

Vegetation on Alpine rock glacier surfaces: a contribution to abundance and dynamics on extreme plant habitats

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Abstract

In the area of Piz Corvatsch (Upper Engadin, Grisons, Switzerland), the actual vegetation on active and inactive rock glacier surfaces has been mapped. The floristic composition (vascular plants and lichens) of the different rock glacier surfaces has been mapped and compared with photogrammetrical measurements of surface movements of the active rock glaciers. In general, the active rock glacier surfaces show a very low cover of vascular plants. Most of them are located at the edge and at the front of the rock glacier where fine-grained soil material occurs in small pockets.

Lichenometry has been used as an additional method on Murtèl rock glacier and on the protalus rampart. Measurements of *Rhizocarpon geographicum* thalli revealed increasing sizes from the root zone of the rock glacier to its front. On the Murtèl rock glacier, *Rhizocarpon geographicum* thalli with a diameter >4cm occur on surfaces with ages between 5000 and 6000 years B.P.

The statistical analysis (MULVA-5) of the dense vegetation cover of the inactive and relict rock glaciers revealed four plant sociological groups, which are composed of species reflecting well consolidated sites: alpine grassland, subalpine dwarf shrubs and small patches with single small trees of Swiss stone pine (*Pinus cembra*) and larch (*Larix decidua*).

Key words: vegetation cover, pioneer plants, *Rhizocarpon geographicum*, permafrost, Upper Engadin (Canton of Grisons, Switzerland), Valais, Livigno-Sondrio (Valtellina, Italy)

Nomenclature: LAUBER & WAGNER (1998), WIRTH (1995)

Introduction

There exist several investigations about the relation between vegetation dynamics and permafrost (and/or rock glacier) dynamics: JOHNSON (1963) explored the plant ecology in permafrost areas in the Rocky Mountains. BURGA (1987) mapped the vegetation cover on inactive and relict rock glaciers in the Poschiavino valley, the regions of Livigno and Bormiese (Italy). FURRER & HUTTER (1994) investigated the relationship between vegetation cover and permafrost in the Corvatsch area (Eastern Swiss Alps). FRAUENFELDER

(1997) studied the flora on active, inactive and relict rock glaciers in the Fletschhorn area (Western Swiss Alps). Her results showed that plants growing on active rock glaciers mainly belong to the vascular species. CANNONE (1997) investigated plant species on rock glacier surfaces and other permafrost forms in the area of Foscagno pass (Bormiese, Italy). Her results revealed a clear relation between vegetation abundance and dynamics and permafrost parameters (air temperature, radiation, snow cover). She established a simple model with geophysical and vegetational data allowing the detection of possible permafrost occurrence and the

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mapping of surface movements. A vegetation cover of *Caricetum curvulae* and *Salicetum herbaceae* and a low abundance of mosses implies a low probability of permafrost occurrence; whereas the *Oxyrietum digynae*, high abundance of mosses, low cover of *Salicetum herbaceae* and surface movement indicators implies a high probability of permafrost. CANNONE (1997) compared her results with BTS (basal temperature of the snow cover) measurements (HAEBERLI 1975); the correspondence of her permafrost map and BTS and seismic data amounts to 91,3% and 93,3%, respectively. In our study, the active rock glacier Murtèl (where a high amount of geophysical, photogrammetrical and climatological data is available from former studies, e.g. BARSCH & HELL 1975; WAGNER 1992; VONDER MÜHLL & HAEBERLI 1990; KELLER & GUBLER 1993; BERNHARD et al. 1998; HAEBERLI et al. 1998, 1999; KÄÄB et al. 1998; FRAUENFELDER & KÄÄB 2000; VONDER MÜHLL et al. 2001; HOELZLE et al. 2002) and an additional inactive rock glacier (Crap da las Ravulaunas) and a protalus rampart in its surroundings were chosen to test and modify the model of CANNONE (1997). The main question of our study can be formulated as follows: (a) do Alpine plant species or plant communities on rock glacier surfaces reflect movements and (b) can some plant species be used as indicators of Alpine rock glacier activity?

The presented study was related to the PACE (Permafrost and Climate in Europe) project which dealt with the following topics: climate change and permafrost occurrence of European high mountains, mapping and

climate modeling of sensitive mountain permafrost areas, shrinking permafrost areas and possible natural hazards in high mountains.

Investigation area

The investigated rock glacier surfaces (Murtèl, Crap da las Ravulaunas, protalus rampart) are located at the northern slope of Piz Corvatsch (Upper Engadin, Grisons, Switzerland, Fig. 1). The Piz Corvatsch area belongs to the lower Eastern Alpine Bernina nappe s.l.; its solid rock consists of granodiorites and calcite-marbles of the Chastelets-Series (SPILLMANN 1993). The studied rock glaciers are mainly composed of coarse granodioritic rock debris.

The investigation area (Fig. 1) is located in a typical continental Alpine valley. The climate is the dry continental climate typical for inneralpine valleys (GENSLER 1978). The average annual air temperature at Piz Corvatsch (3303 m a.s.l.) amounts to -4.9°C , the annual air temperature amplitude is 15.8°C and the average annual precipitation reaches approximately 1077 mm.

During the Late-Würmian, the main valley glacier (Inn) and several tributary glaciers (e.g. Bernina glacier) advanced several times, e.g. during the glacier stages Cinuoschel, Samedan and Pontresina (MAISCH 1992, 1995). The investigation area was totally glaciated during the Egesen stage (Younger Dryas); during the last glacier maximum of the 19th century, i.e. around 1850, the upper zone of the Murtèl rock glacier was still glaciated (MAISCH & SUTER 1982).

The study area is located in the Central Alpine continental larch-Swiss stone pine forest belt with a natural potential forest limit at ca. 2300 m a.s.l. (actual forest limit at the northwestern

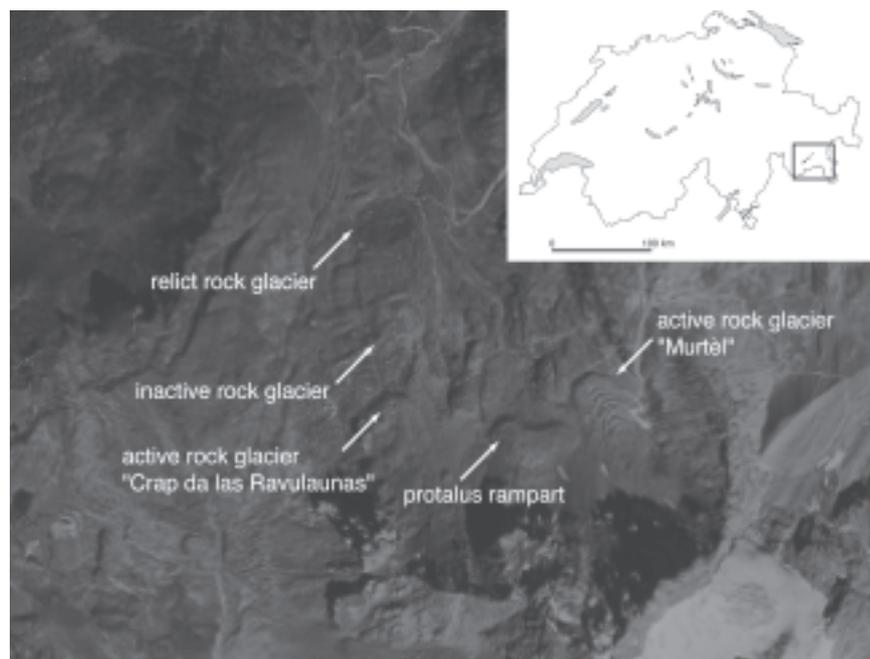


Fig. 1. Investigated rock glaciers Murtèl, Crap da las Ravulaunas and protalus rampart located at the northern slope of Piz Corvatsch (2400 and 2700 m a.s.l.)

slope of Piz Corvatsch: 2150 m). The investigated rock glaciers are situated between 2360 and 2740 m a.s.l. in the alpine vegetation belt.

Methods

Following methods have been applied: vegetational survey, mapping of vegetation, statistical analysis with MULVA-5, lichenometry and GIS (ARC/INFO).

The vegetational survey has been carried out according to the modified Braun-Blanquet method: plots of 2 × 2 m on surfaces of inactive and relict rock glaciers (BRAUN-BLANQUET 1964). Lower coverages of <1–5% of the generally very low vegetation cover of the active rock glacier have been monitored with a finer scale (plots of 1 × 1 m or even smaller, mainly at the edge of the rock glacier tongue). Mapping of vegetation of the inactive and relict rock glaciers (Crap da las Ravulaunas, protalus rampart) has been carried out with a 50 × 50 m grid and with the help of aerial photographs. The main plant sociological groups of the inactive and relict rock glaciers have been established as ordination, based on the multivariate statistic program MULVA-5. For the plant ecological characterization the indicators of Landolt (LANDOLT 1977) have been used.

The lichenometry using *Rhizocarpon geographicum*, which is the dominant crust lichen on the active rock glacier Murtèl and the protalus rampart, has been performed according to BESCHEL (1957, 1961) and MATTHEWS (1992). Besides the biggest diameter of the lichen thallus, also its total surface has been measured. On the surfaces of the inactive and relict sections of the rock glacier (Crap da las Ravulaunas) the age of some dwarf shrub species have been identified dendrochronologically.

Results

Plant species on the investigated rock glaciers and the protalus rampart

The very low vegetation cover of the rock glacier Murtèl and the adjacent protalus rampart is concentrated on lateral and terminal zones of the tongue where finer detritic rock material or very thin humus layers occur. A total of 121 vascular plants has been recorded. These plant species are well adapted for very poor and dry soils and mechanical disturbance, and the plant root system must be considered as very robust against mechanical stress occurring on the steep slopes of the rock glaciers. Typical abilities or strategies of pioneer plants seem to be required to survive in this high mountain environment with harsh climatic conditions (permafrost, long lasting snow cover).

Abundant pioneer plant communities are *Oxyrietum digynae* and *Androsacetum alpinae* with the following species: *Oxyria digyna*, *Geum reptans*, *Cardamine rese-*

difolia, *Ranunculus glacialis*, *Arabis alpina*, *Saxifraga oppositifolia*, *Cerastium uniflorum*; *Androsace alpina*, *Poa laxa*, *Gentiana bavarica*, *Leucanthemopsis alpina* and *Saxifraga bryoides*. These plant species are successful colonists of mobile rubble and scree-stabilisers. On consolidated zones, mainly at the edge of the rock glacier tongue or in furrows with long lasting snow cover, *Salicetum herbaceae* (with *Salix herbacea* and *Sibbaldia procumbens*) is abundant. On the rock glacier surface occur besides lichens very few vascular plants like *Salix retusa* or *Saxifraga oppositifolia*. But generally, high mobility of coarse detritic rocks, lack of fine substrate, permafrost and long lasting snow cover inhibit a denser cover of vascular plants. *Saxifraga oppositifolia* is the only one vascular plant occurring at the highest elevation up to 2700 m a.s.l. of the investigated site. On the protalus rampart, *Oxyrietum digynae* has been recorded up to 2690 m a.s.l.

The lower located active rock glacier Crap da las Ravulaunas has a higher vegetation cover (average 38%) of *Oxyrietum digynae*, *Androsacetum alpinae* and a mosaic of both compared to Murtèl rock glacier. Recorded plant species are: *Oxyria digyna*, *Geum reptans*, *Linaria alpina*, *Cerastium uniflorum*, *Saxifraga oppositifolia*, *S. bryoides*, *S. exarata*, *S. seguieri*, *Poa laxa*, *P. alpina*, *Androsace alpina*, *Arabis alpina*, *Gentiana bavarica*, *Leucanthemopsis alpina*, *Artemisia mutellina*, *Erigeron uniflorus*, *Prizelago alpina* ssp. *alpina* and *Cetraria islandica*. At the front of the rock glacier tongue, the vegetation cover varies between 13% and 74%. In more horizontal areas occur *Salix herbacea*, *S. retusa*, *Silene exscapa* and *Taraxacum alpinum* (total 21 plots).

The vegetation cover of the inactive and relict rock glacier below the active rock glacier Crap da las Ravulaunas is significantly denser and consists mainly of Alpine climax plant communities (Fig. 2): Alpine dwarf shrubs, Alpine grassland and small trees of *Pinus cembra* and *Larix decidua*. Only the inactive upper section is covered with typical pioneer plants and single ground shrubs of *Loiseleuria procumbens* forming a fragmentary vegetation cover. The following dwarf willows and dwarf shrubs growing on the surface of the inactive and relict rock glacier have been dated dendrochronologically: *Salix retusa*: 16–74 years (4 samples), *Juniperus nana*: 48–94 (!) years (5 samples), and *Rhododendron ferrugineum*: 28 years (1 sample).

The total of 121 vascular plant species recorded at the investigation site can be linked to the following life forms (cf. fig. 3, according to RAUNKIAER 1904): hemicryptophytes: 62% (>70 plant species, mainly Poaceae, herbs, especially *Geum reptans* and *Oxyria digyna*); herbaceous chamaephytes: 17% (>20 plant species, chiefly pioneer plants, e.g. *Linaria alpina*, *Saxifraga aizoides*, *S. bryoides*, *S. exarata*, *S. oppositifolia*, *S. paniculata*,

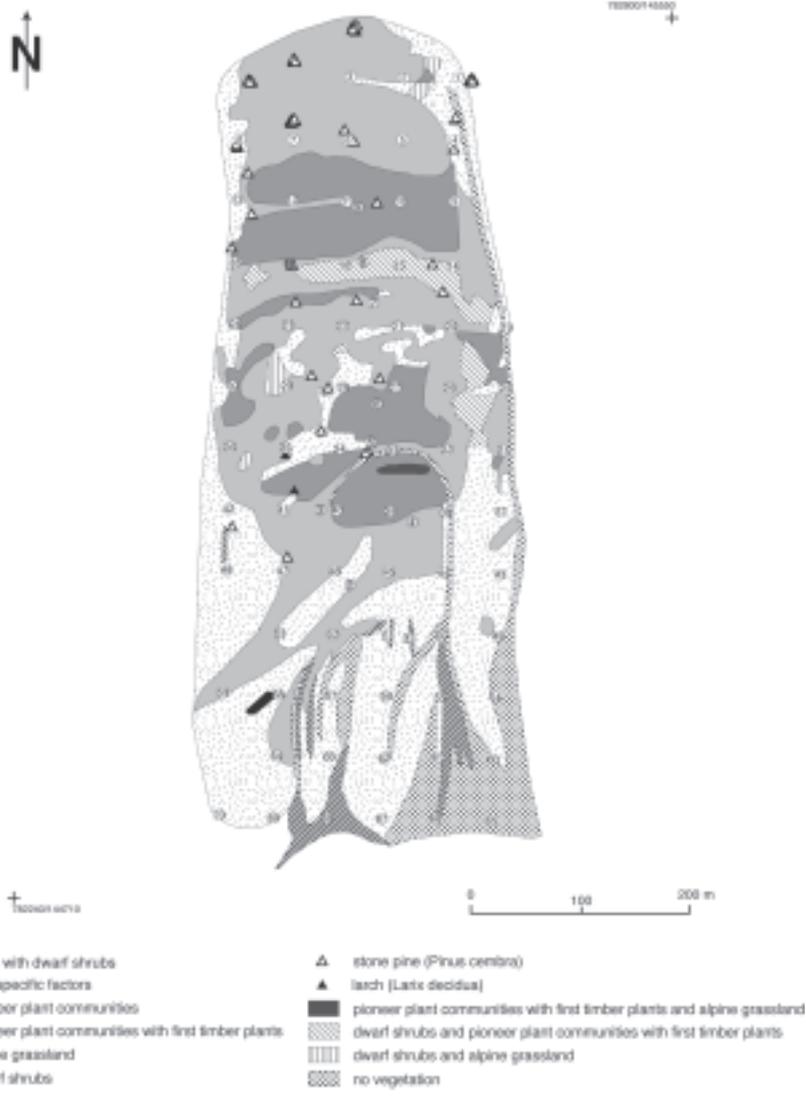
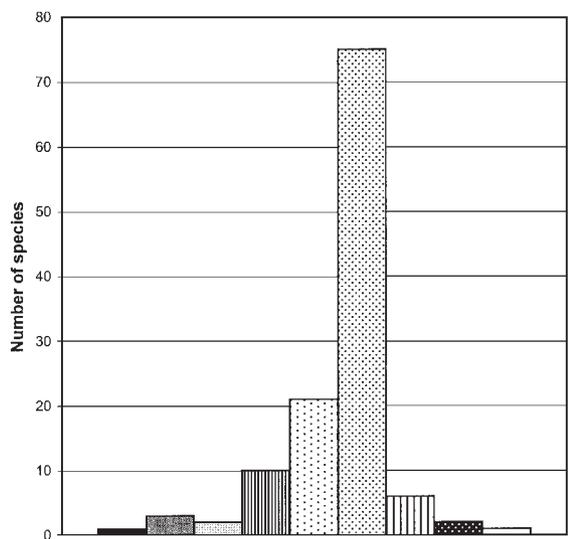


Fig. 2. Vegetation map of the inactive and relict rock glaciers, as mapped in July 1999 by RUFFET (2001)



- evergreen phanerophytes
- ▣ evergreen nanophanerophytes
- ▣ herbaceous chamaephytes
- ▣ geophytes
- ▣ therophytes and geophytes
- ▣ summer-green nanophanerophytes
- ▣ woody chamaephytes
- ▣ hemikryptophytes
- ▣ therophytes

Fig. 3. Liveforms of vascular plant species on the inactive and relict rockglaciers in the Corvatsch area (absolute values), as mapped in July and August 1999 (modified after RUFFET 2001)

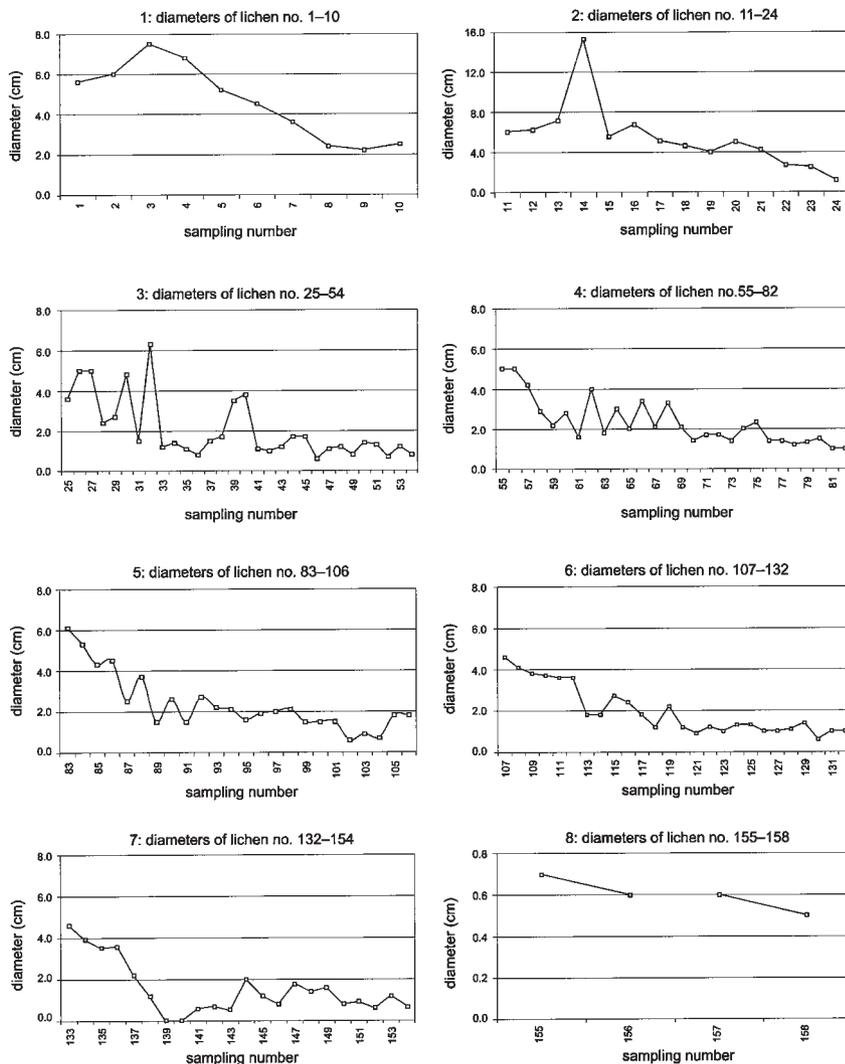


Fig. 4. Diameter of *Rhizocarpon geographicum* thalli on the active rock glacier surface of Murtèl and protalus rampart (modified after RUFFET 2001)

S. seguieri, *Androsace alpina*, *Arabis alpina*, *A. caerulea*, *Cerastium uniflorum*, *Leucanthemopsis alpina*); woody chamaephytes: 8% (10 plant species, e.g. *Salix herbacea*, *S. retusa*, *S. reticulata*, *Vaccinium gaultherioides*, *V. myrtillus*, *V. vitis-idaea*); geophytes: 5% (e.g. *Crocus albiflorus*, *Lloydia serotina*).

Lichen thalli diameters on Murtèl rock glacier compared to its flow and age structure

Surface movements of the active rock glacier Murtèl have been measured with the help of high resolution photogrammetry (KÄÄB et al. 1998; FRAUENFELDER & KÄÄB 2000, KÄÄB 2002).

Along the stream of the rock glacier Murtèl and the protalus rampart, the biggest diameters of *Rhizocarpon geographicum* thalli and their exposures have been

recorded (seven transects with a total of 220 records, largest thallus diameter 7.5 cm, largest thallus surface >800 mm²) (fig. 4).

The largest lichens are located at the front of the rock glacier tongue; with increasing altitude the lichen thalli become successively smaller and younger. The lichen-free zone above 2700 m of the rock glacier surface is covered longer than nine months with snow and moreover it is very mobile. In 2700 m, the granitic rocks move >10 cm/a, in the lower section 6 cm/a (KÄÄB et al. 1998; FRAUENFELDER & KÄÄB 2000).

Also the age of Murtèl rock glacier (>6000 years) has been estimated with the help of photogrammetrical technics (KÄÄB et al. 1998; cf. also HAEBERLI et al. 1998, 1999, 2003). Due to the lack of absolute data, it was not possible to establish a local curve of lichen growth rates. But the overlap of surface movement vectors and lichen diameters shows a clear correlation between these two parameters (see below).

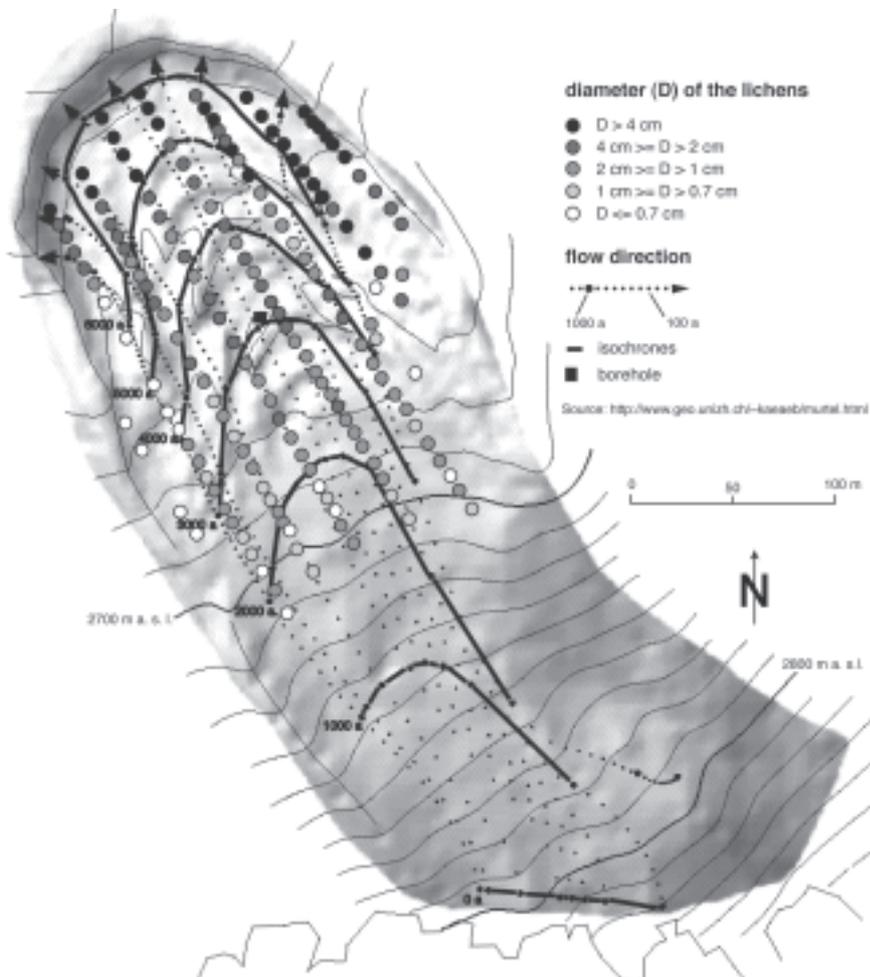


Fig. 5. Flow trajectories, age isochrones and lichen thalli on active rock glacier Murtèl (modified after RUFFET 2001; flow trajectories and age isochrones according to KÄÄB et al. 1998)

The flow rates (in our calculations assumed as a constant parameter, which is certainly a disputable assumption) have been overlaid with the sizes of diameters of the largest thalli of *Rhizocarpon geographicum* (fig. 5). This overlap shows a clear correlation between size (i.e. a function of the age of the lichen) of the lichens thalli and the flow pattern: the largest lichen thalli occur at the front of the rock glacier tongue. The largest lichen individuals with diameters >4 cm are located on boulders between the 5000 and 6000 years isochrones (as described in HAEBERLI et al. 1999). It can be assumed that rock debris which fell inside the rock glacier root zone (at 2800 m a.s.l.) 6000 years ago lies now at the front of the rock glacier at 2645 m. The lichens are concentrated on ridges, whereas in snow niches the lichen abundance is very low. This finding corresponds well with results by LEVESQUE & SVOBODA (1999) who showed that lichen are very sensitive to the duration of snow coverage. 50% of the *Rhizocarpon geographicum* thalli are N-exposed, 17% are exposed to W and 3% to S.

Comparison to similar studies in other regions of the Alps

FURRER & HUTTER (1994) found pronounced differences between vegetation on ground that was free of permafrost during the last decades and vegetation on ground that was influenced by historic (19th century) permafrost. Modelling tests revealed that the composition of the number of higher evolved plant species would increase under conditions of permafrost melt (due to climate warming) in favour of less evolved plant species, a finding supported by investigations by MATTHEWS (1992).

FRAUENFELDER (1997) investigated the vegetation cover of active, inactive and relict rock glaciers in the area of Fletschhorn (Valais). The active and inactive rock glaciers show more or less the same plant species spectra and comparable vegetation patterns on siliceous rocks; but there were recorded some typical Western

Table 1. Numerical exploration of community patterns (Mulva-5)

RELEVE NO.	341222333113163	115554443455535	212242414352214432	1	5
RELEVE GROUP NO.	333333333333333	444444444444444	222222222222222	11111111111	
7 <i>Loiseleuria procumbens</i>	22	5 62 2 3			
68 <i>Pedicularis rostrato-spicata</i>	11	+ ++ +			
53 <i>Geum montanum</i>	69	1 r	2 r +r211 +		
16 <i>Vaccinium myrtillus</i>	13	2 2 ++ 3 +	r		2
103 <i>Veronica alpina</i>	88		2 r+r r		r
105 <i>Anthoxanthum alpinum</i>	32	3222 r 1211	222 1 2+12+21	+ + 1 1 + +	
56 <i>Homogyne alpina</i>	61	++ ++ ++1+ 2 2	1 ++2+r1 r	++r r r2 ++r +r	
50 <i>Gentiana punctata</i>	61	++ 1 + 2+ 1 ++	+ 22 r	2 + r	
5 <i>Empetrum n. ssp. hermaphroditum</i>	10	22 22 34		+ +	
107 <i>Carex curvula</i>	62	223 21 +33 +22	2 2	3 3 + 22 1	
122 <i>Cetraria islandica</i>	19	22 212+1+2 +	+	+11 +++	2
15 <i>Vaccinium gaultherioides</i>	29	23224 2 3++	3+1	3 4+ 26++ +23 24	
13 <i>Salix retusa</i>	25	2612 + + +	4++1 2 2	232+63 + 332 31242	+
20 <i>Achillea nana</i>	25	+ r + + +	1++++ ++ +	+2r2 + ++ +21 + r	
109 <i>Carex parviflora</i>	25	++	1++ 2 r +	+ 12++2r221+ 132r	
72 <i>Polygonum viviparum</i>	25	+++r r+r+1 4++	r++ r+ 1+ +2	1 1+ 2+++++++ +	
93 <i>Sempervivum tectorum ssp. alpinum</i>	50	+ + + + +	+ + 2+ + ++++2	+2 2++	1
58 <i>Leontodon helveticus</i>	16	++++ ++1+1+1	++r + +r + 1 r	r 3+ r +	r +
114 <i>Helictotrichon versicolor</i>	16	+22 2 222+ ++	+2 + r +	+ +	
12 <i>Salix reticulata</i>	27	+	1	2 24 + + 3 + 222	r +
87 <i>Saxifraga oppositifolia</i>	47		r	++ ++ 2++ 2 r	13 1212+2+3
85 <i>Saxifraga bryoides</i>	47	+		+ + ++ + +2+ r1r	2 + +2+2422
28 <i>Arabis caerulea</i>	46		r		+ + r 2
67 <i>Oxyria digyna</i>	48		1		2 ++ 2 +1 1
27 <i>Arabis alpina</i>	48	+	r		+r++++ +
77 <i>Pritzelago alpina ssp. alpina</i>	45				2 + + r
23 <i>Androsace alpina</i>	45	r		r	+ 1 ++ 1
54 <i>Geum reptans</i>	76		2		2 r r1321
40 <i>Cerastium uniflorum</i>	75				r512+1 +
84 <i>Saxifraga androsacea</i>	75				+ + +
59 <i>Leucanthemopsis alpina</i>	999	rr r +r ++ ++r	1 ++rr	+1 +r r + ++ r+r	1 + + +1++
66 <i>Myosotis alpestris</i>	999	r rr r+r +	+r ++r ++r +	++ + 1 r +r + +	r r r + +
31 <i>Aster bellidiasterum</i>	999	rr1 + 1++	+ + r 2	++++ 1 ++1 r 1	
24 <i>Androsace obtusifolia</i>	999	r r r r	1r+ 1	r + r rr r rrrrr	1
51 <i>Gentiana verna</i>	999	+ r r r +	r+r	r +11r ++r	+ +
120 <i>Poa alpina</i>	999	+ 2 +2 +	+22 ++ 2r 2 +1	1 1 + +	
81 <i>Ranunculus montanus</i>	999	+1 +r+ ++r	++ 1 + r	+ rr	
97 <i>Silene acaulis</i>	999	+ + +	1r 2	2 +++++ r 22 3 +	+ +
11 <i>Salix herbacea</i>	999	1 1	2r 46 2	+ + + r +	1 + 2
36 <i>Campanula scheuchzeri</i>	999	r r +	r+r r1++ +	r +	+ +
88 <i>Saxifraga paniculata</i>	999	+ + 2 +	2r +++	+ + r+1	r
117 <i>Luzula lutea</i>	999	r + +1	+r ++ +r2	r r +r	
61 <i>Ligusticum mutellinoides</i>	999	+ + r	3 +	+ + ++r+2 rr	
76 <i>Primula latifolia</i>	999	1 2	r r r2	+ + + + 2r	
57 <i>Huperzia selago</i>	999	r r+ + r1	r	+ r 1+ 1	
44 <i>Erigeron uniflorus</i>	999	r r +	r + + r	+ r	+ +
73 <i>Potentilla aurea</i>	999	+ +2 + 22	+ 2	+ +1	
82 <i>Saussurea alpina</i>	999	1 1 1 +	1	+ + + +11 +	
95 <i>Senecio incanus ssp. carniolicus</i>	999	+ + + +1 +	1 + 2 1	2	
60 <i>Ligusticum mutellina</i>	999	+ 1 2 2	2 r2 3	+ 1	
100 <i>Soldanella pusilla</i>	999	+ 2 +	+ 1	+ 1 2++	
8 <i>Rhododendron ferrugineum</i>	999	+ + + 1 3	1	+ 2 +	
75 <i>Primula integrifolia</i>	999	2 r+ 2 +		+ 3 + +	
49 <i>Gentiana bavarica</i>	999	+ +	r	r11 + 2	+ +
63 <i>Lloydia serotina</i>	999	r	r r +	+ 3 +	
125 <i>Stereocaulon alpinum</i>	999	2 2 +22		1 1 1	1
32 <i>Bartsia alpina</i>	999	1		+ +1 2 2 +	
89 <i>Saxifraga seguieri</i>	999		rr	r	r 1 r 1
116 <i>Luzula alpinopilosa</i>	999	r	r 2+2	2 +	
121 <i>Poa laxa</i>	999	+		r + +	+++

Table 1. continued

124	Polytrichum norvegicum	999 +	1+	+	+				r		2
64	Lotus alpinus	999	r 22	76	+						
6	Juniperus c. ssp. nana	999	1	2+	4		3				
42	Doronicum clusii	999	+			1	+		1	+	
65	Minuartia verna	999				r r	2 r		r		
104	Veronica bellidioides	999	1			rr	1 2				
106	Carex atrata	999				2+	2		1+		
110	Elyna myosuroides	999				2 5	61		1		
4	Dryas octopetala	999	+		2				22		
10	Salix helvetica	999 +		3					2	5	
25	Antennaria carpatia	999		2		1 2	1				
41	Cirsium spinosissimum	999	+				3 1				+
74	Potentilla crantzii	999		+		+2	2				
79	Pulsatilla alpina ssp. apiifolia	999	+1				+ r				
92	Sedum atratum	999	r			+			+	r	
113	Festuca violacea	999					4 4 2				2
126	Thamnia vermicularis	999 +	2			+					+
26	Anthyllis vulneraria ssp. alpestris	999					12			3	
34	Botrychium lunaria	999	r				1				
38	Cardamine resedifolia	999					r		+	+	
46	Euphrasia minima	999					2+				1
55	Gnaphalium supinum	999		r			+1				
70	Plantago alpina	999	+		++						
91	Sedum alpestre	999				r			r	r	
94	Senecio doronicum	999					r 2 1				
96	Sibbaldia procumbens	999					r				1
99	Silene vulgaris ssp. vulgaris	999	1				r 2				
9	Salix hastata	999					2 1				
14	Salix glaucosericea	999						2		9	
71	Polygala alpestris	999					+ r				
78	Pulsatilla alpina ssp. alpina	999			+			1			
80	Pyrola rotundifolia	999	+	r							
115	Juncus trifidus	999			5		2				
118	Oreochloa disticha	999						2	+		
1	Pinus cembra	999							+		
2	Arctostaphylos alpinus	999		r							
3	Daphne striata	999					2				
17	Vaccinium vitis-idaea	999		+							
18	Asplenium adiantum-nigrum	999					+				
19	Asplenium viride	999	+								
21	Alchemilla pentaphyllea	999						+			
22	Alchemilla xanthochlora	999						+			
29	Arnica montana	999		+							
30	Artemisia umbelliformis	999						r			
33	Biscutella laevigata	999	2								
35	Campanula barbata	999					+				
37	Cardamine alpina	999								r	
39	Cerastium cerastoides	999			+						
43	Draba hoppeana	999				r					
45	Euphrasia alpina	999					r				
47	Galium anisophyllum	999					r				
48	Gentiana acaulis	999	2								
52	Geranium sylvaticum	999			+						
62	Linaria alpina	999									+
69	Phyteuma hemisphaericum	999							r		
83	Saxifraga aizoides	999							2		
86	Saxifraga exarata	999									r
98	Silene rupestris	999						1			
101	Taraxacum alpinum	999			+						
102	Trifolium alpinum	999			+						
112	Festuca halleri	999			5						
119	Phleum alpinum	999					r				
123	Polytrichum piliferum	999									1

Alpine and Valaisian plant species like *Achillea nana* and *Senecio halleri*. There are also some local differences in the density of the plant cover. The relict rock glaciers of the Fletschhorn area show the same plant successional development of the plant cover with nanophanerophytes and chamaephytes like the Piz Corvatsch area, viz. *Larix decidua*, *Pinus cembra*, *Juniperus nana*, *Rhododendron ferrugineum* and *Vaccinium gaultherioides*. FRAUENFELDER (1997) could also show that – in contrast to the widely accepted idea (e.g. BARSCH 1996) that active rock glaciers show no plant coverage – they can exhibit plant coverages of up to 10%. The plant succession on relict rock glaciers within the timberline ecotone of the Central Alps tends to a fragmentary Larici-Pinetum cembrae.

CANNONE (1997) investigated the relationship between discontinuous permafrost (rock glaciers) and Alpine vegetation cover in the area of Livigno-Bormiese, Province of Sondrio, Italy. One of the principal aims of her work consisted in mapping permafrost occurrence with the help of the vegetational cover of rock glaciers. Her work hypothesis consisted in the question how far indicator plant species or phytocoenoses reflect permafrost occurrence and different activity degrees of rock glaciers in Alpine areas. Within the above mentioned test area, CANNONE investigated nine rock glaciers with regard to their morphogenesis and vegetation cover as indicators of rock glacier activity and evidence of their relative age (see also GUGLIELMIN et al. 2001).

Discussion and conclusions

In all test areas of Switzerland and Italy the vegetation cover shows marked differences between active, inactive and relict rock glaciers. With the help of the multivariate statistical program MULVA-5, different plant groups growing on active, inactive and relict rock glacier surfaces could be distinguished (tab. 1). **Active** rock glaciers with dynamic surfaces are characterized by low vegetational cover with low coverage (<10%) of vascular plants (pioneer plants). The latter are mainly located on fine substrate (sand, silt) of the marginal zone of the rock glacier Murtèl using different growth strategies against slow moving rock material: creeping shoots, creeping roots, extension growth, caespitose life form and cushion plants. Between the very coarse rock debris of the main surface there are scattered very few single vascular plants (espalier shrubs and some herbs). The vegetation of **inactive** rock glaciers is almost continuous with higher coverage (ca. 70%) and is composed by subalpine dwarf shrubs, herbs, grasses and few pioneer plants at the upper edge of the rock glaciers. Surfaces of **relict** rock glaciers are characterized by a dense vegetation cover (>80%) of subalpine and alpine successional and climax plant species like small coniferous trees, subalpine dwarf shrubs and grass communities.

These data show that surface disturbances produced by permafrost creep are an important environmental factor controlling plant growth. The vegetation pattern, mainly the coverage percentages and the abundance of pioneer plants and lichens (thallus sizes of *Rhizocarpon geographicum*), and the measured movements of the rock glacier Murtèl show a clear correlation: Generally, vegetation cover decreases with increasing movement and where rock debris change to significant coarser debris. With movements higher than ca. 30 cm/year, vascular plants and most of lichens tend to be absent. As the environmental factors on the rock glacier surface change locally, the vegetation pattern shows a high variability which is not in all cases explicable. Surfaces with finer detritic material and decreasing movement are colonized by typical stress tolerant vascular plants (pioneer plants like in a glacier forefield; see e.g. BURGA 1987, 1999) which can be used as "movement indicators": e.g. *Linaria alpina*, *Oxyria digyna*, *Saxifraga bryoides*, *S. oppositifolia*, *Cerastium uniflorum*, *Geum reptans*, *Arabis alpina* and *Poa laxa*, mainly located at the steep front or lateral parts of the rock glaciers.

Regarding the environmental conditions on rock glacier surfaces (character of substrate, surface deformation) the key question arises about the crucial parameters controlling the establishment of vascular plants on such surfaces. As already mentioned, mainly pioneer

plants colonize active rock glaciers. These are the same plants growing in glacier forefields (e.g. Morteratsch near Pontresina; BURGA 1999) which represent a typical primary succession on lithosoils of subalpine and alpine environments. As known from numerous case studies of alpine glacier forefields (see e.g. MATTHEWS 1992), crucial factors of colonization are fine detritic material (clay/silt-fine sand; coarse sand-gravel; coarse gravel-boulders), water supply and favorable microclimatic conditions on consolidated sites ("safe sites"). Furthermore, there is a certain correlation between grain size of the substrate and the occurrence of defined vascular plant species: Some species prefer mainly clay/silt and fine sand, other species rather coarser material (see e.g. BURGA 1999).

Surface deformation can be considered within a certain range of velocity gradients as a locally crucial parameter of occurrence of plants, but in some cases surface deformation can affect the vegetation cover only as a secondary factor in a rather modifying way. In most cases, quality of substrate and surface deformation are connected parameters; regarding this case study, there is no clear evidence of a statistical separation of the releasing factors and mechanism.

So, in addition to CANNONE's (1997) results we conclude that not only the movement of substrate, but also the quality of substrate like size grain, size of fine rock debris, and other plant growth controlling parameters (such as microclimate, water supply, nutrient, length of growing season, duration of snow cover etc.) must be considered regarding the vegetational cover and its correlation with permafrost occurrence. Nevertheless, the comparison of abundance and cover of plants and plant community development with the actual dynamics and age of rock glacier surfaces shows a clear correlation between the occurrence of pioneer plants (vascular plants and lichens) on both active and inactive or relict rock glacier surfaces with and without occurrence of permafrost respectively.

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