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VEGETATION PATTERNS AND DYNAMICS ON A ROCK GLACIER IN THE NORTHERN APENNINES[1]

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ABSTRACT.- The vegetation colonizing a rock glacier in the north-western cirque of M. Giovo (Northern Apennines) was recorded according to the Braun-Blanquet method. Numerical methods were employed both to classify and to order the phytosociological relevés. Relevés were classified by average linkage based on the similarity ratio. Four main vegetation types were so identified. They were ecologically characterized by an indirect gradient analysis based on correspondence analysis. Furthermore, dynamic connections between vegetation types were hypothsized by principal component analysis.

RESUMEN.- Modelos de vegetación y dinámica en un glaciar rocoso de los Apeninos del Norte (Norte de Italia). *Se ha muestreado, según el método fitosociológico de Braun-Blanquet, la colonización vegetal de un glaciar rocoso en el circo glaciar noroeste del M. Giovo (Norte de los Apeninos). Los muestreos han sido clasificados por métodos de análisis numérico. Se definen cuatro modelos de vegetación con la ayuda de la clasificación numérica. El estudio ecológico de los modelos de vegetación se ha realizado con la ayuda del análisis de correspondencias y se ha verificado con el empleo de los valores indicadores ecológicos de LANDOLT (1977). Las tendencias dinámicas de la vegetación se definen con el análisis de componenetes principales.*

RESUMÉ.- Groupments végétaux et dynamique de la végétation sur un glacier rocheux dans les Apennins du Nord (Italie du Nord). *La végétation colonisant un glacier rocheux dans le cirque glaciaire nord-ouest du M. Giovo (Apennins du Nord) à été relevé selon le method phytosociologique. Les relevés ont été classifiés et ordonnés par des méthodes d'analyse numérique. 4 types de végétation ont été définis a l'aide de la classification numérique. L'étude ecologique des types de végétation à été realisée par l'analyse des correspondances et verifié avec l'emploi des valeurs indicatrices ecologiques du Landolt. Les tendances dynamiques de la végétation ont été définis à l'aide de l'analyse en composantes principales.*

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The study of the correlations between landforms and vegetation is of great interest to both geomorphologists and geobotanists. This is especially true in the regions above the timberline, where vegetation cover strictly interacts with weathering processes in modelling landscape.

In particular, geomorphologists are mainly concerned with the role played by vegetation in slope dynamics (SOUTADÉ, 1980) and in the evolution of glacial and periglacial landforms (TRICART & CAILLEUX, 1967), whereas geobotanists analyze the influence of morphotypes on vegetation cover (PIROLA, 1959; MÜLLER, 1962; CARBIENER, 1966).

In recent years, there has been a growing interest in the study of vegetation patterns related to geomorphology (RITTER & MATHIEU, 1976; KLUG-PÜMPEL, 1982; BALCERKIEWICZ & WOJTERSKA, 1985; BAUDIERE *et al.*, 1985; DELPECH, 1985). In several cases, a quantitative approach, based on the adoption of numerical analyses, was followed (PETIT *et al.*, 1984; GERDOL *et al.*, 1985; TOMASELLI *et al.*, 1989).

This paper examines the relationships between landforms and vegetation in the widest and best characterized rock glacier of the Northern Apennines, a well-documented mountain system from the geomorphological viewpoint. The study is based on a numerical treatment of vegetation data.

1. The field area

The Northern Apennines form a narrow mountain barrier 250 kms long between the Po plain northwards and the Italian Peninsula southwards at latitude 44° N. They include only very few peaks exceeding 2000 m above sea level. The highest peak is M. Cimone (2165 m).

In the summit areas the geological substratum mostly consists of sandstones and marls deposited from the upper Oligocene to the lower Miocene. Most of them correspond to the so-called "Macigno" formation (DALLAN NARDI & NARDI, 1974).

The Northern Apennines were subjec to glaciation during the Quaternary (LOSACCO, 1982), but owing to the lower altitude of the mountains and the relatively mild climate, influenced by the Tyrrhenian Sea, the extent of the glaciers was not as great as in the Alps. At present, active glaciers are lacking completely; nevertheless both glacial and periglacial modelling left evident features on the northern slope of the chain (CARTON & PANIZZA, 1988).

This paper is concerned with a large accumulation of debris located in the northwestern glacial cirque of M. Giovo, a summit of the Northern Apennines lying not far from Modena, Emilia-Romagna region, Italy (Fig. 1). It was interpreted as a rock glaciar (CARTON PANIZZA, 1988) and extends over a surface of 0,20 Km^2 ranging from 1760 to 1850 m of altitude. The form is

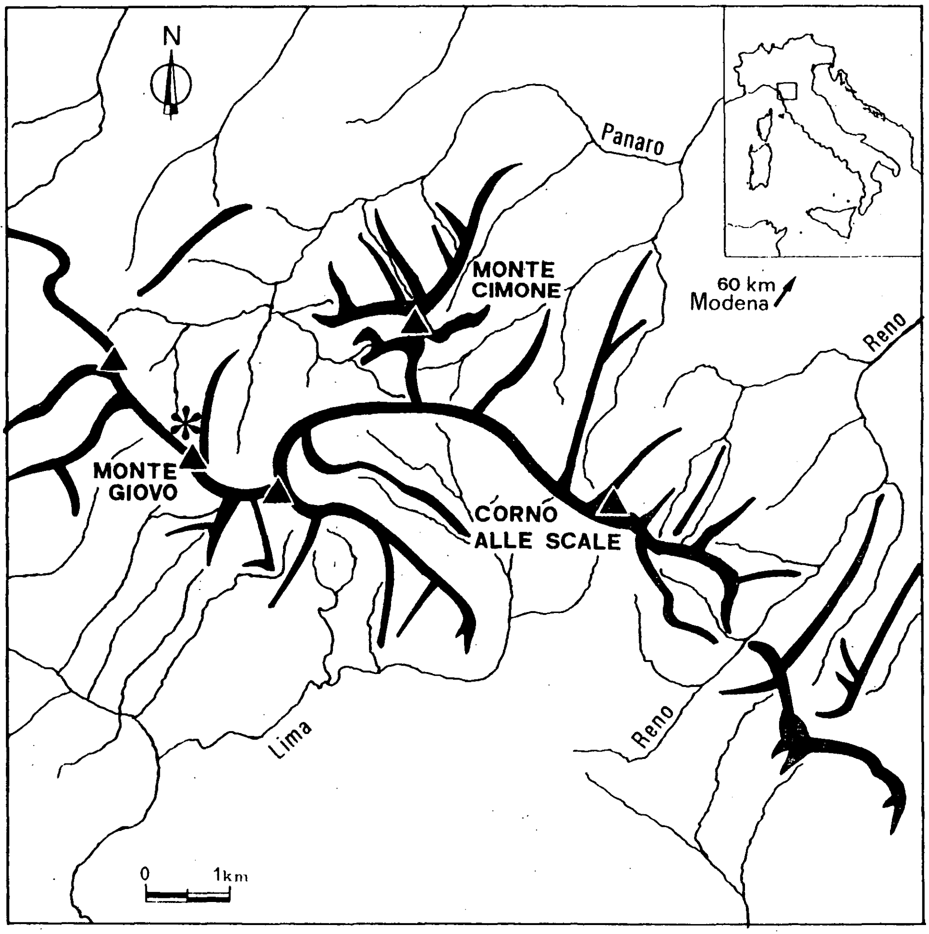

Fig. 1: Location of study area. The asterisk corresponds to the glacial cirque of M. Giovo.

elongated and the deposits consist of angular boulders, locally overlain by finer talus debris. The front is rounded off and not too steep (25° at the angle of repose). Topographic features such as lateral furrows, flow ridges and slumping structures associated with the melting of the internal ice-core are clearly evident. Nowadays the debris body of the rock glacier is for a large part covered by vegetation. Figure 2 illustrates the essential geomorphological characteristics of the area.

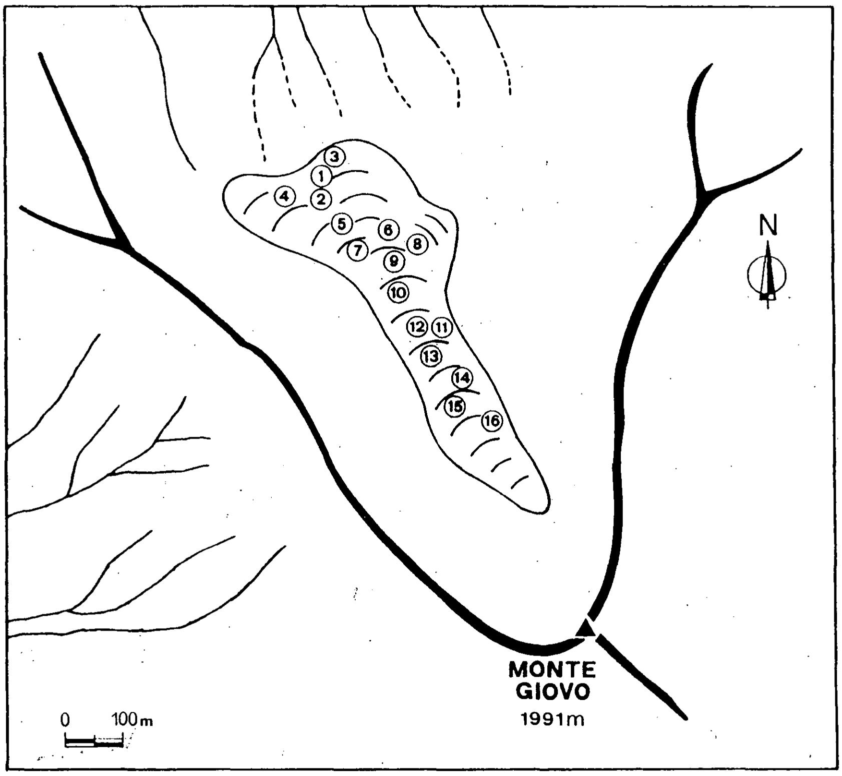

Fig. 2: Geomorphological map of the norhwestern cirque of M. Giovo. Numbers within circles indicate the sites of relevés.

2. Methods

This study was based on a set of 16 phytosociological relevés carried out in geomorphological units identified on the field. Vegetation types were defined by the numerical classification of the matrix including 59 species and 16 relevés. The method was average linkage clustering between merged groups based on the similarity ratio as resemblance index (ORLOCI, 1978). Calculation was based on presence-absence data.

Species were grouped according to their discriminant power with respect to vegetation types at the probability threshold of 95%. To this aim, a technique based on the information theory was adopted (FEOLI, 1976). Computer program NESTOFL (FEOLI *et al.,* 1984) was used for computations.

Ecology of vegetation types was inferred through an ordination of relevés based on the reciprocal averaging (HILL, 1973). To correlate the patterns in ordination with that in environmental factors the ecological indicator values of LANDOLT (1977) were calculated on the basis of species frequencies.

Vegetation dynamics was hypothesized on the basis of a numerical ordination of relevés. With this aim, we have applied principal component analysis based on the log-transformation of the similarity ratio matrix (FEOLI-CHIAPELLA & FEOLI, 1977).

Species nomenclature was based on PIGNATTI (1982) for vascular plants, on CORLEY *et al.* (1981) for mosses and on NIMIS (1987) for lichens.

The basic syntaxonomical scheme was taken from OBERDORFER (1983).

3. Results

Typology

Four main clusters of relevés (NS, CC, VM, VG) can be recognized at the value of about 0.28 of the similarity ratio (Fig. 3). They correspond to

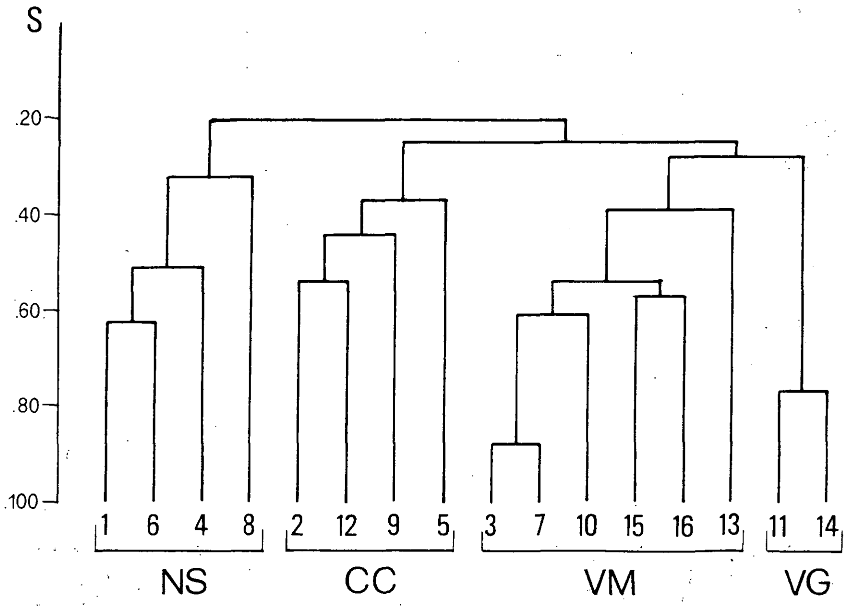

Fig. 3: Dendrogram of classification of the relevés (S = similarity ratio). NS: community of *Nardus stricta;* CC: community of *Cryptogramma crispa;* VM: community of *Vaccinium myrtillus;* VG: community of *Vaccinium gaultherioides.*

vegetation types floristically characterized by species groups 1-4 (Table 1). With regard to syntaxonomy, the vegetation types are designated here as "communities", based on the dominant species. Syntaxonomy is not analyzed here because this study is restricted to a limited area and many syntaxonomical problems concerning vegetation in the Northern Apennines are still open.

TABLE 1

The vetegation data ordered according to the numerical classification of relevés and subdivision of species. Denomination of vegetation types as in Fig. 3.

Relevé n.	1	6	4	8	2	12	9	5	3	7	10	15	16	13	11	14	
Elevation (m x 10)	176	176	176	177	177	179	177	176	177	177	178	181	181	180	179	180	
Aspect	-	-	-	-	N	N	WNW	E	WSW	-	NE	NW	NW	NW	ESE	WNW	
Slope angle (°)	2	-	-	-	40	10	20	-	25	25	25	10	10	20	-	10	
Relevé area (m²)	8	5	5	5	20	50	30	10	10	20	30	10	10	10	10	5	
Covered surface (%)	100	100	100	100	40	20	10	40	80	90	90	90	100	90	65	70	
Total number of species	6	6	7	6	24	17	14	12	17	15	16	19	14	24	20	19	
	NS				CC				VM						VG		Presences
1 *Nardus stricta*	5	5	5	5	+		1	1	2	4	1	+	+				12
2 *Cryptogramma crispa*				+	2	1	1	2									5
Festuca macrathera					1	+	1	+									4
Viola biflora					+	1		+									3
Luzula alpino-pilosa		+		+			+	1									4
Dryopteris expansa					1	+											2
Polystichum lonchitis					r	r	r	r									4
Cardamine resedifolia					+		+										2
Thelypteris phegopteris					+	+											2
3 *Vaccinium myrtillus*					1				+	+	3	3	4	3	+	+	7
Juncus trifidus					1	1	+		1	+	1	+	+	2	1	2	11
Festuca rubra					+	+	+	1	1	1	1	1	1	1			10
Phyteuma hemisphaericum					+	+	+		1	1	+	+		+	+	1	10
Hypericum richeri					+	+		+	+	+	+	+	1	+			9
Geum montanum	+	+	+		+			+	1	1	+	1	1	+			11
4 *Antennaria dioica*															2	1	2
Cetraria islandica												+		1	2	2	4
Alchemilla flabellata															+	+	2
Agrostis rupestris															+	+	2
Hieracium pilosella															+	+	2
Thymus alpigenus															+	+	2
Vaccinium gaultherioides									+	+	1	2	+	1	3	3	8
Juniperus nana					+				+		2			+	+	+	6
Poa alpina	1	1	1	1	+	+	+	+	+	1	1	+	1		+	+	15
Alchemilla saxatilis	+	+	+		1	1	+	+	+	+	+	+	+	+	+	+	15
Carex sempervirens	+		+		+	+			2	1	+	1	+	1	1	+	12
Crepis aurea subsp. glabrescens	+	+		+	+		+		+	1							7
Plantago alpina				+					+	+	+				+		5
Leontodon helveticus											+	+	+	+			4
Aster bellidiastrum						r								+	+	+	4
Homogyne alpina											+	+		1			3
Euphrasia minima														+	+	+	3
Polygala alpestris											+	+		+			3
Viola calcarata subsp. cavillieri									+	+				+			3
Campanula scheuchzeri					+								+				2
Cladonia sp.												+		+			2
Dryopteris filix-mas					1										+		2
Huperzia selago														+		+	2
Potentilla aurea									+			+					2
Pulsatilla alpina					+									+			2
Sedum alpestre						r	+										2
Saxifraga paniculata															r	r	2
Number of rare species			2		2	1		1				1		4	2	1	

Community of Nardus stricta (NS). This community is characterized by species group 1, including only *Nardus stricta*. Physiognomically, it appears as a grassland dominated by *Nardus stricta*. Floristically, it is very poor with a mean number of species for relevé of 6.2. On the basis of the occurence of *Geum montanum* and *Gentiana kochiana* this community can be referred to the alliance *Nardion*.

Community of Cryptogramma crispa (CC). This community is characterized by species group 2 and has *Cryptogramma crispa* as dominant species. The species group includes some species belonging to the class *Thlaspietea rotundifolii (Cardamine resedifolia, Polystichum lonchitis)* and other ones locally linked to talus slopes or block-fields *(Dryopteris expansa, Viola biflora, Thelypteris phegopteris)*. Syntaxonomically, this phytocoenon can be referred to the class *Thlaspietea rotundifolii*.

Comunity of Vaccinium myrtillus (VM). This community is characterized by species group 3 and has *Vaccinium myrtillus* as the dominant species. Physiognomically, it appears as a heath enriched by several grassland species such as *Nardus stricta, Juncus trifidus, Carex sempervirens* and *Festuca rubra*. Syntaxonomically, this community probably corresponds to the *Vaccinio-Hyperichetum richeri* Pirola e Corbetta 1971. Relevés 3 and 7 are characterized by a reduced occurrence of *Vaccinium myrtillus* and by high cover values of *Nardus stricta*, becoming the dominant species. They show transitional features towards the *Violo cavillieri-Nardetum* Credaro e Pirola 1975.

Community of Vaccinium gaultherioides (VG). This community is characterized by species group 4 and has *Vaccinium gaultherioides* as the dominant species. It shows a relatively high similarity with the community of *Vaccinium myrtillus* (0.28 of similarity ratio). Physiognomically, this community appears as an open heath particularly rich in *Nardetalia* and *Caricetalia curvulae* species. Syntaxonomically, it can be referred to the *Loiseleurio-Vaccinion*.

4. Ecology

Four main grouplings exactly agreeing with the above vegetation types, are individuated by reciprocal averaging (Fig. 4). The positions of these groupings in the diagram having the two first canonical variates as axes reflect two different environmental gradients. Axis 1 can be explained as an ecocline of soil moisture, mostly conditioned by the length of the snow cover. It is, in fact, correlated with the humidity value (F) indicating the average moisture of the soil during the growing season (Table 2). The gradient decreases from the communities of *Nardus stricta* and *Cryptogramma*

TABLE 2

Correlation coefficients between ordination axes 1 and 2 and Landolt's ecological indicator values F and D. In parentheses Student's T value at the 1% level of significance for 14 degrees of freedom.

Canonical Variate	Ecological Indicator Value	Correlation Coefficient	Student's T at 14 degrees of freedom
I	F	0.90	7.71(6.96)
II	D	-0.89	7.51 (6.96)

crispa (positive values) to the community of *Vaccinium gaultherioides* (negative values). Axis 2 is negatively correlated with the dispersion value (D) defining the size of the particles and the aeration of the soil (Table 2). Therefore, it can be interpreted as an ecocline of soil texture, with the gradient decreasing from the community of *Cryptogramma crispa* (positive values) to the community of *Nardus stricta* (negative values). The community of *Vaccinium myrtillus* occupies a central position in the ordination plot corresponding to intermediate conditions along both gradients.

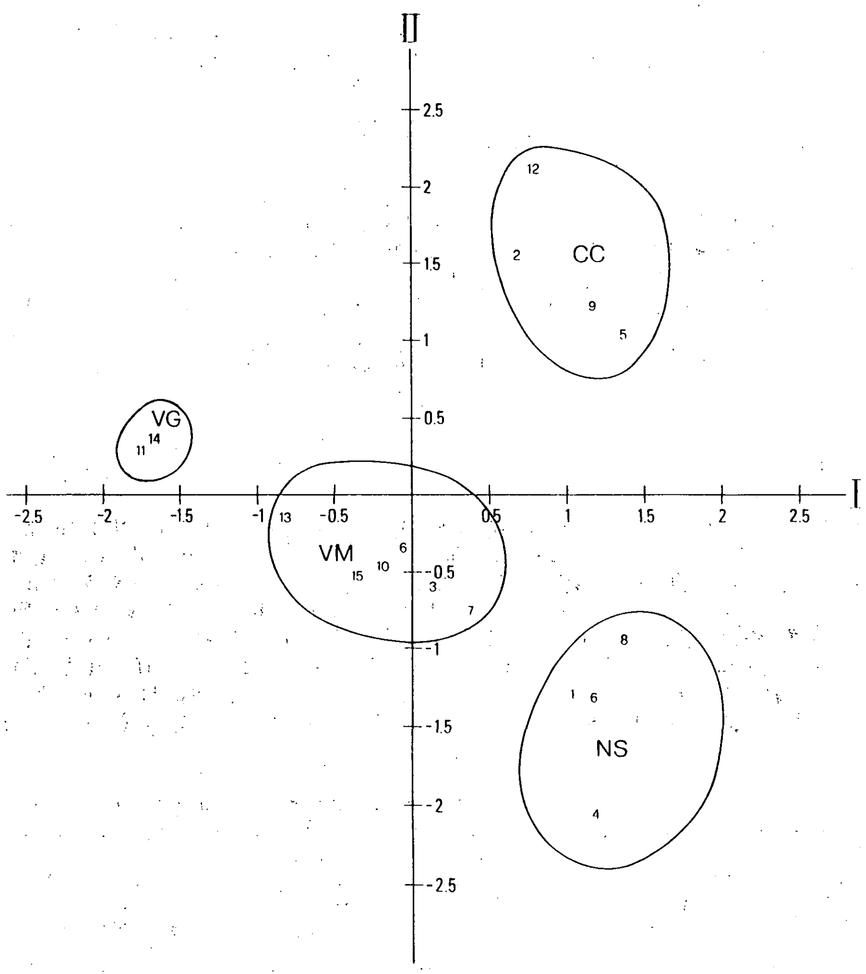

Fig. 4: Ordination of 16 relevés according to the two first canonical variates of the reciprocal ordering. Symbols as in Fig. 3.

The correlations between vegetation types and geomorphological units within the rock glacier clearly result from the scheme in Fig. 5 representing a vegetation transect within the central part of the rock glacier where different morphotypes occur.

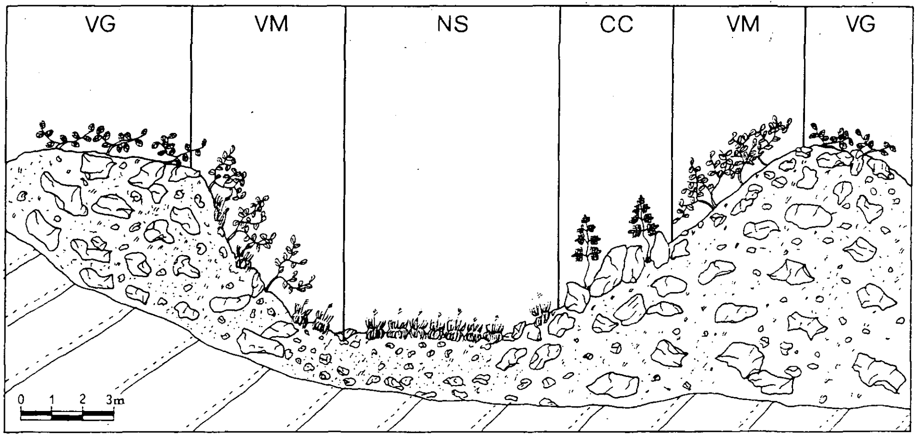

Fig. 5: Vegetation transect within the central part of the rock glacier. Symbols as in Fig. 3.

The community of *Nardus stricta* occurs at the bottom of the hollows originated by the collapse of the debris cover. In such hollows originated by the collapse of the debris cover. In such habitats snow accumulates and its release is generally slow. As a consequence, soil is waterlogged, mostly at the beginning of the growing season. Moreover, fine detritus moved down along the overhanging slopes by the surface run-off of the melting water, is deposited at the bottom of the hollows. Such conditions enhance the settlement of *Nardus stricta* that can withstand waterlogged and temporarily anoxic soils (CARBIENER, 1966).

The community of *Cryptogramma crispa* develops on stabilized block fields ocurring on N-faced slopes as well as on the bottom of small grooves. Microclimate is relatively cold and moist, due to both the shading effect of the blocks and the long persistence of snow cover. Soil consists of an organic horizon directly resting on boulders or on smaller rock fragments.

The community of *Vaccinium myrtillus* occurs on slightly inclined slopes or on flattened surfaces, formed by relatively fine debris. Such sites are sooner free from snow (towards the end of spring) and the surface stoniness of the soil is relatively low (10%).

The community of *Vaccinium gaultherioides* is restricted to the summits of debris cover and to the flow ridges. Soil is generally free from snow before the end of May and surface stoniness is fairly high (30-35%).

5. Dynamics

Two different dynamical trends, corresponding to environmental gradients, may be hypothesized from the results of principal component analysis (full-lined arrows in Fig. 6). They converge towards the community of *Vaccinium myrtillus,* representing the climax vegetation type in the areas above the timberline of the Northern Apennines (CREDARO *et al.,* 1980). The first succession starts from the community of *Nardus stricta* and correspnds to a reduction of soil moisture. Relevés 3 and 7, assigned to the community

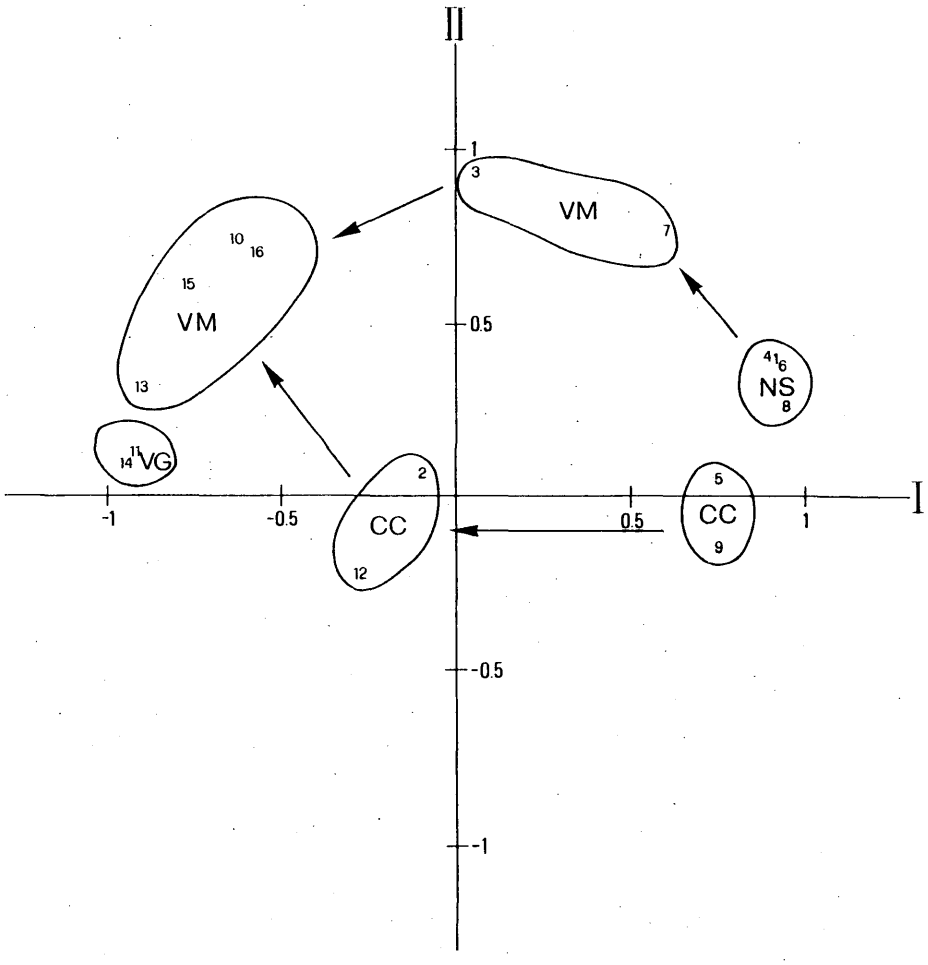

Fig. 6: Ordination of 16 relevés according to the two first principal components. Symbols as in Fig. 3.

of *Vaccinium myrtillus* by the numerical classification, form an independent grouping in the diagram. They probably correspond to an intermediate stage in this succession.

The second succession starts from the relevés 5 and 9 belonging to the community of *Cryptogramma crispa.* It corresponds to a reduction of soil stoniness. Numerical classification assigned also the relevés 2 and 12 to this community. In the ordination plot they form, however, an independent grouping. This can be interpreted as an intermediate stage along the series. The interpretation is confirmed by the floristic composition of these relevés, characterized by a higher weight of species group 3, linked to the community of *Vaccinium myrtillus.*

The relevés of the community of *Vaccinium gaultheriodies* are placed in the left hand part of the ordination plot. From this it may be argued that they are not involved in the above described successional trends. This community corresponds, in fact, to a xeric and open variant of the climax heath locally represented by the community of *Vaccinium myrtillus.*

6. Conclusions

The outward features suggest that the rock glacier under study is no longer active. The tongue turns out, in fact, rather depressed and the front shows a relatively gentle slope. Moreover, hollows originated by collapses in the debris cover were observed. All these features indicate the absence of internal ice and, consequently, the stability of the debris body.

This is confirmed by the study of vegetation. All the detected vegetation types are, in fact, settled on stabilized soils. Also the blocks colonized by the community of *Cryptogramma crispa* show a high degree of stability. This is connected with their low weathering rate, documented by the large size of the lichens colonizing the blocks. Debris movements, however restricted to the surface of the eluvial sheets, occur only in the community of *Vaccinium gaultherioides.* They are determined by cryoclastic processes hindering the evolution of this vegetation type to the community of *Vaccinium myrtillus.*

The vegetation dynamics, revealed by principal component analysis, must be regarded as a really long-term successional trend. This is certainly true for the series starting from the community of *Cryptogramma crispa.* The block fields colonized by this vegetation type date back, in fact, to the early post-glacial, though the problem of their exact datation is still open (FEDERICI &TELLINI, 1983). Also the succession from the community of *Nardus stricta* to the *Vaccinium-heath* is likely to be regarded as a very long-term process. It could be, in fact, determined by a progressive filling of the hollows with fine debris or by climatic modifications reducing the lenght of snow cover.

Based on these geomorphological and vegetational considerations, the rock glacier is therefore to be regarded as a relict landform, practically blocked in its evolution by the stabilizing effect of vegetation cover.

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Appendix

List of rare species

Rel. 2: *Gentiana purpurea* (r), *Sedum monregalense* (+); rel. 4: *Phleum alpinum* (+), *Gentiana kochiana* (+); rel. 5: *Athyrium filixfoemina* (+); rel. 10: *Lotus alpinus* (r); rel. 11: *Asperula oreophila* (+), *Minuartia verna* (+); rel. 12: *Asplenium viride* (r); rel. 13 *Dicranum scoparium* (1), *Empetrum hermaphroditum* (1), *Rhytidiadelphus triquetrus* (+); rel. 15: *Gentianella campestris* (r); rel. 16: *Avenella flexuosa* (+).