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LATE GLACIAL TO HOLOCENE DEGLACIATION OF THE COLLE DEL VEI DEL BOUC-COLLE DEL SABBIONE AREA (ARGENTERA MASSIF, MARITIME ALPS, ITALY-FRANCE)

ABSTRACT: FINSINGER W. & RIBOLINI A., *Late Glacial to Holocene deglaciation of the Colle del Vei del Bouc-Colle del Sabbione area (Argentera Massif, Maritime Alps, Italy-France)*. (IT ISSN 0391-9838, 2001).

Glacier advances and rock-glacier activity are reconstructed for the Late-Glacial and Holocene periods in the Colle del Sabbione-Colle del Vei del Bouc area (French-Italian Alps). Detailed geomorphological mapping and pollen analysis of radiocarbon-dated sediment cores reveal three pre-Little Ice Age glacial phases (S_1, S_2, and S_3) and two rock-glacier generations (R_1, R_2). Former Equilibrium Line Altitudes (ELA) were obtained using the Balance Ratio method. Micro- and macro-scale features of glacial erosion were used to reconstruct the paleoshape of glaciers and their movement directions. The ELA_S of the Vei del Bouc and Sabbione glaciers were located respectively 500, 300, and 200 m below Present (about 2800 m a.s.l.). Rock glacier generations are correlated with glacial phases on the basis of their spatial relationships with end moraines. The three glacial phases are related to global climatic oscillations: Oldest Dryas, Younger Dryas, and late Subboreal.

During the Younger Dryas, glacier fronts were located at about 2400 m, with the mean ELA at about 2500 m and the Lower Discontinuous Permafrost Boundary (LDPB) at 2300-2400 m. During the Hypsithermal the Vei del Bouc and Sabbione glaciers were probably strongly reduced and divided into minor bodies. Timberline rose and *Abies* likely reached altitudes of 2000 m. Evidence for a pre-LIA maximum Holocene glacial advance is dated to the late Subboreal on the basis of regional vegetation history.

A quantitative reconstruction of temperature and precipitation was calculated for the S_2 and S_3 phases using past ELA and LDPB. During these phases, a depression compared to present of about 4 °C and 1.8 °C of mean annual air temperature was obtained, with correspondent 50% and 23% reduction of mean annual precipitations. Permafrost today still characterizes the Subboreal rock glaciers and the flow units above 2600 m of the Lateglacial rock glaciers.

KEY WORDS: Holocene, Deglaciation, Rock glacier, Pollen-analysis, Argentera Massif, Maritime Alps.

RIASSUNTO: FINSINGER W. & RIBOLINI, A. - *Deglaciazione Tardiglaciale-Olocenica dell'area Colle del Sabbione-Colle del Vei del Bouc (Massiccio dell'Argentera, Alpi Marittime, Italia-Francia)*. (IT ISSN 0391-9838, 2001).

Sono state ricostruite le avanzate glaciali e la diffusione dei rock glaciers Tardiglaciali ed Olocenici dell'area Colle del Sabbione-Colle del Vei del Bouc (Alpi franco-italiane). Il rilevamento geomorfologico e l'analisi pollinica di sedimenti palustri datati con il radiocarbonio hanno evidenziato tre fasi glaciali precedenti la Piccola Età Glaciale (S_1, S_2, e S_3) e due generazioni di rock glaciers (R_1, R_2). Per ricostruire l'estensione e la direzione di flusso dei ghiacciai estinti sono state usate le micro e macro forme di erosione glaciale. La posizione delle antiche linee di equilibrio (ELA) è stata ricostruita utilizzando il metodo del Balance Ratio. Le linee di equilibrio dei ghiacciai della Valle del Vei del Bouc e della Valle del Sabbione erano localizzate rispettivamente 500, 300 e 200 m più in basso rispetto alla posizione attuale. Sulla base delle relazioni spaziali con le morene frontali, le generazioni di rock glaciers sono state correlate con le fasi glaciali rinvenute. Sulla base dei dati paleobotanici e delle datazioni radiocarbonio le tre fasi glaciali sono state attribuite alle tre oscillazioni climatiche globali Oldest Dryas, Younger Dryas e Subboreale.

Durante lo Younger Dryas la fronte dei ghiacciai stazionava a circa 2400 m, con un ELA medio di circa 2500 m ed un limite inferiore del permafrost discontinuo (LDPB) a circa 2300-2400 m. Durante l'optimum climatico olocenico i ghiacciai delle valli del Vei del Bouc e del Sabbione si sono fortemente ridotti e suddivisi in corpi minori. La linea del bosco è risalita e *Abies* ha probabilmente raggiunto la quota di 2000 m. L'evidenza di una avanzata glaciale pre- Piccola Età Glaciale è stata datata al Subboreale sulla base di dati paleobotanici regionali.

Una ricostruzione quantitativa delle temperature e delle precipitazioni è stata valutata per le fasi S_2 e S_3 utilizzando i paleo ELA e LDPB. Durante queste fasi, è stato calcolato un decremento rispetto al presente di circa 4 °C e 1.8 °C della temperatura media annua, con una corri-

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spondente riduzione delle precipitazioni medie annue di circa il 50% e 23%. Attualmente il permafrost interessa i rock glacier Subboreali e le unità di flusso al di sopra dei 2600 di rock glacier tardiglaciali

TERMINI CHIAVE: Olocene, Deglaciazione, Rock glacier, Analisi pollinica, Massiccio dell'Argentera, Alpi Marittime.

RÉSUME: FINSINGER W. & RIBOLINI, A - *Déglaciation de la région du Colle del Vei del Bouc-Colle del Sabbione (Massif du Argentera, Alpes Maritimes, Italie-France) au Holocène Glaciaire Ancien*. (IT ISSN 0391-9838, 2001).

L'avancé et l'activité des glacier rocheux ont été reconstruites pour les périodes Tardiglaciaire et Holocène dans la région Colle del Sabbione-Colle del Vei del Bouc (Alpes franco-italiennes). La carte géomorphologique montre l'abondance de paysages glaciaires et périglaciaires bien conservées, en particulier moraines et glaciers rocheux. Les caractéristiques de l'érosion glaciaire à l'échelle micro et macroscopique permettent de reconstruire la paléomorphologie des glaciers et des directions de leurs mouvements. Les moraines frontales permettent de évaluer les Lignes d'Altitude à l'Equilibre (LAE) de l'ancien glacier à travers la «Balance Ratio méthode». Les glaciers de la Vallée du Vei del Bouc et de la vallée du Sabbione ont subi une diminution de LAE respectivement d'environ 500, 300 et 200 m par rapport à la valeur actuelle des Alpes Maritimes (environ 2800 m a.s.l.). Deux générations de glaciers (R_1, R_2) sont présentes dans la région et montrent des relations avec les morphologies glaciaires à la fois pour leur localisation à l'intérieur des cirques glaciaires et pour leur interaction avec les moraines terminales. Les données venant de sept zones identifiées de pollen régional sont en accord avec les sites voisins dans le Alpes Françaises. Les deux données de ^{14}C (7525±90 BP, 5745±90 BP) confirment les hypothèses. La carte géomorphologique, l'analyse du pollen et les datations au radiocarbone sur des échantillons de sédiments révèlent trois phases glaciaires pour cette durée (S_1, S_2, S_3), relatives aux oscillations climatiques globales: Dryas Ancien, Dryas Récent et Subboreal Ancien. Pendant le Dryas Récent les phases glaciaires étaient situés à environ 2400 m avec un LAE moyen d'environ 2500 m et une Limite Inférieure Discontinue du Permagel (LIDP) à 2300-2400 m. Pendant le Hypsithermal les glaciers Vei del Bouc et Sabbione se sont fortement réduits, en se divisant en quelques plus petites parties et la limite supérieure de la croissance du genre Abies aurait pu augmenter atteignant probablement des altitudes de 2000 m. On a trouvé les avancées glaciaires Holocène maximale pre-LIA que l'on a daté du Subboréal Ancien sur base de l'historique régionale de la végétation. Une reconstruction quantitative des paramètres climatiques (température et précipitations) a été obtenue en utilisant les passées LAE et les passées LIDP pour les trois phases. Pendant les phases S_2/S_3 la température moyenne annuelle de l'air au LIDP était d'environ 4/2°C inférieure par rapport au Présent. Actuellement la présence de permafrost caractérise toujours les glaciers rocheux du Subboreal et ceux qui se sont formés pendant le Dryas Récent.

MOTS-CLÉS: Holocène, Déglaciation, Glacier rocheux, Palinologie, Argentera Massif, Maritime Alpes.

INTRODUCTION

The historical and present-day behaviour of glaciers and distribution of periglacial landforms in the Argentera Massif is well known (Federici & Pappalardo, 1995; Federici & *alii*, 2000). However, in contrast to other European regions, the magnitude and timing of Lateglacial and Holocene glacier fluctuations are not known. The reconstruction of variations in the activity of small mountain glaciers and rock glaciers is an important facet of research into environmental and climatic changes during the past. Numerical models developed in recent years facilitate the interpretation of distribution patterns of permafrost and glaciers and of mean annual temperature and precipita-

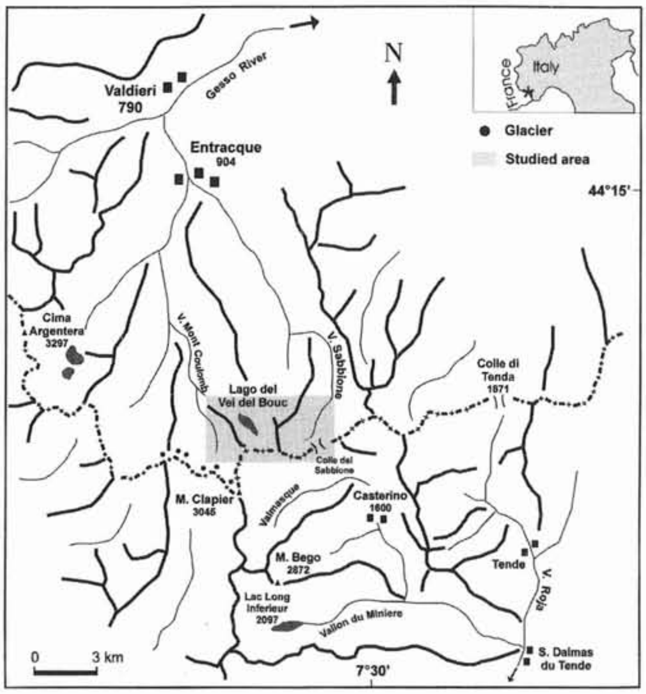
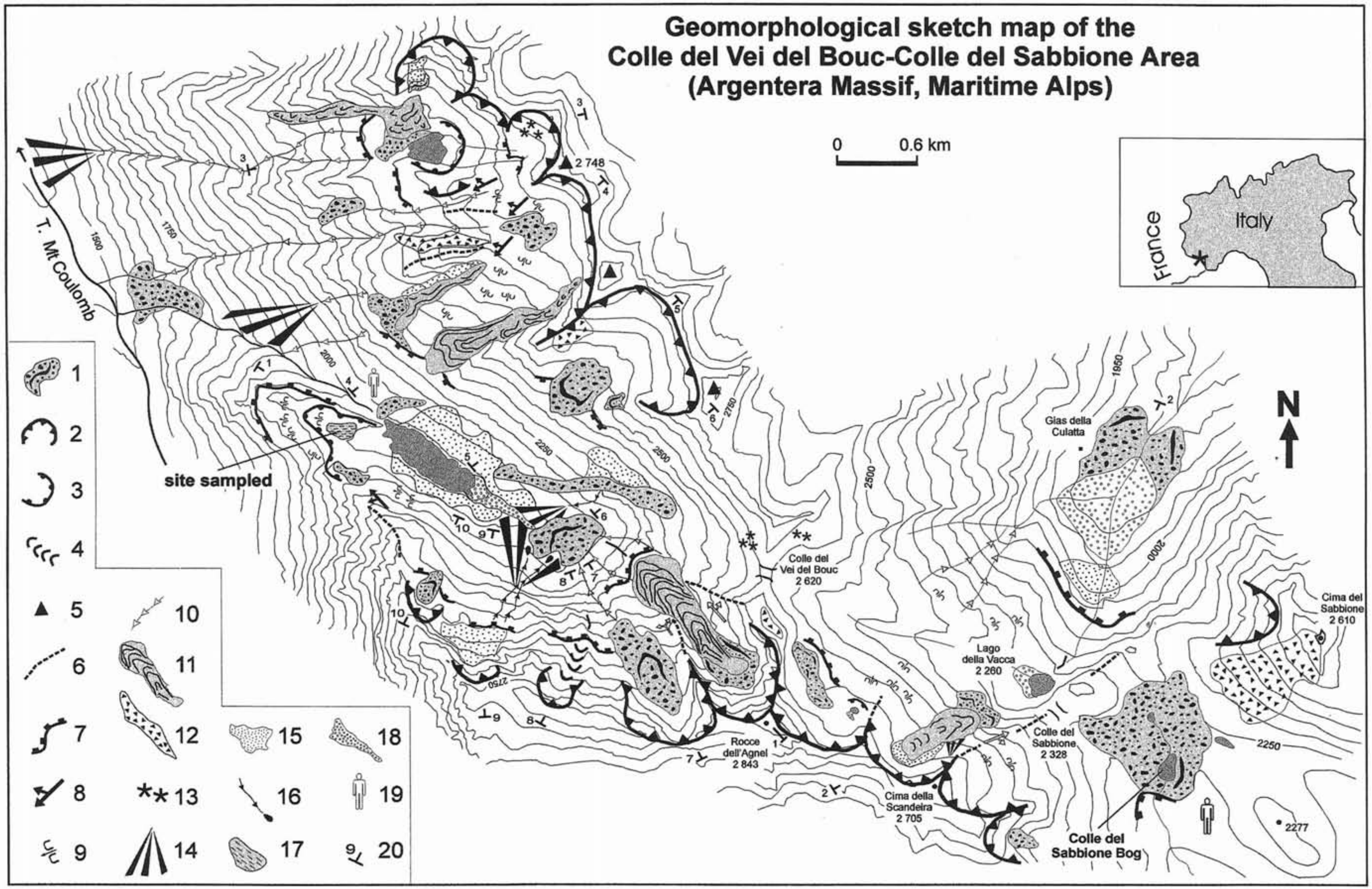


FIG. 1 - Geographic sketch map of the Gesso Basin (Italy) and the Roja Basin (France). The studied area is shaded.

tion (Ohmura & *alii*, 1992), thus providing the opportunity to quantify climatic reconstructions.

In the present study the Lateglacial and Holocene glacial and periglacial activity in the Valle del Vei del Bouc - Colle del Sabbione area (fig. 1) is reconstructed on the basis of detailed mapping of the glacial and periglacial landforms (e.g. moraines and rock glaciers) with classical methods. The palynological study and radiocarbon dates on a sediment core outside a frontal-moraine in the valley (Finsinger, 2001), in addition to palynological studies at the Colle del Sabbione and the Lac Long inferieur (De Beaulieu, 1977), were used to (i) identify the cold phases to which both vegetation and geomorphological processes are sensitive and (ii) to obtain dates *ante quem* or *post quem* of frontal moraines. The Equilibrium Line Altitudes (ELA) reconstructed here are compared to regional data (Chardon, 1991; Dijkstra & *alii*, 1990; Jorda, 1983; Julian, 1980; Schweizer, 1968), and a quantitative reconstruction of the climate during the glacier advances is proposed.

FIG. 2 - Geomorphological sketch map of the Valle del Vei del Bouc and the upper Valle del Sabbione. 1: glacial deposit and moraine ridge; 2: glacial cirque; 3: hollow; 4: glacial funnel; 5: horn; 6: smoothed crest; 7: glacial step; 8: transfluence saddle; 9: glacial striae; 10: fluvioglacial channel; 11: rock glacier; 12: block field; 13: periglacial micro-landform; 14: paraglacial cone; 15: scree detritus; 16: debris flow channel and lobe; 17: mire; 18: fluvial deposit; 19: rock art location.



Geomorphological sketch map of the
Colle del Vei del Bouc-Colle del Sabbione Area
(Argentera Massif, Maritime Alps)
0
0.6 km
France
Italy
N
T. Mt Coulomb
1500
1750
2000
2250
2500
2750
2748
2760
1950
site sampled
Colle del Vei del Bouc 2 620
Gias della Culatta
Lago della Vacca 2 260
Colle del Sabbione 2 328
Cima del Sabbione 2 610
Rocce dell'Agnel 2 843
Cima della Scandeira 2 705
Colle del Sabbione Bog
2277
1
2
3
4
5
6
7
8
9
10
11
12
13
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15
16
17
18
19
20

The area can be considered suitable for the aims of this study because of (1) the abundance of well preserved glacial and periglacial landforms and (2) its closeness to glaciers still present in the Maritime Alps (fig. 1), which in turn permits a link to past glacier behaviour.

General framework

The Valle del Vei del Bouc lies between 1500 m and 2800 m. At the NW edge of the Lago del Vei del Bouc (2054 m) there is a small mire that is hydrologically connected to the lake. The Colle del Vei del Bouc (2620 m) connects the Vei del Bouc valley to the Sabbione Valley, whose main peaks reach over 2700 m (fig. 1).

The Vei del Bouc valley is developed along a tectonic depression corresponding to a Permian-Triassic intracrystalline syncline that was partly reversed by a SW thrusting movement of the Argentera crystalline basement during the Late Alpine orogenetic phase (Malaroda, 1974; Ribolini, 1998, Ribolini, 2000). Besides high-grade metamorphic and granitoid rocks of the crystalline basement, quarzites, sandstones, and mylonitic outcrops are present in the area.

The short distance from the Mediterranean Sea (only about 40 km) and the high mean elevation strongly influence the climatic conditions of the Maritime Alps (Rapetti & Vittorini, 1992), leading to intermediate characteristics between a maritime and a continental climate. The specific climatic characteristics (temperature, precipitation, and snow cover) of the Gesso Basin at 2000 m can be summarised as follows: slightly negative air temperatures from December to March (–1 to –3 °C mean monthly temperature), precipitation with a maximum in spring (about 140 mm/season) and a secondary one in autumn (about 120 mm/season), mean annual snow cover of 596 cm with a maximum (110-115 cm/month) in spring.

The 6 glaciers still present in the Argentera Massif are the southernmost in the European Alps, with a present-day Equilibrium Line Altitude (ELA) estimated at about 2800 m. Federici & Pappalardo (1995) and Pappalardo & Rapetti (2001) investigated their recent behaviour. The Lower Discontinuous Permafrost Boundary (LDPB) was estimated at about 2600 m (Federici & *alii*, 2000; Ribolini 2001, in press).

The vegetation of the Maritime Alps shows characteristics of both maritime Mediterranean and continental dry vegetation. Ozenda (1988) divides the mountain chain into three zones according to the dominant vegetation: the internal zone is characterised by the dominance of *Pinus cembra*, *Larix decidua*, and *Pinus sylvestris*. In the transition zone, *Abies* is more abundant in the western borders, and *Fagus* forests reach up to 1750 m. In the external zone *Ostrya* plays an important role in the supramediterranean belt, and *Abies* in the montane belt, where *Fagus* is nearly absent. In this sector of the Alps *Picea* is scarcely represented.

In the Gesso basin the subalpine forest is formed by *Abies alba* in the lower part and by *Larix decidua* and *Pinus cembra* in the upper part. *Abies* forests reach 1500 m, single trees 1700 m. The upper forest limit reaches 2200-2250 m a.s.l., single trees of *Pinus cembra* still live at 2400 m. At altitudes between forest and subalpine/alpine meadows and pastures *Alnus viridis* is found, preferentially on more humid, northern exposed, slopes.

Methods

Geomorphological mapping (fig. 2) was carried out during 1999-2000 on topographic maps (scale 1:10.000). Subsequently colour aerial photographs (scale about 1:18.000) were used to survey the most inaccessible parts of the slopes. Detailed mapping was restricted to glacial and periglacial landforms in order to reconstruct paleoglacier shapes and distribution of permafrost features.

To extract paleoclimatic information from glacial landforms, ELAs of former glaciers was calculated by means of the Balance Ratio method (Furbish & Andrew, 1984), using a free spreadsheet programme (Benn & Gemmel, 1997). For the ELA calculation a balance ratio of 1.67 was used.

The mire of the Lago del Vei del Bouc was cored with a Russian corer 50 cm long and 5 cm in diameter. The core of 275 cm length (VB1) ends on a gravel layer, probably the ground moraine. A parallel core (VB2) was taken 30 cm away to sample the sediment disturbed at the core sections of the first core. In VB2 because of technical problems the intervals 200-210 and 250-260 were not sampled and are not described in the lithostratigraphic section (fig. 7). Cores were correlated by litho- and biostratigraphic inspection. The sediment was described with Munsell colour charts, and grain-size was estimated by feel. Pollen was prepared with standard KOH, HF, and acetolysis treatment. *Lycopodium* tablets were added to each sample in order to calculate pollen concentrations (grains/cm^3) (Stockmarr, 1971). Pollen was identified with a Leitz Dialux 22 microscope to the lowest possible taxonomic level at x400 magnification. Percentage values were calculated on the sum of arboreal pollen (AP, i.e. trees and shrubs) plus non-arboreal pollen (NAP, or upland herbs). Pteridophytes, aquatics, and fungal spores were calculated in relation to the pollens sum (AP + NAP), which ranges between 400 and 1000 pollen grains. Nomenclature of plants follows Pignatti (1982). Local pollen assemblage zones (LPAZ) were determined by visual inspection of the pollen assemblages.

GEOMORPHOLOGY

The landscape of the Vei del Bouc and the high Sabbione valleys is mainly characterised by glacial and periglacial landforms (fig. 2). During the Pleistocene glaciation the slopes of the Sabbione Valley were deeply scoured, large moraines were deposited in the lower part of the valley, outside the studied area (Federici & Pappalardo, 1991; Ribolini, 1996), and glaciers flowed across low-altitude passes, e.g. the Colle del Sabbione (2250 m).

Field evidences of glaciation

Several glacial cirques are eroded on the slopes of both the Vei del Bouc and the Sabbione valleys, generally with irregular landforms and partly coalescent. Depression in the lateral sides of cirques, long smoothed ridges, and directions of glacial striae define a phase characterised by glaciers with accumulation basins merged by means of transfluence saddles (fig. 2 and fig. 3).

The longitudinal profiles of the Vei del Bouc valley and the Sabbione valley show glacial steps at 2250-2300 m and 1900-2000 m (Profile 1-2 in fig. 4a): The first attributed mainly to a difference in subglacial erosion, the latter to a glacial terminus as confirmed by remnants of an end moraine.

Cross profiles parallel to the cirque axis, show several glacial steps that can be grouped in three main elevation levels: 2250-2300, 2450-2500, and 2600-2650 m (fig. 4b). The lower steps (at 2250-2300 m) of profile 3 and 6 may be the expression of lateral erosion of the glacier tongue, and the higher ones (at 2450-2500 and at 2600-2650 m) coincide with cirque thresholds (fig. 2).

Numerous micro- and meso-scale features of glacial erosion permit the reconstruction of the direction of glaciers movement. The rock basin that contains the Lago della Roccia corresponds to a depression that was filled by the glacier tongues moving from two cirques. *Roche moutonnée* and intensely striated whalebacks, glacial funnels, rock drumlins, and crag and tail features can be observed, especially near the glacial steps (fig. 5). Striated rock grooves and sinuous channels characterise the very marked glacial step of the Vei del Bouc valley.

Glacial deposits are widespread in the studied area, both as terminal and ground moraines, their preservation depending on altitude, i.e. their age. Most of these deposits are made up of massive diamicton, generally matrix-supported, characterised by heterometric blocks with a maximum diameter of about 1-2 m and a sandy-gravel matrix. Some glacial drift and small moraines show a clast-supported fabric with scarce sandy-gravel matrix limited to isolated pockets.

The end moraines in the high Sabbione Valley are located near the Gias della Culatta and at the threshold of the westernmost glacial cirque of the Cima della Scandeira (fig. 2) and show a well-preserved morphology (Ribolini, 1996) like the deposits in the uppermost part of Vei del Bouc Valley. In contrast, the end moraine to the southeast of the Lago del Vei del Bouc (fig. 2) is not well preserved although it is very thick; on the rocky threshold of the Lago della Roccia, sparse glacial deposits and block alignment suggest the position of an end moraine that has not been preserved (fig. 6).

The shallow depressions that are present on the glacial deposits of the Colle del Sabbione area have developed small mires. A side-frontal moraine dams the mire studied by De Beaulieu (1977).

The presence of end moraines allows an estimation of the ELA of former glaciers by means of the Balance Ratio method. To use this method the hypsometry of the glacier must be known, and the accumulation and ablation gradient must be considered as linear. This method is based on the fact that, for equilibrium conditions, the total annual accumulation above the ELA is exactly balanced by the total annual ablation below the ELA (steady-state ELA).

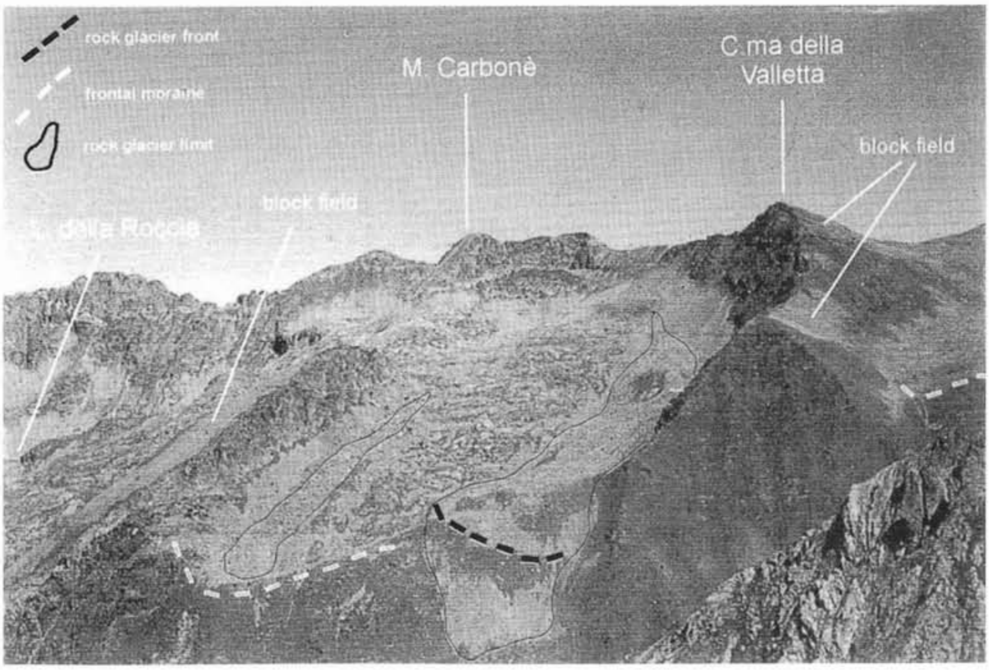


FIG. 3 - Frontal moraine (S_2) partly dismantled by a rock glacier (Valletta West Rock Glacier).

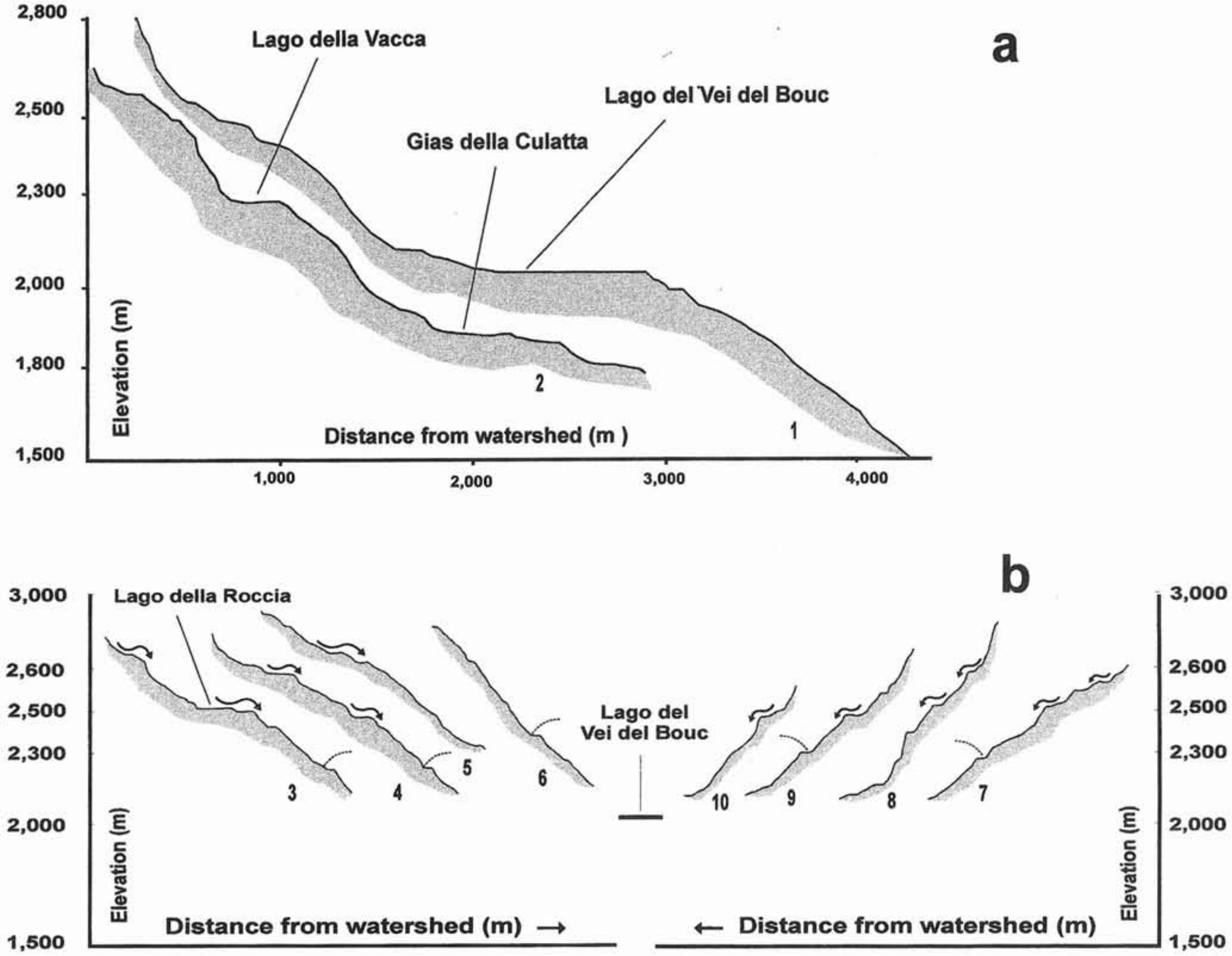


FIG. 4 - Longitudinal (a) and cross profiles (b). For profile locations see fig. 2. The arrows are located in correspondence of the cirque thresholds, the lines in correspondence of lateral glacial steps.

Frontal and lateral moraines, trimlines, and striae directions (fig. 2) allow the reconstruction of glacier shapes and the hypsometry by means of the 100 m contour topography. The ELA values (tab. 1) can be subdivided into three groups: 2200-2250 m (Lago del Vei del Bouc end moraine, Gias della Culatta end moraine), 2500-2550 m (end moraine of the left side and of the headwall of the Vei del Bouc Valley), and 2600-2650 m (end moraine of both valley headwalls).

The cirque-floor method does not consider the glacier mass balance and it is not linked to the concept of steady-state ELA. Moreover, the method simply summarises some aspects of the glaciated catchment, and it does not take into account that the cirque floor may be a rock basin eroded below a large valley glacier before the onset of the cirque-glaciation climatic conditions. Anyway, if we have some geomorphological features like sparse glacial debris or erratics on the threshold, the area of deepest erosion in an overdeepened basin or in a glacial cirque marks the long-term average position of maximum ice discharge, which may broadly coincide with the ELA on the ice surface (Benn & Evans, 1996; Federici, 1997). For this reason, some authors refer the cirque-floor to a «*Glaciation Elevation Index*» (GEI) (Benn & Lehmkuhl, 2000; Taylor & Mitchell, 2000). The elevation of cirque floors in the studied area was estimated in cross profiles (fig. 4b).

If the extrapolated ELA values are compared with those of the GEI (tab. 1), it is apparent that the studied area recorded three glacial phases (S_1, S_2, and S_3). The glaciers of the Vei del Bouc and of the Sabbione valleys experienced an ELA decrease respectively of about 500, 300, and 200 m in respect to the present-day value.

The inner side of some end moraines of the S_1 and S_2 phases are partly overlapped by the terminal ridge of rock glaciers (fig. 3), and in some cases permafrost creeping affected or totally dismantled former moraines, making the

TABLE 1 - Paleoglaciological topography data, ELAs, and GEIs calculated for glaciers in the study area. * = main valley glaciers

Paleoglacier	Aspect	Estimated chatchment area (m^2)	Highest summit (m)	Estimated upper limit of ice (m)	Lower limit of ice (m)	Main trought heads (m)	ELA (m)	GEI (m)	Valley
Lago del Vei del Bouc *	NW	2003,213	2845	2750	2100	2300	2260		
Lago della Roccia	WSW	311,038	2802	2700	2400		2530		
Lago della Roccia upper	SW	20,195	2803	2750	2550		2625		
Passo Carbonè	SE	?	2802	2700	2650			2650	Vei del Bouc
C.ma La Valletta	SW	531,69	2782	2700	2250	2250	2470		
q. 2808	SW	240,426	2743	2700	2450		2575		
Colle del Vei del Bouc	NNW	63,744	2845	2650	2450		2540		
Rocce dell'Agnel	NNW	71,907	2776	2650	2550		2605		
Cima del Toro 1	NNE	22,958	2686	2550	2400		2450		
Cima del toro 2	N	?	2703	2600	2450			2450	
Cima del Toro 3	NNE	?	2751	2750	2650			2650	
Gias della Culatta *	NE	1796,792	2845	2700	1900	2100	2220		
Vernasca Est	NNE	?	2704	2650	2450			2550	Sabbione
Vernasca West	NE	133,905	2845	2700	2550	2550	2635		

separation between glacial deposit and rock glacier difficult. Thus in the sketch map (fig. 2) landforms are represented according to their present-day morphology and not to their history.

Periglacial features

Several rock glaciers, stratified slope deposits, block fields, block streams, and gelifluction lobes testify to the intensity of periglacial processes in the Maritime Alps (Ribolini, 1997; Pappalardo, 1999; Pappalardo & Spagnolo, 1999). Present-day Lower Discontinuous Permafrost Boundary (LDPB) was estimated at about 2600 m (Federici & *alii*, 2000; Ribolini 2001, in press).

In the studied area most of the surveyed rock glaciers are of the valley-floor type and extend downward to the cirque thresholds (fig. 2). They show a well-preserved fluidal surface texture, with concentric and transversal ridges and spoon-shaped depressions. Of the five rock glaciers mapped three show a minimum elevation of the front at 2350-2400 m (R_1 generation) and two at about 2500-2550 m (R_2 generation). Moreover, the Vei del Bouc Rock Glacier can be subdivided into two flow units with minimum elevations of about 2350 m and 2500 m.

FIG. 5 - The glacial threshold of the Vei del Bouc Valley. The location of the cored mire is also indicated. *Roche moutonnée* and striated whalebacks characterizing the glacial threshold of the Vei del Bouc Valley.

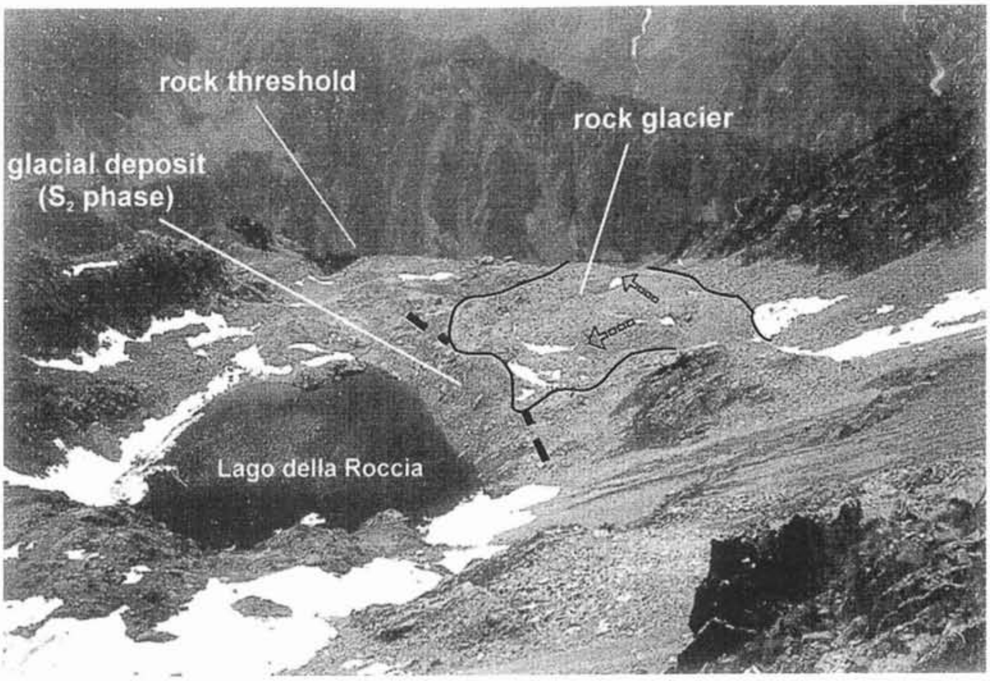


FIG. 6 - Glacial deposit (S_2) overlapped by rock glacier (R_3) in the Mt Carbonè and Lago della Roccia area.

During 1998-99 a continuous monitoring of surface ground temperature of the rock glaciers in the Argentera Massif was carried out by means of digital data loggers (Ribolini 2001, in press). Two data loggers were placed on the Vei del Bouc Rock Glacier, which experienced a mean annual surface ground temperature of –0.5 °C in its lower part (2440 m), with 193 days constantly below zero (from 11/11 to 24/5), and of –1.6 °C in the upper part (2500 m), with 233 days of constantly negative temperatures. The average surface ground temperature of the winter months (December-February) (–5.9 °C and –5.5 °C respectively), considered to be representative of the Bottom Temperature of Snow cover (BTS window), suggests a probable permafrost presence, a condition favoured by the sheltered location of the rock glacier with respect to direct solar radiation.

All the surveyed rock glaciers (R_1 and R_2) show relationship with glacial landforms, both for their location inside of glacial cirques and for their interaction with end moraines. The lower flow unit of the Vei del Bouc Rock Glacier reached down to the cirque threshold, while the upper flow developed from a lateral moraine and totally overrode the corresponding end moraine. Moreover, creep of the rock glaciers in the Cima della Valletta (Valletta West Rock Glacier) and Monte Carbonè (Carbonè Rock Glacier) areas affected end moraines, as suggested by geomorphological and sedimentological observations, e.g. the Carbonè Rock Glacier, located in the Lago della Roccia rock basin (fig. 2 and fig. 6), which partly overlaps sparse coarse till and a glacial ridge near the cirque threshold.

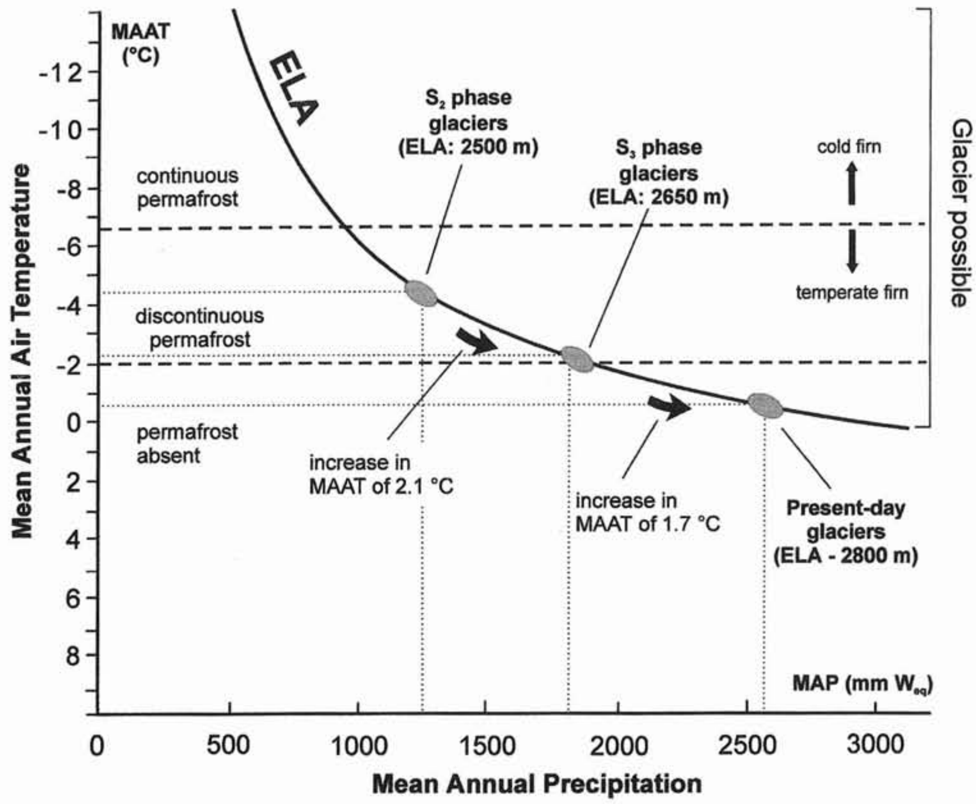
Block fields are spread over the upper part of the slopes, above the glaciation trimline and on top of the ice divide ridge (fig. 2). Several block streams characterise the northern slope of the Colle del Sabbione area, while gelifluction lobes affect fine-grained detritus near the Colle del Sabbione and the Colle del Vei del Bouc. At present, most active block fields, block streams, and gelifluction lobes are generally located above the LDPB (2600 m).

Paleoclimatic inferences

To reconstruct climatic conditions during glacier advances and rock-glacier formation, geomorphological evidences can be used. On the basis of the relationships between moraines and rock glaciers, the cold phases that determined the S_2 and S_3 glacial stages can be considered contemporaneous with the stages of rock-glacier formation R_1 and R_2. Different methods to infer paleoclimatological information were widely used in Northern Europe (Humlum, 1998), in the Alps (Kerschner, 1985; Buchenauer, 1990), and were recently tested also in the Apennine chain (Giraudi & Frezzotti, 1997). Using the general model of glacier-permafrost environment proposed by Haeberli (1983), we combined the relative LDPBs and ELAs to evaluate Mean Annual Air Temperature (MAAT) and Mean Annual Precipitation (MAP, expressed as water-equivalent, mm W_{eq}) at the ELAs during Lateglacial-Holocene cold phases (fig. 7).

Recent climatologic results indicate a MAAT at 2000 m a.s.l. (Lago del Chiotas meteorological station) of 3.7 °C and a thermal lapse rate of 0.53 °C/100 m (Rapetti & Vittorini, 1993; Pappalardo & Rapetti, 2001). Given a MAAT at the modern ELA (2800 m a.s.l.) of –0.54 °C,

FIG. 7 - Paleoclimatic reconstruction of S_2 and S_3 glacial phases using the criosphere model of Haeberli (1983) (modified and redrawn).



we obtain a MAP of about 2550-2600 mm W_{eq} (fig. 7). R_1-R_2 altitudinal difference allows to evaluate a lowering of the MAAT at the S_2 cold phase of −1.7 °C (calculated assuming a paleo-thermal lapse rate of 0.7 °C/100 m). MAAT at the S_2 ELA (2500 m a.s.l.) was about −4.4 °C to which, according to the model, correspond about 1200-1250 mm W_{eq} of precipitation. Using the same procedure, the climatic conditions during the S_3 cold phase were characterized by a MAAT of about −2.3 °C and a MAP of about 1850-1900 mm W_{eq} (fig. 7).

If a modern vertical precipitation lapse rate of 30 mm/100 m (Pappalardo & Rapetti, 2001) is used, past precipitation at the altitude of modern ELA can be inferred: during the S_2 and S_3 glacial stadia about 1300 and 2000 mm W_{eq} occurred respectively at the modern ELA.

Therefore, during the S_2 and S_3 glacial stadia MAATs were about 4 °C and 1.8 °C lower than at present with respectively 50% and 23% reduction of MAPs.

SEDIMENT AND POLLEN ANALYSIS OF THE LAGO DEL VEI DEL BOUC CORE

Sediment description and chronology (fig. 8)

The core consists at its base of yellowish silt (275-267 cm) that passes sharply into a grain-supported sandy to gravelly sediment (267-260 cm). From 250 cm to 230 cm an alternation of silty clay layers (5 Y 6/6) and sand layers (10 YR 5/6) dominates. In some cases the layers are thinner than 1 cm. This section is overlain by a ca. 10 cm silty sediment (230-220 cm) grey-yellow in colour (2.5 GY 6/1). At 220-210 cm depth and at 200-188 cm depth, alternating silt and sand layers similar to those in the interval 250-230 cm are again found. These are overlain by a grey silty clay with fine laminations (188-171 cm) passing abruptly into a brownish (5 Y 3/2) silty clay (171-148 cm), which is interrupted by a cm-thick sand layer at 164 cm. A coarsening upward of the sand fraction is observed between 148 cm and 77 cm. Here a grain-supported sand layer (77-66 cm), yellow-red in colour (7.5 YR 4/1), is overlain (66-50 cm) by a matrix-supported sandy silt (10 YR 2/3). The top 50 cm consist of brown (7.5 YR 2/3) detritus gyttia (50-20 cm) and a loose, undecomposed peat (20-0 cm). Because pollen grains were strongly corroded, pollen was not analysed at the top 20 cm.

Two ^{14}C dates on terrestrial plant macrofossils, taken respectively at 171 cm and 161 cm in the VB1 core, were ^{14}C-dated (Ua-16175: 7525±90 BP; Ua-16176: 5745±90 BP) (fig. 8).

Paleobotanical data (fig. 9)

Assuming the synchroneity of major pollen biostratigraphical boundaries between neighbouring sites and the age-equivalence of comparable boundaries in different

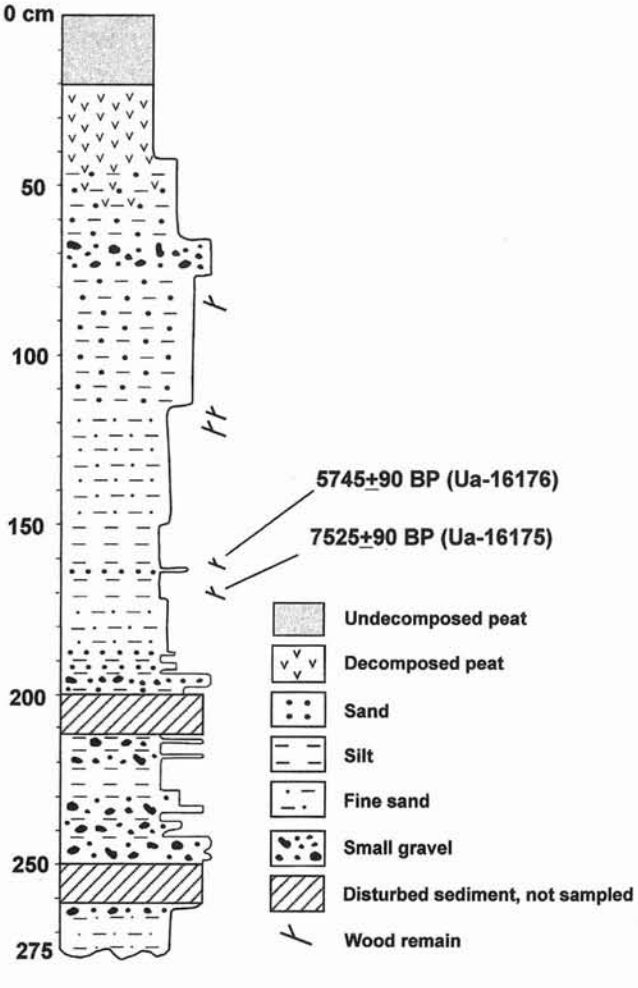


FIG. 8 - Stratigraphic section and location of dated terrestrial plant macrofossils.

cores, the identification of regional pollen zone boundaries (De Beaulieu, 1977; De Beaulieu & *alii*, 1994) in the Vei del Bouc core was possible. In fact a well dated core, namely the Lac Long inferieur (De Beaulieu, 1977) is located few kilometres away at a similar altitude (2090 m). The two ^{14}C-dates in the Vei del Bouc core confirm this correlation.

At the base of the core (LPAZ VB-1) the decrease of *Artemisia*, Rubiaceae, *Rumex acetosella*-type, *Thalictrum*, *Juniperus,* and to a lesser extent Gramineae is accompanied by an increase of *Pinus* and mesophilous trees (*Quercus*, *Ulmus*, *Tilia*, *Corylus*, and *Alnus*) (fig. 8). An AP increase, mainly due to *Pinus*, and a slight reduction of cold steppe taxa such as *Artemisia*, *Rubiaceae*, *Thalictrum*, and *Juniperus* (LPAZ VB-2), suggest a warming of the climate in LPAZ VB-3 (227-189,5 cm). Steppe taxa then increase again. Although interpretation is hindered by low temporal resolution in this core section, this palynostratigraphical succession seems to be comparable to the regional vegetation history of the Southwestern Alps for the Lateglacial period. The base of the core, i.e. the formation of shallow lake deposits, is in this sense correlated with the end of the Bølling pollen zone, the climatic amelioration of the Allerød is represented in LPAZ VB-2, and the Younger Dryas is correlated with LPAZ VB-3.

The YD/Holocene transition (LPAZ VB-3 to VB-4) is one of the sharpest in the pollen diagram (around 190 cm). It is marked by an increase in *Pinus* and mesophilous trees of the *Quercetum mixtum* (deciduous *Quercus*, *Ulmus, Corylus,* and *Fraxinus*). Low sediment-accumulation rates could explain the absence of a clear *Betula* phase. Because of this, the Preboreal and Boreal biozones could not be identified (LPAZ VB-4). Organic content and sediment-colour change at this boundary (from grey-yellow: 2.5GY5/1 to brown: 5Y3/2) point to increased productivity of the lake and the catchment. At this stage, slightly after the rise of pteridophytes, *Alnus glutinosa*-type pollen increases. Local vegetation consisted mainly of heliophilous herbs.

The Immigration of *Abies* (dated at 7525±90 BP) marks the onset of the Atlantic (LPAZ VB-5). Ericaceae shrub pollen is present with a low frequency after the end of LPAZ VB-4. Its increase is a sign for the development of Ericaceae shrub vegetation, accompanied by *Salix spp.*, near the site. It seems likely that *Abies* forests reached altitudes of ca. 2000 m as suggested by De Beaulieu (1977) and by the high pollen percentages (up to 30%); however, no stomata have been found. *Betula* and *Alnus* wood fragments at 120-115 cm depth show that these trees were living at the lakeshores and on the valley slopes at least at the end of the zone.

During LPAZ VB-6, grazing indicators (e.g. *Plantago lanceolata, Ligusticum mutellina, Polygonum bistorta*-type, *Rumex alpinus, Rumex acetosa*) in the pollen diagram show local human impact, and AP decreases sharply at the end of the zone (~ 82 cm). Two major deforestation phases were identified (Finsinger, 2001): at the beginning of LPAZ VB-6, synchronously with the first grazing indicators, and at the end of LPAZ VB-6, with the sharp AP decrease and a further increase of grazing indicators and coprophilous fungal spores (fig. 9). From VB-6 onwards *Alnus viridis* colonized the slopes of the valley, *Picea abies* immigrated in the region, and *Fagus* spread at lower altitudes, where it had been present at least since the early Holocene.

Picea abies expansion in the Swiss Alps have been interpreted as due to human impact (Markgraf, 1970), but a climatic control is suggested for the Eastern Alps (Tallantire, 1973). However, recent observations of timberline fluctuations in the Swiss Alps (Wick & Tinner, 1997) point to cold phases accompanied by increasing oceanicity as an explanation for the *Picea* spread, whereas *Alnus viridis* seems to be more favoured by human impact.

FIG. 9 - Pollen diagram of the Vei del Bouc core with some selected pollen-types. Gaps between sections in the two cores are shown in black on the left side of the diagram.

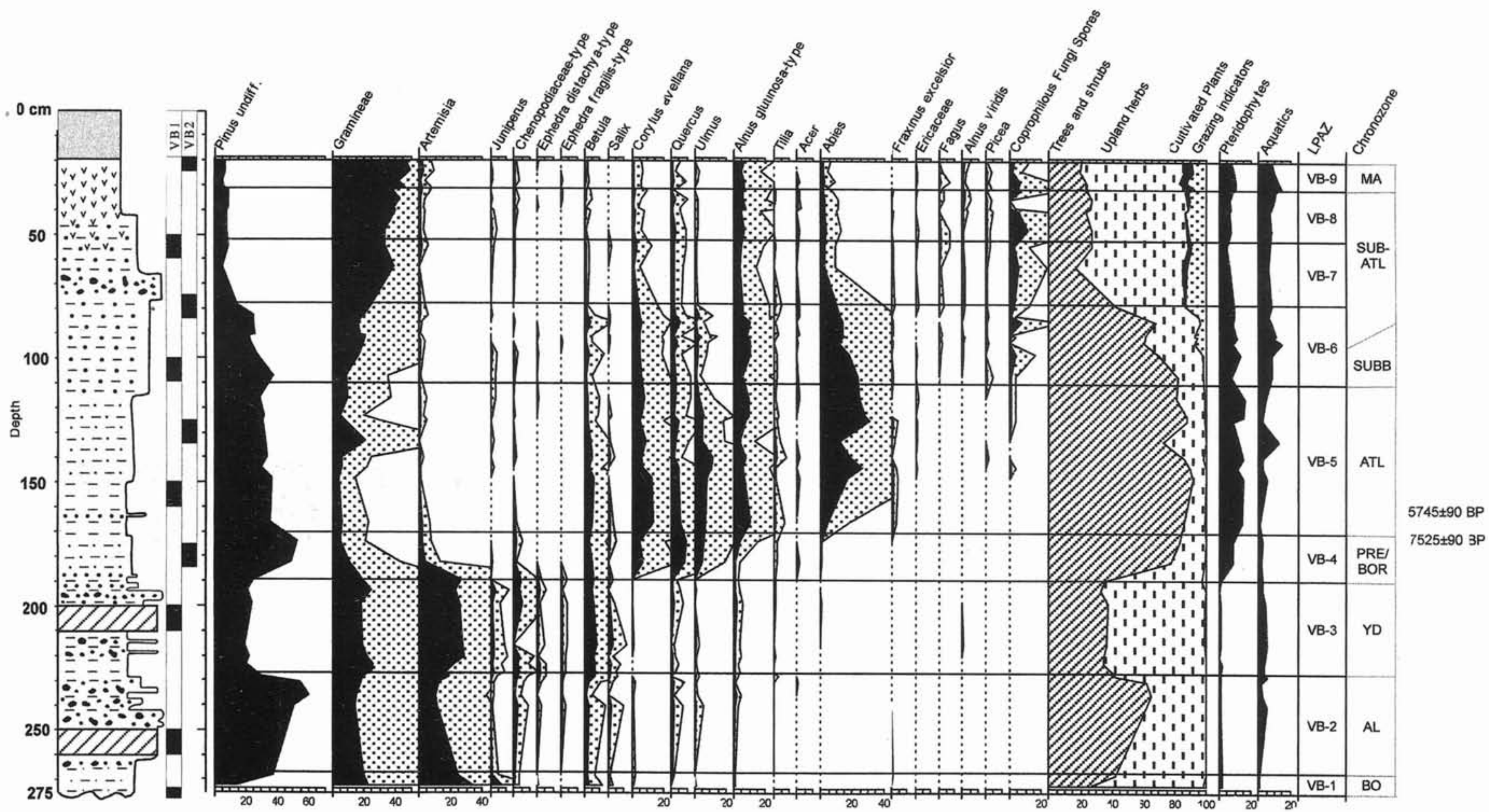

0 cm
50
100
150
200
250
275
Depth
VB1
VB2
Pinus undiff.
Gramineae
Artemisia
Juniperus
Chenopodiaceae-type
Ephedra distachya-type
Ephedra fragilis-type
Betula
Salix
Corylus avellana
Quercus
Ulmus
Alnus glutinosa-type
Tilia
Acer
Abies
Fraxinus excelsior
Ericaceae
Fagus
Alnus viridis
Picea
Coprophilous Fungi Spores
Trees and shrubs
Upland herbs
Cultivated Plants
Grazing indicators
Pteridophytes
Aquatics
LPAZ
Chronozone
VB-9
VB-8
VB-7
VB-6
VB-5
VB-4
VB-3
VB-2
VB-1
MA
SUB-ATL
SUBB
ATL
PRE/BOR
YD
AL
BO
5745±90 BP
7525±90 BP
20 40 60
20 40
20 40
20
20
20
20 40
20
20 40 60 80 100
20
20

TABLE 2 - Comparison of the ELAs obtained in the study area with regional previously published data. [1,6] this work; [2] modified from Schweizer (1968), calculated after Höfer (1897); [3a] Jorda (1986); [3b] Dijkstra & *alii* (1990), calculated after Höfer (1897), dated older than Younger Dryas; [4,5] Jorda (1983); [7] Evin & Fabre (1990); [8] Jorda (1993); [9] Julian (1980); +: formation of rock glaciers, elevation not specified

	SITE	SUBATLANTIC	SUBBOREAL	ATLANTIC	BOREAL	PREBOREAL	YOUNGER DRYAS	ALLERØD	BØLLING	OLDEST DRYAS
ELA	Studied area [1]		2600-2650				2500-2550 m			2300 m
	Tinée [2]		2685 m			2560 m	2415 m			2140 m
	Terre Plaines [3a]						2600 m [3a]			2400 m [3b]
	Clapouse [4]						2600 m			
	Ubayé [5]	2800 m	2700-2750 m			2500-2600 m	2250-2500 m			2100 m
GEI	Studied area [6]		2650							
RG	Studied area [6]		2500-2550 m				2350-2400 m			
	Southwestern Alps [7]		2500-2600 m							
	Durance [8]	+	+			+	+			+
	Ubayé [9]	2600 m	2500 m				2100 m			1800-1900 m

The onset of LPAZ VB-7 is dated at ca. 2000 BP with the cultivation of *Juglans regia* and *Castanea sativa*. Grazing indicators are from then on represented by high percentages; alpine pasture dominates the high-altitude landscape.

Vegetation development in the Maritime Alps was anthropogenically influenced at least since the Late Subboreal. Independent records point to local human land-use of the Vei del Bouc valley: grazing indicators and coprophilous fungal spores in the pollen samples, and rock-art found at the lake shores, at the Colle del Sabbione, and in the nearby Mont Bego area (de Lumley, 1995). Local deforestation and intense grazing activity of the developing summer pastures could have been the cause of erosion and the deposition of a grain-supported sand layer at the beginning of VB-7 (between 77 and 66 cm). Nevertheless, climatic factors, such as increased precipitation, could also be envisaged to explain this grain-size variation in the core.

DISCUSSION

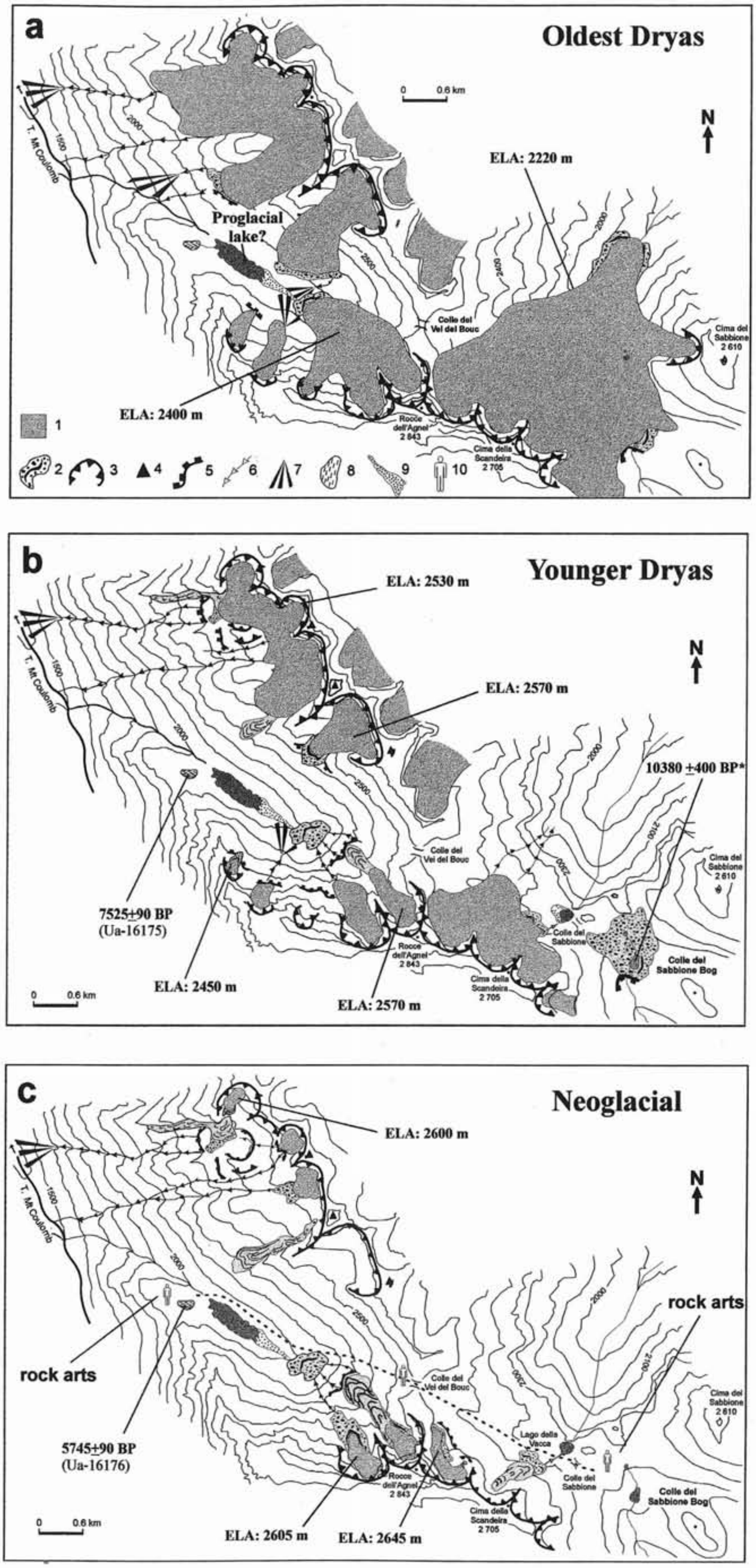
The regional vegetation history and the reconstruction of glacier advances (S_1, S_2, and S_3) and of rock-glacier formation phases (R_1 and R_2) are used to reconstruct past climatic fluctuations. Vegetation, glaciers, and rock glaciers are sensitive to different climatic parameters: vegetation is commonly interpreted as being sensitive to mean summer air temperature, the ELA on a glacier mainly depends on precipitation during the accumulation season and on air temperatures during the ablation season (Ohmura & *alii*, 1992), and the LDPB, i.e. where rock glacier fronts are generally found, is mainly dependent upon the $-1{,}5\pm0{,}5$ °C annual air isotherm. Thus we expect climatic fluctuations to be recorded by each one of the three proxies if critical thresholds of climatic parameters are passed.

S_1 PHASE (fig. 10a) - During the Lateglacial Interstadial, i.e. Bölling and Allerød chronozone, the threshold of the Vei del Bouc valley (2060 m) was already deglaciated. To better constrain the timing of the threshold deglaciation a comparison with surrounding area results could be performed. Radiocarbon data and palinological evidences clearly show that the threshold of the Lac Long inf. (2090 m a.s.l.) was already deglaciated before the Oldest Dryas (De Beaulieu, 1977). As these two sites are quite close (fig. 1) and are at similar altitude, we can infer that during the Oldest Dryas the Vei del Bouc glacier was not down-valley the coring location (fig. 2).

Thus we referred to the Oldest Dryas the end moraine at the SE border of the lake (2054 m, ELA: 2400 m), as well as the Gias della Culatta endmoraine (1900 m, fig. 2) with an ELA of 2220 m. The Vei del Bouc Glacier then was separated from the main glacier of the Mont Coulomb valley. The Sabbione glacier extended downward to 1990-2000 m (fig. 2) and flowed into the Valmasque valley by means of the Colle del Sabbione. Vegetation at this time consisted of a cold and arid steppe with abundant *Artemisia,* Chenopodiaceae, Gramineae, and other heliophilous herbs.

The mean ELA of the Oldest Dryas (2250 m) is slightly higher than corresponding ELAs in the Tinèe (Schweizer, 1968) and Ubayè valleys (France) (Jorda, 1983) (tab. 2). These discrepancies can be attributed to the different methods used (Höfer method in the French Alps and the Balance Ratio method in the Italian Alps), to local topoclimatic conditions and to wider catchment areas.

FIG. 10 - Sketch maps of Late-glacial to Holocene deglaciation phases (S_1, S_2, and S_3) in the studied area. 1: paleo-glacier; 2: glacial deposit and moraine ridge; 3: glacial cirque; 4: horn; 5: step; 6: fluvioglacial channel; 7: paraglacial cone; 8: mire; 9: fluvial deposit; 10: Bronze Age rock arts location and Colle del Sabbione-Lago del Vei del Bouc route.



a
Oldest Dryas
0 0.6 km
N
ELA: 2220 m
T. Mt Coulomb
1500
2000
Proglacial
lake?
2500
Colle del
Vei del Bouc
Cima del
Sabbione
2 610
ELA: 2400 m
Rocce
dell'Agnel
2 843
Cima della
Scandeira
2 705
1
2
3
4
5
6
7
8
9
10
b
Younger Dryas
ELA: 2530 m
N
ELA: 2570 m
10380 ±400 BP*
Colle del
Vei del Bouc
Cima del
Sabbione
2 610
7525±90 BP
(Ua-16175)
Colle del
Sabbione
Colle del
Sabbione Bog
Rocce
dell'Agnel
2 843
Cima della
Scandeira
2 705
0 0.6 km
ELA: 2450 m
ELA: 2570 m
c
Neoglacial
ELA: 2600 m
N
rock arts
rock arts
Colle del
Vei del Bouc
Cima del
Sabbione
2 610
Lago della
Vacca
5745±90 BP
(Ua-16176)
Colle del
Sabbione
Colle del
Sabbione Bog
Rocce
dell'Agnel
2 843
Cima della
Scandeira
2 705
0 0.6 km
ELA: 2605 m
ELA: 2645 m

S_2 PHASE (fig. 10b) - In the Vei del Bouc core the cold period of the Younger Dryas is evident. Local vegetation is similar to the Oldest Dryas, although higher *Quercus* values point to a development of broadleaf forests at low altitude. Cold-climate phases during the Lateglacial do not seem to have occurred in the region, according to pollen data (De Beaulieu & *alii*, 1994) and oxygen-isotope records in Northwestern Italy (Eicher, 1987). Thus we consider the end moraines of the S_2 phase (ELA of about 2550 m) to be of Younger Dryas age, with an ELA increase of about 300 m with respect to the S_1 phase. This value fits quite well with the ELAs calculated in the French Southwestern Alps (tab. 2). A long-term average position of maximum ice discharge at about 2450 m is also suggested by the GEI values (tab. 1). The Vei del Bouc Glacier retreated above about 2400 m, dividing into tributary tongues. Also the Valle del Sabbione glacier was placed above altitudes of 2400 m and did not pass to the Valmasque by means of the Colle del Sabbione (2300 m), as evidenced by the ^{14}C dates at the base of the Sabbione core (10380 (400 BP) (De Beaulieu, 1977).

The cold conditions of the Younger Dryas determined the formation of rock glaciers with lower front at about 2300-2400 m altitude, sometimes developing immediately below the glacial deposits of the same age, as in the case of the Vei del Bouc Rock Glacier. Paleobotanical results highlight dryer, beside colder, conditions in respect to the Present, confirming that the paleo-thermal lapse rate of 0.7 °C/100 m used in the paleoclimatic reconstruction is more realistic.

S_3 PHASE (fig. 10c) - Several glacial deposits in the Gesso Basin, with frontal elevation ranging from 2500 m to 2650 m, were recently dated to the Little Ice Age by the lichenometric method (Federici and Stefanini, 2001). The authors recognised three main glacial advances during the Little Ice Age (LIA): between the 13th and the 15th centuries, during the 17th century, and between the 18th and 19th centuries. The mean ELA of LIA glaciers in the Gesso Basin, calculated using the Accumulation Area Ratio method, was located at 2650-2700 m (Pappalardo, personal communication). The ELA of moraines belonging to the S_3 phase are at slightly lower altitudes, and we presume they are older than the LIA. Moreover, rock glaciers with fronts located at about 2500 m (R_2 phase) have to be considered to be of Holocene age. According to Barsch (1996), rock-glacier neoformation during the LIA is unlikely, but it is not *a priori* excluded that a strong impulse in the permafrost creeping could cause the formation of new lobes. We thus infer at least one Holocene cold-climate phase during which glaciers advanced and new rock glacier lobes formed.

The chronological attribution of the S_3 phase is problematic, as pollen diagrams in the region do not show clear evidences for short-lived cold periods during the Holocene, in opposition to other Alpine regions (Patzelt, 1977; Wick & Tinner, 1997; Zoller, 1960). The rapid warming during the early Holocene is shown by the increase of mesophilous taxa (*Quercus* dec., *Ulmus, Acer, Corylus*). It seems likely that *Pinus cembra* and maybe also *Abies alba* forests reached the site during VB-5 (correlated to the Atlanticum). At the beginning of VB-6, simultaneously with the *Fagus, Picea* and *Alnus viridis* immigration, anthropogenic indicators appear, making the interpretation of climate signals difficult.

During the Holocene the amplitude of mean annual temperature fluctuations was not so great as during the Late Glacial. Nevertheless geomorphological responses to Holocene short-lived cold phases (e.g. glacier fluctuations, enhanced solifluction, and rock glaciers) are known (Baroni & Carton, 1991; Haeberli, 1983; Kerschner, 1985; Maisch, 2000; Porter & Denton, 1967). Even if not everywhere in the Alps, commonly a climatic optimum (also called the 'Hypsithermal') is recognised between ca. 8000 BP and 5000 BP during which minor glacial activity occurred (Porter & Denton, 1967; Nesje & Dahl, 1993; Orombelli & Mason, 1997). In the Italian Alps mainly glacier advances referring to the Neoglacial period (past 5000 years) are documented. Four main glacier advance phases have been recognised: 5300-5000 cal BP, around 3000 cal BP, 2050-950 cal BP, and the LIA (350-100 cal BP). Among these cold phases, the LIA glacier advance seems to have been the most intense, being wider than other Holocene cold phases.

The datings of rock-glacier formation phases are by far less abundant. The only data available up to now is a ^{14}C date of 2250±100 BP on the permafrost at the base of an active rock glacier in the Swiss Alps (Haeberli & *alii*, 1999). For the Southwestern Alps, Evin & Fabre (1990) suggested a late Subboreal formation.

On the basis of these considerations, we suggest that the end moraines belonging to the S_3 phase (ELA of about 2600-2650 m) are of late Subboreal age. The following LIA advances likely added new glacial material to the deposits of this period, and formed more internal ridges.

Correlation of rock glaciers belonging to the R_2 phase with moraines of the S_3 phase is supported by their closeness, as is the case of the Lago della Roccia rock glacier, which developed from the apron of the S_3 moraine and overlapped the S_2 moraine (fig. 5).

ELAs and elevations of rock glacier fronts of the S_3 phase are in accordance with data proposed in the Tinèe and Ubayè-Queyras Valleys for the Subboreal (Schweizer, 1968; Evin & Fabre, 1990) (tab. 2).

CONCLUSION

Our investigations in the Vei del Bouc and Sabbione valleys indicate the occurrence of at least three phases of glacial formation (S_1, S_2, and S_3) and two for rock-glaciers (R_1 and R_2), which can be referred to Lateglacial and Holocene global climate oscillations, namely the Oldest Dryas, the Younger Dryas and the late Subboreal periods. However, in our opinion it is not excluded that other short-lived Holocene cold events have had an influence on glacial and periglacial activity in the studied area.

The clearest cold-climate periods represented in the pollen diagrams can be correlated with the Oldest Dryas (S_1 phase) and the Younger Dryas (S_2 phase). During the latter period glacier fronts were located at about 2400 m, with a mean ELA of about 2500 m and LDPB at 2300-2400 m. Our climatic reconstruction suggests that the mean annual air temperature at the ELA was about 4 °C below the present with a reduction in precipitation of about 50%. Similar values have been calculated for the same period in the Swiss and Austrian Alps (Haeberli, 1983; Kerschner, 1985; Buchenauer, 1990; Wohlfarth & *alii*, 1994), suggesting that the Argentera Massif is as sensitive to climatic oscillations as other parts of the Alps.

During the Hypsithermal the ELAs of the Vei del Bouc and Sabbione glaciers were strongly elevated, and glaciers were reduced and probably divided to some minor bodies inside the cirques. Timberline may have risen and *Abies* likely reached altitudes of 2000 m.

The unique Holocene pre-LIA glacial phase found in the Valle del Vei del Bouc and the Valle del Sabbione (S_3 phase) is represented by moraines and GEIs at about 2600-2650 m. We suggest, mainly on the basis of regional vegetational changes, a late Subboreal age for this phase. At this time permafrost creeping affected the coeval moraines, and rock-glaciers formed again (R_2 phase). We suggest a mean annual air temperature difference of about −2 °C at the LDPB compared to the present. A reactivation during the Subboreal period affected the upper part of the Younger Dryas rock glaciers. The present-day occurrence of permafrost still characterises the Subboreal rock glaciers and the rock glacier flow units above 2600 m, which formed during the Younger Dryas.

The results of this work provide new chronological and paleoenvironmental constraints for the Lateglacial and Holocene deglaciation in the Italian side of the Argentera Massif that may be matched to the Little Ice Age and to present-day behaviour of glaciers in the Maritime Alps. Moreover, the finding of a pre-LIA glacial advance of greater magnitude than the LIA-advances is of great interest for the reconstruction of Holocene climatic variability and demands further work and better dating.

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