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New radiometric and geomorphologic evidences of a last glacial maximum older than 18 ka in SW European mountains: the example of Redes Natural Park (Cantabrian Mountains, NW Spain)

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Abstract

The first numerical age determinations from radiocarbon dating establish the chronology of glacial events in Redes Natural Park (Cantabrian Mountain, NW Spain). A core drilled in an ice-dammed deposit provided a minimum age of 28 990 ± 230 years BP for the maximum glacial expansion (phase I). Another core from a cirque bottom-fill provided organic sediment with 20 640 ± 300 years BP, a minimum age for the first glacial retreat (phase II). Radiometric dating of proglacial deposits interpreted as synchronous with the last glacial maximum phase in neighbouring Comella basin (Picos de Europa), yield ages of 40 480 ± 820 years BP. The chronological data presented in this work are consistent with the model of glacier evolution established in the Pyrénées, with a glacial maximum phase for the last glacial period older than 18 ka. © 2002 Éditions scientifiques et médicales Elsevier SAS. All rights reserved.

Keywords: Cantabrian Mountain; Deglaciation; Drillhole; Glacial geomorphology; Last Glacial maximum; Radiometric evidence

1. Introduction

Radiometric, geomorphologic, sedimentologic and palynologic evidence in Pyrénées (NE Spain and S France), has allowed the establishment of a chronology of glaciation for the Late Quaternary [1–14]. As summarized in some of these works [8–10,15], the established chronology for the last glacial cycle includes the development of a glacial maximum phase between 5 ka and 45 ka, followed by a deglaciation episode between 45 ka and 13 ka and another glacial phase with a periglacial environment between 11 ka and 10 ka. It is interesting that the timing of maximum glaciation in the Pyrénées is asynchronous with ice sheets in North America and North Europe, as well as with marine sediment records of global ice volume, such as ^{18}O [8–10,15]. However, in other areas of N Spain (Galicia), Late Pleistocene paleoclimatic evolution appears to be that of SW Europe, with stadial conditions between 25 ka and 15 ka [16]. The inferred evolution pattern and chronology of glaciers in this area of NW Spain fits global models, with a maximum expansion between 20 ka and 18 ka [17].

The Cantabrian Mountain Range, trending E–W, is the western extension of the Pyrénées as far as the Galicia Mountains and shows an altitude distribution progressively descending from South, where 2000 m are exceeded, to North, on the Cantabrian Coast. The present landscape of the Cantabrian Mountains results from a structural relief created by a monoclinal flexure with an E–W trend during the Alpine Orogeny [18]. In the highest part of this relief, periglacial and glacial features are preserved. At present, glacial ice has only been reported in Picos de Europa [19,20]. However, since the beginning of the century [21,22] several studies have focused on the influence of glaciers over the Cantabrian Mountain landscape, particularly since the 1980s [23–38]. In all these studies, glacial features are described and different interpretations about the age and number of glaciations, glacial phases, glacial ice extent and the height of glacial fronts are offered. However, chronological data are restricted to Holocene events recorded in peat bogs [39–41], or quantitative inferences on the age of hanging lacial surfaces based on fluvial incision rates in the western massif of Picos de Europa [37]. No

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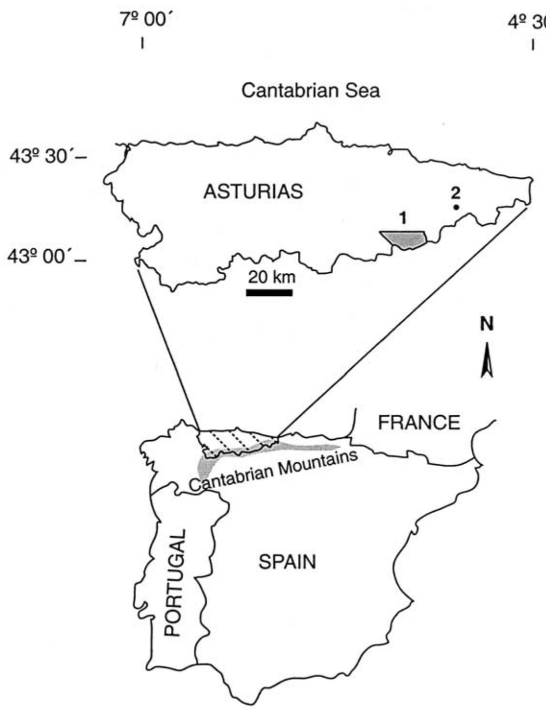

Fig. 1. Geographical setting: 1) Redes Natural Park; 2) Comella Basin.

pre-Holocene absolute ages have been reported yet. This lack of chronological data precludes the development of a glacial history for this region, which would be key to identifying a discrepancy between regional and global evolution of glaciation.

In the highest area of Redes Natural Park (SE Asturias, NW Spain, Fig. 1A), glacial and periglacial features have been described [33–35,42]. The reconstruction of the glacial evolution has led to the identification of a glacial maximum phase followed by two others with retreat and stabilization of glacial fronts, and a later periglacial environment, all of them interpreted as belonging to the last glacial period. However, no chronological data has been reported until now. From a relative chronology point of view, the glacial model established in Redes Natural Park shows a similarity with that established for the Pyrénées, which suggests the possibility of a similarity in absolute chronology as well. The aim of this work is to date glacial events in Redes Natural Park, in order to establish if the timing of these events is similar to comparable events in the Pyrénées.

2. Study site

2.1. Geographical and geological settings

Redes Natural Park is located on the Northern Slope of the Cantabrian Mountain Range, in the NW of Spain (Fig. 1). The area studied in this paper includes a surface of 50 km^2 in the highest sector of Redes Natural Park, inside the Nalón River basin. The elevation ranges from 800 m to 2104 m. *Betula alba* extend to elevations of 1400–1500 m, marking the timberline, although *Fagus sylvatica* is the dominant species. The climate is oceanic temperate, with rainfall values in excess of 1800 mm·year^{-1} in the highest peaks and well distributed rainfall values peaking in the spring and winter. For the closest weather station (Bezanes, 654 m), the average annual temperature was 10ºC in the period 1970–1991.

From a geological point of view, the study area is located in the Ponga Unit of the Cantabrian Zone [43,44]. The bedrock consists of sedimentary rocks of Cambrian–Ordovician age including Lancara Limestone, Oville Sandstone and Lutite and Barrios Quartzite, and rocks of Carboniferous age including Barcaliente and Escalada Limestone as well as Beleño and Fito Formations, composed of an alternation of sandstone, siltstone, lutite and limestone. The bedrock presents Hercynian structures such as folds and folded thrusts cut by straight fractures like Ventaniella Fault, with a NW–SE trend.

2.2. Landscape evolution: previous research on glacial geomorphology in Redes Natural Park

In Redes Natural Park, the main mountain range is located at the South and trends E–W. Glacial features can be recognised above 950–1100 m in the upper part of the fluvial valleys in this range (Fig. 2). Among these features, glacial cirques showing maximum length azimuths trending N–NW and N–NE appear between 1500 and up to 2000 m over mainly quartzitic rocks (Barrios Formation). Till appears as lateral and terminal moraines, or as irregular deposits between 950 and 1700 m. Fluvioglacial deposits are located between 800 and 1500 m down glacial terminal deposits, while peat deposits appear above 1300 m, filling the bottom of old cirques. Ice-dammed deposits are present in the confluence of small torrential basins with lateral moraines.

Glacial feature analysis [45] led to the identification of three glacial phases (Fig. 3), interpreted as pertaining to the last glacial period [33–35]. The lowest deposits show that at maximum glacial extension, glacier fronts descended to 1300–950 m increasing from E to W, and glaciers extended up to 5 km in length (phase I). The altitude of the lowest cirque bottoms shows that the snowline reached 1550 m. An icefield can be reconstructed, with glacial ice flowing towards the N, NE and NW, following the preglacial drainage network. Cirque glaciers would be active in the W. Ice-dammed deposits, such as Vega de Brañagallones, would have appeared due to the obstruction of torrential basins by lateral moraines. The glacial retreat was punctuated by stabilization of glacial fronts first at 1300–1500 m (phase II) and afterwards at 1500–1700 m (phase III); both phases are marked by moraine arcs at these altitudes. During phase II, glacial cirques of phase I would have disappeared and valley glaciers would have been shortened, being partly confined to glacial cirques. During phase III, a new glacial

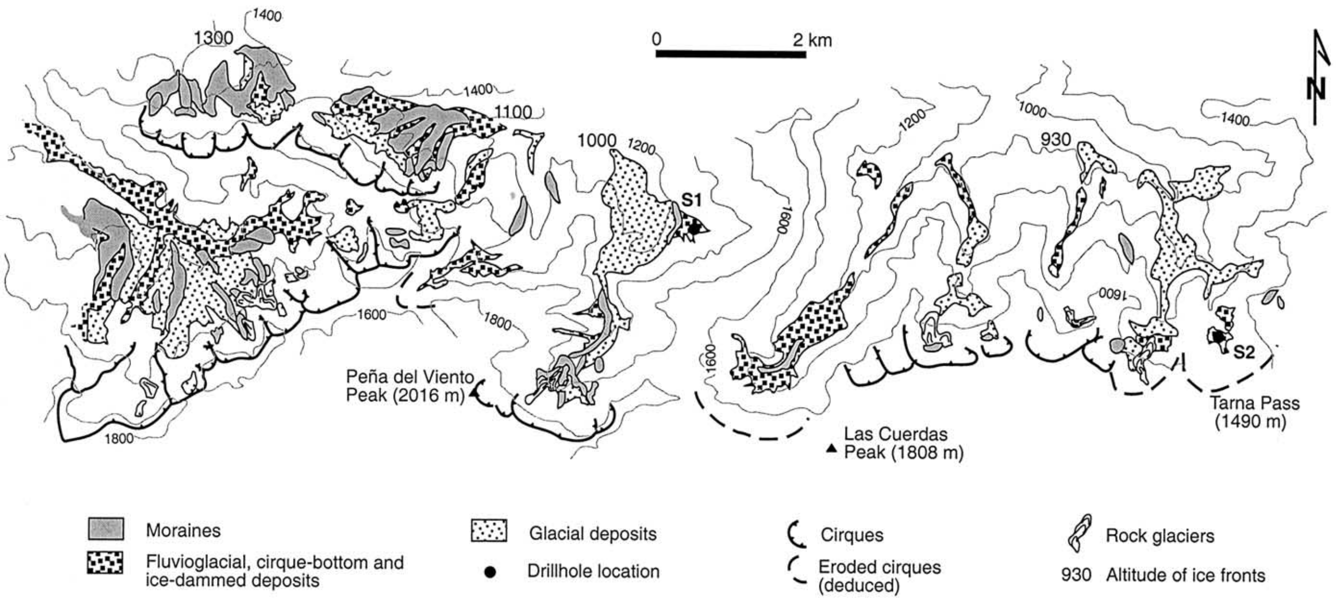

Fig. 2. Sketch of distribution of glacial morphological evidence in Redes Natural Park (modified from [35]); location of drillholes S1 and S2.

retreat would have occurred with some of the cirque glaciers of phase II disappearing and the last valley glaciers reduced to glacial cirques. The filling of bottom cirques would have begun after phase II and continued through phase III.

A later periglacial environment is inferred from the presence of rock glaciers, also recognised in other areas of the Cantabrian Mountains [46], appearing superimposed on the highest moraines, between 1450 and 1840 m, in slopes with N–NE and NO azimuths. The postglacial evolution of the area is due to the action of snow, fluvial, mass wasting processes and also water action in slopes. Nivation ridges appear above rock glaciers, being located at altitudes higher than 1600 m, in glacier cirques' walls, while snow avalanche gullies appear over quartzite and calcareous bedrock in glacial walls of N exposures, frequently in altitudes higher than 1750 m. Lateral unloading in glacially eroded hillslopes has been related to the development of slope instability processes as landslides [47,48] and antislope scarps [49]. This mechanism during and after the deglaciation episode also could have determined landslide-triggering phenomena above 950 m [50], as suggested for glacial valley walls in Pyrénées [51,52].

3. Methods

Drillhole locations were selected on the basis of previous geomorphological mapping in the area. We selected an ice-dammed deposit, which must contain a synglacial and/or postglacial sedimentary record (phase I), and a bottom of a preserved glacial cirque filled with postglacial sediment (phase II).

The first drillcore was taken in Vega de Brañagallones, an ice-dammed deposit located at 1225–1230 m altitude. Our working hypothesis is that this deposit was formed when drainage was blocked by a lateral moraine pertaining to an alpine glacier active during phase I. Therefore, its age must be synchronous or younger than phase I. In this deposit, a core hole 38 m deep and 88 mm diameter (S1) was drilled with a Pocket Schott Dubon machine. At the second site, we obtained another core 7 mm diameter and 2.3 m deep (S2) with a hand drill 'Boring' in the proximity of Tarna Pass, at 1415 m, over a deposit filling the bottom of a glacial hollow active during phase II. Therefore, this deposit is younger than phase II. Logging of both drillcores permits refinements in our interpretations of the glacial history of the area. Bulk sediment samples near the bottom of each core were selected and dated by ^{14}C at Beta Analytic laboratory (Miami, Florida, USA). The first sample was dated with standard–AMS analysis, and the second one with a radiometric–standard analysis. The results were compared with unpublished radiocarbon results of peat bog coming from a drillhole undertaken in Comella hollow [53,54], dated by radiometric–standard analysis also at Beta Analytic.

4. Results

Figs 2 and 3 show location for drillholes S1 and S2. Chronological results are shown in Table I. Vega de Brañagallones, with a surface of 600 000 m^2 is interpreted as an ice-dammed deposit. S1 drillhole, with an altitude of 1228 m, reached 38 m deep, exceeding the 36.7 m thickness of Quaternary fill (Fig. 4). The deposit of Vega de Brañagallones is a torrential fan dammed by a lateral moraine in the E wall of Monasterio River valley (Fig. 5A). This alpine glacier was active during phase I, and its head was located in the S of Brañagallones deposit, over a mainly quartzitic

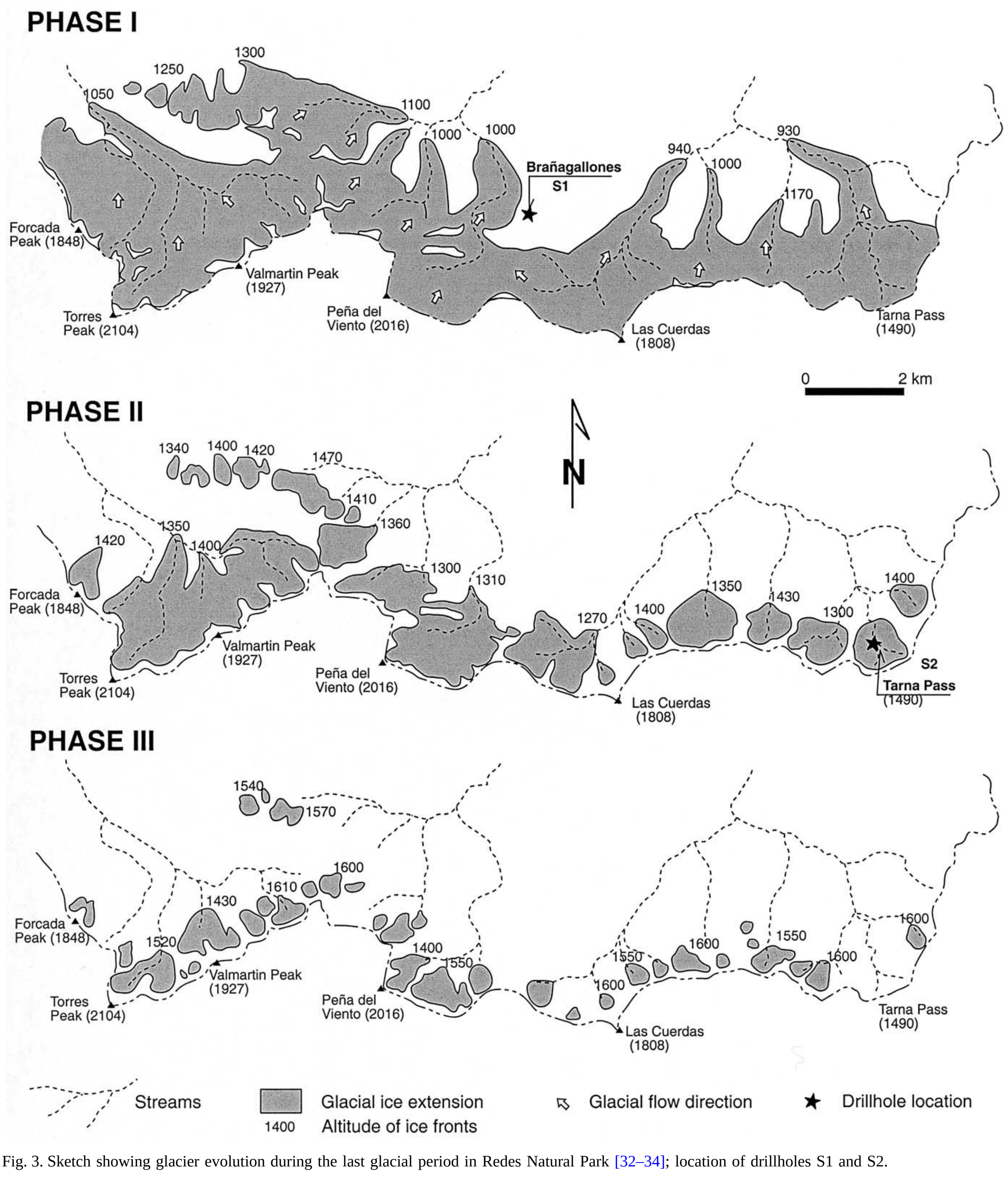

Fig. 3. Sketch showing glacier evolution during the last glacial period in Redes Natural Park [32–34]; location of drillholes S1 and S2.

bedrock (Barrios Formation). The bedrock of the torrential basin is composed of Carboniferous rocks: grey limestone (Escalada Formation), outcropping between 1500 m and 1840 m high and alternations of sandstone, limestone and lutite (Fito Formation). Rockfall and snowfall avalanche deposits from Escalada Limestone cliffs appear superimposed on the main fan. Deposits with similar geomorphologic features have been described in the Pyrénées as ice-lateral till complexes, showing rhythmites (laminated muds) under alluvial fan deposits [4,5,11]. In this case, the core lithology and the geomorphologic evidence show that the deposit results from the activity of a torrential system in

Table I
Chronological data for Redes Natural Park and Comella basin.

Drillhole	Sample data	Conventional ^{14}C age	$^{13}C/^{12}C$ ratio
S1 (Brañagallones)	Beta-129359	28 990 ± 230	–24.2‰
S2 (Tarna)	Beta-132819	20 640 ± 300	–25.0‰
S’1 (Comella)	Beta-93164	40 480 ± 820	–25.0‰

The ages are presented in radiocarbon years BP. The sample from S1 is dated by standard-AMS analysis and the other two samples by radiometric standard ^{14}C.

the E (levels with subrounded limestone and sandstone pebble gravel), as well as by the development of mass movement in the eastern slope of the lateral moraine (levels containing quartzite, showing an angular morphology). The interpretative sketch is represented in Fig. 5B. Also, the fragments of limestone boulder gravel are thought to result from the instability of the highest part of the basin, in which Escalada limestone appears. No evidence of rhythmites was found, although the presence of a layer of fine deposits (grey clay and silt) with a thin level (0.5 cm) of limestone and sandstone granule between 36.6 and 36.5 m is related to a low energy environment. A bulk sample from this level was dated with AMS to 28 990 ± 230 years BP (Fig. 4, Table I). According to the geomorphological evidence formerly described, our working hypothesis is that the beginning of the fill of this deposit took place in relation to the presence of a lateral moraine pertaining to phase I. Therefore, this deposit is synglacial and/or postglacial and its age would be at least a minimum age for phase I in this area.

S2 drillhole was made at 1415 m near Tarna Pass (Figs 2 and 3) and reached a depth of 2.30 m (Fig. 6). From a geomorphological point of view, the deposit is located in the bottom of an ancient depression hollow, which probably belonged to an eroded cirque, carved in Carboniferous alternations of lutite and sandstone (Beleño Formation) and also over Barrios Quartzite. The deposit is the result of the filling of the cirque bottom, after the retreat of phase II and the later development of peat. Grey clay with organic matter and plant remains prevail, suggesting a low energy and low drainage environment. A layer of subangular pebble gravel and sand with coal remains appearing between 90 and 105 cm is consistent with the activity of an old torrential stream. A sample of bulk sediment from the bottom of the core gave a radiometric age of 20 640 ± 300 y BP (Fig. 6, Table I). As the glacial hollow was still active during phase II (Fig. 3), this is a minimum age for this phase.

Complementary radiometric evidence is given by deposits in Comella polje, located in the occidental massif of Picos de Europa, also in Cantabrian Mountains, 20 km E of Redes Natural Park. The polje, with a surface of 1.2 km^2, is limited S and W by alpine faults trending WNW–ESE, which allow the inference of a tectonic factor in its origin. Glacial, torrential, fluvial, karstic and mass wasting processes have conditioned the geomorphological evolution of the area. From two drillholes of 42.5 m (S’1) and 56.7 m (S’2) we interpret the origin of the fill as the result of

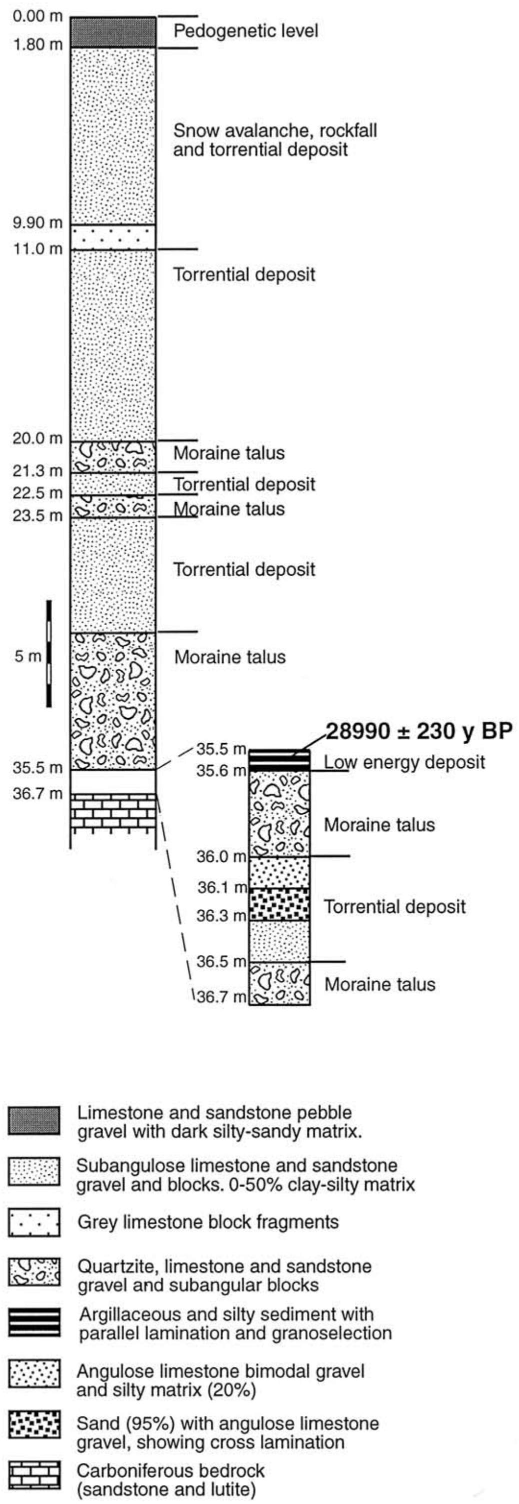

Fig. 4. Drillhole log and chronological data for drillhole S1 (Brañagallones).

colluvial, torrential and lacustrine processes (Fig. 7). Lacustrine sediments are interpreted as the result of the ablation of the glacier, with its front located at 1030 m, as shown by the presence of terminal moraines at this altitude, in the SE of the hollow [53,54]. The lack of glacial evidence downstream indicates that glacier fronts reached this altitude

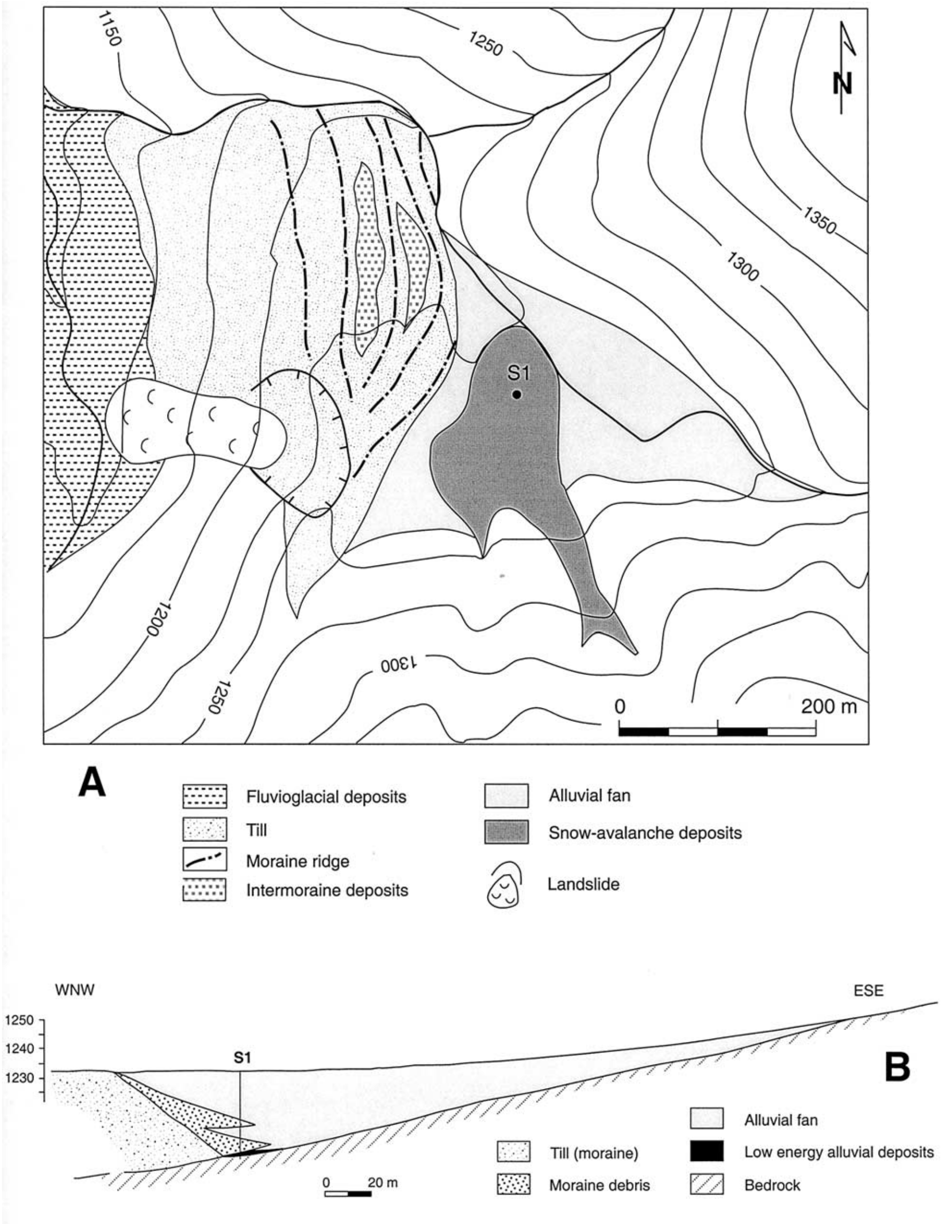

Fig. 5. **A.** Geomorphological map of Brañagallones area, showing the ice-dammed deposit in the East of moraine and drillhole S1 location. **B.** Interpretation of Brañagallones deposit from geomorphological evidence and S1 drillhole log.

during their maximum extent. This allows a correlation with phase I formerly described in Redes Natural Park. Radiometric evidence was provided by a clay level with organic matter located 35.5 m deep, which was dated as 40 480 ± 820 year BP, interpreted as synchronous with the presence of the glacier front.

5. Discussion

The pattern of glacier evolution in Redes Natural Park shows a relative chronology similar to that established in the Pyrénées [8–10,13], although morphological evidence does not allow us to detect in Redes Natural Park the existence of the phases of pre-maximum stabilization and glacial maximum established in the Pyrénées, prior to the deglaciation. However, ice-dammed deposits suggest that phase I would correspond to a phase of stabilization related to the maximum extent of glaciers in the Redes area. phase II and phase III are correlative episodes of glacial retreat and stabilization, as are the valley glacier phase and the altitude glacier phase of the Pyrénées. Finally, in the Redes study site, rock glaciers superimposed on the highest moraines could also be related to a periglacial environment, possibly corresponding to a later rock glacier phase, as the Late Glacial phase established in the Pyrénées [55]. Chronologi cal and geomorphological data in Redes Natural Park give a minimum age for the glacial maximum phase (phase I) of

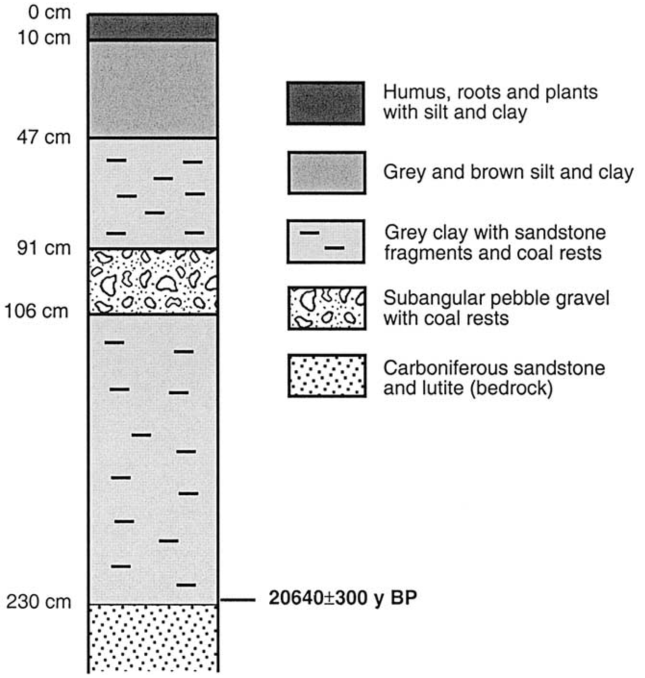

Fig. 6. Drillhole log and chronological data for drillhole S2 (Tarna).

28 990 ± 230 years BP. Subsequently, a second phase involving glacial retreat and stabilization of glacier fronts took place before 20 640 ± 300 years BP. Also, in the neighbouring Picos de Europa, proglacial deposits interpreted as synchronous with phase I show ^{14}C radiometric standard results of 40 480 ± 820 years BP. Although these chronological data do not confirm a direct correlation between the glacial phases in Redes and the glacial phases in Pyrénées, they suggest the possibility of a last glacial maximum older than 18 ka in this part of Cantabrian Mountain, which is in line with the results of the research in Pyrénées [7].

6. Conclusions

The research developed in Redes Natural Park, including radiometric and geomorphologic evidence, has allowed us to assign minimum ages for two of the glacial phases previously recognized in the area. The chronology established shows a phase of glacial maximum synchronous or older than 28 990 ± 230 BP in which glacier fronts extended as far as 950 m (phase I). This was followed by

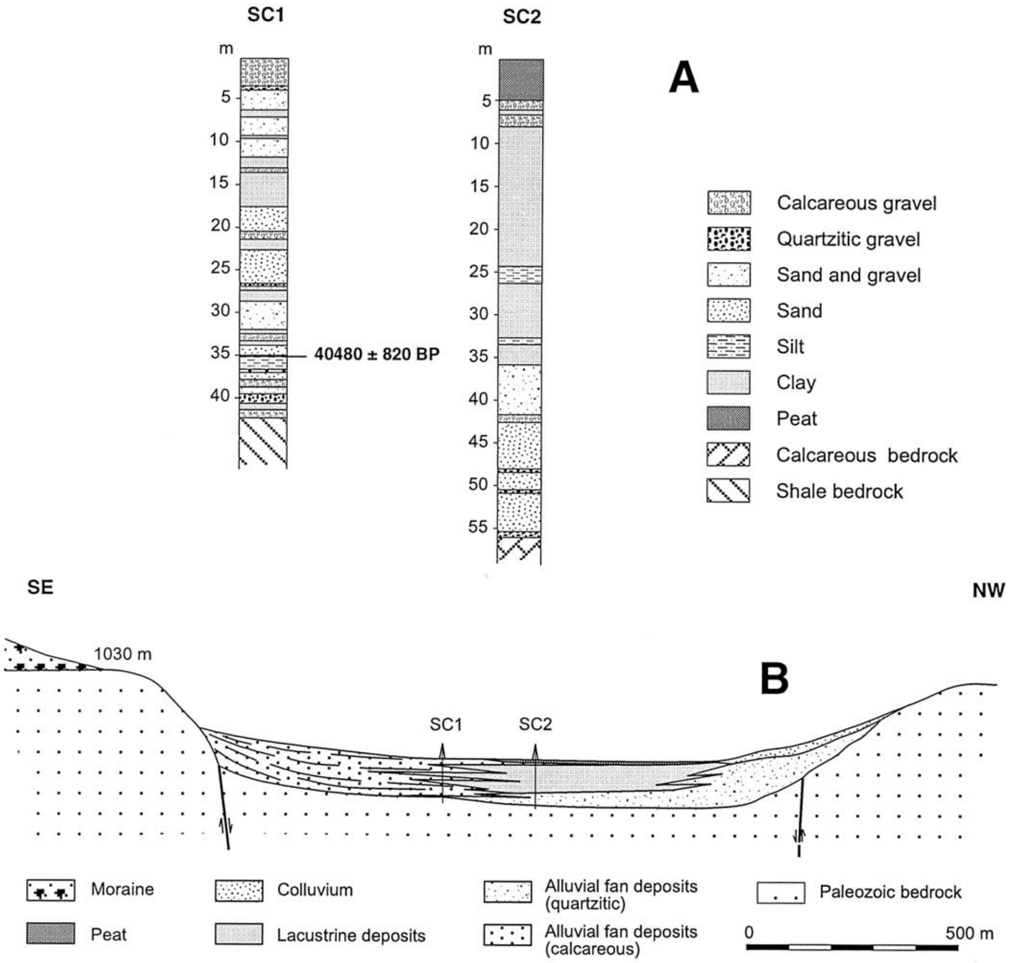

Fig. 7. **A.** Drillhole logs for SC1 and SC2 drills in Comella Basin [53] and chronological data for SC1. **B.** Reconstruction of Comella Basin fill from geomorphological and lithological evidence [53].

glacial retreat and a stabilization (phase II) at 1300–1500 m before 20 640 ± 300 years BP. These data have been complemented with the ages obtained in proglacial deposits related to glacial maximum in neighbouring Picos de Europa (40 480 ± 820 years BP). Radiometric evidence presented in this paper suggest a glacial maximum episode older than 18 ka, a result in line with the glacier evolution model established in the Pyrénées for the last glacial period.

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