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CORRELATION BETWEEN VEGETATION PATTERN AND MICROMORPHOLOGY IN PERIGLACIAL AREAS OF THE CENTRAL ALPS

RENATO GERDOL* and CLAUDIO SMIRAGLIA**

ABSTRACT.- The distributional patterns of plant species were analyzed within periglacial microforms belonging to the collective groups of patterned grounds and sorted stripes in the Ortles-Cevedale group (Lombardy, Italy). The edges of primitive polygons are practically free of vegetation, whilst the central areas are colonized by pioneer plants of detritic slopes. This is clearly correlated with a low degree of sediment sorting. The morphological evolution of the forms proceeds at a faster rate at the edge of polygons than in the central areas. Vegetation, on he other hand, colonizes the coarse débris at the poligons' edges slowly but colonizes the fine material in the central areas actively. The centre of the most evolved polygons is covered by a carpet of Salix herbacea. Age determinations of Salix shoots are not useful for dating purposes, but provide information about the local microclimate.

RESUMEN.- Se han analizado los modelos de distribución de especies vegetales en microformas periglaciares pertenecientes al tipo de suelos estructurales en el Ortles-Cevedale (Lombardía, Italia). Los límites de los polígonos de piedras están prácticamente libres de vegetación, mientras las áreas centrales están colonizadas por plantas pioneras de laderas pedregosas. La evolución morfológica actúa a mayor velocidad en el borde de los polígonos que en las áreas centrales. Por otro lado, la vegetación coloniza lentamente los bordes de los polígonos, y más activamente las zonas centrales. El centro de la mayoría de los polígonos está cubierto por un manto de Salix herbacea. La determinación de la edad de los vástagos de Salix no ha sido un método útil a efectos cronológicos, pero proporciona información sobre el microclima local.

RESUMÉ.- On étude les modèles de distribution d'espéces végétaux dans microformes périglaciaires appartenants au type de sols structurales dans l'Ortles-Cevedale (Lombardie, Italie). Il n'y a pas de végétation sur les

* Faculty of Agricultural Sciences, University of Padova, Via Gradenigo 6, I-35121 Padova, Italy.
** Faculty of Foreign Languages and Literatures, University "G. D'Annunzio", Viale Pindaro 42, I-65127 Pescara, Italy.

limites des polygones de pierres, tandis que les zones centrales sont couvertes par espéces pionières de versants pierreusses. L'évolution morphologique agit plus rapidement sur le bord des polygones que sur les zones centrales. Au contraire, la végétation colonise lentement les bords des polygones, et plus rapidement les zones centrales. Le centre de la pluspart des polygones est couvert par un tapis de Salix herbacea. La determination de l'âge des rejetons de Salix n'a pas été un méthode très utile pour la chronologie, mais il donne information sur le microclimat local.

Key words: *Patterned grounds, periglacial, plant colonization, Central Alps.*

In periglacial regions the upper surface is subject to modelling due mainly to the activity of discontinuous frost (alternation of freezing and thawing) and to snow. This gives rise to peculiar microforms such as hummocks, patterned grounds, sorted stripes and nets. In most cases the environment is partitioned into a mosaic of microhabitats more or less sharply differentiated from each other with respect to factors such as soil texture, amount of incident radiation, etc. This may, of course, affect the competitive equilibria among plant species, as determined by climatic factors only.

Some attempts have been made so far in relating vegetation pattern to micromorphology in areas subject to periglacial modelling (GIACOMINI & PIROLA, 1959; CARBIENER, 1966; LABROUE & LASCOMBES, 1972; NIMIS, 1985). Though most of them have led to promising results, research in this field is not progressing as one could expect, maybe due to an objective difficulty of standardizing the approach and generalizing the results of such studies.

In this paper we aim to find out how far a collaboration between workers operating in different fields can contribute to throw light onto this matter.

1. The study area

The study area (Fig. 1) is situated in the western part of the Ortles-Cevedale group (region Lombardy, Italy). Research was carried out in two valleys having different characteristics as far as both morphology and lithology are concerned.

1) Valle di Cedèc. The substratum consists of metamorphic rocks (phyllites and micaschists belonging to the Bormio phyllites Formation), with intercalations of diorites, saccharoidal marbles and meso- or subsilicic dykes. The northern sector of the valley, culminating in the Gran Zebrù (3851 m), is made of carbonatic rocks (Ortles dolomites) with intercalations of fine black limestones. In the upper valley there is a large cirque carved by the Pleniglacial and Lateglacial ice masses. It shelters at present two glaciers: the Cedèc Glacier and the Gran Zebrù one. In the Little Ice Age they joined, flowing down until 2500 m above sea level (CATASTA & SMIRAGLIA, in press).

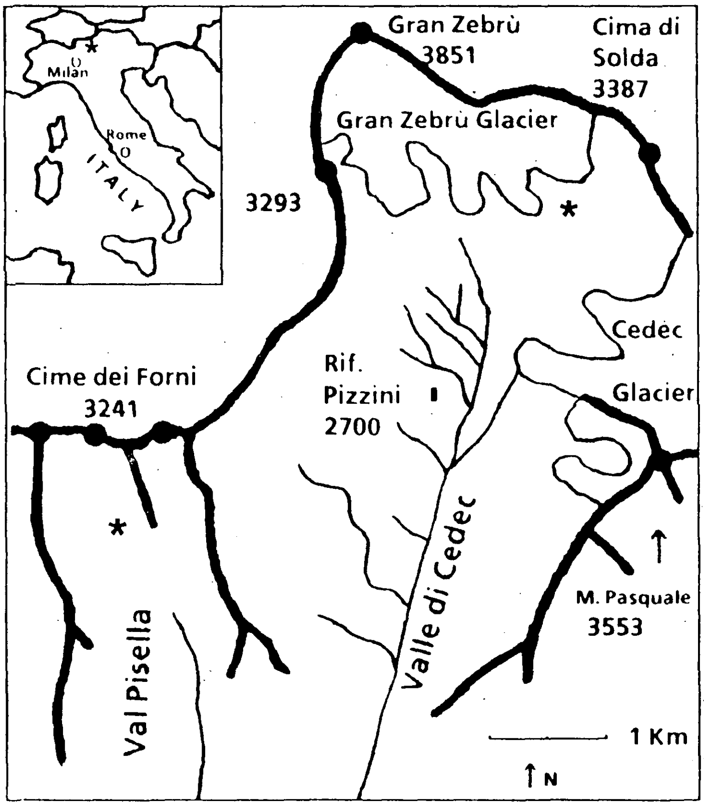

Fig. 1. Schematic map of the study area.

2) Val Pisella. The substratum consists of Bormio phyllites, with more frequent intercalations of quarzites and dykes. Carbonatic rocks do not occur. This valley is delimited by a sharp ridge culminating to considerably lower peaks than those in Valle di Cedèc (Cime dei Forni, 3241 m). The upper section of Val Pisella, fronted downwards by a large Lateglacial moraine, is presently free of glaciers but has three well-developed rock glaciers (GRUPPO NAZIONALE GEOGRAFIA FISICA E GEOMORFOLOGIA C.N.R., 1987).

Research was focused on the areas showing evidence of actual and recent periglacial modelling actions. This happens on the till accumulated in front of the present-day glaciers in Valle di Cedèc and of the rock glaciers in Val Pisella, at altitudes between 2750 and 2950 m. A broad series of forms was observed, the most abundant and interesting of which can be included in the collective categories of patterned grounds and sorted stripes.

The study area has a mountain continental climate. At 2300 m the mean annual temperature is ca. 1.5°C, with a maximum of 9.8°C in July and a minimum of -6.9°C in January, and the mean annual precipitation ca. 922 mm. Unfortunately, there are no meteorogical stations at higher altitudes. On the basis of a mean thermal gradient of 0.64°C x 100 m calculated for this region (BELLONI, 1967), a mean annual air temperature of -1.4°C -2.5°C can be estimated for the altitudinal range covered by this study. Accordingly, the 0°C isotherm of the mean annual temperature should be found at 2534 m. Here the snow cover lasts on the average more than 200 days.

2. Methods

A preliminary campaign was devoted to a speditive survey of the forms (localization and visual description). These were classified and correlated with the available data on the chronology of glacial deposits. A successive campaign was devoted to more detailed investigations on a selected sample of patterned grounds.

A few samples of fine material were collected in the central part of some forms for granulometric analyses and pH determinations. Standard sieving methods were used for the fractions up to sand particles; aerometry for the finer fractions. Mean sizes and standard deviations were calculated by a graphical method. The pH was measured potentiometrically in H_2O.

Vegetation was analyzed separately in the edges and central parts of patterned grounds. The occurrence of all vascular plants, lichens and bryophytes was recorded in small areas of ca. 1 m^2. The cover of every species was estimated visually by the following scale (VAN DER MAAREL, 1979): 1 = rare species; 2 = cover < 1 %; 3 = cover 1-20 %; 5 = cover 21-40 %; 7 = cover 41-60 %; 8 = cover 61-80 %; 9 = cover 81-100 %.

The matrix of floristic data was then treated by a numerical technique of classification (average linkage clustering based on the similarity ratio; ORLOCI, 1978) in order to detect the pattern of floristic similary among the different forms. The nomenclature of species follows PIGNATTI (1982) for vascular plants, FRAHM & FREY (1987) for bryophytes and POELT (1974) for lichens.

In the areas occupied by a dense carpet of dwarf willows (cover of *Salix herbacea* > 50 % of the examined area), a sample of *Salix* shoots was taken for age determinations. All aerial shoots were picked in a 10 x 10 cm area, cut to the rhizome and their ages were determined by counting the number of annual stem segments (WIJK, 1986). The length of the basal segment of each shoot was then measured.

3. Results

Geomorphology

Five main groups of forms were recognized in the field, of which three in Valle di Cedèc (C) and two in Val Pisella (P).

C1) Asymmetrical polygons slightly patterned in the central part, developed on inclined slopes (Fig. 2). Their main axis, ca. 2 m in length, follows the maximal inclination of the slope (10-12°) and their width rarely exceeds 1 m. These forms are well sorted as regards the edge of the stones and the fine-grained central part. The edges consist of phyllite clasts (maximum 20 cm long) with few dioritic ones, very rarely verticalized. The internal zone, 10-15 cm deep, is rich in fine material, with many small-sized clasts. It has a neutral pH (Table 1). This type of form is common not far from the present E snout of the Gran Zebrù glacier at altitudes between 2860 and 2890 m.

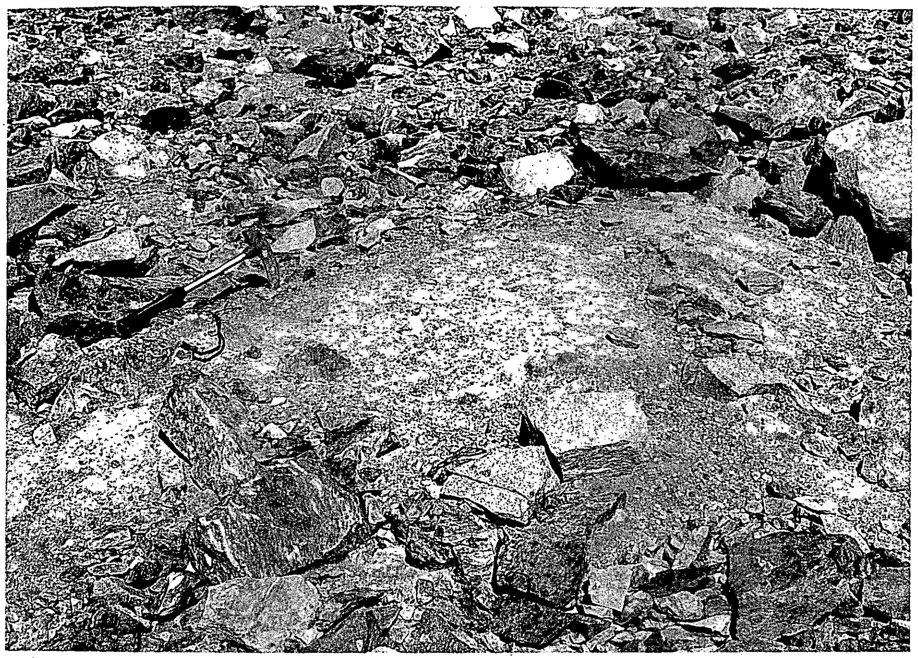

Fig. 2. Asymmetrical polygon in Valle di Cedèc near the snout of the Gran Zebrù glacier, at 2880 m. (C1 in the text).

C2) Regular polygons (main axis 1.5-2 m long), developed on more gently inclined slopes (6-8°). The edges are formed of middle-sized dolomitic pebbles and blocks, rarely verticalized (Fig. 3). The fine central part is up to 25 cm deep, in turn patterned with 1.5 cm deep cracks filled by 3-4 mm large granules. In the fine material there are also many coarse fragments. The pH is basic (Table 1). The degree of development of this type of form seems slightly greater than that of the preceding one. These forms are common near the Gran Zebrù glacier too, but at lower altitudes, (2820-2840 m).

TABLE 1
Texture and pH of the debris in the central part of polygons.
C = Valle di Cedèc; P = Val Pisella.

	C1	C2	C3	P1	P2
Texture (%)					
Gravel and pebbles	43	38	26	9	32
Sand	25	48	30	41	33
Silt	21	13	41	47	32
Clay	11	1	3	3	3
pH	6.7	8.1	6.1	4.9	5.5

Fig. 3. Regular well-sorted polygon in Valle di Cedèc at 2820 m. (C2 in the text).

C3) Large patterned grounds including irregular polygons 5-8 m in length and 3-5 m in width, developed on flat terrains (Fig. 4). The edges are made of large verticalized, mainly phillitic stones (long axis up to 40 cm). The central zone, in turn slightly patterned, is 20-25 cm deep, rich in fine material and a little convex, with a few coarse flat fragments on its surface. The pH is subneutral (Table 1). This type of form is most frequent near the small Lake of Cedèc, in front of a large moraine deposited by the Gran Zebrù glacier, at a lower altitude than both C1 and C2 (2745 m). This type of form can be regarded as more evolved than the preceding ones because of (i) the presence of many verticalized clasts, (ii) the very good sorting between the edges and the inner zones, and (iii) the presence of a distinct pattern in the central areas.

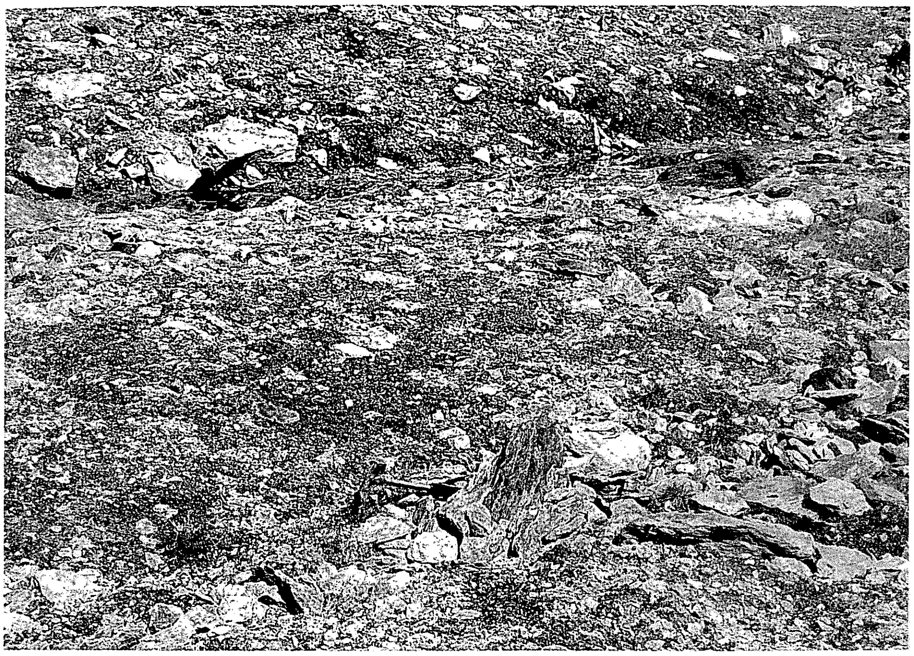

Fig. 4. A part of a large patterned ground with irregular polygons in Valle di Cedèc near the Lake of Cedèc at 2750 m. Note the verticalized clasts in the foreground. (C3 in the text).

P1) Asymmetrical polygons having their main axis ca. 2 m long, developed on little inclined slopes (less than 8°). The stones in the edges are often large (long axis up to 50-70 cm) and sometimes verticalized (Fig. 5). The central zone is 10-15 cm deep, in turn patterned, rich in fine material with only a few coarse flat clasts on its surface. The pH is acid (Table 1). This type of form was observed both in front of the central rock glacier in Val Pisella at 2900 m and near the NE lake of Val Pisella at 2850 m. It is gradually replaced by sorted stripes on steeper slopes (see P2).

P2) Polygons tending to sorted stripes on more inclined slopes (steeper than 8°). They consist of well sorted alternating bands of fine debris (10 cm deep), with an abundant matrix and some coarse fragments, the latter being rarely verticalized. The fine material has an acid pH (Table 1). This type of form was observed in the same area as P1, at altitudes between 2850 and 2920 m.

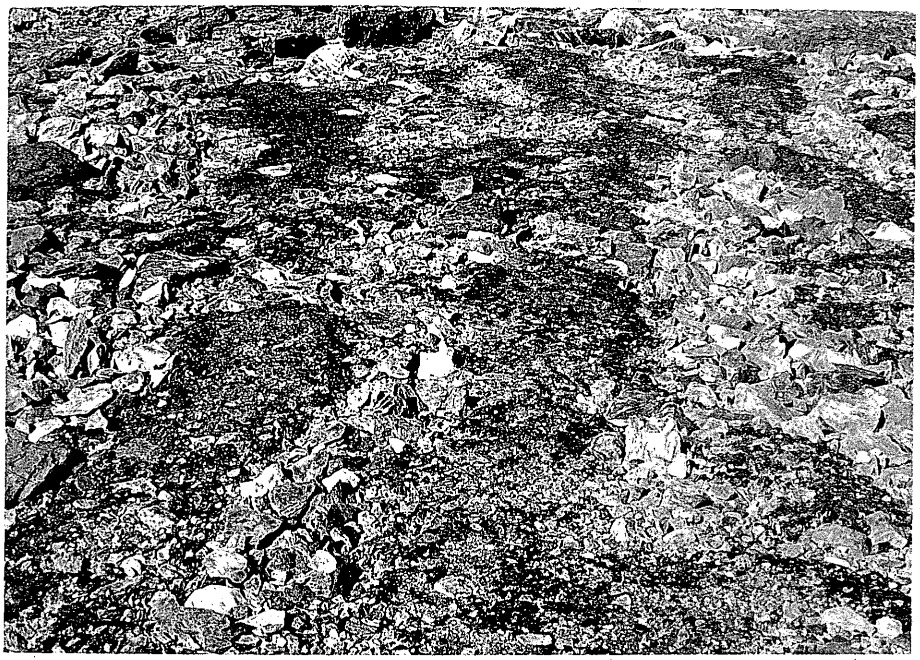

Fig. 5. Asymmetrical polygons tending to sorted stripes in Val Pisella at 2900 m. (P1 in the text).

Historical evidence shows that the upper areas in Valle di Cedèc (C1 and C2) were covered by glaciers at least till the first ten years of the present century. Most of them were probably covered even for a longer period by the Gran Zebrù glacier, which should have waned between the Twenties and the Sixties. The lower area of Valle di Cedèc (C3) was certainly free of ice during the last phase of the Little Ice Age (19th century) and had been probably bare throughout at least the whole Little Ice Age, i.e. for several centuries.

The areas in Val Pisella were deglaciated from the beginning of the Holocene. In fact, the frontal moraine in the upper valley presumably dates back, in fact, to the Tardiglacial.

Vegetation

The vegetation in the examined habitats is characterized by two main groups of plants, the one being characteristic of detritic slopes (class

Thlaspietea rotundifolii) and the other of snow-beds (class *Salicetea herbaceae)*. There is moreover a relatively low number of plants not specifically linked to any type of habitat, of which several are mosses and lichens (Table 2).

TABLE 2

Floristic table structured according to the numerical classification of data. The symbols in the heading refer to the clusters in the dendrogram (see Fig. 5). c = central area of polygons; e = edge.

Cluster	A					B1						B2				
Relevé n.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Location	c	c	e	c	c	c	c	e	e	c	e	e	e	c	c	c
<u>Thlaspietea rotundifolii</u>																
Poa laxa	2	2	2		2		2	2							2	
Geum reptans	3	3	2		2	2		3	3	2	3					
Ranunculus glacialis	2	2										2	2			
Oxyria digyna			3		3					2	2					
Saxifraga bryoides						5	2	2	3							
Androsace alpina														2	2	
Arabis alpina	2	2									2					
Linaria alpina		2	2		2											
Saxifraga oppositifolia					3	2	3	2		3	2					
Cerastium uniflorum			2		2		3			2						
Cerastium pedunculatum		2										2	2			
Achillea nana						2				3	3					
Artemisia genipi						2	2	2								
<u>Salicetea herbaceae</u>																
Arabis caerulea	2	3	2	2	3	2			2	2	2					
Saxifraga androsacea										2				2		2
Pohlia cucullata					7	2	3	2				3	2	3	5	3
Salix herbacea						3	2		2	7	2			2		7
Cerastium cerastioides										2		2		3	2	2
Gnaphalium supinum									2	2	2	2	2	2	2	2
Anthelia juratzkana						3	5		2	2						
Polytrichum sexangulare						2	2			2				7	2	3
Leucanthemopsis alpina						2	2	3	2		2	3		2	2	
Cardamine bellidif. ssp. alpina												2	2	2		2
Kiaeria starkei													2			3
Veronica alpina						2			2	3	2	2	3	3	2	3
Sagina saginoides										2	2	2		2	2	
Gentiana bavarica						2								2		2
Arenaria biflora													2			2
Companions																
Vascular plants																
Taraxacum alpinum										3	3		2			2
Euphrasia minima						2				3						
Poa alpina						2			2	2	2		2			2
Sedum atratum										2						2
Bryophytes																
Desmatodon latifolius	2	2	2											2	2	
Polytrichum piliferum	2	3				3	3	3					3			
Bryum mildeanum	2	2	3	5	2					2	2					
Ditrichum heteromallum										3	2					
Bryum capillare										2	2					
Brachythecium glaciale											2					2
Weisia tortilis														3	2	
Marsupella varians															2	2
Lichens																
Solorina crocea										2				3		2
Saccomorpha uliginosa						5	5		2							
Rare species	-	-	1	-	1	2	1	-	-	2	-	-	-	1	-	-

The numerical classification of the floristic data gives rise to 2 main clusters of relevés (Fig. 6). The first of them (Table 2, cluster A) corresponds to the pioneer habitats in Valle di Cedèc (soil samples C1 and C2). Four of the five relevés refer to the central areas of polygons, their edges being usually free of vegetation. The cover of vascular plants is low, usually not exceeding 10 % (Table 3). The mosses, on the other hand, may develop over 50 % of the surface, especially in the more distinctly patterned areas (C2).

TABLE 3

Synthesis of the floristic data (see Table 2). The references to soil samples refer to Table 1.
c = central part of polygons; e = edge.

Relevé n.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Location	c	c	e	c	c	c	c	e	e	c	e	e	e	c	c	c
Soil sample		C1		C2						C3				P1		P2
Number of species	8	10	9	2	10	19	13	8	9	24	18	9	11	16	12	17
Percentage cover																
Vascular plants	5	10	5	1	35	50	20	10	5	80	40	5	15	20	2	50
Cryptogams	1	5	5	30	50	70	60	5	1	30	5	5	10	90	40	50
Thlaspietea r.	53	56	61	-	54	30	35	58	30	22	32	20	17	5	15	-
Salicetea h.	12	13	11	28	38	42	41	26	50	44	38	80	54	75	63	69
Comp. vascular pl.	-	-	-	-	-	9	-	-	10	18	14	-	17	-	-	18
" bryophytes	35	31	28	72	8	7	9	16	-	13	16	-	12	12	22	9
" lichens	-	-	-	-	-	12	15	-	10	3	-	-	-	8	-	4

The vegetation of cluster A is poor in species, the total number of which does not exceed 10 per relevé. The set of *Thlaspietea rotundifolii* plants is far the most abundant. The *Salicetea herbaceae* group, on the other hand, is poorly represented, with the only exception of *Arabis caerulea.* This species, in fact, is linked to the basiphytic snow-beds that are frequently developed on detritic grounds (OBERDOFER, 1977). The basiphilous moss *Bryum mildeanum* is clearly linked to this cluster too.

The second main cluster (Fig. 6) corresponds to more evolved forms, whose vegetation is denser and richer in species (Tables 2 and 3), occupying both the edges and the central areas of the patterned grounds. This cluster splits into two distinct subclusters (B1 and B2; Fig. 6), the first of which corresponds to the forms in Valle di Cedèc and the other to those in Val Pisella.

The vegetation of subcluster B1 is made of plants included in both main phytosociological groups: *Thlaspietea rotundifolii* and *Salicetea herbaceae.*

The cover of the former, however, is on the average higher in the edges (mean cover 37 %) than in the central parts (mean cover 29 %) of polygons. Subcluster B1 further splits into two smaller groups. The first of them (Table 2, rel. 6-9) corresponds to more primitive forms richer in *Thlaspietea rotundifolii* species, among which *Saxifraga bryoides* and *Artemisia genipi* are exclusive of this subgroup. The second one (Table 2, rel. 10-11) corresponds, on the other hand, to more evolved forms rich in species of the *Salicetea herbaceae.* The vegetation is denser and richer in species (Table 3). The central part of these polygons is entirely covered by a carpet of *Salix herbacea,* under which a layer of raw humus develops (Table 2, rel. 10, corresponding to sample C3).

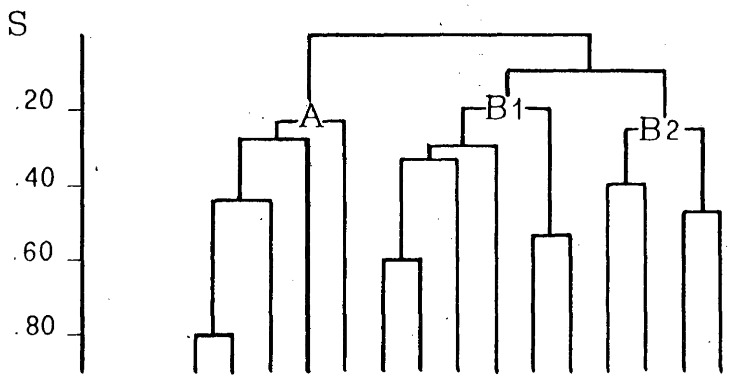

Fig. 6. Classification dendrogram of the floristic data. The sequence of relevés is the same as in Table 2. A, B1 and B2 are the main clusters; S = similarity ratio.

The vegetation of subcluster B2 (Table 2), including all of the patterned grounds examined in Val Pisella, is mainly formed by plants typical of snow-beds (*Salicetea herbaeeae;* Table 3). In the relevés there are only four species typical of detritic slopes, i.e. *Poa laxa, Ranunculus glacialis, Androsace alpina* and *Cerastium pedunculatum.* All of them are acidophilous. All *Salicetea herbaceae* species occurring in this subcluster (see Table 2) are more or less markedly acidophilous. Only the basiphilous *Arabis caerulea,* frequently recorded in Valle di Cedèc, is completely lacking in the Val Pisella patterned ground. These observations, based on the indicator value of the plants, are in good accordance with the pH values measured in the soil samples (Table 1).

The vegetation of the edges and that of the central parts of the polygons included in subcluster B2 are clearly separated from each other, giving rise to 2 different subgroups (Fig. 6). The former is somewhat richer is species typical of detritic slopes (mean cover of the *Thlaspietea rotundifolii* group, 18 %; see Table 3), than the latter (mean cover 7 %). In the more primitive forms the vegetation of the central parts of polygons is richer in cryptogams, especially *Polytrichum sexangulare* (Table 2, rel. 14, corresponding to sample P1). In the more evolved ones (Table 2, rel. 16, corresponding to sample P2), more than half of the surface is covered by *Salix herbacea*.

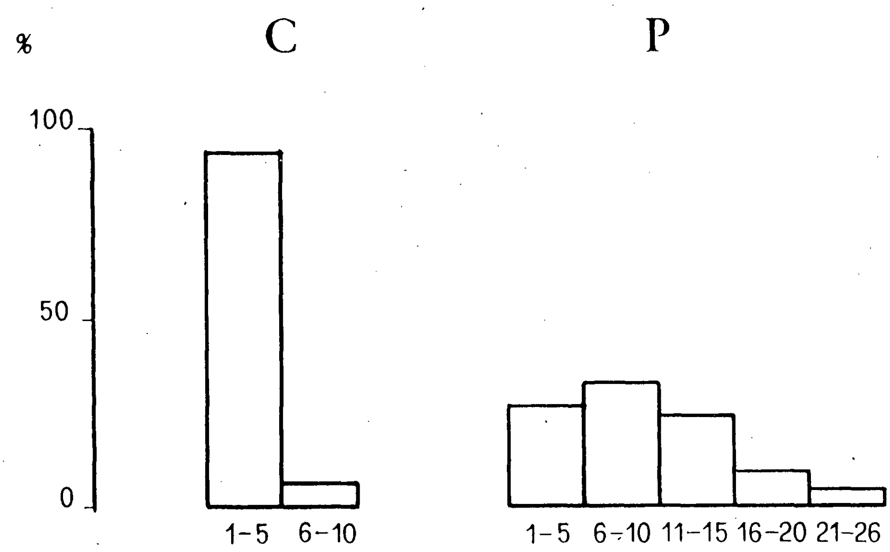

Fig. 7. Age distributions of *Salix herbacea* shoots. The proportions of shoots in each distribution class are represented for Valle di Cedèc (C) and Val Pisella (P).

The shoot-age distributions recorded in the *Salix herbacea* populations of Valle di Cedèc (Table 2, rel. 10) and Val Pisella (Table 2, rel. 16) are very different from each other. In the former, young shoots dominate and no shoot is more than 6 years old. In the latter, the shoot ages are spread over five distribution classes with a slight peak in the 6.10 years one (Fig. 7). The oldest shoot in the Val Pisella population is 26 years old. Though belonging to younger individuals, the basal segments of aerial shoots in the Val Cedèc *Salix* population are significantly longer (Table 4) than those in the Val Pisella one.

4. Discussion

The evolution of the periglacial forms included in the collective categories of patterned grounds and sorted stripes can be schematically partitioned into three phases:

TABLE 4

Mean lengths (mm) of the basal segments of Salix herbacea shoots measured in the two polygons convered by a carpet of dwar willows.
N = 30 aerial shoots.
C = Valle de Cedèc (Site corresponding to rel. n. 10 in Table 2);
P = Val Pisella (site corresponding to rel. n. 16 in Table 2).

	C	P
Mean length ± st. dv.	11.14 ± 2.52	5.06 ± 1.41

$t = 11.34$ ($P < 0.01$)

1) Initial phase, corresponding to the beginning of debris selection.

2) Mature phase, during which a clear sorting of the debris is achieved. As a consequence, pebbles are moved away from the centre and gradually accumulate at the edges, where they tend to assume a vertical orientation. The finer debris in the central part may be further structured giving rise to a smaller-scale pattern.

3) Senile phase, during which no appreciable process of debris sorting is active any longer.

The lapses of time involved in both the initial and the mature phases are affected by environmental factors such as climate and soil-water content, in turn conditioned by altitude, aspect and lithology. Vegetation cannot be included amongst the major factors controlling the evolution of these forms, at least not in the regions presently subject to periglacial modelling. Only in the senile phase, which can theoretically last indefinitely, vetegation may contribute to modify the soil patterns derived by periglacial modelling or even entirely mask them, usually by pedogenetic processes.

There is a substantial coincidence between micromorphology and vegetation in the study area, at least as far as the main results are concerned.

The forms that can be categorized as primitive (C1 and C2) usually have in fact a low degree of plant cover. The edges of the polygons are mostly free of vegetation, whilst the central areas are covered by cryptogams and some pioneer vascular plants indicating detritic habitats. This is clearly related to a low degree of sediment sorting.

With regard to the evolution of the forms, there is a photographic documentation showing that the position of the biggest pebbles in the edge of polygons has not undergone any appreciable change for decades (SMIRAGLIA, 1987). The edges of polygons, however, are colonized slowly by plants. On the other hand, the fine material in the central areas of polygons moves actively year after year, as demonstrated both by field observations and by laboratory experiments (PISSART, 1980; C.N.R.S., 1980). Vegetation probably plays some role in stabilizing the fine debris. The colonization of the central areas proceeds in most cases centripetally, as shown by the presence of small areas free of plants in the very centre of some primitive polygons.

This might represent a general process, as it entirely reproduces the pattern observed in the Svalbard Archipelago (MATTICK, 1952).

The primitive forms are presumably still progressing. It is difficult however to make any prevision both about the rate of sediment sorting and the amount of variation in vegetation. Both may vary considerably in relation to the habitat. We think that a periodical small-scale mapping, combining micromorphology and vegetation pattern (see BROSSARD *et al,* 1984) in permanent plots, is required to further investigations in this field.

All mature forms (C3, P1, P2) have a denser vegetation cover richer in vascular plants. Especially in the mature forms of Valle di Cedèc (C3) the sediments show evidence of pedogenesis (Table 1) which is completely lacking in primitive polygons.

The edges of these mature forms have several plant species of detritic habitats, whereas the central areas have a vegetation typical of snow beds. The latter seems to have reached a steady state more or less close to the climax, which is locally represented by the *Salicetum herbaceae.* Such a vegetation can therefore persist practically unmodified provided the climate does not change dramatically.

The age structures of *Salix herbacea* populations are not fit for dating mature grounds, since the oldest individuals of dwarf willow never exceed an age of 50 years (PALMER & MILLER, 1961). They can give, however, good indications about the local microclimate. The aerial shoots of *Salix herbacea* grow faster in Val Cedèc than in Val Pisella, indicating a shorter duration of snow in the former. Dwarf willow has, in fact, its physiological optimum in microclimatically not too severe habitats, but it is confined to late-exposed areas by competition from other species (WIJK, 1986). The lower average shoot age in Val Cedèc may be due either to a competitive effect reducing shoot survival, or to a more rapid rate of turnover within the population itself.

The vegetation in the edges of polygons, on the other hand, is subject to progress as the sediment will be affected by pedogenesis. Such an evolution can be expected to proceed extremely slowly, since weathering of coarse debris is greatly hindered in periglacial regions.

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