrock.

Figure 7. Correlation between numerical dates of the areas studied in this work (a) and neighbouring massifs in the Cantabrian Mountains and Sanabria. (b) Moreno et al. 2010, (b) Jiménez et al. 2002, (d) Jalut et al. 2010 and (d), Rodríguez et al. 2011.

Table 1a. Data of reconstructed glaciers in the Picos de Europa:

Massif	Glacier	Stage	Max. Altitude (m)	Front Altitude (m)	Length (m)	Or.	Glacier type	Basin	E.L.A. (A.A.R.) (m)
PICOS DE EUROPA URRIELES	Remoña S	I-II	2.247	1.310	1.600	SSE	Alpine	1	1.537
	Torre Alcacero	I-II	2.247	1.535	1.080	SSE	Alpine	1	1.825
	Peña Regaliz	I-II	2.229	1.605	960	SSE	Alpine	1	1.770
	Pedabejo	I-II	2.176	1.530	1.080	SSE	Alpine	1	1.652
	Joyas Pedabejo	I-II	2.446	1.660	1.000	SE	Alpine	1	1.815
	Salinas	I-II	2.446	1.515	1.540	SO	Alpine	1	1.815
	Hoyo Liordes S	I-II	2.474	1.460	1.500	SO	Alpine	1	1.812
	Chavida	I-II	2.445	1.060	2.860	SO	Icefield	1	1.535
	Las Mojosas	I-II	2.020	1.140	1.430	O	Cirque	1	1.374
	Mermejo	I-II	2.598	870	2.440	O	Alpine	1	1.470
	Moeño	I-II	2.470	620	2.190	NO	Alpine	1	1.530
	Dobresengos	I-II	2.642	490	6.200	NO	Alpine	1	1.985
	Torre La Celada	III	2.470	1.950	690	NNE	Cirque	1	2.140
	Palanca N	III	2.621	2.020	1.020	NNE	Cirque	1	2.245
	Trasllambrión	III	2.642	2.288	860	N	Cirque	1	2.390
	Tesorero	III	2.570	2.046	660	NO	Cirque	1	2.232
	G. Arenizas	III	2.520	2.050	800	O	Cirque	1	2.210
	Palanca	IV	2.609	2.300	289	N	Cirque	1	2.356
	Llambrión	IV	2.642	2.320	470	NNO	Cirque	1	2.381
	Trave	I-II	2.237	1.350	1.420	NNE	Cirque	1	1.586
	Albo	I-II	2.414	795	1.770	N	Alpine	1	1.482
	CerredoAmuesa	I-II	2.648	795	5.690	N	Icefield	1	2.040
	La Pardida	III	2.596	2.326	450	NO	Cirque	1	2.380
	Cerredo	III	2.648	2.240	960	N	Cirque	1	2.320
	Jou Negro	III	2.648	2.220	710	NNE	Cirque	1	2.305
	Cabrones	III	2.553	2.017	715	NNE	Cirque	1	2.126
	Jou Negro	IV	2.648	2.235	280	NNE	Cirque	1	2.287
	Acebuco	I-II	2.414	740	1.610	NE	Alpine	1	1.215
	Moñas	I-II	2.095	1.195	2.000	NNO	Alpine	1	1.617
	Aliva -Duje	I-II	2.615	1.260	5.600	ENE-N	Alpine	1	1.595
	Salgardas	I-II	2.430	1.460	3.090	NE	Alpine		1.635
	Asotín	I-II	2.642	750	5.400	NO	Icefield	1	1.917
	Los Llagos	III	2.642	2.040	780	S	Circo	1	2.190
	Llambrion S	III	2.642	2.250	390	SSE	Circo	1	2.315
	Liordes	I-II	2.474	1.090	4.500	ESE	Icefield	1	1.922
	Hoyo Liordes	III	2.474	1.990	740	ENE	Cirque	1	2.132
	Hoyo Chico	III	2.474	2.070	550	NE	Cirque	1	2.170
	T- Llago S	III	2.567	2.140	660	SSO	Cirque	1	2.225
	Deva	I-II	2.617	905	7.800	SE	Alpine	1	1.840
	Hoyo Oscuro	III	2.417	2.160	610	SE	Cirque	1	2.185
	Torre Blanca	III	2.617	2.245	476	NNE	Cirque	1	2.334
	T. Llago N	III	2.567	1.970	1.050	NE	Cirque	1	2.272
	Hoyo Sin Tierra	III	2.417	1.940	840	NE	Cirque	1	2.100

PICOS DE EUROPA ÁNDARA

Lloroza	III	2.430	1.850	590	SO	Cirque	1	1.900
Peña Vieja E	III	2.615	1.780	640	ESE	Cirque	1	1.925
Vueltona	III	2.615	1.950	590	SSO	Cirque	1	2.100
Santa Ana Sur	III	2.601	2.250	350	S	Cirque	1	2.342
Moñetas	I-II	2.615	880	6.600	NE	Alpine	1	1.715
Jou del Infanzón	III	2.602	2.310	440	NE/NE	Cirque	1	2.342
Villasobrada	III	2.554	2.167	440	SE/SE	Cirque	1	2.237
Torre del Oso	III	2.461	2.086	470	E/E	Cirque	1	2.212
Urriellu-Bulnes	I-II	2.601	615	6.640	N	Alpine	1	2.034
Boches	III	2.602	2.140	800	NO	Cirque	1	2.272
Campanarios	III	2.572	1.985	780	NO/NO	Cirque	1	2.205
Carnizoso	III	2.432	1.912	630	N/N	Cirque	1	2.005
Vega de Urriellu	III	2.519	1.895	880	NO/NO	Cirque	1	2.037
Neverón Urriellu	III	2.559	2.030	640	NE/NE	Cirque	1	2.174
Torre Pomelo	III	2.596	2.108	470	SE/SE	Cirque	1	2.212
Boada	III	2.596	2.004	1000	SE/SE	Cirque	1	2.225
Lueje	III	2.395	2.005	480	E/E	Cirque	1	2.085
Jisu	I	2288	1850	285	ESE	Cirque	1	2005
	II	2288	1850	280	ESE	Cirque	1	2035
Prao Cortés	I	2373	1600	570	ESE	Cirque	1	1920
	II	2373	1600	570	ESE	Cirque	1	1935
Cortés	I	2273	1850	430	SE	Cirque	1	1990
	II	2273	1850	400	SE	Cirque	1	2010
Lechugales	I	2444	1130	1800	S	Icefield	1	2005
	II	2444	1130	1500	S	Cirque	1	1990
Las Arredondas	I	2437	1450	1300	SSE	Icefield	1	1940
	II	2437	1450	1300	SSE	Cirque	1	1950
	III	2438	2300	250	NE	Cirque	1	2275
Jonfría	I	2211	1630	650	SSW	Cirque	1	1848
	II	2211	1630	600	SSW	Cirque	1	1760
San Carlos	I	2211	1750	700	SE	Icefield	1	1832
	II	2211	1750	700	SE	Cirque	1	1890
Las Verdianas	I	2024	1600	850	S	Icefield	1	1730
La Aurora	I	2024	1180	2070	NE	Alpine	1	1995
	II	2024	1350	1860	NE	Alpine	1	2045
Pos del Jierru	I	2371	1680	650	NNW	Cirque	1	2200
	II	2371	1680	650	NNW	Cirque	1	2006
	I	2194	1830	430	NW	Cirque	1	2175
Pica Jierru	II	2194	1830	430	NW	Cirque	1	2165
Valdiezma	I	2425	800	7500	NNE	Alpine	1	1510
	II	2425	800	700	NNE	Alpine	1	1600
Valdominguero	III	2265	2050	400	ESE	Cirque	1	2085
b.Jierro-Lleroso	III	2425	1940	850	N	Cirque	1	2078
c. Vallejucos	III	2248	1765	1500	NNE	Cirque	1	1981
Torno	I	2281	700	6650	NNE	Alpine	1	1450
a. La Rasa	III	2281	1880	500	NE	Cirque	1	2095

b. Junciana N.	III	2263	2150	280	N	Cirque	1	1967
c. Samelar	III	2229	2020	400	NW	Cirque	1	2047
Los Lobos	I	2024	700	3600	N	Alpine	1	1450
Las Brañas	I	2024	1280	1700	NE	Icefield	1	1590

Table1b. Data of reconstructed glaciers in Fuentes Carrionas and Sierra de Cebolleda:

Massif	Glacier	Stage	Max. Altitude (m)	Front Altitude (m)	Length (m)	Or.	Glacier type	Basin	E.L.A. (A.A.R.) (m)
FUENTES CARRIONAS	Carrión	I	2526	1400	14913	E	Icef./Tongue	Duero	1754
		II	2526	1430	12988	E	Icef./Tongue	Duero	1747
		III	2526	1604	4592	NE	Tongue (s)	Duero	1883
		IV	2270	1978	655	N	Cirque	Duero	2084
	Riofrío	I	2536	1162	8301	E	Icef./Tongue	Deva	1754
		II	2536	1266	7691	E	Icef./Tongue	Deva	1747
		III	2536	1690	4818	E	Tongue (s)	Deva	1979
		IV	2536	1896	430	N	Cirque	Deva	1944
	Valdenievas	I	2190	1470	2835	E	Tongue	Duero	1745
		II	2190	1560	1618	E	Tongue (s)	Duero	1785
		III	2190	1687	899	N	Cirque	Duero	1878
		IV	2190	1875	276	N	Cirque	Duero	1952
	Cardaño	I	2450	1290	13200	S	Icef./Tongue	Duero	1754
		II	2450	1317	12600	S	Icef./Tongue	Duero	1747
		III	2430	1584	3475	S	Tongue (s)	Duero	1904
		IV	2430	1960	1235	E	Cirque	Duero	2090
	Lechada	I	2450	1329	7509	W	Icef./Tongue	Duero	1754
		II	2450	1456	5918	W	Icef./Tongue	Duero	1747
		III	2450	1669	3917	N	Tongue (s)	Duero	1874
		IV	2450	1918	511	N	Cirque	Duero	2076
	Naranco	I	2400	1462	3711	N	Tongue	Duero	1754
		II	2400	1500	2768	N	Tongue	Duero	1747
		III	2400	1595	1421	N	Tongue (s)	Duero	1820
		IV	2400	1905	609	N	Cirque	Duero	1989
CEBOLLEDA	Freñana	I	1866	1328	2440	NW	Alpine	1	1500
		II	1866	1365	2122	NW	Alpine	1	1538
		III	1866	1588	567	NW	Alpine	1	1688
		IVa	1866	1689	188	NW	Cirque	1	1722
		IVb	1842	1742	130	NE	Cirque	1	1768
	Cebolleda	I	2078	1228	4314	NW	Alpine	1	1540
		II	2078	1338	3864	NW	Alpine	1	1619
		III	2078	1538	1868	NW	Alpine	1	1739
		IV	2054	1859	421	N	Cirque	1	1908
	Gildar	I	2078	1009	5033	NW	Alpine	1	1488
		II	2078	1240	3596	NW	Alpine	1	1606
		IV	1929	1748	260	NE	Cirque	1	1821
	Anzo	I	1979	1042	3513	NW	Alpine	1	1512
	Monte Redondo	I	1856	1000	2684	NW	Alpine	1	1375
	Gabanceda	I	2042	1115	5205	NE	Alpine	1	1600

	II	2042	1168	4417	NE	Alpine	1	1615
	III	2042	1424	2254	NE	Alpine	1	1671
	IVa	1918	1590	830	E	Cirque	1	1806
	IVb	2042	1749	339	NO	Cirque	1	1688
Gildar S.	I	2078	1761	460	SE	Cirque	2	1868
Cosoya	I	2078	1698	877	SE	Cirque	2	1835
Las Verdes de Cable	I	1987	1825	285	S	Cirque	2	1883
Orza	I	1996	1670	738	S	Cirque	2	1782
	II	1996	1730	463	S	Cirque	2	1811
La Requejada	I	1912	1710	442	SE	Cirque	2	1817

Table 1c. Data of reconstructed glaciers in the Campoo-Valdecebollas and Pas Mountains:

Massif	Glacier	Phase	Max. Altitude (m)	Front Altitude (m)	Length (m)	Or.	Glacier type	Basin	E.L.A. (A.A.R.) (m)
	G. Cordel 1	I	1.801	1.370	1.620	E	Alpine	3	1.542
	G. Cordel 2	I	1.974	1.440	1.760	E	Alpine	3	1.547
	G. Cordel 3	I	1.974	1.190	1.970	S	Cirque	3	1.447
	G. Cordel 3	II	1.974	1.250	1.960	S	Cirque	3	1.470
	G. Cordel 4	I	2.061	1.450	1.520	S	Cirque	3	1.675
	Alto Campoo	I	2.171	1.295	6.200	E	Alpine	3	1.685
	(A.C.)	II	2.171	1.620	2.610	O	Alpine	3	1.810
	A.C. Cordel 5	II	2.085	1.600	1. 360	SSE	Cirque	3	1.787
C		III	2.085	1.700	210	S	Cirque	3	1.714
A	A.C. Cordel 6	II	2.111	1.760	890	S	Alpine	3	1.863
M		III	2.111	1.940	132	SSE	Cirque	3	1.965
P	A.C. Cordel 7	II	2.067	1.700	1.080	S	Cirque	3	1.842
O		III	2.111	1.940	210	SSO	Cirque	3	1.974
O	A.C. Cordel 8	II	2.125	1.870	600	S	Cirque	3	1.960
	A.C.Las Ollas	III	2.106	1.860	440	NE	Cirque	3	1.909
	A.C.Cuchillón	III	2.174	2.020	270	NE	Cirque	3	2.070
V	P. Labra N. 1	II	2.092	1.580	1.910	O	Alpine	3	1.705
A	P. Labra N. 2	II	2.144	1.600	1.610	O	Alpine	3	1.795
L	2a	III	2.144	1.830	530	NE	Cirque	3	1.907
D	2b	III	2.144	1.740	216	NE	Cirque	3	1.772
E		I	2.144	1.460	2.690	E	Alpine	3	1737
C	P. Labra N. 3	II	2122	1.610	2.020	E	Alpine	3	1.755
E		III	2.122	1.800	950	E	Cirque	3	1.845
B	P. Labra S. 1	I	2.171	1.460	1.180	SSO	Cirque	3	1.835
O	P. Labra S.2	I	2.151	1500	1.270	SO	Cirque	3	1.680
L	P. Labra 3	I	2.174	1.820	790	SO	Cirque	3	1.945
L	P. Labra 4	I	2.143	1.700	740	SO	Cirque	3	1.915
A	Brañosera	I	2.063	1.435	2.608	SE	Alpine	2	1705
S		II	2.063	1.630	1.482	SE	Cirque	2	1815
	Sel de la	I	2.143	1.715	2.733	NO	Alpine	2	1880
	Fuente	II	2.143	1.815	982	NO	Cirque	2	1887
		III	2143	>1950	300	NO	Cirque	2	> 1950
	La Cárcava	I	2.143	1.580	2.184	SE	Alpine	2	1848
	Rubagón	I	2.143	1.580	2.615	SE	Alpine	2	1862
	Trueba	I	1718	740	16500	SE	Icefield	3	1340
		II	1718	783	12500	SE	Icefield	3	1350
	Miera	I	1563	600	6200	N	Icefield	1	1120
		II	1563	810	2000	N	Cirque	1	1350
		III	1512	870	900	n	Cirque	1	1470
P	Asón	I	1637	425	8500	E	Icefield	1	1230
A	Valdició	I	1440	780	2500	N	Alpine	1	1150
S	Porracolina	I	1414	1040	1000	NW	Cirque	1	1267
	La Uriza	I	1158	700	2500	NE	Cirque	1	1100
	La Brenia	I	1640	600	5250	E	Icefield	1	1160
	Peña Lusa	I	1568	640	3300	NE	Alpine	1	1140

II	1568	1040	1100	NE	Cirque	1	--

Table 2. Data on relict rock glaciers in the study area.

Área	Name	Altitude (m)		Lenght (m)	Width (m)	Orient.	Lithology	Stage
		Front	Root					
Fuentes Carrionas	Curruquilla	1937	2140	774	560	N	Conglomerates	III
	CurruquillaSW	2062	2407	670	198	SSW	Conglomerates	I/II
	Campollo	1993	2033	218	137	E	Several	III
	Riuplanes	1905	1945	154	118	NNE	Quartzite	III
	Agua del Manzano	1820	1875	153	147	NNE	Quartzite	III
	Canchas de Ojeda	1886	2030	166	470	ENE	Quartzite	III
	Hoya Contina	1911	1991	229	192	NNW	Conglomerates	III
	Fuentes Carrionas	1727	1803	223	322	N	Conglomerates	III
	Agujas de Cardaño	2228	2243	67	104	N	Granite	IV
	Tres Provincias SW	2436	2476	64	109	SW	Granite	III
	Circo Hontanillas	2066	2092	55	99	SSW	Conglomerates	III
	Brezo	1594	1.644	381	126	N	Quartzite	I
	Orvillo N	1731	1770	91	386	N	Quartzite	II
	Orvillo NE	1.701	1739	165	111	NE	Quartzite	II
	Orvillo E	1.712	1820	563	306	E	Quartzite	II
	Orvillo SE	1.705	1798	701	269	SE	Quartzite	II
Picos de Europa	Lloroza	1865	1930	200	150	SSW	Limestone	IV
	Cordiñanes	950	1075	570	340	W	Limestone	I/II
	El Gato	1995	2085	340	150	S	Limestone	IV
Campoo	Asnos	1900	1960	320	215	N	Conglomerates	III
Cebolleda-Solvorón	Tabla Malrota	1780	1830	205	136	WNW	Quartzite	II
	Montó 1	1680	1800	505	162	NE	Quartzite	II
	Montó 2	1590	1850	750	300	NE	Quartzite	II
	Montó 3	1690	1740	135	90	SE	Quartzite	II
	Horcada Cable	1690	1890	650	420	N	Quartzite	II
	Verdes de Cable	1820	1920	290	156	NW	Quartzite	II

Table 3. Dates in the study area:

<table>
<tr><th colspan="5">AMS dates</th></tr>
<tr><th>Site</th><th>Depth (m)</th><th>Lab. Code</th><th>^{14}C a BP</th><th>cal a BP</th></tr>
<tr><td rowspan="8">Áliva,

Picos de Europa</td><td>1</td><td>Beta-269555</td><td>6660+/-40</td><td>6720-6640</td></tr>
<tr><td>1.33</td><td>Beta-264113</td><td>8310 +/- 50</td><td>9400-9300</td></tr>
<tr><td>3</td><td>Beta-269556</td><td>17300+/-100</td><td>17,400-17,300</td></tr>
<tr><td>5.50</td><td>Beta-26557</td><td>21390+/-100</td><td>21,500-21,390</td></tr>
<tr><td>7.80</td><td>Beta-264115</td><td>27570+/-320</td><td>32,580-31,900</td></tr>
<tr><td>10.55</td><td>Beta-264116</td><td>26090+/-240</td><td>31,400-30,660</td></tr>
<tr><td>14.10</td><td>Beta-264117</td><td>27460+/-300</td><td>32,426-31,850</td></tr>
<tr><td>15.50</td><td>Beta-264118</td><td>31200+/-440</td><td>35,700-34,850</td></tr>
<tr><td rowspan="4">Trueba Valley, Montañas Pasiegas</td><td>1</td><td>UBA-15876</td><td>26082+/- 118</td><td>29149- 28572</td></tr>
<tr><td>0.50</td><td>UBA-15877</td><td>8768+/- 42</td><td>7968- 7633</td></tr>
<tr><td>1.40</td><td>UBA-15878</td><td>8186+/- 35</td><td>7310- 7077</td></tr>
<tr><td>1.60</td><td>UBA-15879</td><td>10467+/- 42</td><td>10,623- 10,420</td></tr>
<tr><td rowspan="2">Vega de Naranco</td><td>2.7</td><td>UBA-15735</td><td>15614+/- 70</td><td>16,900- 16,740</td></tr>
<tr><td>2.4</td><td>UBA-15736</td><td>25591+/- 141</td><td>28,630- 28,330</td></tr>
<tr><td rowspan="2">Cardaño de Abajo</td><td>0.5</td><td>UBA-15733</td><td>6831+/- 50</td><td>5750- 5660</td></tr>
<tr><td>20.5</td><td>UBA-15734</td><td>14275+/- 49</td><td>15,570- 15,240</td></tr>
<tr><th colspan="5">OSL date</th></tr>
<tr><th>Site</th><th>Depth (m)</th><th>Lab. code</th><th colspan="2">a BP</th></tr>
<tr><td>Vega de Naranco</td><td>0.4 (M-1)</td><td>MAD-5980SDA</td><td colspan="2">36,028±2350</td></tr>
</table>

Table 4. Correlation and chronology of glacial stages in the central Cantabrian Mountains.

Massifs	Glacial stages			
	I Glacial maximum	II Advance and stabilization	III High mountain advance	IV Historical advance
Picos de Europa. Urrielles	I Rg	II	III Rg	IV
Picos de Europa. Andara	I	II	IIIa IIIb	--
Cebolleda	I	II	IIIa IIIb Rg IV Rg	--
Fuentes Carrionas	I Ib	II	III- Rg	IV Rg
Campoo	I	II	III	--
Valdecebollas	I	II	IIIa IIIb	--
Pas Mountains	Ia	Ib II	III IV	--
Chronologies Ka BP	>29 (1) 40-35 (2) >35-34 (3) 36 (4)	<29 (1) ±24 (3) <16 (4)	±14 (3) 14,5-13. (2) Cold period.	Little Ice Age (5)

Rg, rock glacier. 1. Trueba, Pas Mountains (Serrano et al. 2011). 2, Enol, Picos de Europa (Moreno et al. 2010). 3, Áliva, Picos de Europa (Serrano et al. in press). 4. Fuentes Carrionas. 5. Picos de Europa (González Trueba 2007a; González Trueba et al. 2008).

Table 5. Number, extent and orientations of glaciers during the Glacial Maximum.

Massif		**Glaciers**	**Ice surface Kms^2**	**Orientations**	
				N	**S**
Picos de Europa	Urrielles	24	68,56	55	45
	Andara	15	30,5	57	43
Cebolleda		11	16,73	77	23
Fuentes Carrionas		20	104,9	45	55
Campoo		10	2,04	15	85
Valdecebollas		4	5,82	43	57
Pas Mountain		8	76,5	67	33
Total		98	304,7	52%	48%

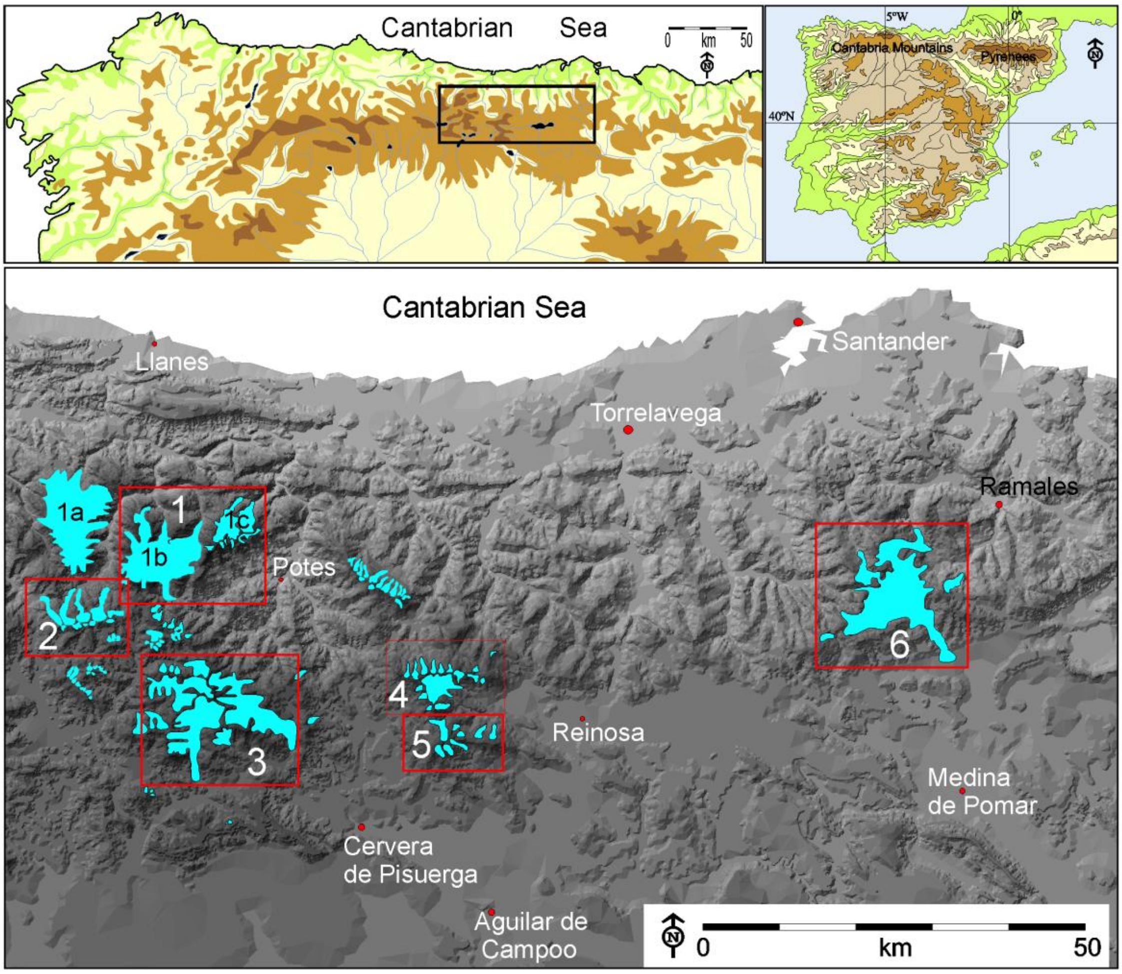

Cantabrian Sea
0 km 50
5ºW
0º
Cantabria Mountains
Pyrenees
40ºN
Cantabrian Sea
Santander
Llanes
Torrelavega
Ramales
1a
1
1c
1b
Potes
2
6
4
3
5
Reinosa
Medina
de Pomar
Cervera
de Pisuerga
Aguilar de
Campoo
0
km
50

Figure 1

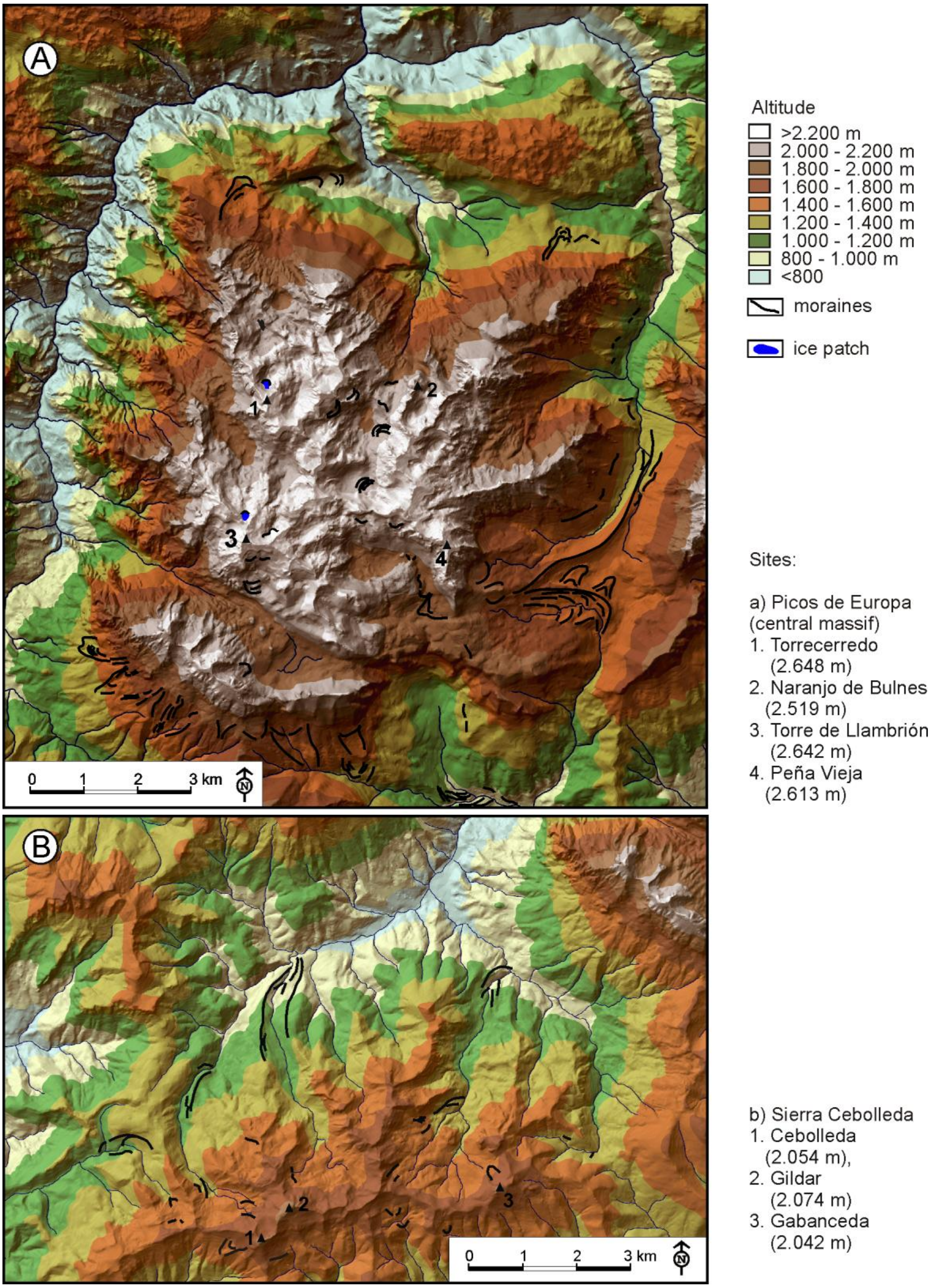
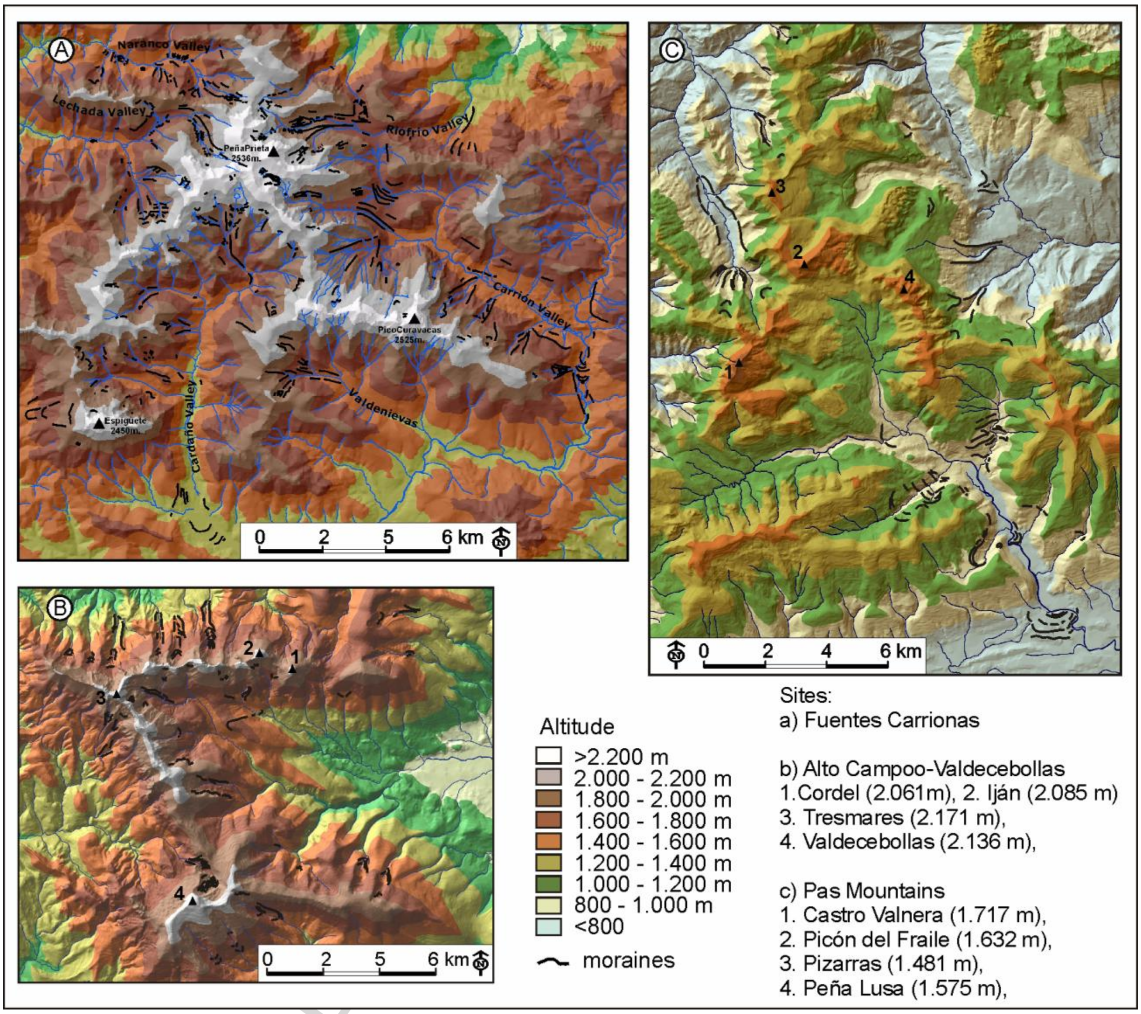

A
B
Altitude
>2.200 m
2.000 - 2.200 m
1.800 - 2.000 m
1.600 - 1.800 m
1.400 - 1.600 m
1.200 - 1.400 m
1.000 - 1.200 m
800 - 1.000 m
<800
moraines
ice patch
Sites:
a) Picos de Europa (central massif)
1. Torrecerredo (2.648 m)
2. Naranjo de Bulnes (2.519 m)
3. Torre de Llambrión (2.642 m)
4. Peña Vieja (2.613 m)
b) Sierra Cebolleda
1. Cebolleda (2.054 m),
2. Gildar (2.074 m)
3. Gabanceda (2.042 m)
0 1 2 3 km
N

Figure 2


A
B
Los Cabrones
C
Torre Cerredo
D
1
2
3
E
Espigüete
1
2
F
Curavacas
1
2
3
Figure 3


A
Naranco Valley
Lechada Valley
Riofrío Valley
Peña Prieta 2536m.
Carrión Valley
Pico Curavacas 2525m.
Espigüete 2450m.
Cardaño Valley
Valdenievas
0 2 5 6 km
B
C
Altitude
>2.200 m
2.000 - 2.200 m
1.800 - 2.000 m
1.600 - 1.800 m
1.400 - 1.600 m
1.200 - 1.400 m
1.000 - 1.200 m
800 - 1.000 m
<800
moraines
Sites:
a) Fuentes Carrionas
b) Alto Campoo-Valdecebollas
1.Cordel (2.061m), 2. Iján (2.085 m)
3. Tresmares (2.171 m),
4. Valdecebollas (2.136 m),
c) Pas Mountains
1. Castro Valnera (1.717 m),
2. Picón del Fraile (1.632 m),
3. Pizarras (1.481 m),
4. Peña Lusa (1.575 m),
Figure 4

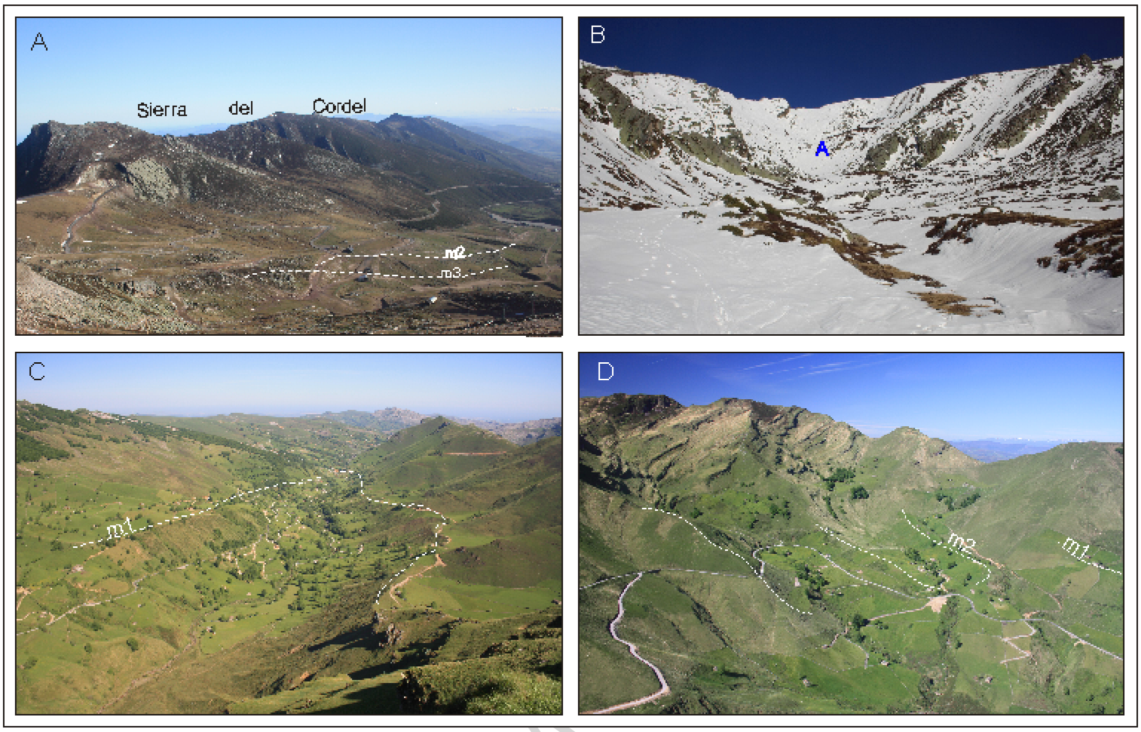


Figure 5

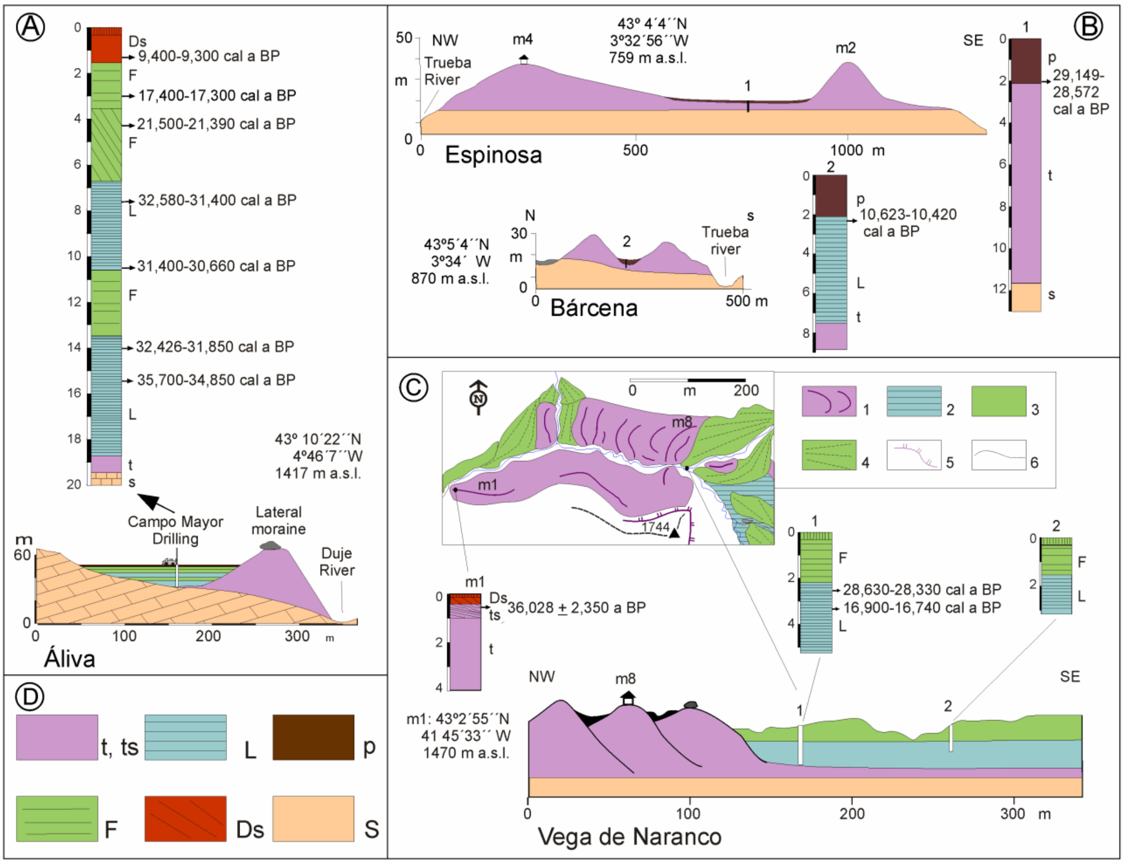

A
Ds
9,400-9,300 cal a BP
F
17,400-17,300 cal a BP
21,500-21,390 cal a BP
F
32,580-31,400 cal a BP
L
31,400-30,660 cal a BP
F
32,426-31,850 cal a BP
35,700-34,850 cal a BP
L
t
s
43º 10´22´´N
4º46´7´´W
1417 m a.s.l.
Campo Mayor Drilling
Lateral moraine
Duje River
Áliva
B
NW
Trueba River
m4
43º 4´4´´N
3º32´56´´W
759 m a.s.l.
m2
SE
Espinosa
p
29,149-28,572 cal a BP
t
s
N
S
43º5´4´´N
3º34´ W
870 m a.s.l.
Trueba river
Bárcena
p
10,623-10,420 cal a BP
L
t
C
m8
m1
1744
Ds
ts
36,028 ± 2,350 a BP
28,630-28,330 cal a BP
16,900-16,740 cal a BP
F
L
m1: 43º2´55´´N
41 45´33´´ W
1470 m a.s.l.
NW
SE
Vega de Naranco
D
t, ts
L
p
F
Ds
S

Figure 6

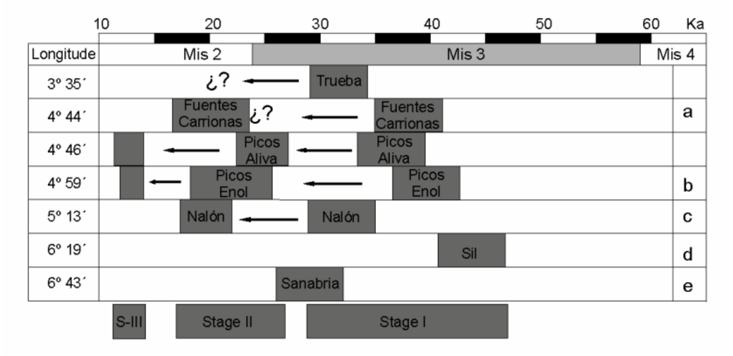

10
20
30
40
50
60
Ka
Longitude
Mis 2
Mis 3
Mis 4
3º 35´
¿?
Trueba
4º 44´
Fuentes Carrionas
¿?
Fuentes Carrionas
a
4º 46´
Picos Aliva
Picos Aliva
4º 59´
Picos Enol
Picos Enol
b
5º 13´
Nalón
Nalón
c
6º 19´
Sil
d
6º 43´
Sanabria
e
S-III
Stage II
Stage I

Figure 7

Highlights

Reconstruction of the glacial evolution in the Cantabrian Mountains
Timing of four glacial stages, three of the Pleistocene age and one of historical age.
Glacial maximum (GM) of the Cantabrian Mountains predates the global LGM, within the MIS3.
Glacial maximum (SI) did not correspond to the greatest volume of ice.
Advance stage (S-II) developed more voluminous glaciers but of lesser extension.