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MASS WASTING FEATURES ABOVE THE TIMBERLINE IN THE CENTRAL PYRENEES, AND THEIR TOPOGRAPHIC CONTROLS[1]

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SUMARY.—Patterns of topographic distribution of the main landforms involved in mass wasting above the timberline have been studied in the Central Pyrenees. Gelifuction lobes, ploughing blocks, landslides, small scarps, terracettes and stone lobes were related to altitude, orientation, gradient, vertical relief, slope position, wind exposure, kind of vegetation, cover and soil texture. The study was carried out in ten representative zones near to Jaca (Lat. 42º 45' N, Long. 0º 31' W, in an altitudinal range between 1.700 and 2.500 m.

By using a Binary Discriminant Analysis the intensity of the linking, either positive or negative, between each variable and each landform was established. This allowed to define a specific rank of preference for every one of them. Furthermore a Principal Components Analysis was brought about to detect the weight of the variables in the determination of the main directions of variation which explain the distribution of the landforms.

The set of landforms can be ordered in a gradient chiefly defined by the slope position. Thus, turf-banked lobes, ploughing blocks and landslides, which are due to processes that occur when the plastic or liquid limits are crossed, take place in the mid or lower part of the slope, where there are concave reliefs, smooth slopes and relatively deep soils. Inversely, in the upper positions, where there are mainly convex reliefs, steep slopes and thin soils, the frost creep being a very important process, the most usual landforms are terracettes or stone-banked lobes. Altitude has shown not to be a significant variable within the range of work, and it seems likely that these processes were occuring in an azonal way, in those microenvironments where there were the optimal combination of variables for each one.

RESUMEN.—Los autores estudian los modelos de distribución topográfica de las principales formas de relieve implicadas en movimientos en masa en el piso supraforestal de los Pirineos Centrales. Los lóbulos de gelifluxión, bloques aradores, deslizamientos, pequeños escarpes, terracillas y lóbulos de piedras se han relacionado con la altitud, orientación, pendiente, relieve vertical, posición en la ladera, exposición ante los vientos dominantes, tipo de vegetación y textura del suelo. El estudio se ha llevado a cabo en 10 zonas representativas cerca de Jaca (Lat. 42º 45' N, Long. 0º, 31' W), en una banda altitudinal que oscila entre 1.700 y 2.500 m.

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Utilizando un Análisis Discriminante Binario se ha establecido la relación, positiva o negativa, entre cada variable y cada forma. Ello ha permitido definir un rango específico de preferencia para cada una de ellas. Posteriormente se realizó un Análisis de Componentes Principales para detectar el peso de las variables en las principales direcciones de variación que explican la distribución de las formas.

El conjunto de formas puede ordenarse en un gradiente definido por la posición de la ladera. Así, los lóbulos, los bloques aradores y los deslizamientos, que se originan por procesos relacionados con la superación de límites plásticos y de liquidez, se producen en la parte media o baja de la ladera, en relieves cóncavos, pendientes suaves y suelos relativamente profundos. Por el contrario, en las áreas superiores, sobre relieves convexos y fuertes pendientes, las formas más usuales son terracillas o lóbulos de piedras. La altitud no se comporta como una variable significativa en los límites en que hemos trabajado y parece como sí estos procesos ocurrieran de forma azonal, en aquellos microambientes en los que se produce una combinación óptima de variables.

RESUME.—On a étudié les modèles de distribution topographique des plus importantes géoformes impliquées dans les mouvements du sol dans les Pyrénees Centrales. Les coulées de solifluxion, blocs silloneurs, glissements de terrain, petits talus, replats en marches d'escalier et lobes pierreux ont eté étudiés en fonction de l'altitude, orientation, pente, rélief vertical, position dans le versant, exposition au vent, couverture vegetal, taux de recouvrement et texture du sol. L'étude á été faite dans dix zones representatives, aux environs de Jaca (Lat. 42º 45' N, Long. 0º, 31' W), embraçant un domaine d'altitudes comprises entre 1.700 et 2.500 m.

Moyennant une analyse discriminante binaire nous avons établi l'intensité de la rélation positive ou negative, entre les variables et les géoformes, dans le but d'obtenir l'ensemble de conditions qui sont préferées par chaque geoforme. En plus, on a fait une analyse en composantes principales pour mettre en évidence l'importance des différents variables dans la détérmination des axes principaux de variation sur la distribution des géoformes.

L'ensemble de géoformes peut s'ordonner sur un gradient fondé sur la position relative dans le versant. Par example, les lobes bordés de tourbe, les blocs sillonneurs, et les coulées de sol, qui dérivent des processus qui ont lieu quand sont croisés les limites des phases plastiques ou liquides, se trouvent en milieu o en bas de pente, où on peut trouver réliefs concaves, pentes faibles et sols relativement profonds. Au contraire, dans les parties superieures des versants, où le rélief convexe l'emporte, où l'on trouve des pentes fortes, et des sols très maigres, et où la montée du gel est un processus d'importance, les géoformes les plus communes sont les replats escalatiformes et les lobes pierreux. L'altitude ne semble être pas une variable significative, et il est, donc, probable que ces phénomenes aient lieu de façon azonale, dans les microenvironements qui réunissent les combinations de variables optimes pour chaque case.

1. Introduction

The Pyrenean Range has been a man-managed mountain for a long time. At the last of the 17th century the increase of livestock management made it necessary to reduce the altitude of the timberline, in order to obtain a larger surface of grasslands used by the animals in summer. In this way, the initial upper limit of the *Pinus uncinata* forest, at 2.000 or 2.200 m. was lowered down to its present altitude, about 1.600-1.700 m.

Most part of the former forestal soils in this altitudinal band are being eroded at present, or have been eroded in the recent past. A starting hypothesis may be that because of the disappearing of the stabilyzing forest cover, these thick soils were exposed to a drastic change in their environmental factors. Microclimatic changes have occurred near to the soil surface, and the lack of a tree root network encourages mass wasting processes. So it is possible to explain the downward extension of the lower limit of active solifluction (del Barrio et al, in press; Hollermann 1985). Thinking in a geoecological scale of time, two or three hundred years could mean not too long for the total adaptation of the mountain ground to its present conditions, and because of that, good part of the responses to the initial change remains active today. To test this hypothesis is one of the aims of the project which is the logistic frame of this work.

Mass wasting processes are the most important erosion systems affecting to the slopes between 1.700 and 2.500 m.a.s.l., and occur both in deep soils and in the horizon C of a soil which has been previously dismantled. Gelifluction, frost creep, slopewash and rapid mass movements take place closely related to snow and ice conditions, which depend on topographic locations. The objective of this work is to stablish the pattern of topographic distribution of these processes in the belt inmediatly above the timberline, by using present active landforms as indicators of their occurrence.

2. The study area

Field work was carried out on the upper Aragón and Gállego basins, in the west sector of Central Pyrenees. In this area, rock types change along a south-north direction, beginning with a strongly folded Eocen flysch following by deep banks of Cetraceses limestones and sandstones tilted to the south, to finish with paleozoic rocks, mainly shales and schists. At a reference altitude of 2.000 m., mean annual temperatures lay around 3º —4º C with a total precipitation of 2.000 mm.. There are two significant precipitation peaks, one in spring (March-May) mainly of snow, and another in autumn (October-November) mainly of rain. Winter temperatures are rather mild, the means of the coldest month lay around —5º with absolute minime of —30º C. Characteristic altitudinal limits for climate are the following:

1.600-1.700 m.: 0º C mean temperature to the december-march period (lower limit of winter snowpack).
2.400 m. : 10º C mean july temperature.
2.700-2.800 m.: 0º C mean annual temperature (lower limit of patterned soils).

Two main snow conditions may be distinguished north and south of the limestone ridges. In the former, snowmelting takes place late (May) and in a flushing way, with measured rates of 30-50 mm. of water per day. In the later, the snow pack may be broken as early as February, with a more gradual and long lasting melting period (Puigdefabregas & Alvera, 1986).

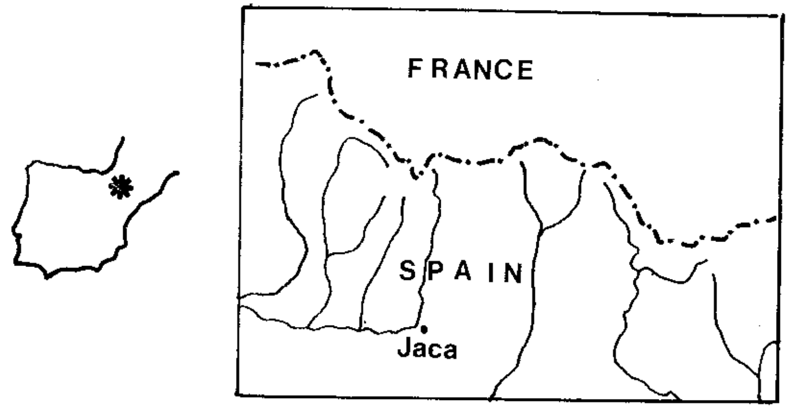

Fig. 1. Location of the study area.

3. Processes and landforms

Four processes (gelifluction, frost creep, slopewash and rapid movements) and six landforms (turf-banked lobes, ploughing blocks, landslides, small scarps, terracettes and stone-banked lobes) have been identified in the study area as the most important sources of sediments for the erosion systems. Almost all of them, excluding small scarps, fit well in previous descriptions, and some of these references are presented in Table 1. Below it is presented some dominant characteristics of the landforms, as they are found in the study area.

1. *Turf-banked lobes (Plate 1)*

They are tongue-shaped and elongate soil accumulations. Usually they have a depressed zone upslope, sometimes with several small ruptures of the soil surface, which are transverse to the longer axis of the lobe. Often, turf-banked lobes are more abrupt at the lee side, because of the snow accumulation, but it is rarely seen true traces of erosion by this fact. Mean dimensions are: 8.5 m. long and 5.1 m. wide; frontal, convex part is 0.75 m. thick. There are much larger lobes, but they were not included in this study because of their present activity was not sure.

TABLE 1

Procedence of definitions of processes and landforms

Gelifluction	Washburn (1979), Williams (1959)
Frost creep	Washburn (1979), Benedict (1970)
Slopewash	French (1976)
Rapid mass movements	French (1976), Puigdefábregas & García-Ruiz (1983)
Turf-banked lobes	Benedict (1970, 1976), Embleton & King (1975)
Ploughing blocks	Washburn (1979), Tufnell (1972)
Landslides	Puigdefábregas & García Ruiz (1982, 1983)
Small scarps	
Terracettes	Vincent & Clarke (1978), Washburn (1979)
Stone-banked lobes	Embleton & King (1975), Benedict (1970, 1976)

2. *Ploughing blocks (Plate 2)*

Those are metric boulders whose downslope movement is faster than that of the surrounding soil, and thus, they leave an elongate depression upslope, pushing on a small soil accumulation downslope. If the boulder is an elongate one, usually its longer axis is parallel to the direction of the gradient.

3. *Landslides (Plate 3)*

They are rapid slope failures where the upper layer of the regolith slips over a flat (the horizon C in many cases) and accumulates downslope, leaving a bare patch of that slipping flat exposed to the atmospheric weathering. A typical landslide has a semicircular scarp, 0.3-0.9 m. high, upslope to the slipping bare ground or socle. After the failure has occurred, the frost action (specially needle ice) causes a retreat of the scarp, which becomes larger in perimeter, and the eroded material accumulates in a talus between it and the socle. The landslide may cover a variable distance from a few meters to 200 m. downslope, and the largest ones show a surface drainage.

4. *Small scarps (Plate 4)*

They consist of closed grasslands whose continuity is broken by small scarps closely disposed. Each scarp has a vertical and bare face 0.1-0.2 m. high, and it extends several meters in a direction which is normal to the gradient. Surfaces occupied by this type of system are variable in size, varying between a few and several thousands square meters.

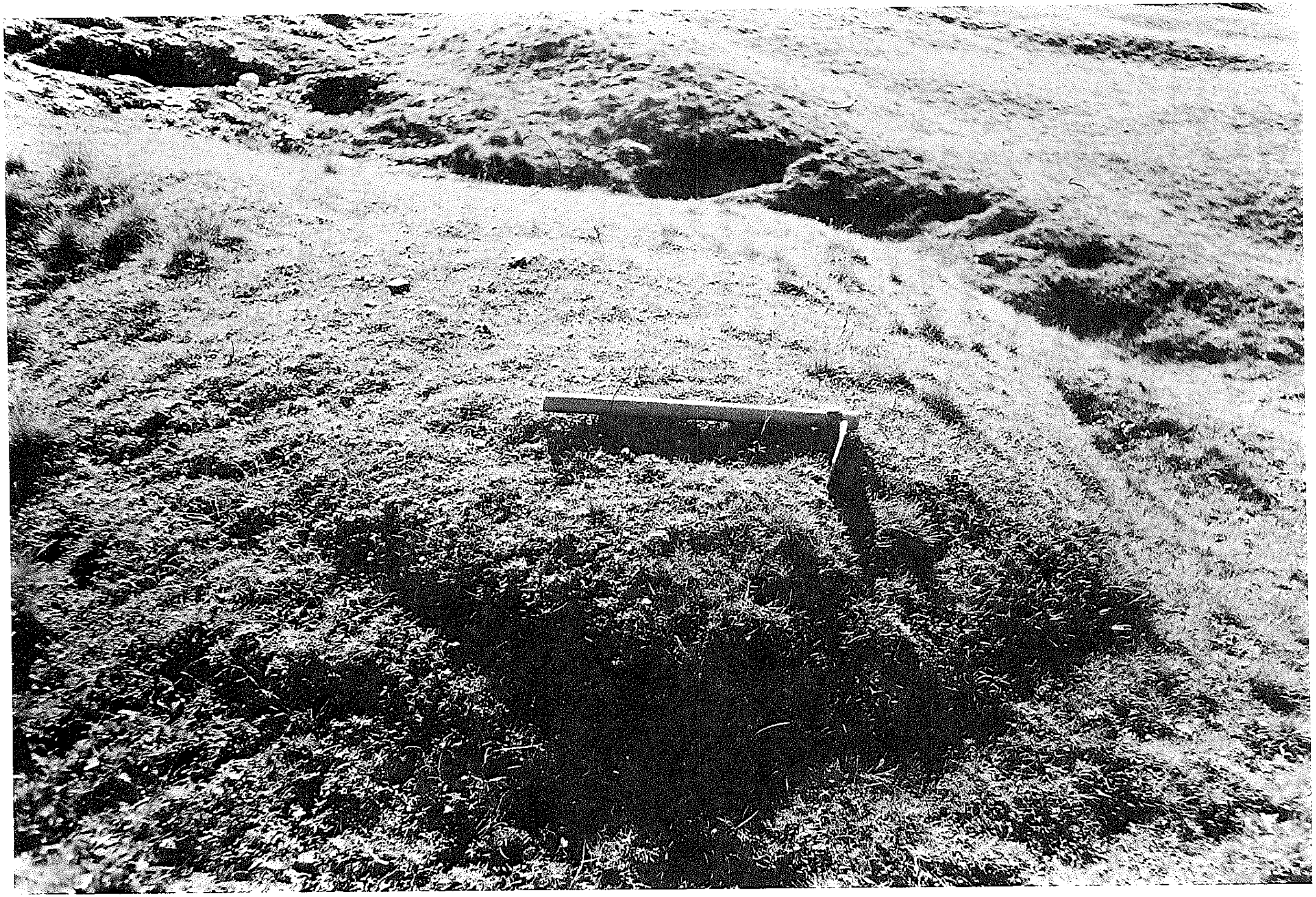

Plate 1.. Turf-banked lobe (1.870 m. a.s.l.; gradient: 19º; 100 % vegetation cover), in Tortiellas.

Plate 2. Ploughing block (2.020 m. a.s.l.; gradient: 22º; 1000 % vegetation cover), in Sierra Bernera.

5. *Terracettes (Plate 5)*

Terracettes in the study area have a downslope convex border of bunch grasses retaining a tread of almost bare ground upslope. The border ranges between 0.2 and 5 m. wide and its average direction tends to be normal to the gradient, although they may be modified by the prevailing winds, in these cases being oblicuous to the contours. A dense cover of *Fescuta eskia* or *F. gautieri* make up the border, while the tread cover is lesser than 10 %. This surface is less steep than that of the slope, and sometimes there are stony accumulations which finally can invade the border, when they are large enough.

6. *Stone-banked lobes (Plate 6)*

They are defined in the literature as "lobate stony enbankments underlain by relatively fine-grained material" (Benedict, 1976). Strictly, those ones in the study area fit to this definition, but they are smaller and on steeper slopes than those described by Galloway (1961) or Benedict. Stone lobes here are 0.8 to 10 m. long, 0.4 to 3 m. wide and as much as 0.3 m. thick at the front. Larger stones lay downslope in the frontal part, while the smaller ones are more frequent in the upslope part of the accumulation. The lobes rest on bare and fine-grained material, existing a clear limit between this one and the stony accumulation.

4. Methods

Collection of field data was carried out along the summer of 1985, proceeding in the following way. Ten representative zones, ranging 5 to 15 km^2 each one and consisting of well individualized ridges and watersheds were chosen into the study area. Each zone was interpreted, identifying every type of mass wasting systems occuring there. Deep and stable soil covered by undisturbed grassland was included too, to have a control. Later, in every type of system, one to three representative sample plots were chosen to record the following variables: landform (measuring a small number of them), altitude, orientation, gradient, relief (convex, straight or concave), slope position (high, medium, low), wind exposure (windside, leeside or indifferent), lithology of the bedrock and vegetation cover, including a list of dominant plant species. Besides it was collected a soil sample below the humic horizon (15-25 cm. depht) to determine the texture.

In this way 95 observations were made, averaging 9 or 10 sample plots in each zone. An Analysis of Variance (ANOVA) was used to test if

Plate 3. Landsilide (2.020 m. a.s.l.; gradient: 18º; 100 % vegetation cover in the affected area), in Sierra Bernera

there were significant diferences in the means of quantitative variables between the seven geomorphic categories. Orientation data were processed according to a special treatment for directional data (Rao & Sengupta, 1972).

These analysis allowed a standard of judgement to fix thresholds, and thus, to convert quantitative variables into qualitative mode. Variables with three possible states (for example, relief: convex, straight and concave) were decomposed into three independent variables, in order to have a presence-absence data matrix. After that a multivariate treatment for the whole variables was carried out.

A Binary Discriminant Analysis (BDA) (Strahler, 1978), was used to test landform-variable relationships and to identify the topographic gradients best ordering the landforms. First step of BDA involves the construction of a set of contingency tables, whose significance is evaluated by evaluation of G-statistic. Later, frequency values of the tables are converted into standarized residuals following the method of Haberman. Considering that positive or negative values of the residuals indicate respectively preference or avoidance between variables and landforms, the Q-mode residuals matrix (where the landforms are in columns and the variables in rows) makes it possible to evaluate the intensity of linking, either positive or negative, between each landform and each variable.

In the second step of BDA, the Q-mode residuals matrix is input to a Principal Component Analysis, to show how the landforms are ordered according to the main orthogonal trends defined by the factor loading of the variables.

5. Results and discussion

5.1. *Results of statistic analysis*

Mean values of the quantitative variables are showed in Table 2 and 3. Table 2 is referred to orientation, altitude, gradient and vegetation cover. Mean values of the last two variables showed significant differences whithin the landforms, whereas altitude did not. Therefore this variable was not converted into qualitative mode and hence it was excluded of subsequent treatments. Later we shall come again over this problem.

Examinating the range of slope mean values, the threshold to discriminate smooth-gradient observations from the steep-gradient ones was fixed in 25º. Plant cover values were very extreme, and a threshold of 50 % was used to divide this variable into two categories. With respect to orientation, it was distinguished between shady- and sunny-aspect observations.

Plate 4. Small scarps (2.140 m. a.s.l.; gradient: 30º; 70 % vegetation cover), in Canal Roya

TABLE 2

Mean values of quantitative topographic variables for the different landforms.

LANDFORM	ALTITUDE (m.a.s.l.)	ORIENTATION (deg.)	GRADIENT (deg.) (*)	COVER (percent.) (*)
Turf-banked lobes	2123	10 (N)	19.8	83.2
Ploughing blocks	2004	22 (NNE)	19.6	100.0
Landslides	2052	208 (SSW)	21.3	99.8
Small scarps	2040	215 (SW)	26.5	82.6
Terracettes	2136	209 (SSW)	27.3	33.8
Stone lobes	2174	295 (WNW)	27.9	30.7
Undisturbed grassland	2098	187 (S)	17.2	92.8

(*) significant at alpha = 0.01

Table 3 shows the mean values for soil texture. There, coarse sand and silts serve both to classify the landforms almost in the same way. Small scarps, terracettes and undisturbed grassland lay in average in the coarse-grained sector, whereas turf-banked lobes, landslides and ploughing blocks are in the fine-grained one. Stone-banked lobes are just between the two groups. Therefore a soil is included either in the coarse or fine grained categories if its content of coarse sand (Ø > 0.2 mm.) is over or below 15 %.

TABLE 3

Mean values of soil texture for the different landforms

LANDFORM	COARSE SAND (> 0.2 mm.) *	SAND (> 0.05 mm.)	SILT ***	CLAY **
Turf-banked lobes	11.4	34.2	45.6	20.2
Ploughing blocks	4.1	25.7	52.3	22.0
Landslides	7.0	27.7	44.9	27.4
Small scarps	19.1	39.0	37.5	23.5
Terracettes	19.9	34.2	39.5	26.5
Stone-banked lobes	8.8	29.0	42.6	28.5
Undisturbed grassland	22.2	35.5	37.3	27.3

* Significant at alpha = 0.01
** Significant at alpha = 0.05
*** Significant at alpha = 0.10

Lists of plant species lead to establish four main vegetation categories in which the larger part of the observations could be disbributed. Three of these groups are designated according to dominant species (*Nardus stricta, Festuca gautieri, Festuca eskia),* and the remaining one, which is named as "snow" in the tables and figures, is refered to vegetation typical of late-melting snow patches and includes *Plantago alpina* and *Horminum Pyrenaicum* between representative species.

Following the former criteria a presence-absence matrix for the BDA was made up from the original data table. Table 4 presents the Q-mode output matrix of D-Haberman values, showing the intensity of positive or negative linking between variables and landforms. All the variables were significant with the only exception of the mid-slope position.

D-Haberman values can be plotted in a graphic to visualize the specific rank of variables which has each landform (Fig. 2). In that figure turf-banked lobes show clear preference to concave sites, lower parts of the slopes, a vegetation cover which indicates winter snow accumulation and late melting in spring, and shady aspects.

They are rare in high-slope positions, steep gradients, straight or convex reliefs, wind side of the hills, sites dominated by *Festuca*

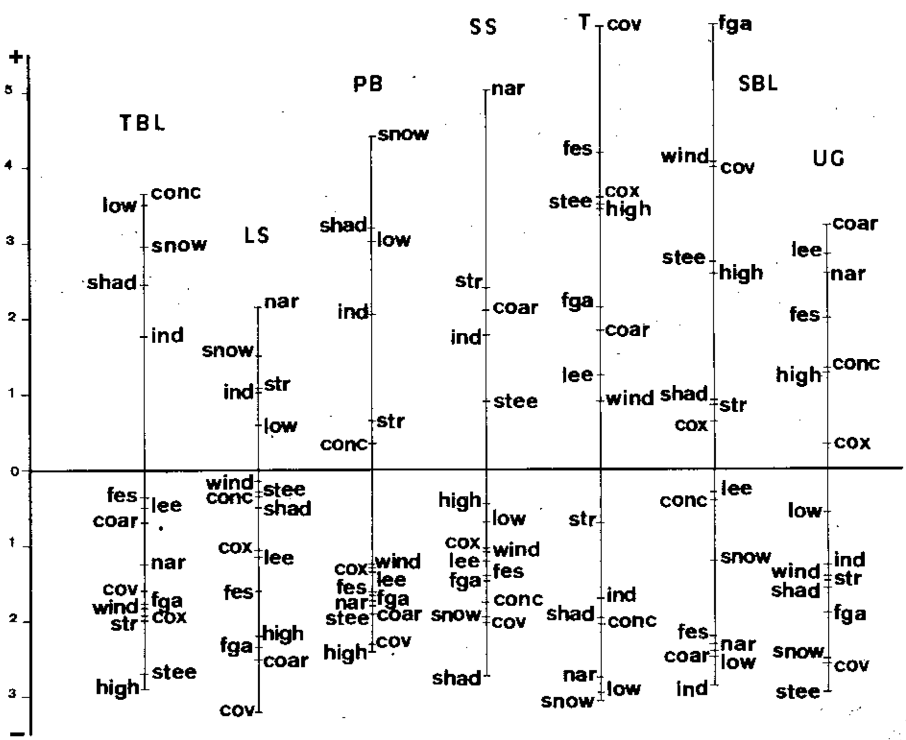

Fig. 2. Ranking of links of the variables for the different landforms (see abbreviations in Table 4).

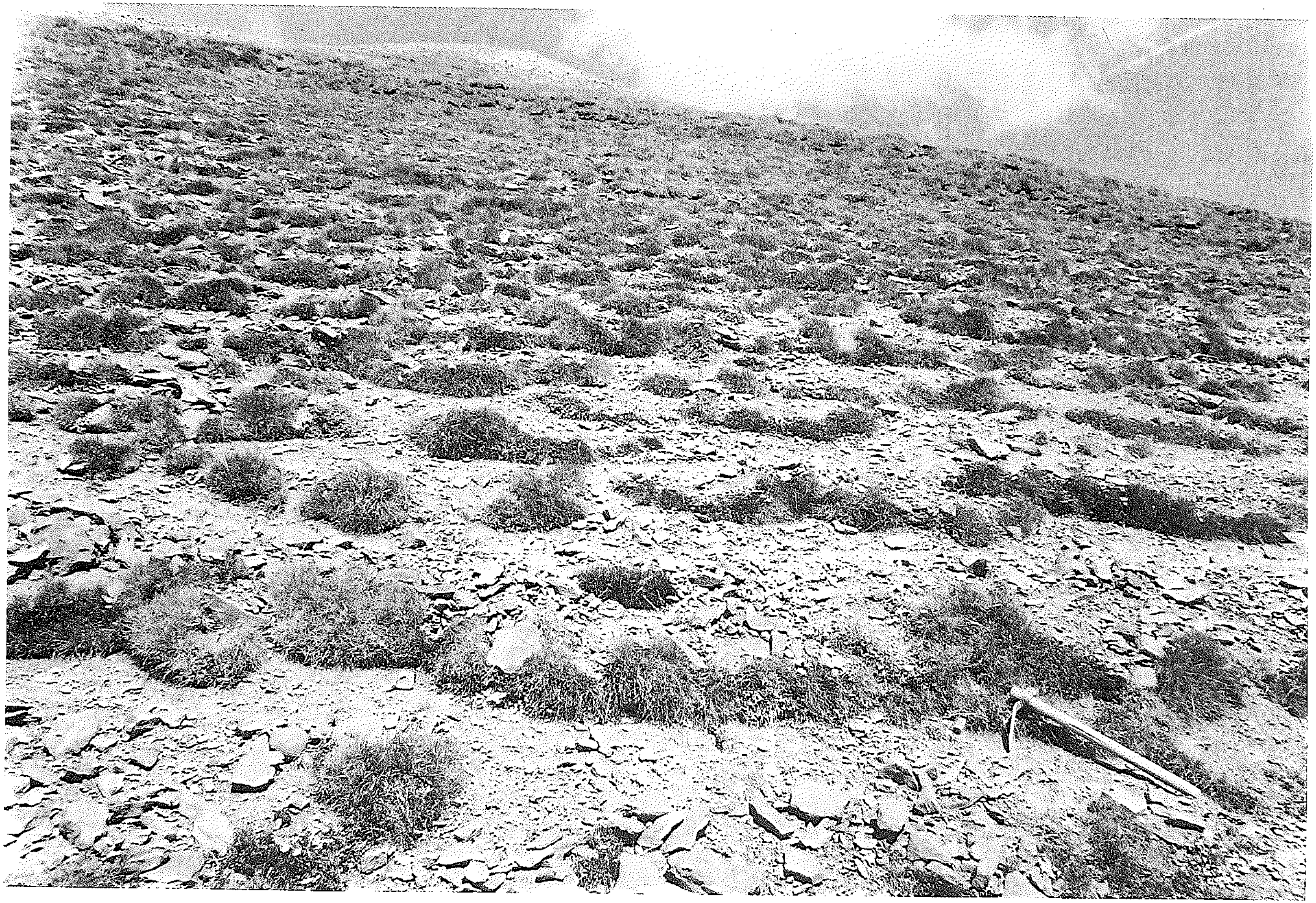

Plate 5. Terracettes (2.140 m. a.s.l.; gradient: 28º, 25 % vegetation comer), in Pico de las Blancas.

gautieri and sites with low plant cover values. Indifferent wind exposures or lee-side ones, *Festuca eskia* or *Nardus stricta* dominance in the plant cover and coarse-grained soils are almost indiferent factors to their occurrence, according to the analysis. A pattern very similar to this is showed by ploughing blocks, although they have a weaker relationship with straight or concave reliefs, and they show a stronger tendency to avoid coarse-grained soils than lobes.

Landslides show the lowest maximum preference value, which happens on sites where *Nardus stricta* is dominant. In contrast, they strongly avoid low vegetation covers and, less strongly, coarse-grained soils, dominance of *Festuca gautieri* and highslope positions.

Small scarps present the maximum value for *Nardus stricta* dominance and, in second place, straight reliefs and coarse-grained soils. They avoid shady aspects, low cover values and snow patches.

Terracettes and stone lobes show the largest range in intensity of linkings. In certain sense they mean an inverted pattern respect to the former landforms, therefore variables that were in the negative part of the graphic in those ones, are now in the positive part. This is true for low plant cover values, vegetation dominated by *Festuca gautieri,* windside of the hills or high position on slopes. Terracettes are positively linked to convex reliefs and, of course, both species of *Festuca,* whereas stone-banked lobes are strongly linked to windward exposures. At the other end, terracettes strongly avoid snow patches and concave sites, while stone-banked lobes tend to be excluded coarse-grained soils and indiferent wind exposures.

Finally, undisturbed grasslands show a conservative pattern, being positively linked to coarse-textured soils, lee sides and plant covers dominated by *Nardus stricta* or *Festuca eskia.* They rarely appear on steep slopes or snow patches.

In the second step of BDA, the matrix of Haberman's d values (Table 4) was processed by using a Principal Component Analysis. Three first factors account for 91.5 % of the variance, and factor loadings of topographical variables on them are presented in Table 5, while landforms are plotted by factor scores on Factors 1, 2 and 3 in Figure 3. First factor explains 49 % of the variance. There is a highly positive correlation with highslope position, convex relief, steep gradient (over 25º) and low plant cover (below 50 %), and a negative one with low position in slope, snow accumulation sites and indiferent wind exposures. So, the first factor can be summarized like a slope position gradient, along of which the terracettes and stone-banked lobes are in the positive extreme and turf-banked lobes, ploughing blocks and landslides in the negative one. Small scarps and undisturbed grassland have a middle position in this ordination. The second factor accounts for 23 % of variance. Straight relief is the main variable at the positive end, and coarse-grain, lee-side and *Festuca eskia* dominance are the most correlated variables with the negative extreme. This is useful to separate stone-banked lobes from terracettes, and ploughing blocks from turf-banked lobes; undisturbed grasslands obtain their most extreme score on the negative side of this factor, being not clearly defined by the other two. The third factor accounts for 19 % of variance. The variables with the highest factor loading at the positive end show windslope position and *Nardus stricta* dominance, while only shady aspect is closely correlated with the negative end. However, the third factor discriminates well the landslides and small scarps (positive) from the ploughing blocks and turf-banked lobes (negative), a distinction which is consistent with the different underlying processes in both groups of landforms.

TABLE 4

Q-mode matrix of d'Haberman values

	Significance (Alpha)	*Turf-banked lobes*	*Landslides*	*Ploughing blocks*	*Small scarps*	*Terracettes*	*Stone-banked lobes*	*Undisturbed grassland*
SHAD	0.01	2.46	—0.50	3.19	—2.72	—1.96	0.89	—1.57
STEE........	0.01	—2.71	—0.32	—1.92	0.90	3.47	2.77	—2.94
COX	0.01	—1.89	—1.05	—1.31	—1.14	3.59	0.63	0.34
STR	0.05	—1.98	1.05	0.63	2.40	—0.70	0.84	—1.46
CONC.......	0.01	3.66	—0.33	0.34	—1.73	—2.06	—1.41	1.33
HIGH........	0.01	—2.92	—2.21	—2.41	—0.47	3.46	2.61	1.29
MID	—	—0.24	1.66	—0.30	1.09	—0.82	—0.40	—0.77
LOW	0.01	3.51	0.60	3.00	—0.69	—2.93	—2.45	—0.57
WIND	0.01	—1.81	—0.15	—1.26	—1.09	0.92	4.05	—1.40
IND	0.01	1.77	1.03	2.04	1.78	—1.71	—2.83	—1.24
LEE	0.05	—0.50	—1.15	—1.37	—1.19	1.27	—0.28	2.87
COV	0.01	—1.63	—3.20	—2.30	—2.01	5.84	4.01	—2.57
FGA.........	0.01	—1.78	—2.34	—1.68	—1.46	2.17	5.89	—1.88
FES	0.01	—0.38	—1.59	—1.63	—1.42	4.19	—2.18	2.11
NAR	0.01	—1.23	2.14	—1.73	5.01	—2.76	—2.32	2.62
SNOW	0.01	2.99	1.51	4.42	—1.96	—3.05	—1.22	—2.51
COAR.......	0.01	—0.07	—2.48	—1.78	2.11	1.86	—2.39	3.25

Abbreviations: COAR: relatively coarse-grained soil. CONC: concave relief. COV: vegetation cover below 50 %. COX: convex relief. FES: vegetation dominated by *Festuca eskia*. FGA: vegetation dominated by *F. gautieri*. HIGH: high position in slope. IND: indiferent wind exposure. LEE: lee-side wind exposure. LOW: low position in slope. MID: mid position in slope. NAR: vegetation dominated by *Nardus stricta*. SHAD: shady-aspect orientation. SNOW: vegetation typical of snowy sites. STEE: slope angle over 25º. STR: straight relief. WIND: wind-side exposure.

5.2. *Discussion of the landforms*

Former results show the response of landforms, or rather of their underlying processes, to the main topographic controls, and how these controls make up a space where each kind of mass wasting feature

Plate 6. Stone-banked lobes (2.140 m. a.s.l.; gradient: 32º; 35 % vegetation cover), in Pico de las Blancas.

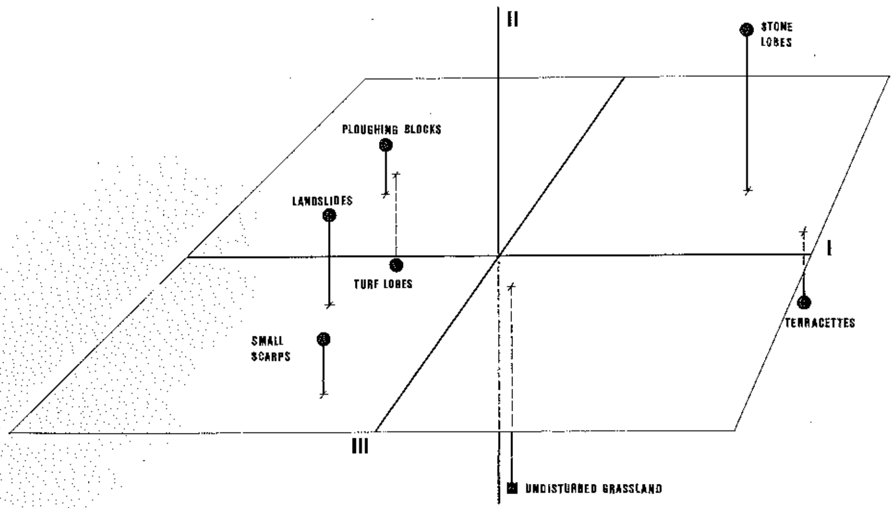

Fig. 3. Landforms plotted by factor scores on Factors 1, 2 and 3 of Q-mode BDA.

finds its optimal place. Now we shall briefly examinate these results to interpret the role that every landform plays in the slope dinamics of the study area.

Turf-banked lobes and ploughing blocks are restricted to thick regoliths in low position on slopes, in smooth gradients, around 20º, on shady aspects (N and NNE respectively, with a great data concentration around the mean, which suggest a limited tolerance in this sense). Concave or straight reliefs and indiferent wind exposures are also preferred conditions, which ensure a normal snow accumulation, avoiding an excesive protection against late-autumn early winter colds. These conditions favour the formation of thick frozen layers in the soil. In addition, these landforms show very high percentages of silt (45-50 %), suggesting a better moisture capacity than coarse grained soils and a lesser cohession than other soils richer in clay. By the way, the percentages of clay are the lowest of all the landforms studied in this work. At this state of knowledge it is difficult to consider whether turf-banked lobes here are inherited or present-day active landforms. We think that some of them are inherited, and probably non active ones, because they are in atypical situations, or they are too large (30 m long). But most part of lobes included in this work are clearly shaped, sometimes with a repetitive vegetation pattern on its surface. Creus and García-Ruíz (1977) measured rates of the movement of lobes in a zone closely located to the study area, obtaining an effective displacement of around 4 cm/year, depending on topographic conditions. Although it is too soon to have definitive rates of movement and stratigraphic profiles,

TABLE 5

Factor loadings from Q-mode BDA of topographic variables. (See abbreviations in Table 4)

	I	*II*	*III*
SHAD	—0.53	0.19	—0.81
STEE	0.79	0.53	0.10
COX	0.93	—0.16	—0.07
STR	—0.03	0.77	0.57
CONC	—0.65	—0.53	—0.43
HIGH	0.99	—0.07	0.02
MID	—0.46	0.50	0.63
LOW	—0.94	—0.14	—0.30
WIND	0.70	0.60	—0.26
IND	—0.89	0.02	0.21
LEE	0.55	—0.77	—0.02
COV	0.87	0.18	—0.34
FGA	0.78	0.44	—0.37
FES	0.56	—0.72	0.00
NAR	—0.31	—0.13	0.90
SHOW	—0.83	0.22	—0.48
COAR	0.30	—0.77	0.46
Variance proportion	0.49	0.23	0.19

it seems likely that these lobes were originated long time ago and a part of them, which were in the adequate topographic conditions, remain active. In contrast, almost all the ploughing blocks probably are active today. Conspicuous linear depressions, sometimes existing a fissure all around the upslope contour of the boulder, and the downslope soil accumulations, suggest an intermitent but present-day movement.

Landslides, unlike the turf-banked lobes and ploughing blocks, are quite widespread, being one of the most important erosion systems affecting to deep regoliths in the Pyrenean high mountain. Slope failures occur when a sudden increase of the soil moisture results in a high pore water pressure (Puigdefábregas and García-Ruiz, 1983). Some conditions favouring this situation are: *Nardus stricta* grassland (which has good capacity of infiltration), snow accumulation sites (which can provide great quantities of melting water), and an average gradient of 21.6º. Mean values of texture and the strongly negative Haberman's d value for relatively coarse soils must be interpreted thinking that the soil sample has been taken from the upper 25 cm of the soil. High pore water pressures may arise when a deep permeable layer, more coarse grained or with voids from old tree root ways, is overlaid by a less permeable, fine grained, soil layer. Landslides present the lowest values of the Haberman's d, which suggests that their linkage to the topographic variables studied here is less intense than the other landforms. Mean orientation values show a relative SW preference, enhancing a quick snowmelting. Nevertheless, even this orientation includes a small concentration (22 %) of cases.

In a certain sense, landslides seem to be landforms of "high variance", occurring as a response to the clearing of forests in any place where there is a suitable combination of factors for local slope failure. Landslides fill the same sub-space than small scarps in the three-dimension space defined by the first factors of Q-mode BDA, and it could be thought than the last landform is an atenuated form of the former.

Terracettes are another important and widespread mass wasting feature at the study area. They tend to occur on thin regoliths, usually on the horizon C of ancient soils which have been previously dismantled. The general shape of a terracette results when the radial and peripheral growing form of the plant is modified by one or more downward vectorial processes: gelifluction, frost creep at the soil surface and slopewash. The final shape depends on the intensity of action of each one of them, and therefore on topographic conditions. According to the results the terracettes are in the high part of the slopes, on convex reliefs and steep gradients, about 27.3º in average. All of them have low cover values, averaging 33.8 %, but it is important to distinguish between two kinds of terracettes, according to the different species of *Festuca*. Such classification is very general, but is supported by the underlying processes. Terracettes of *F. eskia* are characteristic of the lee side of the divides. Those are sites where snow drifts by the wind action forming cornices, and the melting season extends until late spring, when the weather is already too warm for frost processes. Their mean orientation is south, averaging 188º. These terracettes are wider than those of *F. gautieri* (about 1.3 m in average, but reaching 5 m in some cases), and the gravel-size material enbanked by the tread can invade it in a sheet-like form. In contrast, the terracettes of *F. gautieri* have a north-west average orientation (289º), normally occuring at the wind side of the divides, where the ground is frozen on late autumn, there are no snow accumulations and the melting of the snow pack begins on early spring. These terracettes are not so wide, averaging 0.7 m, and there are abundant stony accumulations on the tread, which sometimes cross and split the vegetation border.

The stone-banked lobes are not a widespread landform, but they show typical conditions of occurrence, very often being associated to terracettes of *Festuca gautieri*. The direct exposure to cold prevailing wind, coming from the north-west (mean orientation is 295º) and steep slope angles (about 27.9º) on the high part of the slopes, are characteristic of them. Dominance of *F. gautieri* is a constant to those places where there are stone-banked lobes, showing low cover values around 28 %. If the lobes are very large, for example 8.5 m long, 1.2 m wide and 0,30 m thick at the front, they are parallel one to each other and the vegetation grows in narrow stripes among them. When they are smaller (1.5 x 0.5 x 0.15 m) the vegetation forms terracettes which restrain the downslope movement of debris, which circulates among them on a rate that depends on the microrelief angle. Non published data of G. del Barrio show that in those sites the ground is frozen further down than 0.60 m. of depht on late autumn. There is a 10 cm thick ice cover just over the soil surface, beneath of the snow mantle. Soil under the lobes is fine-textured, averaging 71 % between silts and clays and it is quite muddy in spring, specially when there is a melting layer below which remains a frozen one. Stones making up the lobes could be moving by slipping over this mud and also by frost action, specially the needle ice.

Finally the undisturbed grassland have a tendency to remain in the more stable locations, typically concave and lee sites on highslope positions, frequently mountain passes. Average orientation is south (187º) and the gradient is smooth, around 23.6º. Those are closed grasslands of *Festuca eskia, Nardus stricta* and *Trifolium alpinum* in variable proportions, normally over more than 1 m thick regoliths. Their extension is variable, but the true undisturbed soils are very restricted to the former topographic locations.

6. Conclusions

Three basic topographic gradients explain the distribution of mass wasting features in the Pyrenean high mountain. The first of them represents the slope position as the main topographic control, while the other two are more related to local microtopographic and soil conditions. The second one involves wind exposure, soil texture and slope relief profile. The third gradient shows the opposition between shady and sunny orientations.

Altitude is not a significant factor in this ordination. Such rather surprising result may arise from the fact that the samples have been taken in a relatively narrow altitudinal belt, where the zonal climatic changes induced by altitude are not strong enough to mask the effects of the combination of local topographic factors. Mass wasting features tend to occur in an azonal way in this altitudinal range (1700-2500 m). Their distribution, and that of their underlying processes, can not be explained by a single gradient.

Under this perspective, the high mountain landscape may be viewed as a mosaic with patches distributed in a rather predictible way. Nevertheless, a problem arises about the relationships among the patches. Two extreme hypothesis may be drawn. One of them is that a nature grassland system on deep soil, with building species such as

Nardus stricta, Trifolium alpinum and *Festuca eskia* in variable proportions, has been eroded by several processes according to topographic controls, and today we can only find some remains of that under the most stable relief conditions. To this simple and unidirectional interpretation it may be opposed a second hypothesis according to which several erosion pathways take place semi continuously under topographic control, but in each stage the process may be inverted by the outset of a building plant succession. This outlook would take into account the interconversion among some of the mosaic patches. The former hypothesis assumes that a significant climatic or man management change occured some centuries ago, activating the erosion systems. The later, takes the present day landscape as a result of small and frequent environmental fluctuations that generate a mosaic of constructive and destructive phases related in a cyclic way along the time course.

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