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 hypothesized 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 componentes 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 (SOUDADÉ, 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; MULLER, 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-PUMPEL, 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 subject 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 glacier (CARTON PANIZZA, 1988) and extends over a surface of 0.20 Km² ranging from 1760 to 1850 m of altitude. The form is
ROCK GLACIER IN THE NORTHERN APENNINES

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

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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.
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-Chiappeleva & 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

![Dendrogram of classification of the relevés](http://pirineos.revistas.csic.es)

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

| NS | CC | VM | VG | Priors 

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 occurrence 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.

Community 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. Releves 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 groupings 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.
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.

![Vegetation transect within the central part of the rock glacier. Symbols as in Fig. 3.](image)

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 occurring 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 corresponds to a reduction of soil moisture. Relevés 3 and 7, assigned to the community

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Fig. 6: Ordination of 16 relevés according to the two first principal components. Symbols as in Fig. 3.
ROCK GLACIER IN THE NORTHERN APENNINES

... 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 gaultherioides* 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 length 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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References


ROCK GLACIER IN THE NORTHERN APENNINES


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), Rhytidadelphus triquetrus (1); rel. 15: Gentianella campestris (r); rel. 16: Avenella flexuosa (+).