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Periglacial and nivo-periglacial landforms in the Sierra del Aramo (Asturian Central Massif)

Periglacial and nivo-periglacial landforms, deposits and processes are analyzed in the Sierra del Aramo, a calcareous mountainous alignment of middle altitude located in the Asturian Central Massif. These morphologies and deposits are inherited mostly from colder past climatic conditions and current mixed processes involving snow, karst dissolution and slope dynamics. The methodology consisted of fieldwork, stratigraphic analysis of deposits, photointerpretation of aerial images and the realization of a detailed cartography, to achieve a better knowledge of this type of processes and forms in the Atlantic mid-mountain domain. As a result, stratified screes, erosion-regulated slopes, nivo-karstic forms (nivo-karst dolines and niches) and snow avalanche paths and deposits have been identified, which contribute not only to complete the inventory of landforms linked to cold processes, but also to evaluate in its just measure, the extent of periglaciarism in this sector.

The periglacial belt in the Cantabrian Mountains is situated in the Holocene above 1,800-2,000 m altitude, so that, below this altitude and up to 1,600 m, the periglacial activity is very limited and restricted to weak processes of solifluction and phenomena of snow erosion. This is the case in the Sierra del Aramo, where snow contributes to the karstification and displacement of materials along the slopes, and there are solifluction processes in the higher areas. However, the set of cold environments landforms and processes is quite broad, highlighting the inherited forms of past processes (regulated slopes with stratified deposits, screes, regulated slopes by erosion), as well as the nivo-karstic forms (wells, niches) and snow avalanche paths and deposits.

I. REGULARIZED SLOPES FOR ACCUMULATION OF PERIGLACIAL DEPOSITS

Although the periglacial processes in the Sierra del Aramo are scarce at present, the morphological inheritances of colder stages are innumerable and are found throughout the whole study area from the high platform surface to 400-500 m, as is the case of the cemented periglacial deposits of the Monsacro or the stratified deposits composed of angular gravelsfrom Las Xanas Gorge. In effect, many of the slopes of the Sierra del Aramo are regularised by the accumulation of debris with cemented layers and angular clasts, the latter of undoubtedly periglacial origin.

Indeed, at the base of the most complete profile, located in the Braña de Linares (Quirós), a cemented and heterometric detrital formation can be seen, that is, of blocks, pebbles and gravels, immersed in a clayei matrix of reddish tones and with a thickness of several meters. Above these breccias there are stratified deposits corresponding to a typical formation of *grèzes litées*, resulting from successive flows formed from the melting of snow. In the basal part of this set, with a thickness of 2 m, the fine ones abound and the clasts are very small, but the upper part consists of angular fragment layers and larger size known as *groizes litées*. Therefore, the domain of the fines fraction is progressively replaced by

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angular clasts and abundant carbonate. In fact, the upper level consists basically of cemented small size clasts with clast-supported structure due to the complete washing of the fine fraction. Finally, over the whole series culminate coarser materials, equally angular and cemented and with a thickness of between 1 and 2 m, which in their contact with the overlying floor return to present a clay matrix. They reflect, therefore, the passage of thermally very cold conditions (formation of gelifracts) to other tempered ones (dissolution and supersaturation of carbonates) and, finally, warmer and more humid (generation of decalcification clays).

II. REGULATED SLOPES BY EROSION

Periglacialism has not only participated in the regularization of the slopes through the accumulation of debris, but also through the erosion of rocks. It is a polygenic and polycyclic process that has also been demonstrated in other similar sites such as the Sierra de Sobia. In this process, the gelifraction has played an important role in the cold periods, especially during the Würmian glaciation: the uncovering of the cryptolapies generated under the edaphic cover, as well as the subsequent action of the snow and the freeze-thaw cycles on such forms have facilitated rock fracturing. Hence, the last generation of gelifracts remain in their place of origin (has not been transported by the surface runoff) covering the slopes, probably already regularized in previous stages. Above 1,500 m, there are many slopes that present this type of small screes together with non-dismantled lapies or karren, which are even located in horizontal or subhorizontal areas of the mountain's summits. Therefore, fracturing occurred in situ and they have not suffered any type of transport.

However, the processes of regularization of slopes and their chronology are still today the object of controversy and debate. The surfaces regularized by erosion, in addition to being associated with ancient karstic morphologies such as conical reliefs, are interrupted by fault escarpments or incised by recent fluvial and mass movement processes, which clearly indicate an origin prior to the Quaternary. In spite of this, they undoubtedly have undergone a periglacial retouching due to their exposure in the rigorous climatic periods. The absence of woody vegetation in the calcareous summits would favor the transport of the edaphic cover, the nival dissolution of the lapies or karren and its fracturing with the freeze-thaw cycles. It is, therefore, a multi-causal and polychronic evolution.

III. NIVOKARSTICS FORMS

On the upper platform of the Aramo there are forms of periglacial and especially nival origin, where the snow has had a remarkable activity and prominence, such as the nivokarstics wells (it can be counted by hundreds), or the nival lapies or karren. The nival dolines are distributed according to geological structures such as fracture lines and bedding planes.

As for the lapies or karren, the activity of the snow is evident in the mäanderkarren scarcely represented in the Sierra del Aramo, the lapies formed by still, stagnant or adhering water (shapes of potholes, wells, etc.) and surfaces with holes, that they have been able to generate under the snow cover and in the processes of snow melt. On the other hand, it is important to highlight the role of snow in the configuration of the nivation niches that dot the ends of the platform, often feeding avalanche paths, many of them still operative, mainly on the eastern slope. Some escarpments on the northern slope have acted as catchment and maintenance areas for the snow, although the most interesting one is under the Gamoniteiro peak. It is a large amphitheater breached to the North with a maximum altitude above 1,700 m and a depth of 1,560 m, of multi-causal origin. The rectilinear escarpments indicate the concurrence of several fractures of orthogonal form that have facilitated the dissolution of the limestone and the generation of a doline with a circular plant of about 2.5 ha. Inside the doline there are rounded boulders of an allochthonous nature that attest to the ancient circulation of water by this great sink. The depression, open to the N, has a shaped-amphitheater, however, a massive deposit consisting of clay materials and with some large blocks seals the whole. This depression, completely shaded for several months of the year, is likely to function as a nivation niche in the cold Pleistocene periods, feeding not only on rainfall but also on snow from the surrounding walls, as well as gelifracts the upper walls. Finally, solifluction processes are also observed in the deposit that closes the depression and that mobilizes the fine fraction both inside the nivokarstic niche and towards the outside, generating scars and lobes.

IV. SNOW AVALANCHE PATHS AND DEPOSITS

At present, the activity of snow avalanches has a great relevance in the Sierra del Aramo and is a major factor in the morphological configuration of the relief and landscape. In fact, the slopes are crossed by active snow ava-

lanche paths, especially on the eastern slope, where there are long paths. They are fed by numerous scarps and small nivation niches excavated in the limestones and located between 1,500-1,600 m asl. In the runout zone of the most important paths (larger than 1,000 m) there are large and extent cone-shaped snow avalanche deposits composed of heterometric clasts also dispersed downhill, even below 700 m asl.

In the starting zones many north-facing scarps act as nivation niches. In transition zones there are also dissymmetries that allow the conservation of snow well beyond the temporary. Therefore, nival activity is operative and has a high modeling capacity, mainly for the transport of materials acting as conduits por sediments and debris.

V. THE PERIGLACIAL COLD PHASES IN THE SIERRA DEL ARAMO

A many of the periglacial manifestations of the Sierra del Aramo are Pleistocene, as shown the stratigraphic analysis of the periglacial deposits and through their comparison with other deposits of similar characteristics dating from mid-mountain areas of the Asturian Massif. In the middle Pleistocene, specifically before the Mindel-Riss interglacial, there was a cold phase that materialized in a first generation of gelifracts. Subsequently, deposits of small angular clasts indicate much colder and more severe thermal conditions in the Upper Pleistocene, around MIS 6. In addition to two periglacial phases there was a third nivoperiglaciar that could coincide in the middle mountains with the Last Glacial Maximum (LGM). It seems evident that the Upper Paleolithic was a period of strong environmental transformations, within the Würmian cold, that conditioned the morphogenetic activity, giving rise to multiple phases with local peculiarities. Changes in humidity could have an effect on a much more active dynamics of snow avalanches on the slopes, supported by steep slopes and structural changes in the snow cover. This would explain the presence of very well developed avalanche paths, that is, over 1 km in length, as well as wide and deep, resulting of large accumulations of snow in shady areas.

In conclusion, the periglacial processes have had a primordial relevance in the generation of landforms in the Asturian Massif, not only on the summits of the high mountain and in the calcareous bastion of the Picos de Europa, but also in the middle mountains, which is still operative, above the 1,600 m of altitude, an activity restricted to phenomena of solifluction and nivation. In fact, the nival activity continues to participate actively in the dynamics and modeling of the Sierra del Aramo, both in the smaller forms, such as the nival karren, and in the larger ones, that is, the nivokarstic wells and snow avalanche paths and deposits. However, the periglacial forms of greater relevance are relicts and constitute an inheritance of the past, in particular, of the extraordinarily cold phases of the Pleistocene.