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COLD CLIMATE FEATURES OF THE CORDILLERA CANTABRICA, NORTHERN SPAIN

Abstract

The evidence for phases of glacial and periglacial activity in the eastern parts of the Cordillera Cantabrica is outlined. It includes till, marginal moraines, cirques, remnant rock glaciers, scree, soliflual terraces and garlands. Phases, thought to represent the late Würm/Vistulian maximum and later episodes, are related to changes in equilibrium snow-line altitudes. Possible climatic and oceanic relations are discussed.

INTRODUCTION

The area under discussion lies where the Spanish provinces of Oviedo, Santander and Leon meet and includes the highest parts of the Cordillera Cantabrica, the Picos de Europa (2648 m; Fig. 1). There, many peaks exceed 2500 m in height and the floors of bounding and penetrating major valleys vary from about 1000 m to below 100 m in elevation. Thus the relative relief ranges from about 1600 m to 2400 m. Slopes are generally very steep, in many places precipitous: there is little flat land at any altitude.

The mountains adjacent to east, west, and south are characterised by summits ranging from 1800 m to 2200 m in height; there are few but prominent isolated higher peaks standing above general summit levels. In these parts of the ranges the dissecting valleys are more deeply cut on the northern wetter Atlantic side and less deeply on the dry southern interior side where rivers, tributary to the Rio Duero, far distant from their outflow to the sea at Oporto enter the Meseta at about 1000 m. There is consequently notable north-south asymmetry in relief and contrast in climate in the parts of the Cordillera south of the Picos de Europa.

In the areas considered here the mountains are built, almost completely, of Carboniferous sedimentary rocks folded and striking predominantly east—west. The highest areas, the three massifs of the Picos de Europa, are composed of the thick, largely Namurian, folded limestones, the Caliza de Montaña. South of the Picos de Europa and into Palencia province the mountains are also built of Carboniferous sediments. Coarse conglomerates, quartzites, and thinner limestone strata give rise to prominent positive features, but much of the ground is built of relatively weak shales and sandstones. The highest ground here is generally smooth compared with the rock walls, towers and sharp ridges of the Picos de Europa. The difference

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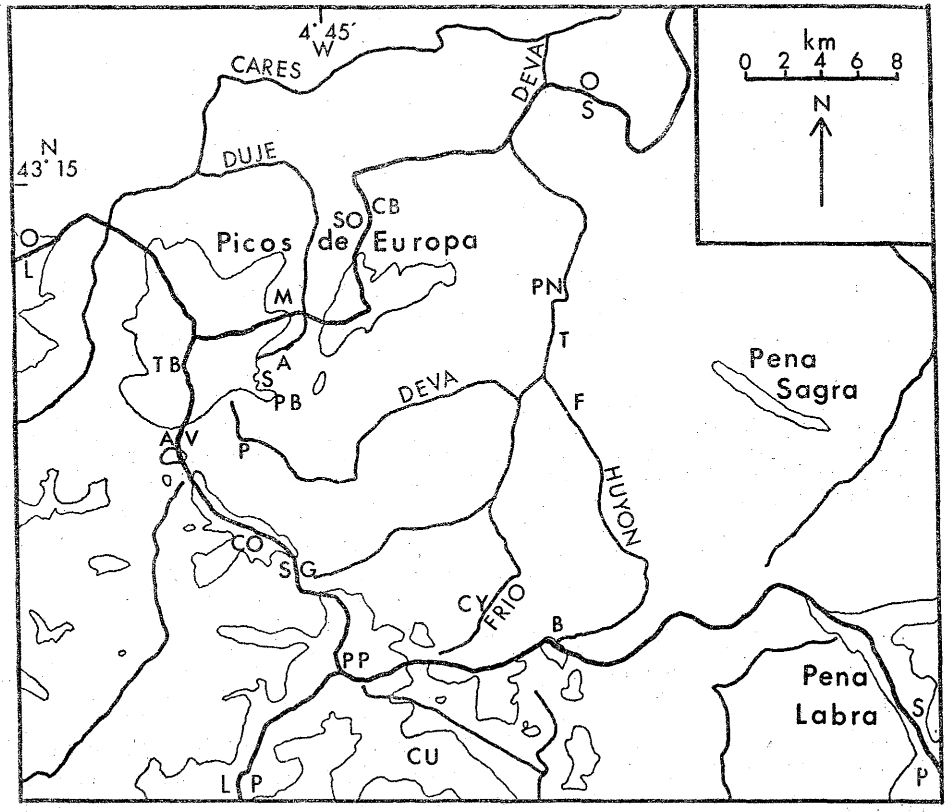

Fig. 1. Location map, part of the Cordillera Cantabrica, northern Spain

Contour at 1800 m. Provinces: L — Leon; O — Oviedo; P — Palencia; S — Santander. Mountains: B — Bistruey; CO — Coriscao; CU — Curavacas; PP — Pena Prieta; TB — Torre Blanca. Villages: CY — Cucayo; F — Frama; P — Pido; PN — Pendes; SO — Sotres; T — Tama. Other places: SG — San Glorio Pass; AV — Alto de Valdeon; CB — Collada Barreda; M — Las Monetas; J — Canal de la Jenduda; S — Las Salgardas; PB — Las Portillas del Boquejon

in summit altitudes between the Caliza de Montaña and the shale — sandstone terrains also seem attributable, at least in part, to the contrasting lithology. Present winters are severe with heavy snowfalls: the mountains experience widespread snow cover for several months.

Presently active periglacial processes are limited to the highest ground: only in the most favoured locations are they active as low as 1600—1700 m. The mountain environment is also marginal for glaciation. There are no longer true glaciers but large and permanent snowfields up to one and 1.5 km in lateral extent. Almost all of these occur within the Picos de Europa; about 70 separate mapped snowpatches occur in addition to less persistent snowpatches, some of which may survive the most cool and cloudy summers. Few of the permanent snowpatches extend below 1900 m and only in gullies and valleys heads of particularly favourable shape or aspect. All of them are associated with ridge crests over 2000 m above sea level and most with ridges over 2300 m. Thus there can be identified a summit zone, 2600—1900 m, where small changes in winter snowfall and/or summer melt potential could initiate a glacial regime or remove permanent snow. It seems evident that the Picos de Europa area is poised to develop glaciers consequent upon a quite minor climatic deterioration.

On the moister sides of the mountains montane woodland extends to over 2000 m in favourable localities and where its limits have not been affected by man's activities. There is clearly a narrow height range in which woods, snowfields, and periglacial phenomena occur. This suggests the immediate susceptibility of the upper edge of woodland to degradation in the event of climatic deterioration, and the possibility that some locations of present periglacial activity may have been wooded and more stable prior to forest destruction by and for grazing.

LANDFORMS AND MATERIALS ASSOCIATED WITH COLD CLIMATES

VALLEY GLACIATION

The prevailing steep slopes and strong relief have facilitated the downslope movement of unconsolidated materials. Limestone scree is found throughout the relief range including on the less-precipitous crests of some of the highest mountains. Cemented scree is not uncommon but it requires further examination to distinguish the effects of age and favourable location for passage of charged water. Amongst the scree, and especially associated with flysch-type rocks, there are unsorted geli-fluction deposits.

The lack of prominent marginal and terminal moraines in the lower valleys has suggested to some students that ice streams did not descend far below 1000 m though WALLACE (1972) indicates that there are clear moraines at 550 m in places within the Cordillera. In the present area till has been noted below 1000 m, for example, near Pido (800 m) in the upper Deva valley, at 500—600 m in the Cares valley, near Tama and Pendes (300 m) in the middle Deva valley, at and near Frama (300—400 m) in the Huyon valley and its tributaries, and near Cucayo (900 m) in the Rio Frio valley. Such observations suggest that ice extended quite far down valleys and that ridges over 1900 m (possibly less) were capable of nourishing valley glaciers.

As well as the Picos de Europa, the Sierras de Peña Sagra, de Peña Ladra, Media-na, and others would act as gathering grounds. The convergence of valleys tributary to the Rio Deva from these ranges could facilitate the build up of ice in that basin. The lack of notable marginal depositional forms in the lower valleys may indicate a rather short-lived maximum extent and few or no halts in retreat until the main valleys were evacuated. The number and volume of cirques on the ridges seems to have no marked relationship to the maximum extent of ice. The occurrence of an extensive alimentation zone is suggested, possibly resulting in a rapid build up of ice. This may have been followed by relatively rapid dissipation with no significant interruptions in climate amelioration that led to halt or to re-advance stage moraines.

UPLAND GLACIATION

High level marginal and terminal moraines occur in the Picos de Europa where there is the greatest extent of upland intervening between narrow crests and deep penetrating valleys within this part of the Cordillera Cantabrica. Such moraines extend to below 1300 m on the Collada Barreda near Sotres from N-facing slopes falling from 2000 m. The high-level Duje valley between the Central and Eastern Massifs presents the best examples. In the main valley and the tributary Valle de las Monetas moraines descend to about 1300 m. In the first case, the Aliva ice, a tongue would have extended down valley from a plateau ice cover that fed lobes diverging south by the Canal de la Jenduda and from Las Salgardas towards Las Portillas del Boquejon below 1500 m. This complex ice mass would extended from the east face of Torre Blanca (2617 m) to a terminus in the Duje valley at about 1300 m, a distance of 8.5 km. Small recesional moraine arcs within the large outer moraine ridges are prominent in the Las Salgardas area.

The phase of glaciation to which these moraines testify may be represented by moraine arcs in the cirques facing north-east in the Coriscao (2234 m) area. This simple narrow ridge has a quite small area above the height zone of the probable Aliva Equilibrium Line. Nevertheless the present existence of persistent snow patches on this ridge indicates that more and larger patches would exist in addition to small cirque glaciers at that time. Higher, more massive areas, lacking the bulk of the Picos de Europa but with major cirques, probably generated small valley — head glaciers at that time; the mountains Pena Prieta (2536 m) and Curavacas (2520 m) are of this sort.

MOUNTAIN GLACIATION

In the Picos de Europa, within the moraines of the 'upland glaciation', there are small apparently fresher moraines and inside some of these are masses of rock debris organised in a ridged and furrowed manner characteristic of some rock glaciers. Such features occur locally and above 1700 m, for example at Hoyo Sin Tierra, Hoyo de Horoza, and high on Las Salgardas in the Central massif. They are associated with steep rock walls and couloirs that have been able to supply abundant rock debris possibly with snow avalanches. It is not clear whether the episode which produced these features was separated from that of the previous features or was a final phase of that episode. However it does appear that this phase was considerable less snowy though still sufficiently cold to favour the development of rock glaciers. It is not easy to compare the present distribution of permanent small snow patches with that of the small glaciers of the 'mountain' glaciation episode. The latter involved the existence of snow and ice on south-facing slopes whereas now very little snow survives on slopes with that aspect even at the highest altitudes. The minimum depression of snow line from that presently prevailing must have been at least 150 m.

CONTEMPORARY PHENOMENA ASSOCIATED WITH COLD-CONDITIONS

These features are classed as involving (1) frost riving (congelifraction) and (2) nivation with solifluction. The two sorts are found separately. The former dominates in the hard, jointed, unvegetated Caliza de Montaña in the Picos de Europa and occurs on a restricted scale elsewhere. Up to about 2200 m, ice-scoured and plucked limestone surfaces have suffered little modification since their last ice cover which for many parts would be in the episode of Upland glaciation. The principal modification has been a small development of karren-fluting and pitting. Above that height, to a degree controlled by topographic setting, rock surfaces are more broken. Frost riving in the higher areas continues a modelling controlled especially by the prominent near-vertical jointing. Thus the characteristic forms are towers and needles, gullies, couloirs, with marked and active paths for debris descent and snow accumulation. In several places scree descends well below the present levels of significant frost action, but no conjunction of scree with apparently active rock glaciers was seen. It should be noted that there are many high, shaded north-facing recesses that would be more favourable for ice and rock combination into rock glaciers than the sites visited. However temperature conditions would be critical, and it is clear that the greater part of the frost debris produced since the last major ice cover has not been incorporated into rock glaciers. Such an assertion is more easily permitted by the absence on the limestone of significant surface drainage so that the basal fringes of scree are substantially unmodified by further transporting processes.

Periglacial processes on the shale-sandstone (flysch) mountains are now dominantly of nivation-solifluction sort. Coarse scree is stable, cliffs show little sign of block detachment; there is a little fall of pebbles from coarse conglomerates. The ridges are grazed by goats, sheep and cattle and there is evidence of damage to wet turf at the edges of melting snow patches. There are also indications that the montane woodland with *Juniperus* and ericaceous species has and is being replaced by grassland containing *Festuca* and *Anthoxanthum* species. These changes may be expected to enhance slope mobility.

Two types of site appear to most favour movement of surface rock debris, (1) crests and spurs with divergent slopes and (2) steep valley head niches. Examples of the former are drawn from the mountain Bistruey (2001 m). On the west side the exposed grass-heath shoulder descends to a col. It is grazed by cattle and there are no permanent or persistent snow beds. The thin cover of small rock pieces drains easily and is windswept: nevertheless it is arranged in flights of turf-banked terraces with treads free of vegetation. Characteristic dimensions are 200—300 mm in width and about 200 mm in height. The features are members of a class widely reported and associated with frost disturbance. It appears possible that the principal occasions of mobility follow snow melt or rain with shallow thaw when both solifluction and frost disturbance would be effective.

On the south-west side of the Coriscas ridge from Puerto San Glorio (1609 m) to Alto de Valdeon (1812 m) above about 1900 m there is a number of valley head niches and more open recesses which hold persistent snow; the north-east side is characterised by a series of cirques. Water from the snow keeps the soil moist for much of the summer while snow delays soil thaw helping to keep the surface layers saturated; convergent slopes concentrate downslope seepage and encourage movement of surface debris. Flights of terraces very similar in type to those on Bistruey are numerous and well-developed especially in niches above 2000 m. Widths extend to 500—600 mm. In some places the lower edges of sets of terraces give way to debris garlands and stone stripes, and these features also occur on steep rubble slopes below the ridge crest where terraces are lacking.

This set of contemporary processes belongs to the periphery of periglacial environments and is associated with severe winters and mobile regolith. Woodland degradation and grazing is a locally-important factor.

DISCUSSION

Field evidence is of landforms, processes, and materials reflecting in a series of declining intensity the effects of cold climates. In summary, the following may be proposed as major parts of the most recent sequence in the Picos de Europa part of the Cordillera Cantabrica (Fig. 2).

(1) a glaciation which included ice occupation of many low valleys,

(2) an upland glaciation of much smaller extent,

(3) a mountain glaciation with small niche, crest wall and cirque glaciers, and with rock glaciers,

(4) the contemporary period of numerous small snow patches and minor periglacial activity.

The first episode demands a large depressions of the snowline from that of the present. It is also necessary to assume a greater snowiness than prevailed at the last glacial maximum in the Sierras of the Central Meseta where, for example, glaciers in the Sierra Gredos are reported as confined to above 1400 m (DRESSER, 1958). The close proximity of the Cordillera to the Biscay coast is a favourable circumstance. The intrusions into the Biscay area of polar water with accompanying drift ice would be conducive to the creation of a very steep ocean surface temparature gradient. Strongly contrasting moist air from the warmer sea and cold air from the ice-chilled and floe-mantled northern waters and ice-clad land would induce frontogenesis with heavy coastal and mountain snowfall. Depression movement into the Bay of Biscay would be expected. The development of such an environment to its fullest would await the near encroachment of the surface polar water. This is believed to have occurred by about 18000 B. P. (MOLINA-CRUZ and THIEDE, 1978). It is thus suggested that maximum Upper Würm/Vistulian snowiness of northern Spain would be broadly contemporary. It is however possible that it did not coincide with the period of greatest cooling. The more effective combination of frontogenesis, humidity and temperature may have preceded and/or followed the maximum cooling.

By analogy with more northerly parts of Western Europe it is suggested that, following amelioration of climate, dissipation of the maximum ice cover would be attained by 13000 B. P., possible a little earlier as the initial northward retreat of polar water would first influence this area.

It is to be expected that the cold episodes of late glacial times and the Little Ice Age would be represented by landforms and materials in the Cordillera Cantabrica. How the Upland and Mountain glaciation features fit these episodes is not clear.

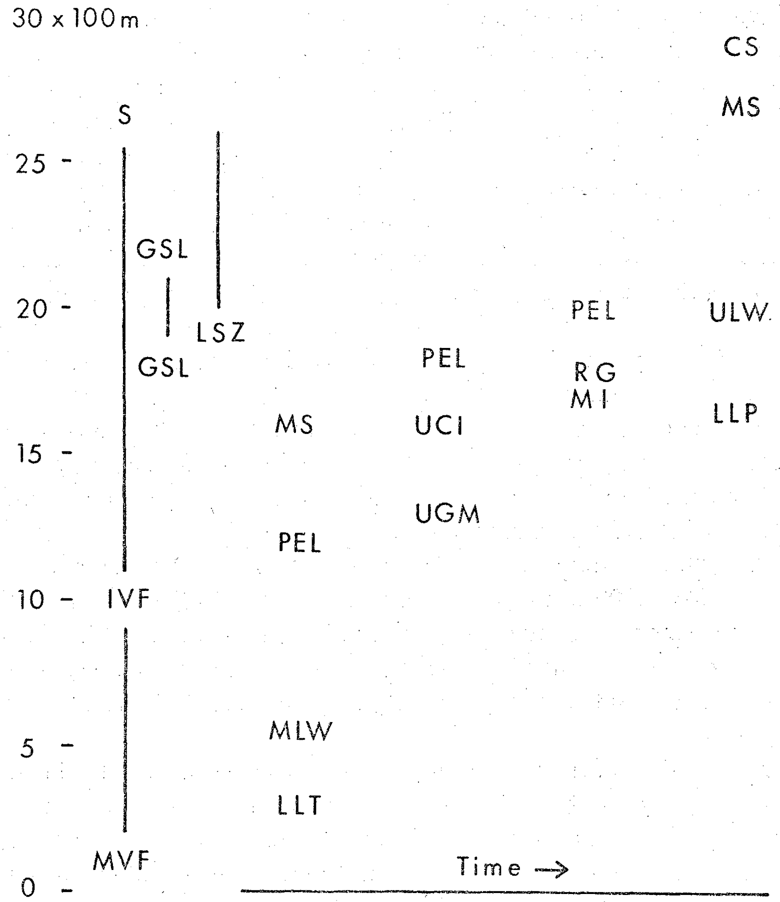

Fig. 2. Heights and height ranges of features in the eastern Cordillera Cantabrica, N. Spain

Key to initials: S — highest summits; IVF — inner valley floors; MVF — marginal valley floors; GSL — general summit levels; LSZ — lower edge of zone with snowpatches; LLT — low level tills; MLW — low level moraines (WALLACE); PEL — possible equilibrium line; MS — snowline (MANLEY); UGM — lower limit of major moraines of Upland glaciation; UCI — cirque ice in Upland glaciation; MI — mountain glaciation lower limits of ice; RG — rock glaciers; LLP — lowest present occurrences of periglacial features; ULW — uppermost limits of woodland; MS — present snowline (MANLEY); CS — present snowline (this interpretation)

The temperature conditions needed for rock glaciers forms an essential element in interpretation. When and how the requisite conditions could be created after the Late Wurm/Vistulian full-glacial in a maritime environment at 43° N latitude, at about 1880 m above sea level requires consideration. In this connection it may be noted that late glacial ice-wedge pseudomorphs occur at sea-level on the western Irish seaboard and that rock glaciers formed on coastal Irish (e.g. Errigal, Donegal) and Scottish hills with favourable rocks (DAWSON, 1977).

Oceanic and atmospheric conditions combined to establish a cold, relatively dry, and continental environment along the northwest European coastlands after the warming which led to the loss of main Upper Wurm/Vistulian ice. Higher parts of the Cordillera Cantabrica could be expected to repeat in some measure the harsh lowland conditions some 1100 km farther north.

The Cantabrian rock glaciers may have been developed through the shrinkage of small heavily debris-laden ice tongues; they may be indicative of likely contemporary occurrence of discontinuous permafrost (*cf.* KERSCHNER, 1978).

The relative contribution of snowiness and cooling to the greater rigours of the cold phases cannot presently be unravelled. Some initial consideration on snow level lowering follows. If a possibly conservative figure of 10 °C for maximum mean annual temperature depression in the Upper Wurm/Vistulian glaciation is applied to the summit zone of the Picos de Europa a mean annual temperature of about −8 °C is indicated, possibly with no month having a mean exceeding 0 °C. The degree of cooling assumed is based on the cooling having been a little less, due to position, than that further north and north-east in Europe (*cf.* MAARLEVELD, 1976). A present near analogy could be found along the west coast of the Antarctic Peninsula, 64—67 °S. There, the present temperature-snowfall regime sustains an ice cover notably less substantial than previously.

MANLEY (1951) extrapolated a "glacial maximum" maritime west European snowline to 1600—1700 m in the region under discussion. This seems rather high for the postulated greatest extent of ice with upland ice caps and valley ice tongues: a figures nearer 1200 m may be required, at least for a short time. The Upland (Aliva) glaciation would appear to have required a local snowline in the height range 1700—1900 m.

The small glaciers of the Mountain phase may have been considerably nourished by avalanches. Also at this time local conditions of aspect, seclusion and shape of gathering ground would strongly influence glacier growth. A preliminary survey of present snow patches distribution and some of the small Mountain phase moraines suggests that equilibrium line altitudes on many snowfields would range between 2100 m and 1900 m. However, as site character is so critical in locating present snowfields, the above figures should not be used to derive a general snowline for the Mountain phase. Rock glacier formation proceeded after an elevation of snowlines at the close of this phase.

MANLEY'S (1951) estimate of current showline altitude in the Cordillera Cantabrica is a little over 2700 m. The present assessment based on local topography, contemporary snow patches, and the degree to which snow at favoured sites can lie below a general equilibrium line, is only a little higher, 2800—2900 m. The difference is not regarded as large in view of the present degree of understanding of the local climatic fluctuations. Lowerings of mean equilibrium line from the present notional position appear to have been about 800 m for the Mountain phase, 1000 m for the Upland phase, and 1600 m for the maximum or Valley phase.

This discussion has been based on a preliminary survey of the area. As more field evidence is accumulated and interpreted it is expected that findings will be modified and refined. It may, however, serve as a contribution towards the analysis of late Pleistocene and Holocene events in the Cordillera Cantabrica.

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