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Late Pleistocene glacial evolutionary stages in the Gredos Mountains (Iberian Central System)

Javier Pedraza[a,*], Rosa M. Carrasco[b], David Domínguez-Villar[c], Javier Villa[b]

[a] Department of Geodynamics, Complutense University, C/José Antonio Novais 2, 28040 Madrid, Spain
[b] Department of Geological and Mining Engineering, University of Castilla-La Mancha, Avda. Carlos III s/n, 45071 Toledo, Spain
[c] National Research Centre on Human Evolution (CENIEH), Paseo Sierra Atapuerca s/n, 09002 Burgos, Spain

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ABSTRACT

During the Last Glacial Period (Late Pleistocene) the summits of the Gredos Mountains (Iberian Central System) were covered by plateau glaciers and later evolved into valley and slope glaciers. The evolutionary sequence of these paleoglaciers has been obtained using geomorphological indicators and taking the "principal moraine" as reference. These moraines show the limit between the glaciation and deglaciation periods. In the glaciation period (G), four chronologically sequenced stages have been identified: the local glacial maximum or maximum ice extent (GM); limited retreat (LR); re-advance (RA); and finally major stabilization, the steady-state stage of greatest glacial stability (MS). In the deglaciation period (D), six chronologically sequenced stages have been identified: an absolute retreat which involved regression and stabilization (D1), two major retreat periods (D2 and D4) and two stabilization periods (D3 and D5). Finally, the last stage represents the complete disappearance of the glaciers (D6). This evolutionary sequence allows more precise studies of the ages assigned through numerical dating procedures and of the correlation of the paleoglaciers in the Gredos Mountains with those of other regions.

1. Introduction

The studies and interpretations of glacial processes of the Iberian Central System (ICS), their chronology and correlation on a regional scale have been traditionally carried out using morainic complexes as the preferred geomorphological indicators. This is a consequence of the lack of other surficial deposits, such as fluvioglacial and glaciolacustrine materials. These are frequently used in other regions (see Vilaplana and Montserrat, 1989; Bordonau, 1992; Lewis et al., 2009; Moreno et al., 2010; Rodríguez-Rodríguez et al., 2011), but have an irregular and limited distribution in the ICS.

On the other hand, the uncertainty of glacial chronology data is a matter of debate for the ICS as well as for other mountains within the Iberian Peninsula, especially in the Pyrenees (see Vilaplana and Bordonau, 1989; García-Ruíz et al., 2003; González-Sampériz et al., 2006; Delmas et al., 2008; Lewis et al., 2009; Pallàs et al., 2010). As far as the ICS is concerned, discrepancies over the chronology for the maximum extent of the glaciers during the Late Pleistocene, or local glacial maximum (GM), and its relationship to the Last Glacial Maximum (LGM), or the global maximum ice extent during Marine Isotope Stage 2 (MIS2), are of particular interest (Vieira et al., 2001; Palacios et al., 2011a, 2011b; Carrasco et al., 2012). These problems represent a stimulating challenge for new research. They also highlight the need to review and contrast the dating methods, procedures and techniques used in these areas (García-Ruíz et al., 2010). Therefore, producing a reliable geomorphic reference model for the glacial evolutionary stages in the ICS is essential for precise dating and correlation with other areas.

As a result of the identification of new glacial deposits in some paleoglaciers of the Gredos Mountains (firstly in the Serra paleoglacier, Fig. 1a; and then in the Cuerpo de Hombre and Endrinal paleoglaciers), a new geomorphological indicator for the GM limit for these paleoglaciers was proposed (Carrasco, 1997; Carrasco et al., 2010). The detailed geomorphological studies carried out in this paper have allowed the presence of this new geomorphological GM indicator to be generalized to all the sectors of the Gredos Mountains. This has also enabled the reclassification of these paleoglaciers, their reconstruction for the GM and the determination of the characteristics and morphostratigraphic significance of the formations recently called "peripheral deposits" and "principal moraine" (Pedraza et al., 2011). With this data, a new model is

* Corresponding author.
E-mail address: javierp@geo.ucm.es (J. Pedraza).

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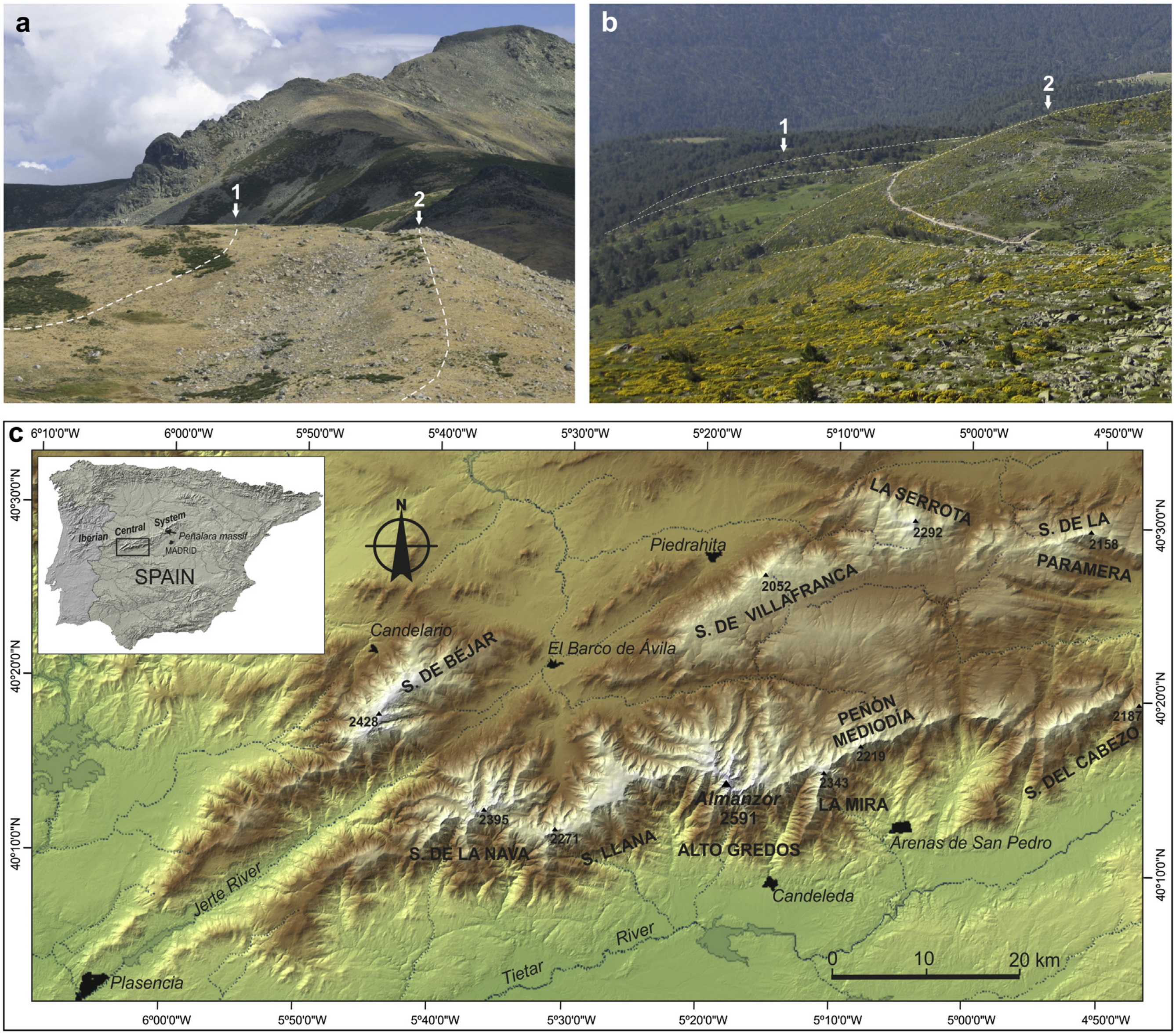

Fig. 1. a) Serra paleoglacier (Gredos Mountains). The glacier was located to the right of the picture. 1: external deposits (scattered boulders), 2: internal deposits (large moraine) (Carrasco, 1997). The large moraine was previously considered the maximum extent of the glacier and correlated with the minor moraines of Peñalara paleoglacier. b) Peñalara paleoglacier (Guadarrama Mountains). The glacier flowed from right to left of the picture. 1: external deposits (minor moraines), 2: internal deposits (large moraine). These moraine complexes were initially assigned to the Riss and Würm stages (Obermaier and Carandell, 1917) and after to the Würm stage (Butzer and Franzle, 1959). Based on Pedraza et al. (2011) and the new data, in this paper the formation 1 is called "peripheral deposits" (PD) and 2 "principal moraine" (PM). c) Location map of the different sectors that hosted glaciers in Gredos Mountains during the local glacial maximum (GM).

presented here of the glacial evolutionary sequence in the Gredos Mountains during the Late Pleistocene. This model is based on a detailed morphostratigraphic sequence and on data from numerical dating recently obtained in the paleoglaciers landforms of these areas. Based on this new methodology, the alpine chronology first used by Obermaier and Carandell (1917) in the Peñalara paleoglacier (ICS central-eastern sector; Fig. 1b), which has been traditionally used for the glacial chronology of the ICS (see Pedraza and Carrasco, 2005), has been ruled out.

2. Regional setting

The Gredos Mountains, the generic name given to the central part of the Iberian Central System (ICS), is an intraplate mountain system in the centre of the Iberian Peninsula (Fig. 1c). The predominant materials in this area were formed during the Hercynian or Variscan cycle and correspond to granitoids (i.e., monzogranites, granodiorites). Some surficial Quaternary deposits are also found (alluvial, glacial, periglacial and slope deposits; Fig. 2).

The origin of the current topography is related to the tectonic evolution during the Alpine Orogeny (Cenozoic). The resulting morphostructure corresponds to a piedmonttreppe with the summit surface reaching 1700–2400 m asl in different sectors. The general orientation is roughly E–W, with a total length of 121 km (E–W) and maximum width 83 km (N–S). This sector includes the highest peak of the ICS (Almanzor 2591 m asl) and the largest areas above 2000 m asl (see Fig. 1c; Table 1).

Table 1
Physiographical features of the Gredos Mountains.

Gredos Mountains sector	General orientation	The highest summit (m asl)	Area 2000 m asl (km^2)	Summit morphology	Morphostructure (1)	Geomorphological types of glaciers in Gredos Mountains[a] (2, 3)
S. de Béjar	NE–SW	2428	31.9	Plateau	Uplifted block	Valley, cirque (a, d, j), slope (p) and plateau (q) glaciers
S. de La Nava	NE–SW	2395	24.4	Ridges and Hills	Tilted block	Valley, cirque (a, h, n), slope (k, l, p) and plateau (q) glaciers.
S. Llana	WNW–ESE/NE–SW	2271	24.0	Plateau	Uplifted block	Slope, cirque (k, l) and plateau (in this paper) glaciers
Alto Gredos	E–W	2591	44.4	Arêtes	Tilted block	Valley, cirque (a, b, c, e, h, i), slope (k, l, m, o) and plateau (in this paper) glaciers
La Mira	NW–SE/NE–SW	2343	6.4	Plateau	Uplifted block	Valley (f) cirque (k, m) and plateau (r) glaciers. Modified in this paper to cirque and slope glaciers with connection to a summit snowfield
Peñón de Mediodía	NE–SW	2219	4.3	Hill	Uplifted block	Slope and cirque (k, m) glaciers
S. de Villafranca	NE–SW/E–W	2052	2.5	Plateau	Tilted block	Only periglacial features
S. del Cabezo	NE–SW/E–W/NE–SW	2187	2.0	Hill	Uplifted block	Only periglacial features
S. de la Paramera	ENE–WSW	2158	1.2	Ridge	Uplifted block	Only periglacial features
La Serrota	NNE–SSW	2292	9.0	Hill	Uplifted block	Cirque (g) glaciers. Modified in this paper to cirque and slope glaciers with connection to a summit snowfield.

1. Block mountains type: steep sides (lifted) or steep-gently sides (tilted).
2. Author references. Includes authors who made the first reference to the type of glacier and also those who completed the inventory of these paleoglaciers. a) Schmieder (1915); b) Huguet del Villar (1915, 1917); c) Obermaier and Carandell (1916); d) Carandell, 1924; e) Vidal Box (1929, 1936, 1948); f) Vidal Box (1932); g) Hernández Pacheco and Vidal Box (1934); h) Hernández-Pacheco (1957); i) Martínez de Pisón and Muñoz Jiménez (1972); j) Sanz-Donaire (1979); k) Pedraza and López (1980); l) Pedraza and Fernández (1981a); m) Pedraza and Fernández (1981b); n) Sanz-Donaire (1982); o) Acaso (1983); p) Rubio (1990); q) Carrasco (1997); r) Acaso et al. (2006).
3. "Slope glaciers". Intermediate between valley and cirque glaciers and located on very steep slopes (Pedraza and López, 1980). A current example in the Alps is the Bossons glacier in the Mont Blanc Massif (Vivian, 1975).
[a] Letters "a" to "r" refer to publications where the typology of those glaciers was described for the first time.

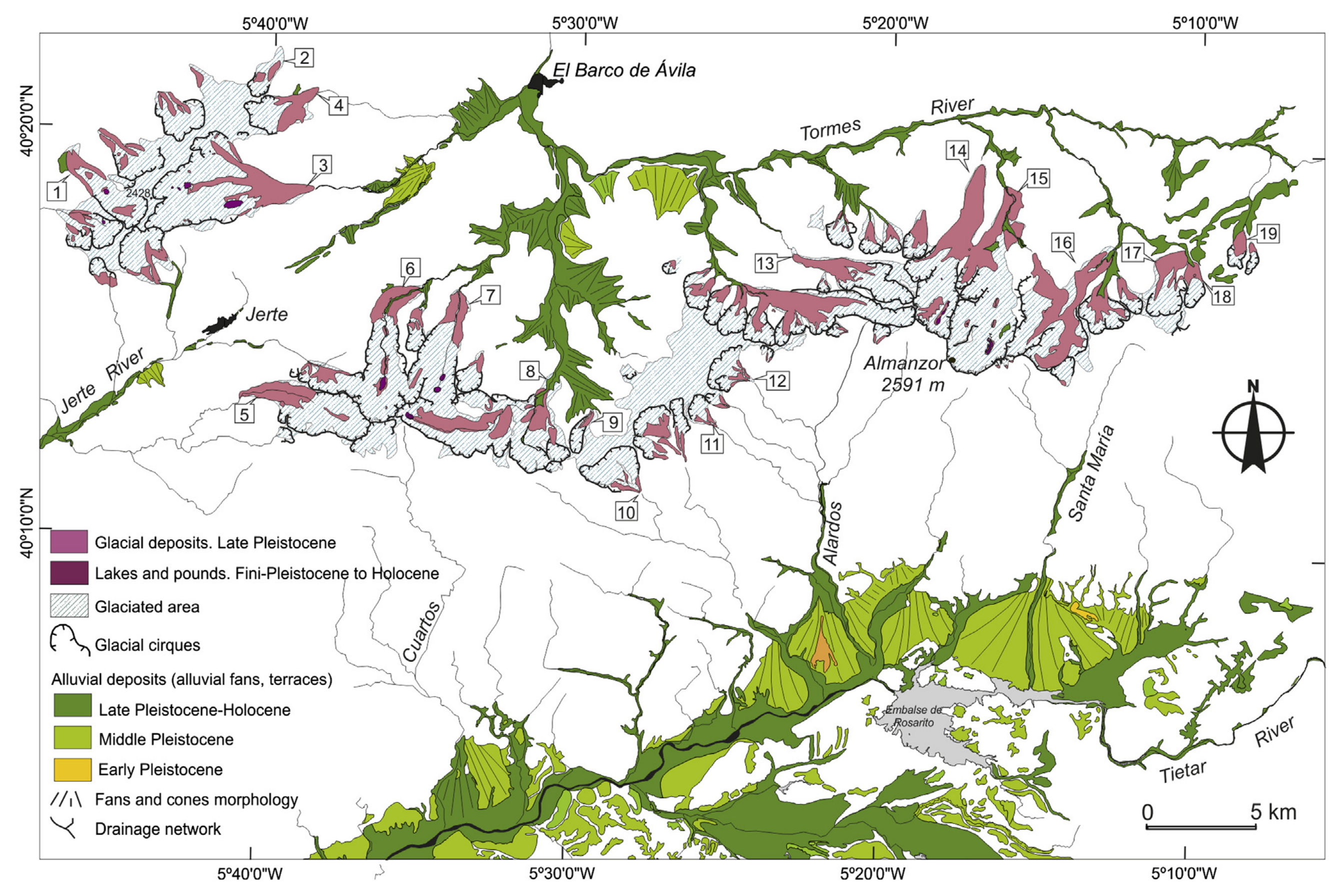

Fig. 2. Map showing the main surficial deposits and geomorphological features in the Gredos Mountains (modified after Pedraza, 1994). The numbers indicate the paleoglaciers selected for detailed study. 1, Cuerpo de Hombre; 2, Peña Negra; 3, Endrinal; 4, Duque–Trampal; 5, Serra; 6, Vega; 7, Nava; 8, Caballeros; 9, Hoya; 10, Chorro; 11, Pulgas; 12, Encinoso; 13, Bohoyo; 14, Pinar; 15, Garganta de Gredos; 16, Prado Puerto; 17, Conventos; 18, Covacha; 19, Javalí.

The ICS lies within the Mediterranean bioclimatic region but the climate is strongly influenced by the continental effect (distance from the Atlantic), which increases markedly from west (more moisture and mild summers) to east (less moisture and harsh summers). The central position of the Gredos Mountains presents a climatic environment midway between these two extremes. Mean annual maximum temperatures on the summits of the Gredos Mountains range from 12.5 to 15.0 °C (up to 5 C° higher than in other massifs in the ICS), and the mean annual precipitation ranges from 1400 to 1800 mm; these values are close to those of the westernmost sector of the ICS, and higher than in the eastern sectors, where the mean annual precipitation is 1000–1400 mm (AEMET/IM, 2011).

3. Gredos Mountains paleoglaciers: general context and chronology

Although during the Last Glacial Period the atmospheric circulation varied significantly (see Butzer, 1957; Florineth and Schlüchter, 2000; Hughes et al., 2006; Hughes and Braithwaite, 2008), the basic regulatory processes for the climate of the Iberian Peninsula were similar to those that exist at present. Within this climatic context, the Gredos Mountains form a biogeographic unit (Rivas-Martínez, 1987) clearly differentiated from the other sectors of the ICS where glacial processes also occurred during the Late Pleistocene (see Pedraza and Carrasco, 2005; Vieira, 2005). These differences are reflected in traditional estimates of the “perpetual snow level” (or Perennial Snow Line, PSL) (Table 2). Given that these environmental variations occur gradually throughout the ICS, between different sectors of the Gredos Mountains there is also a gradual W–E increase in continentality. This is clearly reflected in the variations in altitude where glaciers are found in the different massifs.

In the Gredos Mountains the glacial morphology only developed in the massifs with summits above 2000–2100 m asl (depending on average total summit surface). These paleoglaciers were initially classified as valley, slope and cirque glaciers but were later described as plateau glaciers that regressed to the above types during deglaciation stages (see Table 1).

Numerical dating has only recently been obtained from glacial features in the Gredos Mountains. In the Alto Gredos, Palacios et al. (2011b) obtain data for the maximum advance stage at 26–24 ka and the subsequent steady-state of the glacier around its maximum position for 3 ka. The retreat stages began after 21 ka and the glaciers had probably disappeared around 15 ka. On the other hand, in the Sierra de Béjar the maximum advance stage has been dated to between 27 and 26 ka and the beginning of the major steady-state of the glaciers after a limited retreat stage around 19 ka (Carrasco et al., 2012).

Numerical chronology for some glaciers has also been obtained in other areas of the ICS. In the Serra da Estrela (ICS western sector) the maximum advance stage has been dated to between 33 and 30 ka (Vieira et al., 2001). In the Peñalara paleoglacier (ICS central-eastern sector), Palacios et al. (2011a) establish that the local last maximum advance took place around 26 ka, lasting with considerable stability from 25 to 19 ka. Between 19 and 16 ka there was a slow retreat, with a very rapid retreat after 16 ka and full deglaciation around 12 ka.

According to this data, the glacial activity in the region corresponds to the Last Glacial Period (Late Pleistocene). Nevertheless, the chronology of the glacial maximum extent and the deglaciation stages is still imprecise. Therefore, the data must be used only as a first approximation in research to date the evolutionary stages of paleoglaciers in the Gredos Mountains.

4. Specific objectives and methods

The main aim of this paper is to establish the evolutionary sequence of the ice masses. This required a careful study of moraine typologies and their sequence, the reconstruction of paleoglaciers during their maximum extent (GM), and the correlation of geomorphological indicators to establish a morphostratigraphic sequence. This enabled the evolutionary sequence of these paleoglaciers to be defined.

In this study, a 1:50,000 Geomorphological Synthesis Map was used, which combines and updates the previous maps and other information of these areas (see Table 1). This Geomorphological Synthesis Map shows that in the great valley paleoglaciers only a few differentiated formations and elements were represented. In the slope and cirque paleoglaciers, however, various moraine complexes and numerous crests are differentiated. As a result, the main paleoglaciers in each sector were selected (Fig. 2) and mapped in detail. The mapping includes three formations (deposit groups) that are considered fundamental for determining the evolutionary sequence of the paleoglaciers in these areas (Pedraza et al., 2011) (Fig. 3). The main geomorphological indicator used as reference in this study is the largest or “principal moraine” (PM). This was chosen because the PM has the best defined and preserved moraine morphology and the largest dimensions and from early research has been well identified in all paleoglaciers in the ICS. According to the Peñalara and Serra paleoglacier model, the deposits located on the external side of the PM (minor moraines and scattered boulders) are referred to as “peripheral deposits” (PD) because they are smaller than the PM, are discontinuous and are always associated

Table 2
Estimated values of the PSL (Perennial Snow Line), paleo-PSL and paleo-ELAs (Equilibrium Line Altitude) in the Iberian Central System. Data presented in meters above sea level (m asl).

	Serra da Estrela	Gredos Mountains	Guadarrama	Somosierra
The highest summit	1993 (Estrela)	2592 (Almanzor)	2430 (Peñalara)	2274 (Pico del Lobo)
Current-PSL[a]	3000	3000–3100	3200–3250	3250–3300
Paleo-PSL during the GM[a]	1650	1800–1900	2000–2050	2050–2100
AABR estimation of Paleo-ELAs during the GM				
Regional value	1650[b]	2010[c]	–	–
Local range values	1278–1913[b]	1812–2205[c]	–	–
Minimum altitude of the glacier fronts during the GM	750	1200	1650	1700

GM, Local Glacial Maximum (Late Pleistocene).
[a] Obermaier and Carandell (1915), Lautensach (1929), Vidal Box (1948), Daveau (1971), Brosche (1978) and Pérez Alberti et al. (2004).
[b] Vieira (2008).
[c] Carrasco et al. (2012).

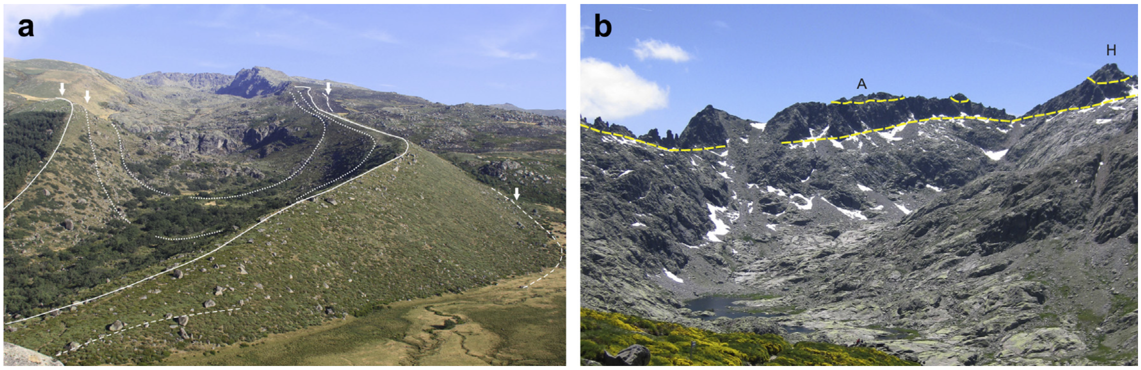

Fig. 3. Examples of geomorphological indicators. a) Cuerpo de Hombre paleoglacier (number 1 in Fig. 2). Moraines and boulders from "peripheral deposits" (dashed line), "principal moraine" (continuous line), "internal deposits" (dotted line). b) Glacier trimlines in the cirque of Garganta de Gredos paleoglacier (number 15 in Fig. 2). A, paleo-nunataks (arête); H, paleo-horn.

with the PM. Finally, other geomorphological indicators (minor moraines and scattered boulders) found in an internal position in relation to the PM are referred to as "internal deposits" (ID).

The geomorphological erosion indicators were essential to define the areas where plateau glaciers were located, their typology and evolution during glaciation (see Glasser and Bennett, 2004; Lukas, 2006; Bennett and Glasser, 2009). Microscale, mesoscale and macroscale features associated with their correlative moraine complex were used in these studies (see Fig. 3).

The paleoglaciers were reconstructed at the ice mass maximum extent stage or local glacial maximum (GM). To establish the limits of the ice masses during the GM and to calculate their thickness, the geomorphological indicator used was the "peripheral deposits" (PD) formations.

The theoretical basis for reconstructing paleoglaciers is a combination of physical-based models supported by geomorphological data to allow validation of results (Schilling and Hollin, 1981; Ackerly, 1989; Rea and Evans, 2007; Vieira, 2008; Carrasco et al., 2012). The reconstruction was carried out by producing theoretical glacier surface profiles using simple steady-state models that assume a perfectly plastic ice rheology. In the Gredos Mountain paleoglaciers the method described by Benn and Hulton (2010) was used, applying the alternative proposed in the Profiler v.2 spreadsheet. The subglacial topographic control is included in the model through a shape factor (Nye, 1952). In total, 107 longitudinal profiles were completed in the Gredos Mountains following the maximum flow lines obtained from geomorphological indicators, 421 transversal profiles were drawn, and shape factors were calculated for each transversal profile. To calculate all of these parameters, a digital elevation model (DEM) with 5 m grid resolution was used.

However, this model is not applicable to areas where there is little excavation and the ice was not confined by the relief. In these areas the glacial maximum (GM) is determined only by the peripheral scattered boulders or erosive landforms; this occurs in some summit areas of Sierra Llana, La Mira massif and Sierra de Béjar. In this case, the method applied to obtain the ice mass topography was based on a model with distances from the margin to the ice divides, using a constant basal stress value of 50 kPa (Orowan, 1949; McDougall, 1995; Rea et al., 1998; Evans et al., 2002; Cowton et al., 2009; Carrasco et al., 2012).

To obtain the final ice mass geometry, a GIS was created with the data obtained from the 107 longitudinal profiles. When the isohypses of the ice surface had been obtained, ARCGIS 10 software was used to generate a triangulation, and this was then interpolated into a DEM with grid resolution 15 m (Golledge, 2007; Carrasco et al., 2010, 2012). The thickness of the ice mass and the nunataks (ice-free summits) were obtained by subtracting the current topographical surface and the DEM of the ice surface.

The availability of recently obtained data from some paleoglaciers in the Gredos Mountains (Palacios et al., 2011b; Carrasco et al., 2012), has allowed a numerical chronology reference baseline to be assigned to the evolutionary sequence. As a result, in this article the traditional methods have not been used for assigning chronologies using correlation procedures with alluvial formations (terrace systems) corresponding to the main rivers draining these basins (Tormes, Tiétar and Jerte) (Pedraza and Fernández, 1981a, 1981b; Acaso, 1983; Rubio, 1990; Carrasco, 1997).

5. Results: geomorphological features and ice-mass parameters

The glacial deposits in the Gredos Mountains are diamictons composed of granitic materials, coarse and very coarse cobbles and boulders with little matrix. Slight variations in the size and morphology of some boulders or of the matrix content and some sedimentary structures are the only differential traits to deduce the primary origin of the debris (extraglacial/subglacial) and the transport and sedimentation modes (supra/en/sub-glacial). This homogeneity of the deposits is largely determined by the geological context: blocks and spheroidal boulders are the most common products of the granitic rock disintegration processes in these areas (see Pedraza, 1994; Molina-Ballesteros et al., 1997).

The greatest volume of deposits is found on the valley sides, generally forming lateral moraines. They may be found attached to the valley sides with few morphological projections or as a crest-shaped ridge (see Fig. 3). The deposits found on the valley floors correspond to a complex system of superimposed sediment formations. This is: (1) a vertical accretion sequence of tills which form the flat topography of the valley, (2) surficial debris accumulations forming morainic arcs (arcuate or crescentic ridges across the valley), and (3) a series of surficial scattered boulders.

Among the deposits found on the valley sides the one called here the "principal moraine" (PM) is the most important. It corresponds to the system formed by the two largest and most continuous lateral moraines, identified in all the paleoglaciers in this area (see Fig. 3). The sedimentological studies carried out of these moraines in different sectors of the Gredos Mountains (Fernández, 1976; Sanz-Donaire, 1979; Pedraza and Fernández, 1981a, 1981b; Acaso, 1983; Rubio, 1990; Carrasco, 1997; Pedraza et al., 2011), have enabled the characterization of these deposits. In general terms they can be described as a structureless accumulation of angular and spheroidal cobbles (6.4–25.6 cm axis), boulders (from fine to coarse, 25.6–102.4 cm) and large boulders (coarse, 102.4–204.8 cm) with scant matrix (from granule to coarse pebbles, 2–32 mm). In some areas, extremely angular boulders are found with exceptionally large dimensions (very coarse, 204.8–409.6 cm), with no signs of having been transported by the ice (no traces of polishing or similar processes, and with edges and evidence of impact-induced fracture) suggesting direct extraglacial contribution to the formation of these moraines (Carrasco et al., 2010). Another characteristic feature of these moraines is that they have a series of secondary or minor ridges on their inner slope and to a lesser extent also on the outer slope.

The "peripheral deposits" (PD) are composed of boulders and large boulders (from fine to coarse, 25.6–102.4 cm). The arrangement and morphology of these deposits vary from one paleoglacier to another or even within the same paleoglacier. The most common types are (Fig. 4): a single moraine attached to the PM, sometimes with overlapping; a moraine and scattered boulders; and a system with two or, exceptionally, three moraines subparallel to the PM.

The vertical accretion formations on the valley floor form a till sequence characteristic of these areas, defined from base to top as: basal deformation till, subglacial lodgement till, subglacial melt-out till and supraglacial melt-out till. The latter is associated with surficial erratic boulders and ridges and the subglacial melt-out-till is related to the subglacial lodgement till. The basal deformation till has only been identified in two places, Duque–Trampal and Prado de la Casa paleoglaciers. One consists of highly deformed lodgement till from debris-rich ice. The other is composed of granitic bedrock detached from its source by subglacial shearing and which should therefore be classified as basal traction till.

The valley floor formations of surficial scattered boulders and morainic arcs are those which have been used as preferred indicators. From their location in the valley and their relationship with the PM these formations are called "internal deposits" (ID). The boulder formations (ID-B) are well defined in all the glaciers and present a wide range of sizes: from fine cobbles to coarse boulders (6.4–204.8 cm) and, locally, very coarse boulders and fine blocks (208.8 cm–8.2 m). However, the morainic arcs (ID-M) are very irregular in both form and distribution. In some cases they are true moraine accumulations with one main and several secondary crests. However, in others they are narrow alignments of boulders (Fig. 5). The most complete sequence of these moraines includes four morainic arcs: two are located in the lower reach of the valley, connected with the PM by lateral crests; the other is located in the ancient accumulation zone; and the last morainic arc is located on the headwall and encloses a small bowl-shaped cirque.

The relationships between these formations are essential to establish the morphostratigraphic and evolutionary sequence of the glaciers and will be analysed in the section below. However, as an initial approach and based on all of its sedimentological and geomorphological characteristics, the series of subglacial tills (traction/deformation, lodgement and melt-out) is considered to form the till blankets. The supraglacial melt-out till is associated with the scattered boulders (ID-B) and morainic arcs (ID-M). The former are erratic boulders which form part of the ablation moraines (or ablation tills); they may appear locally as scarcely structured or massive accumulations. The latter are end moraines of retreat (or recessional moraines) and no signs of terminal moraines have been found in any paleoglacier.

Finally, in most of the paleoglaciers the till blanket generally advances slightly (a few meters) providing a gentle transition to the lateral moraines. This change abruptly (with a very clear slope break) within a few meters and the lateral moraine is then composed of coarse debris materials (boulders and large boulders with scant matrix) in which subglacier sedimentation structures cannot be recognized.

During the glacial maximum (GM) the most important summits of the Gredos Mountains were covered by ice masses accumulated on topographic plateaus or forming coalescent valley headwall systems. In the Sierra de Béjar the ice masses formed a plateau icecap (domelike ice masses). The other sectors can be classified overall as a plateau icefield. This was a system of coalescent headwall glaciers, with some local variations due to the plateau icecap in the Sierra Llana, or to the valley and cirque glaciers which remained outside the plateau glacier system. The reconstructed topography of the plateau glacier system is shown in Fig. 6 and the morphometric parameters of the paleoglaciers are shown in Tables 3 and 4. 85 glaciers of different sizes and morphologies have been reconstructed, covering a land surface of 220 km^2 with an ice volume of $\sim 12.8 \times 10^9$ m^3.

Table 3
Basic ice mass parameters for the reconstructed paleoglaciers of the Gredos Mountains during the Glacial Maximum (GM).

Sector	Plateau type	Area		Volume		Larger paleoglaciers	
		km^2	%	m^3	%	*N°*	Valley
S. de Béjar	Icecap	57.5	26.1	2.9×10^9	23.0	1	Cuerpo de Hombre
						2	Peña Negra
						3	Endrinal
						4	Duque–Trampal
S. de la Nava	Icefield	52.4	23.8	3.6×10^9	28.7	5	Serrá
						6	Vega
						7	Nava
						8	Caballeros
S. Llana	Icecap	32.8	14.9	1.1×10^9	9.0	9	Hoya
						10	Chorro
						11	Pulgas
						12	Hencinoso
Alto Gredos	Icefield	69.0	31.4	4.8×10^9	37.3	13	Bohoyo
						14	Pinar
						15	Garganta de Gredos
						16	Prado Puerto
La Mira	–	7.1	3.2	2.2×10^8	1.8	17	Conventos
						18	Covacha
Peñón de Mediodía	–	1.4	0.6	3.1×10^7	0.2	19	Jabalí
	Total	220.2		12.8×10^9			

Table 4
Summary of reconstructed spatial parameters of the larger paleoglaciers from different sectors of the Gredos Mountains.

N°	Paleoglacier	Length (m)	Min. Altitude (m asl)	Area			Max. ice thickness (m)	Volume		
				km²	(%) sector	(%) Gredos Mountains		(m³)	(%) sector	(%) Gredos Mountains
1	Cuerpo de Hombre	6038	1350	5.3	9.3	2.4	180	3.7×10^8	12.6	2.9
2	Peña Negra	4205	1487	1.9	3.3	0.9	115	7.2×10^7	2.4	0.6
3	Endrinal	4580	1730	4.6	8.0	2.1	105	1.9×10^8	6.4	1.5
4	Duque–Trampal	8267	1210	19.2	33.5	8.7	211	1.2×10^9	39.9	9.2
					54.0	14.1			61.4	14.1
5	Serrá	5913	1519	8.5	16.3	3.9	220	6.3×10^8	17.0	4.9
6	Vega	7336	1344	9.2	17.6	4.2	265	8.8×10^8	23.7	6.8
7	Nava	5954	2347	8.0	15.2	3.6	218	5.9×10^8	15.9	4.6
8	Caballeros	9021	1249	17.5	33.5	8.0	223	1.3×10^9	34.7	9.9
					82.5	19.6			91.4	26.2
9	Hoya	3609	1566	2.7	8.4	1.2	110	7.5×10^7	6.5	0.6
10	Chorro	2962	1309	3.8	11.5	1.7	78	1.3×10^8	11.2	1.0
11	Pulgas	3200	2264	1.5	4.7	0.7	98	6.3×10^7	5.5	0.5
12	Hencinoso	3992	1305	4.5	13.8	2.1	69	1.8×10^8	15.5	1.4
					38.4	5.7			38.7	3.5
13	Bohoyo	8543	1417	11.2	16.3	5.1	215	7.0×10^8	14.7	5.5
14	Pinar	8985	1352	11.2	16.2	5.1	295	1.1×10^9	22.6	8.4
15	Garganta de Gredos	10,485	1392	15.2	22.0	6.9	355	1.7×10^9	34.8	13.0
16	Prado Puerto	7833	1509	7.7	11.2	3.5	171	4.0×10^8	8.4	3.1
					65.7	20.6			80.4	30.0
17	Conventos	4562	1628	4.4	61.6	2.0	115	1.5×10^8	68.1	1.2
18	Covacha	2232	1691	1.2	16.3	0.5	73	3.0×10^7	13.5	0.2
					78.0	2.5			81.6	1.4
19	Jabali	1804	1701	1.0	69.6	0.4	85	2.5×10^7	80.4	0.2
					69.6	0.4			80.4	0.2

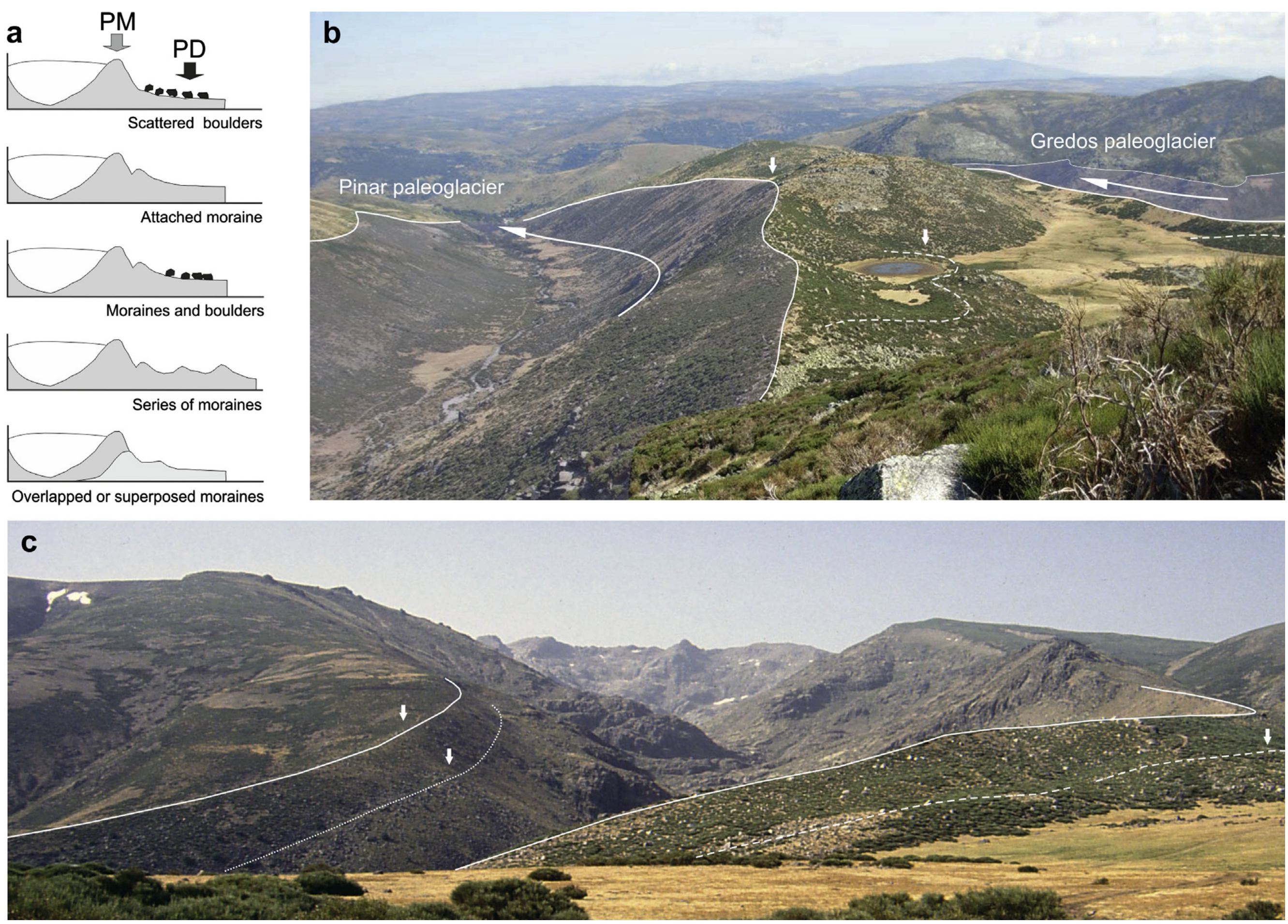

Fig. 4. Typologies of stratigraphic relationships between the “principal moraine” (PM) and other formations. a) Diagram showing the stratigraphic relationships between the “peripheral deposits”' (PD) and PM. b) PM (continuous line) and PD (dashed line) from Pinar and Garganta de Gredos paleoglaciers (numbers 14 and 15 respectively in Fig. 2). Note the PM from Pinar paleoglacier overlapping the PD. c) PD (dashed line) and internal deposits (dotted line) attached to the PM from the Nava paleoglacier.

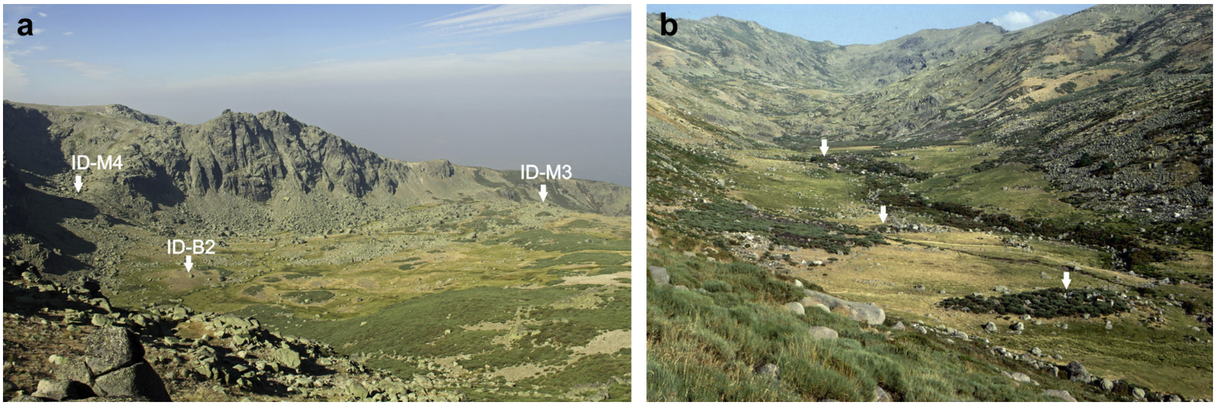

Fig. 5. Internal deposits formations (ID). a) Moraine complexes located in the upper sector of the Cuerpo de Hombre valley (number 1 in Fig. 2). They show the moraines (M3 and M4) and scattered boulders (B2). b) Scattered boulders and moraine arcs (arrows) from the Serra paleoglacier (number 5 in Fig. 2). Some boulders have a slight alignment as an intermediate state between scattered boulders and moraine arcs.

The maximum thickness of the ice on the summits of the plateau icecap was 111 m in the Sierra de Béjar and 85 m in Sierra Llana. According to the erosive geomorphological indicators, the nunataks of the plateau icefield protruded a maximum 200–300 m above the surface of the ice. The maximum ice thickness in these glaciers was found in the Pinar (295 m) and Garganta de Gredos (355 m) glaciers (numbers 14 and 15, respectively, Fig. 2).

6. Discussion: morphostratigraphic sequence and evolution of the glaciers

Altitude was the determining factor for the location of glaciers in the Gredos Mountains. Paleoglaciers were not found in massifs with summits lower than 2000 m asl. A good example of this limit is the Sierra del Valle (E sector Gredos Mountains), with 17.4 km of

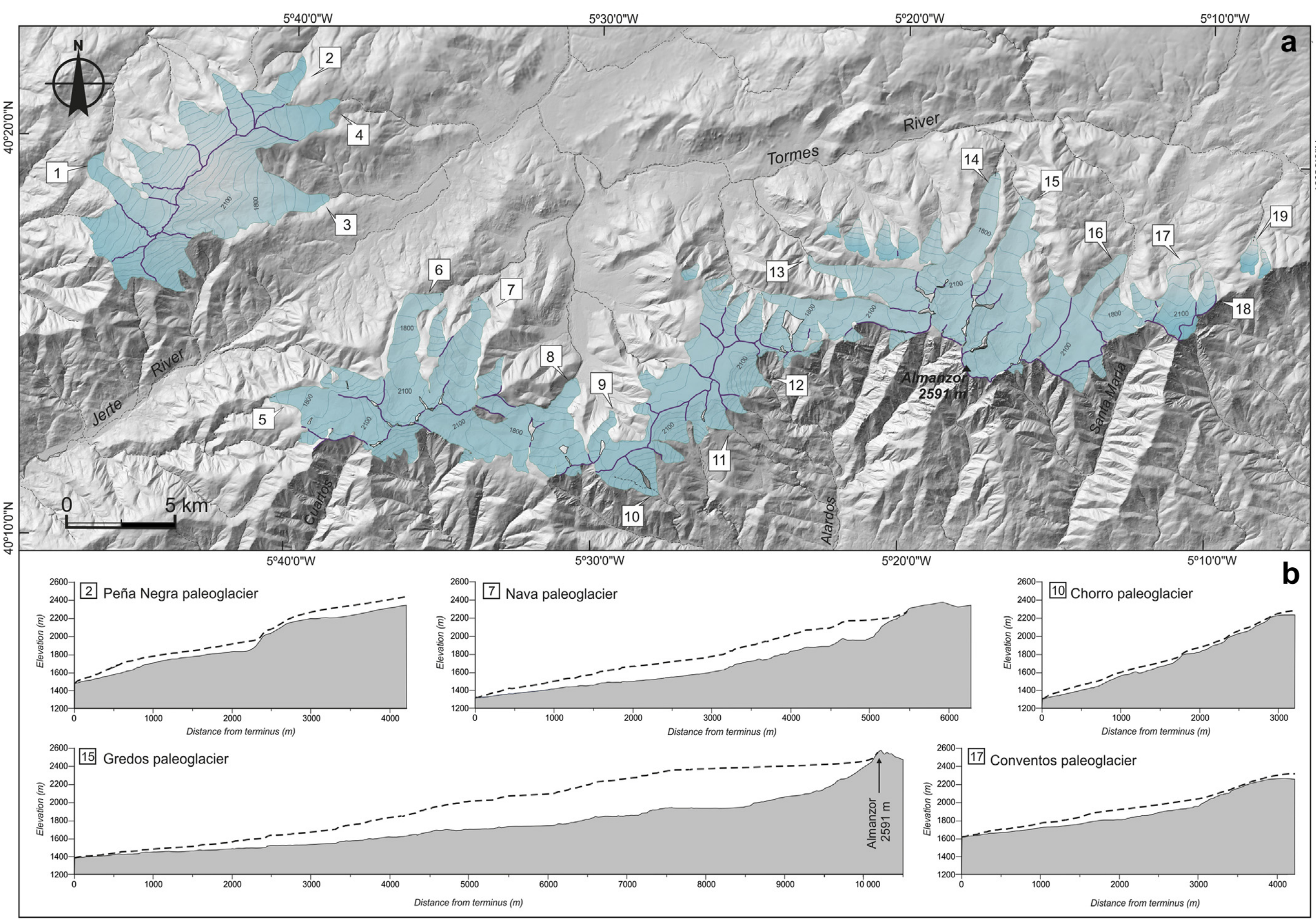

Fig. 6. The glaciers of the Gredos Mountains during the maximum extent of the ice masses. a) Reconstructed hypsometry of paleoglaciers. Elevation contours are shown at 100 m intervals. The numbers refer to the larger paleoglaciers from different sectors of the Gredos Mountains (see Tables 3 and 4). The lines indicate drainage boundaries between glaciers. b) Examples of longitudinal profiles from the paleoglaciers of the Gredos Mountains. Reconstructed ice surface (dashed line) and bedrock topography in the centre of the valley (grey area).

flat summits between 1900 and 2000 m asl, and no glacial modelling. On the other hand, variations in latitude (southern factor) between different sectors in the Gredos Mountains had hardly any effect on this location. However, the differences due to variations in longitude (continental factor) are perceptible (see Table 1). The most southerly paleoglacier (40° 12′ 4.40″ N), was in a massif with a summit of 2169 m asl (La Buitrera, Sierra de la Nava). La Sierra de la Paramera, however, which is one of the most northern massifs (40° 29′ 35.39″ N) and with peaks over 2000 m asl (La Joya, 2137 m asl; Pico Zapatero, 2146 m asl), does not present glacial modelling. The effect of the continental factor is clearly seen as the altitude level where glaciers are found rises from W to E (higher to lower Atlantic influence): the most westerly paleoglacier (5° 46′ 26.23″ W) is found in a massif with a summit of 2088 m asl (Pinajarro, Sierra de Béjar); the most easterly paleoglacier (5° 6′ 20.82″ W) is in a massif with a summit of 2219 m asl (Peña Mediodía, E sector of La Mira massif). The former was a well-developed slope glacier, the latter an under-developed cirque glacier. In the most easterly area of Peña de Mediodía, there are massifs over 2000 m asl (Torozo, 2021 m asl; El Cabezo, 2191 m asl; Centenera, 2058 m asl) which do not present glacial modelling. These variations agree with the "high sensitivity" of the glacial mass balance to the proximity to distance from moisture sources (Owen et al., 2009).

If altitude is a determinant factor to explain glacier location, morphostructure and pre-glacial modelling are the most relevant factors to explain their morphology and dimensions (see Table 1). The amount of accumulated ice, the type of glaciers during the glacial maximum (GM), their later evolution and total route were directly dependent on the following factors: total surface area of the flat summit or topographic plateau at altitudes above 2000 m asl, which controlled the development and dimensions of the dome-shaped plateau glaciers (icecap); type and dimensions of the pre-glacial torrential basins which controlled the development and dimensions of icefields formed by the coalescent glaciers; morphostructure of fault blocks (uplifted or tilted blocks) and their slopes (steep or gentle),which conditioned the length of the glacial tongues depending on the accumulation/ablation ratios. This topographical control of some morphometric, morphologic and even dynamic parameters of the ice masses, is characteristic of mountain glaciers (see Kessler et al., 2006; López-Moreno et al., 2006; Schiefer et al., 2008; Pratt-Sitaula et al., 2011).

The incidence of topoclimatic factors on glacier distribution has been examined in detail in recent years. The slope orientation and snow redistribution by the wind, among other factors, may have significant implications for glacial development and estimated ELA (Equilibrium-Line Altitude) values (Evans and Cox, 2005; Cossart, 2011). As the Gredos Mountains form a range with notable tectonic control and with a simple orographic structure defined by a single main alignment, the orientation was not a determining factor for glacier location. The preferred orientation of most of the valleys is generally orthogonal to the direction of the main alignment whatever the orientation of the massif. However, lower ELA values have been detected in paleoglaciers located on leeward slopes. This is attributed to the effects of the snow redistribution (Carrasco et al., 2012) or, as described in other mountains, the phenomenon of drifting snow on gentle summit and windward slopes (Evans, 2006b).

"Peripheral deposits" formations have been identified in all sectors of the Gredos Mountains, indicating the general evolutionary stages of the glaciers. The discontinuity of formations in this area can be explained by a series of inter-related processes: differences between the surface areas of the accumulation zones (smaller ones are more sensitive to minor climate oscillations and record fewer stabilization stages); quantity of extraglacial debris contributed to the glacier (icecap type plateau glaciers and non-confined tongues in the valleys generally receive less debris and form smaller moraines or scattered boulders); post-sedimentary remobilization/modification processes. This last factor has been described as one of the most important for determining the final configuration of the lateral moraines (see Iturrizaga, 2001, 2008, 2011; Evans, 2006a). As shown by the indicators analysed (see Fig. 4), the peripheral deposits in the Gredos Mountains have been subjected to a process of superimposition or overlap by the later deposits of the principal moraine.

The "principal moraine" has traditionally been considered as the most external and, given its dimensions, as corresponding to the longest steady-state stage of the ice. It was therefore the indicator of the glacial maximum (GM) and major stabilization (MS). However, as has been documented throughout this paper, the most external deposits belong to the "peripheral deposits" and these are therefore the indicator of the maximum extent of the ice or GM.

With later attached moraines superimposing or overlapping part of previous deposits, the physiognomy of the principal moraine is characteristic of a great compound moraine formed at various evolutionary stages (see Boulton and Eyles, 1979; Benn et al., 2005; Iturrizaga, 2011). To define the "principal moraine" and use it as an evolutionary indicator, its main crest must therefore be identified. It is also essential to determine which secondary crests form part of this moraine and which belong to earlier moraine complexes (peripheral deposits) or later ones (internal deposits). The internal position of the "principal moraine" with respect to the "peripheral deposits" indicates that they are separated by a glacial retreat stage, here called "limited retreat" (LR). On the other hand, the deposits of "principal moraine" overlapping on "peripheral deposits" show that they were formed during a re-advance stage (RA). Finally, according to its dimensions, morphology and continuity, the principal moraine required a longer steady state of the ice than any other moraine of these paleoglaciers, and therefore represents the major stabilization stage (MS).

From the "principal moraine", all the indicators show a continuous retreat of the glaciers until they disappeared in these mountains. They therefore represent the deglaciation period (D), which began with the moraines attached to the internal slope of the principal moraine. In both the Gredos Mountains and in other areas in the ICS (Acaso et al., 1998; Palacios et al., 2011a), it has been shown that the glaciers may have re-advanced immediately before they disappeared. However, the data are still not consistent and correspond to ill-defined moraine formations contaminated by paraglacial processes. Deglaciation (D) is marked by "internal deposits" defined by moraine arcs which indicate very short stabilization periods and scattered boulders which indicate periods of ablation or rapid fusion. All the arcs are non-peripheral frontal moraines, and so should be classified as "recessional moraines". There are no frontal deposits forming terminal moraines in any of the paleoglaciers in the valley. However, there are boulders corresponding to peripheral deposit formations, although sometimes mixed with alluvial formations (proglacial and postglacial). The scattered boulder formations are clearly associated with the supraglacial melt-out till. The quantity of the boulders and their dispersion throughout the different reaches of the valley is a clear indicator of widespread rapid fusion stages and so can be considered as ablation till or ablation moraine.

These considerations can be used to propose an outline synthesis showing the overall arrangement of paleoglacial deposits in the Gredos Mountains. From this outline, the morphostratigraphic and evolutionary sequence corresponds to the following indicators and processes (Figs. 7 and 8).

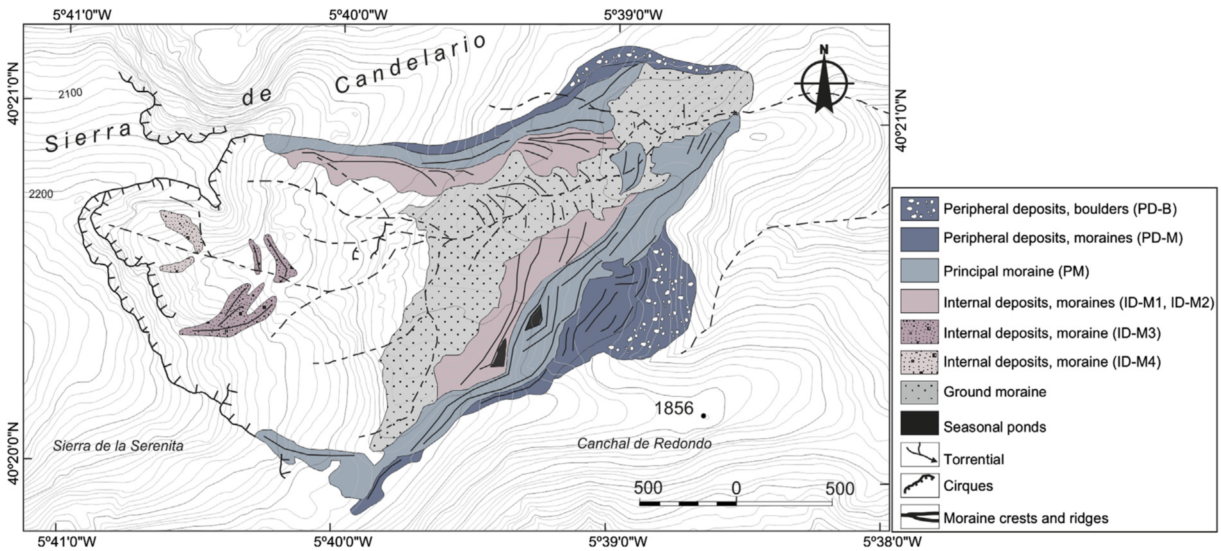

Fig. 7. Simplified geomorphological map of the Endrinal paleoglacier (Sierra de Béjar, number 2 in Fig. 2) (modified after Carrasco, 1997). This paleoglacier is one of the best examples from the Gredos Mountains containing the complete sequence of moraines.

6.1. *G: Glaciation period, consolidation stages and permanence of the ice*

GM. Glacial maximum. The maximum ice extent in the Gredos Mountains and represents the "local glacial maximum" of these mountains. This stage is indicated by the moraine or most external boulders of the "peripheral deposit" formations. During this stage the plateau glaciers reached their maximum dimensions, with a dome-shaped tendency and a minimal percentage of ice-free relief on the summits (nunataks).

LR. Limited retreat. This stage is indicated by the moraines and boulders of the "peripheral deposit" formations in internal positions relative to these. Given that these deposits have been re-elaborated by later processes during the re-advance stage, some of these formations may have been eroded during this re-advance.

RA. Re-advance stage. This is deduced from the overlapping or superimposition, including fossilization, of the deposits of the "principal moraine" on the "peripheral deposits". The scale of this re-advance depends on the extent of the previous retreat, which as mentioned above, has not been determined.

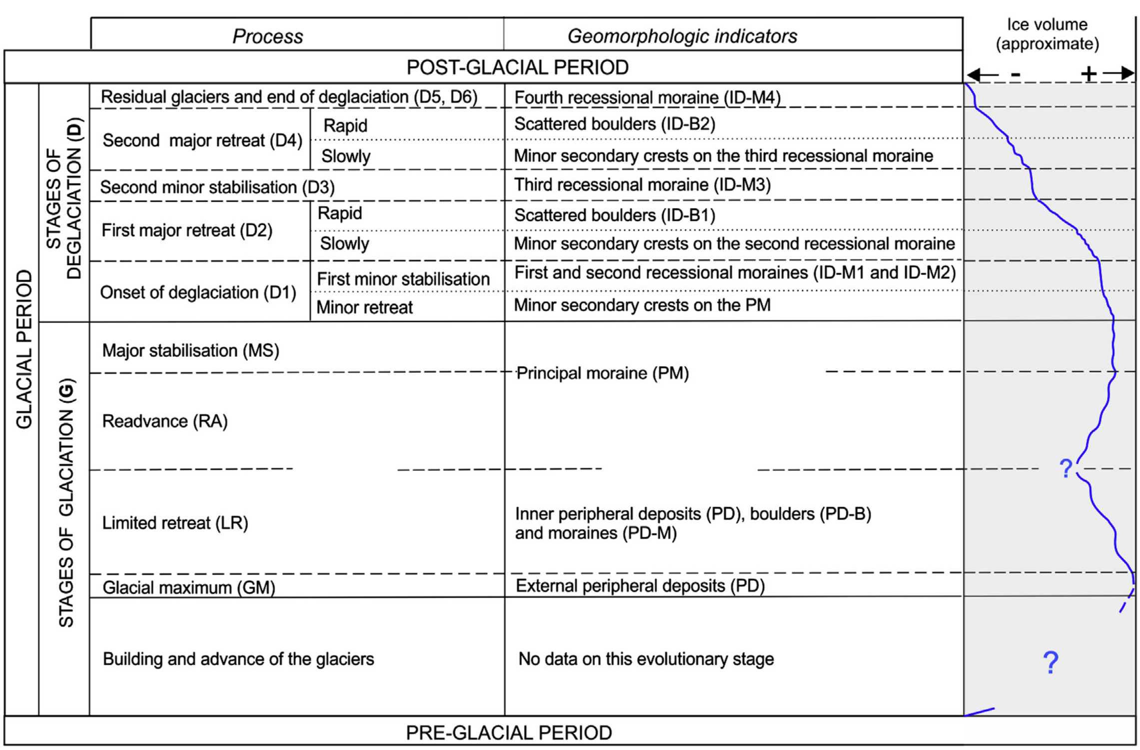

Fig. 8. Summary of the evolutionary stages of the glaciation in the Gredos Mountains. Includes an approximation of variations in ice volume.

MS. Major stabilization. Steady-state period of the ice around the maximum re-advance stage. This is indicated by the formations called here the “principal moraine”, formed by the two largest lateral moraines. According to the erosive indicators (trimlines and shoulders in continuity with the moraines, nunataks), in this stage the glacier accumulation zones were interconnected, forming icefields. However, these erosion features indicate a notable increase of extra-glacial relief and consequently a reduction in the ice plateau thickness. In the case of the icecap type plateaus, these variations may have implied their disintegration and transformation into accumulation zones of some valley, slope or cirque glaciers.

6.2. D: Deglaciation period, stages with general retreat and disappearance of ice

D1. Onset of deglaciation. Slow, minor retreat of the fronts of the large tongues with short periods of stabilization. This process is indicated by the internal moraines (M1 and M2) attached to the principal moraine. Although the ice thickness is reduced, glacier fronts are still found in the lower valley areas. From the erosion indicators it can be deduced that at this stage there was gradual fragmentation of the ice masses in the accumulation basins. The final result was the disappearance of the icefields and their transformation into valley, slope and cirque glaciers.

D2. First major retreat. Rapid, general retreat, until the tongue was confined in the ancient accumulation zone. This stage corresponds to the formation of scattered erratic boulders (B1). Possible disappearance of most old cirque and slope glaciers. The thickness and length of the valley glaciers is reduced by approx. 50%.

D3. Second minor stabilization. Short stage of steady-state ice, originating a well-defined moraine complex (lateral and frontal) (M3).

D4. Second major retreat. Rapid general retreat indicated by scattered boulder deposits (B2). Disappearance of valley glaciers in the Gredos Mountains.

D5. Residual glaciers. The ice is contained in small cirque-type depressions occupying the headwall. Formation of moraine arcs enclosing the cirques (M4) which are frequently mixed with materials originating from paraglacial processes.

D6. Disappearance of the glaciers in the Gredos Mountains.

6.3. Chronology

The numerical chronology of the morphostratigraphic sequence is still in the early stages due to a limited number of dates available in the region. Preliminary data (Palacios et al., 2011b; Carrasco et al., 2012) suggests that the GM stage could have taken place slightly earlier than LGM, whereas the LR stage seems to have occurred during the LGM. The GM stage has been dated in 26.7 ± 2.8 ka and 27.2 ± 2.7 ka for the most external boulders of the “peripheral deposits” (PD) in two different paleoglaciers of Sierra de Béjar (Duque–Trampal and Endrinal, numbers 3 and 4 respectively in Fig. 2; Carrasco et al., 2012). These data have been obtained using ^{10}Be, and include the correction for erosion rates that considers an optimum calculation of the ages. In addition, the close correspondence of dates from different glacier catchments suggests a reliable chronology for this stage, although a larger number of glaciers need to be studied in order to confirm the age of this stage in the Gredos Mountains. On the other hand and based on ^{36}Cl and a zero erosion rate, Palacios et al. (2011b) presented the dates of 24.2 ± 0.9 ka to 25.2 ± 1.2 ka for two morainic arcs representing the maximum extent (GM) of the paleoglacier from Garganta de Gredos (number 15 in Fig. 2). However, based on new data obtained for this morphostratigraphic sequence, the presence of erratic boulders beyond these moraines suggests that they did not represent the GM stage but the subsequent LR stage. Carrasco et al. (2012) dated the LR stage in Sierra de Béjar from 19.0 ± 2.1 ka to 21.8 ± 2.2 ka. This example highlights the importance of having a reliable morphostratigraphic sequence so that the chronologies can be compared. Finally, with two ^{36}Cl dates from polished surfaces in Garganta de Gredos, Palacios et al. (2011b) suggest ages of around 15 ka for the ice disappearance in these areas. Consequently, a more reliable deglaciation chronology is needed, involving more dates in different stages of the sequence at different glacier catchments and from more reliable geomorphic indicators (i.e., boulders).

7. Conclusions

In the Late Pleistocene during the maximum extent of glaciers in the Gredos Mountains or local glacial maximum (GM), the summits of these mountains were occupied by icefield and icecap type plateau glaciers. The first lasted until the onset of deglaciation (D); the second gave way to individual accumulation zones, possibly fragmented at the start of the major stabilization (MS) stage. All these plateau glaciers evolved later into valley and slope glaciers. This new interpretation of the glaciation of the Gredos Mountains generalizes the existence of the plateau glaciers to all the most important massifs in these mountains.

The series of glacial deposits making up the “peripheral deposits” (PD) have been identified in all the paleoglaciers selected for detailed study. They represent major evolutionary stages in these mountains. Earlier interpretations which considered these to be exceptional cases of some paleoglaciers regulated by local topographical, morphological or microclimatic factors can therefore be discarded. The most external formations of these PD are those which mark the local maximum extent of the ice or GM. The “principal moraine” (PM), which had been considered to be the GM indicator, represents later evolutionary stages.

The system formed by the largest and best defined lateral moraines of all the paleoglaciers is a complex or polygenic moraine. The most important volume of deposits which form this system corresponds to the “principal moraine” (PM). This originated in two stages: a re-advance stage (RA) and a subsequent major stabilization stage (MS). The “peripheral deposits” that have been overlapped by the principal moraine and the “internal deposits” attached to it (generally two minor moraines) also form part of this complex lateral moraine system. Finally, these “internal deposits” attached to the PM represent recessional moraines which indicate the onset of deglaciation (D). Therefore, the PM marks the limit between the glaciation (G) and deglaciation (D) periods in these areas.

The re-advance stage (RA), identified for the first time in these areas, may represent a maximum secondary advance. This data open up a new area for research into the glaciation of the Iberian Central System.

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References

Acaso, E., Pedraza, J., Centeno, J., 1998. Nuevas aportaciones al modelo evolutivo del glaciar de Peñalara (Sistema Central Español). In: Gómez-Ortiz, A., Salvador-

Franch, F. (Eds.), Investigaciones recientes en la geomorfología española. Geoforma Ediciones, Logroño, Spain, pp. 691–696.
Acaso, E., Moya-Palomares, M.E., Centeno, J., 2006. Nuevas aportaciones sobre el glaciarismo pleistoceno en la Sierra de Gredos (Sistema Central Ibérico). In: Alberti, A., López-Bedoya, J. (Eds.), Geomorfología y Territorio. Actas de la IX Reunión de Geomorfología. Universidad de Santiago, Spain, pp. 51–58.
Acaso, E., 1983. Estudio del Cuaternario en el Macizo Central de Gredos. Ph.D. thesis, University of Alcalá, Alcalá de Henares, Madrid, Spain, 442 pp.
Ackerly, S.C., 1989. Reconstructions of mountain glacier profiles, northeastern United States. Geological Society of America Bulletin 101, 561–572.
AEMET/IM, 2011. Atlas Climático Ibérico-Iberian Climate Atlas. AEMET and IM, Madrid. http://www.aemet.es/es/divulgacion/publicaciones/.
Benn, D.I., Hulton, N.R.J., 2010. An Excel™ spreadsheet program for reconstructing the surface profile of former mountain glaciers and ice caps. Computers & Geosciences 36, 605–610.
Benn, D.I., Kirkbride, M.P., Owen, L.A., Brazier, V., 2005. Glaciated Valley Landsystems. In: Evans, D.J.A. (Ed.), Glacial Landsystem. Hodder Arnold, London, UK, pp. 372–431.
Bennett, M.R., Glasser, N.F., 2009. Glacial Geology: Ice Sheets and Landforms. John Wiley & Sons, Chichester, UK, 400 pp.
Bordonau, J., 1992. Els complexos glacio-lacustres relacionats amb el darrer cicle glacial als Pirineus. Geoforma Ediciones Logroño, Spain, 251 pp.
Boulton, G.S., Eyles, N., 1979. Sedimentation by valleys glaciers: a model and genetic classification. In: Schlucter, C. (Ed.), Moraines and Varves. Balkema, Rotterdam, NL, pp. 11–23.
Brosche, K.U., 1978. Beiträge zum rezenten und vorzeitlichen periglazialen Formenschatz auf der Iberischen Halbinsel. In: Abhandlungen des Geographischen Instituts, Sonderhefte, Band I. Selbstverlag des Geographischen Instituts der Freien, Universität Berlin.
Butzer, K.W., Franzle, O., 1959. Observations on pre-Würm glaciations of the Iberian Peninsula. Zeitschrift für Geomorphologie 3, 85–87.
Butzer, K.W., 1957. Mediterranean pluvials and the general circulation of the Pleistocene. Geografiska Annaler 39, 48–53.
Carandell, J., 1924. La topografía glaciar del macizo Trampal-Calvitero (Béjar). Boletín del Instituto Geológico y Minero de España 5, 1–24.
Carrasco, R.M., Pedraza, J., Sanz, M.A., Domínguez-Villar, D., Willenbring, J., 2010. El glaciar de Cuerpo de Hombre (Sierra de Béjar, Sistema Central Español) durante la deglaciación: génesis primaria del till supraglaciar de Los Hermanitos. Geogaceta 49, 39–42. http://www.sociedadgeologica.es/publicaciones.html.
Carrasco, R.M., Pedraza, J., Domínguez-Villar, D., Villa, J., Willenbring, J.K., 2012. The plateau glacier in the Sierra de Béjar (Iberian Central System) during its maximum extent. Reconstruction and chronology. Geomorphology. http://dx.doi.org/10.1016/j.geomorph.2012.03.019.
Carrasco, R.M., 1997. Estudio Geomorfológico del Valle del Jerte (Sistema Central Español): secuencia de procesos y dinámica morfogenética actual. Ph.D. thesis, Complutense Univ., Madrid, Spain, 340 pp.
Cossart, E., 2011. Mapping Glacier Variations at Regional Scale through Equilibrium Line Altitude Interpolation: GIS and Statistical Application in Massif des Écrins (French Alps). Journal of Geographic Information System 3, 232–241.
Cowton, T., Hughes, P.D., Gibbard, P.L., 2009. Palaeoglaciation of Parque Natural Lago de Sanabria, northwest Spain. Geomorphology 108, 282–291.
Daveau, S., 1971. La glaciation de la Serra da Estrela. Finisterra 6, 5–40.
Delmas, M., Gunnell, Y., Braucher, R., Calvet, M., Bourlès, D., 2008. Exposure age chronology of the last glaciation in the eastern Pyrenees. Quaternary Research 69, 231–324.
Evans, I.S., Cox, N.J., 2005. Global variations of local asymmetry in glacier altitude: separation of north-south and east-west components. Journal of Glaciology 51, 469–482.
Evans, D.J.A., Rea, B.R., Hansom, J.D., Whalley, W.B., 2002. Geomorphology and style of plateau icefield deglaciation in fjord terrains: the example of Troms-Finnmark, north Norway. Journal of Quaternary Science 17, 221–239.
Evans, D.J.A., 2006a. Glacial landsystems. In: Knight, P.G. (Ed.), Glacier Science and Environmental Change. Blackwell Publshing, Malden, USA, pp. 83–88.
Evans, I.S., 2006b. Glacier distribution in the Alps: statistical modelling of altitude and aspect. Geografiska Annaler: Series A, Physical Geography 88, 115–133.
Fernández, P., 1976. Estudio Geomorfológico del Macizo central de Gredos. Ph.D. degree, Complutense Univ., Madrid, Spain, 119 pp.
Florineth, D., Schlüchter, C., 2000. Alpine evidence for atmospheric circulation patterns in Europe during the Last Glacial maximum. Quaternary Research 54, 295–308.
García-Ruíz, J.M., Valero-Garcés, B.L., Martí-Bono, C., González-Sampériz, P., 2003. Asynchroneity of maximum glacier advances in the central Spanish Pyrenees. Journal of Quaternary Science 18, 61–72.
García-Ruíz, J.M., Moreno, A., González-Sampériz, P., Valero, B., Martí-Bono, C., 2010. La cronología del último ciclo glaciar en las montañas de Europa. Una revisión. Cuaternario y Geomorfología 24 (1–2), 35–46.
Glasser, N.F., Bennett, M.R., 2004. Glacial erosional landforms: origins and significance for palaeoglaciology. Progress in Physical Geography 28, 43–75.
Golledge, N.R., 2007. An ice cap landsystem for palaeoglaciological reconstructions: characterizing the Younger Dryas in western Scotland. Quaternary Science Reviews 26, 213–229.
González-Sampériz, P., Valero-Garcès, B.L., Moreno, A., Jalut, G., García-Ruíz, J.M., Martí-Bono, C., Delgado-Huertas, A., Navas, A., Otto, T., Deboubat, J.J., 2006. Climate variability in the Spanish Pyrenees during the last 30,000 yr revealed by the El Portalet sequence. Quaternary Research 66, 38–52.
Hernández Pacheco, F., Vidal Box, C., 1934. El glaciarismo cuaternario de la Serrota (Ávila). Publicaciones de la Junta de Ampliación de Estudios e Investigaciones Científicas, Memoria n° 1, Madrid, Spain, 59 pp.
Hernández-Pacheco, F., 1957. Livret guide de l"excursión C-1. V Congreso Internacional INQUA, T1, Madrid, Spain, 58 pp.
Hughes, P.D., Braithwaite, R.J., 2008. Application of a degree-day model to reconstruct Pleistocene glacial climates. Quaternary Research 69, 110–116.
Hughes, P.D., Woodward, J.C., Gibbard, P.L., 2006. Late Pleistocene glaciers and climate in the Mediterranean region. Global and Planetary Change 46, 83–98.
Huguet del Villar, E., 1915. Los glaciares de Gredos. Boletín de la Real Sociedad Española Historia Natural 15, 379–390.
Huguet del Villar, E., 1917. Nueva contribución a la glaciología de Gredos, Las Hoyuelas del Hornillo. Boletín de la Real Sociedad Española Historia Natural 17, 558–567.
Iturrizaga, L., 2001. Lateroglacial valleys and landforms in the Karakoram Mountains (Pakistan). GeoJournal 54, 397–428.
Iturrizaga, l., 2008. Post-sedimentary transformation of lateral moraines – the tributary tongue basins of the Kviarjokull (Island). Journal of Mountain Science 5, 1–16.
Iturrizaga, L., 2011. Lateroglacial landform system. In: Singh, V.P., Singh, P., Haritashya, U.K. (Eds.), Encyclopedia of Snow, Ice and Glaciers. Springer, Dordrecht, NL, pp. 704–708.
Kessler, M.A., Anderson, R.S., Stock, G.M., 2006. Modeling topographic and climatic control of east-west asymmetry in Sierra Nevada glacier length during the Last Glacial Maximum. Journal of Geophysical Research 111, F02002. http://dx.doi.org/10.1029/2005JF000365.
Lautensach, H., 1929. Eiszeitstudien in der Serra da Estrela (Portugal). Zeitschrift für Gletscherkunde 17, 324–369.
Lewis, C.J., McDonald, E.V., Sancho, C., Peña, J.L., Rhodes, E.J., 2009. Climatic implications of correlated Upper Pleistocene glacial and fluvial deposits on the Cinca and Gállego Rivers (NE Spain) based on OSL dating and soil stratigraphy. Global and Planetary Change 67, 141–152.
López-Moreno, J.I., Nogués-Bravo, D., Chueca-Cía, J., Julián-Andrés, A., 2006. Glacier development and topographic context. Earth Surface Processes and Landforms 31, 1585–1594.
Lukas, S., 2006. Morphostratigraphic principles in glacier reconstruction - a perspective from the British Younger Dryas. Progress in Physical Geography 30, 719–736.
Martínez de Pisón, E., Muñoz Jiménez, J., 1972. Observaciones sobre la geomorfología del Alto Gredos. Estudios Geográficos 32, 597–690.
McDougall, D.A., 1995. The identification of plateau glaciers in the geomorphological record: a case study from the Lake District, northwest England. In: McLelland, S.J., Skellern, A.R., Porter, P.R. (Eds.), Postgraduate Research in Geomorphology: Selected Papers from the 17th BGRG Postgraduate Symposium. BGRG, Leeds, pp. 1–8.
Molina-Ballesteros, E., García-Talegón, J., Vicente-Hernández, M.A., 1997. Palaeoweathering profiles developed upon the Iberian Hercynian Basement: their relationship to the oldest Tertiary surface in Central and Western Spain. In: Widdowson, M. (Ed.), Tertiary and Pre-tertiary Palaeosurfaces: Recognition, Reconstruction and Environmental Implications, 120. Geological Society of London, Special Publication, pp. 175–185.
Moreno, A., Valero-Garcés, B.L., Jiménez Sánchez, M., Domínguez, M.J., Mata, P., Navas, A., González-Sampériz, P., Stoll, H., Farias, P., Morellón, M., Corella, P., Rico, M., 2010. The last deglaciation in the Picos de Europa National Park (Cantabrian Mountains, Northern Spain). Journal of Quaternary Science 25, 1076–1091.
Nye, J.F., 1952. A method of calculating the thickness of ice-sheets. Nature 169, 529–530.
Obermaier, H., Carandell, J., 1915. Datos para la climatología cuaternaria en España. Boletín de la Real Sociedad Española de Historia Natural 15, 402–411.
Obermaier, H., Carandell, J., 1916. Contribución al estudio del glaciarismo cuaternario de la Sierra de Gredos. Trabajos del Museo Nacional de Ciencias Naturales. Serie Geológica 14, 54.
Obermaier, H., Carandell, J., 1917. Los glaciares cuaternarios de la Sierra de Guadarrama. In: Trabajos del Museo Nacional de CC. Naturales, vol. 19, Madrid, Spain, 94 pp.
Orowan, E., 1949. Remarks at joint meeting of the British Geological Society, the British Rheologists Club and the Institute of Metals. Journal of Glaciology 1, 231–236.
Owen, L.A., Thackray, G., Anderson, R.S., Briner, J., Kaufman, D., Roe, G., Pfeffer, W., Yi, C., 2009. Integrated research on mountain glaciers: current status, priorities and future prospects. Geomorphology 103, 158–171.
Palacios, D., Andrés, N., Marcos, J., Vázquez, L., 2011a. Glacial landforms and their paleoclimatic significance in Sierra de Guadarrama, Central Iberial Peninsula. Geomorphology 139-140, 67–78.
Palacios, D., Marcos, J. de, Vázquez-Selem, L., 2011b. Last Glacial Maximum and deglaciation of Sierra de Gredos, central Iberian Peninsula. Quaternary International 233, 16–26.
Pallàs, R., Rodés, A., Braucher, R., Bourlès, D., Delmas, M., Calvet, M., Gunnell, Y., 2010. Small, isolated glacial catchments as priority targets for cosmogenic surface exposure dating of Pleistocene climate fluctuations, southeastern Pyrenees. Geology 38, 891–894.
Pedraza, J., Carrasco, R.M., 2005. El glaciarismo pleistoceno del Sistema Central. Enseñanza de la Ciencias de la Tierra 13, 178–288. http://www.aepect.org/.

Pedraza, J., Fernández, P., 1981a. Cuaternario y Terciario. In: Ruiz, P., Gabaldón, V. (Eds.), Mapa Geológico de Bohoyo. Map 577. Instituto Geológico y Minero de España (IGME), Madrid, Spain. http://www.igme.es/.
Pedraza, J., Fernández, P., 1981b. Cuaternario y Terciario. In: Ruiz, P., Gabaldón, V. (Eds.), Mapa Geológico de Arenas de San pedro. Map 578. Instituto Geológico y Minero de España (IGME), Madrid, Spain. http://www.igme.es/.
Pedraza, J., López, J., 1980. Gredos: geología y glaciarismo. Obra Social de la Caja de Ahorros de Ávila, 31. Ávila, Spain.
Pedraza, J., Carrasco, R.M., Dominguez-Villar, D., Willenbring, J.K., 2011. Late Pleistocene Glacial Evolutionary Stages in the Spanish Central System. XVIII INQUA, Abstract, ID 1438, Bern, Switzerland. http://www.inqua2011.ch/.
Pedraza, J., 1994. Geomorfología del Sistema Central. In: Gutiérrez Elorza, M. (Ed.), Geomorfología de España. Rueda, Madrid, Spain, pp. 63–100.
Pérez Alberti, A., Valcárcel Díaz, M., Blanco Chao, R., 2004. Pleistocene glaciation in Spain. In: Ehlers, J., Gibbard, P.L. (Eds.), Quaternary Glaciations–Extent and Chronology, vol. 1. Elsevier, Europe Amsterdam, pp. 389–394.
Pratt-Sitaula, B., Burbank, D.W., Heimsath, A.M., Humphrey, N.F., Oskin, M., Putkonen, J., 2011. Topographic control of asynchronous glacial advances: a case study from Annapurna, Nepal. Geophysical Research Letters 38 (L24502), 6. http://dx.doi.org/10.1029/2011GL049940.
Rea, B.R., Evans, D.J.A., 2007. Quantifying climate and glacier mass balance in North Norway during the Younger Dryas. Palaeogeography, Palaeoclimatology, Palaeoecology 246, 307–330.
Rea, B.R., Whalley, W.B., Evans, D.J.A., Gordon, J.E., McDougall, D.A., 1998. Plateau icefields: geomorphology and dynamics. In: Owen, L.A. (Ed.), Mountain Glaciation, 6. Quaternary Proceedings, pp. 35–54.
Rivas-Martínez, S., 1987. Memoria del Mapa de Series de Vegetación de España. In: Series Técnicas. ICONA, Ministerio de Agricultura Pesca y Alimentación, Madrid, Spain, 268 pp.
Rodríguez-Rodríguez, L., Jiménez-Sánchez, M., Domínguez-Cuesta, M.J., Rico, M.T., Valero-Garcés, B., 2011. Last deglaciation in northwestern Spain: new chronological and geomorphologic evidence from the Sanabria region. Geomorphology 135, 48–65.
Rubio, J.C., 1990. Geomorfología y Cuaternario de la sierras de la Nava y Béjar (Sistema Central Español). Ph.D. thesis, Complutense Univ., Madrid, Spain, 353 pp.
Sanz-Donaire, J.J., 1979. El corredor de Béjar. Instituto de Geografía Aplicada, CSIC, Madrid, Spain, 195 pp.
Sanz-Donaire, J.J., 1982. El macizo glacializado de El Barco de Ávila (Provincias de Ávila-Cáceres). Cuadernos de Geografía de la Universidad Complutense 1, 183–206.
Schiefer, E., Menounos, B., Wheate, R., 2008. An inventory and morphometric analysis of British Columbia glaciers, Canada. Journal of Glaciology 54, 551–560.
Schilling, D.H., Hollin, J., 1981. Numerical reconstructions of valley glaciers and small ice caps. In: Denton, G.H., Hughes, T.J. (Eds.), The Last Great Ice Sheets. Willey, New York, USA, pp. 207–220.
Schmieder, O., 1915. Die Sierra de Gredos. Mitteilunger der Geographischen Gesellschaft in München, Zehnter Band 1, 60 pp.
Vidal Box, C., 1929. Nuevos estudios sobre glaciarismo cuaternario Ibérico. Memorias de la Real Sociedad Española de Historia Natural 15, 585–592.
Vidal Box, C., 1932. Morfología glaciar cuaternaria del Macizo Oriental de la Sierra de Gredos. Boletín de la Real Sociedad Española de Historia Natural 32, 117–135.
Vidal Box, C., 1936. Contribución al conocimiento morfológico del segmento Occidental de la Sierra de Gredos (Bohoyo). Boletín de la Real Sociedad Española de Historia Natural 36, 17–37.
Vidal Box, C., 1948. Nuevas aportaciones al conocimiento geomorfológico de la Cordillera Central. Estudios Geográficos 9, 5–52.
Vieira, G., Ferreira, A.B., Mycielska-Dowgiallo, E., Woronko, B., Olszak, I., 2001. Thermoluminescence Dating of Fluvioglacial Sediments (Serra da Estrela, Portugal). V REQUI/I CQPLI, Lisboa, Portugal, pp. 85–92.
Vieira, G., 2005. Características generales del glaciarismo de la Sierra de Estrela, Portugal. Enseñanza de la Ciencias de la Tierra 13, 289–295. http://www.aepect.org/.
Vieira, G., 2008. Combined numerical and geomorphological reconstruction of the Serra da Estrela plateau icefield, Portugal. Geomorphology 97, 190–207.
Vilaplana, J.M., Bordonau, J., 1989. Dynamique sédimentaire lacustre de marge glaciaire: le paléolac de Llestui (Noguera Ribagorçana, Versant sud des pyrénées). Bulletin de l'Association Française pour l'Étude du Quaternaire 40, 21.
Vilaplana, J.M., Montserrat, J., 1989. Recent progress in Quaternary stratigraphy: the lake Llauset sequence in the Spanish Pyrenees. In: Rose, J., Schlüchter, C. (Eds.), Quaternary Type Sections: Imagination or Reality? Balkema, Rotterdam, NL, pp. 113–124. 9-224.
Vivian, R., 1975. Les glaciers des Alpes occidentals, étude géographique. Ph.D. thesis, Allier, Ophrys éditeur, Paris, France.