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EQUILIBRIUM LINE ALTITUDE (ELA) VARIATIONS RECORDED BY ORTLES-CEVEDALE GLACIERS (LOMBARDY, ITALY) FROM LITTLE ICE AGE TO PRESENT

ABSTRACT: PELFINI M., *Equilibrium line altitude (ELA) variations recorded by Ortles-Cevedale Glaciers (Lombardy, Italy) from Little Ice Age to Present* (IT ISSN 0391-9838, 1994).

In this study, both present-day and Little Ice Age equilibrium line altitudes (ELA) were obtained for glaciers located in Upper Valtellina (Central Alps) with the AAR method. Utilizing the hypsographic curve, the altitude corresponding to a ratio of accumulation area to total area equal to 0.66 ± 0.05 was calculated. The same method was applied to calculate the ELA for the Little Ice Age, after the reconstruction of the glacier surface. The altitude of the equilibrium line has shifted upwards of 102 m from the Little Ice Age to the present. This upward shift corresponds to an increase in mean annual temperature of about 0.5°C, as calculated by taking into account the temperature lapse rate recorded in Lombardy.

KEY WORDS: Equilibrium line altitude, Little Ice Age, Glaciers, Ortles-Cevedale Group (Alps).

RIASSUNTO: PELFINI M., *Le variazioni della linea di equilibrio (ELA) nei ghiacciai del Gruppo Ortles-Cevedale (Settore Lombardo) dalla Piccola Glaciazione ad oggi* (IT ISSN 0391-9838, 1994).

Nel presente lavoro, mediante il metodo AAR (AAR = 0,66 ± 0,05), è stata calcolata l'altitudine attuale della linea di equilibrio dei ghiacciai del Gruppo Ortles-Cevedale, nonché l'altitudine della linea di equilibrio durante la Piccola Glaciazione. La ELA risulta essere risalita di 102 m in un intervallo di poco più di 120 anni. Tale aumento corrisponde ad un incremento della temperatura media annua pari a circa 0,5°C, sulla base del gradiente termico valido per la Lombardia.

TERMINI CHIAVE: Linea di equilibrio, Piccola Glaciazione, Ghiacciai, Gruppo Ortles-Cevedale.

INTRODUCTION

During the Holocene many glacial fluctuations occurred as a response to climatic variations; the snout fluctuations occur after mass balance variations. The equilibrium line altitude (ELA) for each glacier is the locus of all points where accumulation of solid-state precipitation and ablation are equal and, therefore, the annual mass balance is zero. During climate cooling periods the ELA shift downward while during the periods of better climatic conditions the ELA growes up. The ELA is determined by measurement of specific mass balance quantities at some point of the glacier surface; in this way it is possible to drawn the isoline of zero balance. In Italy only on very few glaciers mass balance measures are done, Sforzellina Glacier (BARSANTI & SMIRAGLIA, 1994) and Careser Glacier (ZANON, 1992).

The ELA varies from year to year; minimum values correspond to years with positive mass balance as maximum values correspond to years with highly negative mass balance. For bigger time interval the variations of glacier ELAs are about some tens of meters per century (BRAITHWAITE & MÜLLER, 1980). Glacier equilibrium line are important; in fact it represents the lowest boundary of the climatic glacierization (OHMURA & *alii*, 1992). The ELA yearly variation is a good indicator of the variations of the total annual mass balance.

According to BRAITHWAITE & MÜLLER (1980) the best parametrizzation of the ELA is the steady state ELA; that means the ELA corresponding to a balanced mass budget. RICHTER (1885) proposed that the firn line divide the glacier into two parts: the accumulation area and the ablation area with a ratio of 8:1. BRÜCKNER (1886) suggested a value of 3:1. Now an area ratio of 2:1 is accepted for the steady state ELA of Alpine glaciers (BRAITHWAITE & MÜLLER, 1980; GROSS & *alii*, 1977). This correspond to an accumulation area ratio (AAR) of 0.67. Sometimes the area ratio is 1:1 (AAR = 0.50) when the glaciers present symmetric hypsographic curve (BRAITHWAITE & MÜLLER, 1980).

The present study evaluates upward shift of the equilibrium line altitude (ELA) from the Little Ice Age maximum expansion to present-day on the glaciers located in the Lombardy sector of the Ortles-Cevedale Group.

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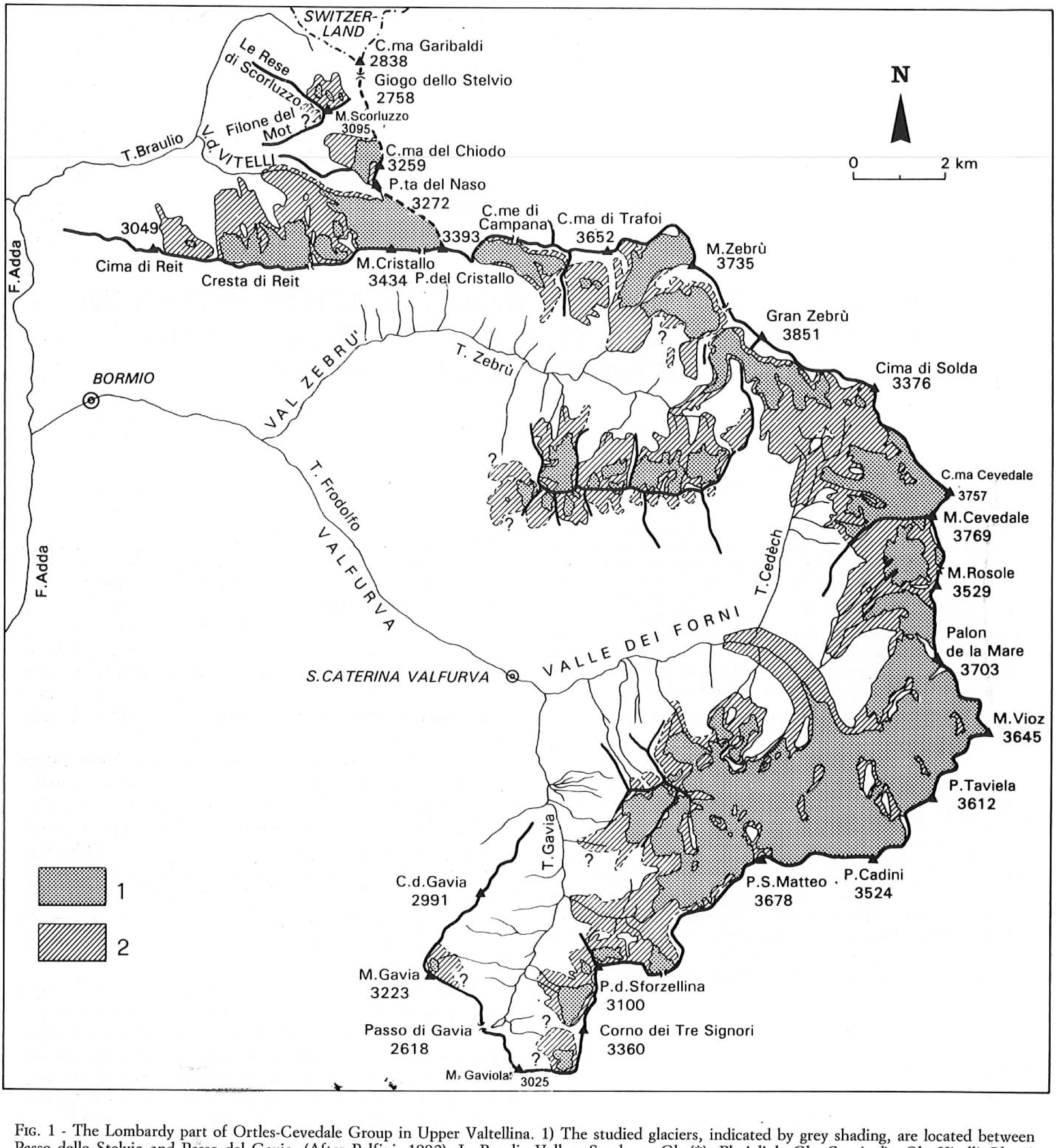


FIG. 1 - The Lombardy part of Ortles-Cevedale Group in Upper Valtellina. 1) The studied glaciers, indicated by grey shading, are located between Passo dello Stelvio and Passo del Gavia. (After Pelfini, 1992). In Braulio Valley, Scorluzzo Gl. (*), Platigliole Gl., Crapinelìn Gl., Vitelli Gl., 5) Cristallo E Gl., Central Cristallo Gl., Cristallo W Gl., Vedrettino Gl. (*) are located. In Zebrù Valley, Campo Gl., Camosci Gl., Zebrù Gl., Cima della Miniera Gl. (*), Miniera Gl., Castelli E Gl., Castelli W Gl., Montagna Vecchia Gl., Forà Gl., Confinale NW Gl. (*) are located. In Valfurva, Lago del Confinale Gl., Confinale S Gl. (*), Confinale SE (or Manzina) Gl. (*), Cime del Forno Gl. (*), New, nameless glacier in W.G.I. are located. In Cedèch Valley, Gran Zebrù Gl., New, nameless glacier in W.G.I., Cedèch Gl., Pasquale N Gl., Pasquale S Gl. are located. In Valfurva-Rosole Valley, Rosole Gl. and Col della Mare Gl. are located. In Valfurva-Forni Valley, Palon della Mare Gl., Forni Gl., New, nameless glacier in W.G.I., San Giacomo E Gl., San Giacomo W Gl., Cerena Gl. and a new, nameless glacier in W.G.I. are located. In Gavia Valley, Tresero Gl., Dosegù Gl., Passo del Dosegù Gl., Punta Sforzellina NE Gl., Punta Sforzellina W Gl., Sforzellina Gl., Lago Bianco Gl., Gavia Gl. and a new, nameless glacier in W.G.I. are located. (Asteriscs indicate glaciers which are considered extinct by the Catasto dei Ghiacciai Italiani). 2) Holocene maximum extension. This event occurred during the Little Ice Age, most probably in the middle of the 19th century. Total surface area reduction amounts to 46-47% (modified after Pelfini, 1992).

FIG. 2 - Vitelli Glacier: part of the tongue and of the accumulation basin. In the foreground, a medial moraine can be observed.

According to NESJE & *alii* (1992) the ancient ELA can be obtained by utilizing the following different parameters: 1) the maximum elevation of lateral moraines (MELM); 2) the median elevation of glaciers (MEG) (AAR = 0.5); 3) the toe-to-headwall altitude ratio (THAR); 4) the ratio of the accumulation area to the total area (AAR) (NESJE & *alii*, 1992). In this study AAR was utilized, because it probably is the most reliable method (HAWKINS, 1985; NESJE & *alii*, 1992; GROSS & *alii*, 1977, BRAITHWAITE & MÜLLER, 1980). According to BRAITHWAITE & MÜLLER (1980) the AAR value = 0.67 is the best for the Alps. According to PORTER (1975) the accumulation area to total area ratio is 0.66 ± 0.05 for temperate glaciers of different regions in the World. The AAR of glaciers is a function of their mass-balance: values lower than 0.5 are indicative of negative mass-balance. AARs ranging from 0.5 and 0.8 correspond to steady state conditions, whereas values greater than 0.8 are indicative of positive mass-balance (ANDREWS, 1975, in NESJE & *alii*, 1992). A value of 0.66 ± 0.05 is commonly considered characteristic of valley and cirque glaciers in dynamic equilibrium. However, errors in calculating AAR from ancient glacier surface extension may stem from the reconstruction of the most external limit reached by the glacier. Fortunately, this error has a uniform distribution and is, therefore, negligible (NESJE & *alii*, 1992).

The study area is located at the head of Valtellina, between Passo dello Stelvio to the N and Passo del Gavia to the S. In particular, the present day and the Little Ice Age ELA were calculated on 39 glaciers chosen between the glaciers studied in the field (PELFINI, 1992).

METHODS

At first, aerial photographs of the studied area, at the scale 1:20.000 were observed. Secondly, Holocene moraines were mapped in detail and the maximum Holocene expansion was recognized on the basis of extensive field-work (PELFINI, 1992). The recognized Holocene maximum expansion limits were subsequently transferred on enlarged aerial photographs at different scales, in the range 1:4.500 to 1:8.000, and then to 1:25.000 maps by Istituto Geografico Militare Italiano (IGMI). Holocene moraines were dated by ^{14}C analyses of soils and buried soils, and by lichenometry. Observation of maps, drawings and pictures provided further information about recent times. All the data thus obtained indicate that the maximum Holocene glacier expansion in the Lombardy sector of Ortles Cevedale occurred during the Little Ice Age, most probably during the first half of last century (fig. 1). Since the Little Ice Age up today the glacier surface reduction is about 46-47% (PELFINI, in press).

Present-day and Little Ice Age equilibrium line altitudes were calculated to estimate the amount of the variation and then find possible relationships with glacier orientations. The total area of each glacier, as well as the areas included between 100-m contour lines, were calculated by utilizing the IGMI 1:25.000 maps relative to the 1972 survey. After drawing the hypsographic curve, the present-day ELA was calculated utilizing an AAR equal to 0.66 ± 0.05. This means that the ELA at present is located in that part of the hypsographic curve between 61% and 71%, probably at 66%.

Furthermore, 100 m-contour lines relative to the surface of glaciers during the Little Ice Age were reconstructed by utilizing as datum point the altitudes of the lateral moraine ridges, because they record the altitude of the glaciers on the slopes. The Little Ice Age ELA was calculated by means of the same technique.

EQUILIBRIUM LINE ALTITUDE (ELA) FLUCTUATIONS FROM THE LITTLE ICE AGE TO THE PRESENT

The ELA given here are results from geometric calculations; consequently, they may differ from the real ones. The results are shown in Table 1.

TABLE 1 - This table shows the data about present-day ELA and ELA values during the Little Ice Age geometrically calculated for each glacier. In the 4th column (+) indicates the upward shift of ELA, whereas (-) indicates a depression. This depression, commonly observed in *glacierets*, must be attributed to a general lowering of the glacier surface which occurs when the glacial surface is entirely in the ablation area. When possible, the values of the snowline calculated by Desio (1973) using three different methods (columns 5) are reported.

Table 1a - Vitelli Valley

Glacier	(orientation)	Present-day ELA (m)	LIA-ELA (m)	Variations (m approx)	ELA (1961) (Desio, 1973)
Scorluzzo	(N)	2801 (+08/-11)	2802 (+14/-16)	-1	
Platigliole	(NW)	2991 (+15/-14)	2914 (+18/-14)	77	
Vitelli	(W)	3154 (+41/-31)	2752 (+32/-24)	402	3005-2953-3008
Crapinelìn	(N)	2853 (+11/-09)	2752 (+32/-24)	101	2828-2835-2857
Cristallo E	(N)	2869 (+19/-15)	2752 (+32/-24)	117	
Cristallo C	(N)	2855 (+17/-13)	2752 (+32/-24)	103	
Cristallo W	(N)	2772 (+12/-09)	2752 (+32/-24)	20	
Vedrettino	(N)	2644 (+07/-05)	2751 (+18/-14)	-107	

Table 1b - Zebrù Valley

Glacier	(orientation)	Present day ELA (m)	LIA-ELA (m approx)	Variation (m approx)	ELA (1961) (Desio, 1973)
Campo	(ESE)	3116 (+21/-16)	3038 (+32/-24)	78	3080-3113-3145
Camosci	(S)	2833 (+05/-00)	2924 (+12/-09)	-91	
Zebrù	(SW)	3079 (+28/-23)	2987 (+37/-32)	92	3200-3163-3260
Miniera	(S)	3108 (+48/-24)	3021 (+33/-35)	87	
Castelli E	(N)	2901 (+10/-13)	2795 (+26/-23)	106	2955-2962-2977
Castelli W	(N)	2900 (+19/-20)	2795 (+26/-23)	105	2955-2962-2977
Montagna Vec.	(N)	2867 (+12/-09)	2806 (+24/-19)	61	
Forà	(N)	2939 (+13/-10)	2829 (+33/-25)	110	

Table 1c - Valfurva Valley

Glacier	(orientation)	Presen-day ELA (m)	LIA-ELA (m)	Variations (m approx)
Lago Confinale	(W)	3079 (+13/-10)	2961 (+12/-00)	118
Merid. Conf.	(S)	3073 (+12/-09)	3123 (+08/-06)	-50
Confinale SE	(SE)	3042 (+07/-05)	3126 (+10/-08)	-84
Cime Forni	(S)	3133 (+05/-04)	3021 (+106/-94)	112

Table 1d - Cedèch Valley

Glacier	(orientation)	Present-day ELA (m)	LIA-ELA (m)	Variations (m approx)	ELA (1961) (Desio, 1973)
Gran Zebrù	(SE)	3074 (+18/-13)	2943 (+30/-23)	131	3165-3238-3395
Cedéch	(W)	3169 (+45/-37)	2943 (+30/-23)	226	3229-3135-3229
Pasquale N	(WNW)	3085 (+18/-13)	2943 (+30/-23)	142	
Pasquale S	(WNW)	3218 (+10/-08)	2943 (+30/-23)	275	

Table 1e - Rosole Valley

Glacier	(orientation)	Present-day ELA (m)	LIA-ELA (m)	Variations (m approx)	ELA (1961) (Desio, 1973)
Rosole	(SW)	3088 (+15/-12)	3014 (+43/-29)	74	
Col di Lamare	(SW)	3052 (+64/-50)	3014 (+43/-29)	38	3217-3156-3219

Table 1f - Forni Valley

Glacier	(orientation)	Present-day ELA (m)	LIA-ELA (m)	Variations (m approx)	ELA (1961) (Desio, 1973)
Forni	(NW)	3010 (+45/-42)	2923 (+73/-59)	87	3052-2968-3052
Palon d. Mare	(SW)	3216 (+24/-19)	2923 (+73/-59)	293	
S. Giacomo E	(N)	2848 (+12/-09)	2866 (+23/-20)	-18	
S. Giacomo W	(N)	3014 (+18/-14)	2866 (+23/-20)	148	
Cerena (N)		2870 (+17/-13)	2866 (+23/-20)	4	

Table 1g - Gavia Valley

Glacier	(orientation)	Present-day ELA (m)	LIA-ELA (m)	Variations (m approx)	ELA (1961) (Desio, 1973)
Gavia	(E)	3055 (+06/-05)	2927 (+16/-12)	128	
Lago Bianco	(NW)	2909 (+07/-06)	2917 (+10/-07)	-8	
Sforzellina	(NW)	2861 (+11/-09)	2849 (+15/-11)	12	
P. Sforzellina	(NNW)	2919 (+06/-05)	2849 (+15/-11)	70	
NE P. Sforzel.	(NNW)	2853 (+14/-13)	2937 (+38/-29)	-84	
Passo Dosegù	(NW)	2946 (+08/-06)	2937 (+38/-29)	9	
Dosegù	(SW)	3166 (+32/-25)	2937 (+38/-29)	229	3185-3184-3242
Tresero	(W)	3124 (+14/-09)	3016 (+23/-20)	108	

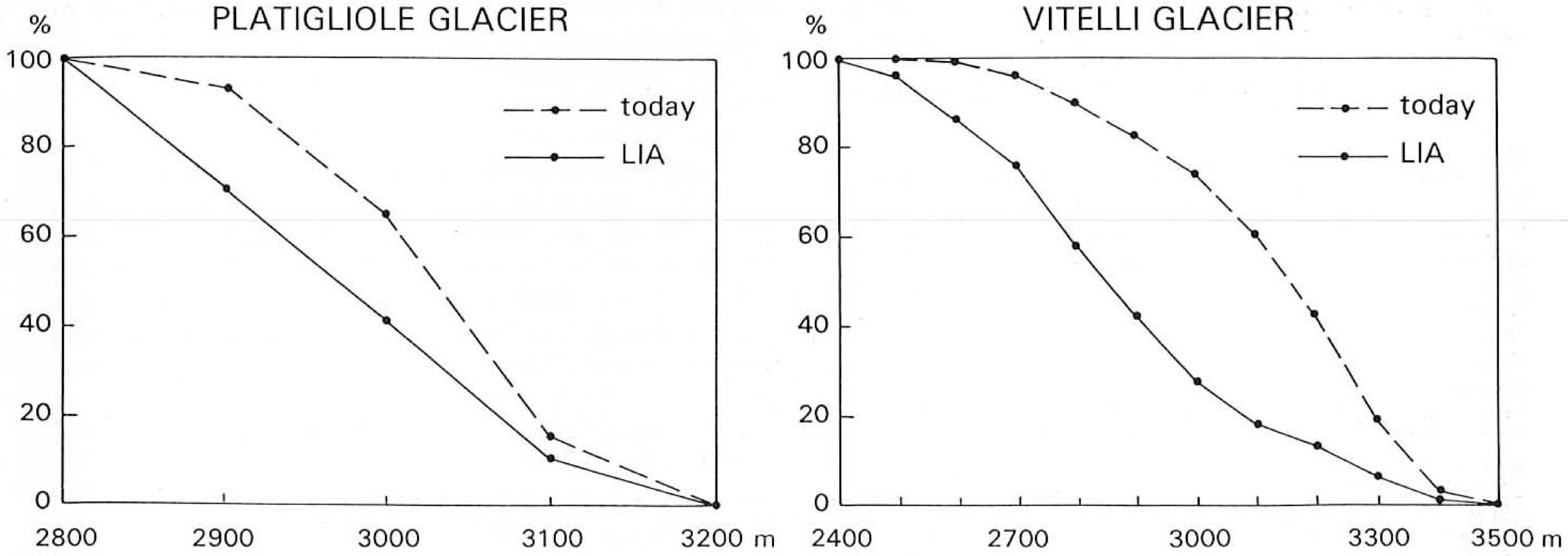


FIG. 3 - Hypsographic curves for Platigliole Gl. (3a) and Vitelli Gl. (3b)

The majority of the glaciers in Vitelli Valley (fig. 2) show N orientation. The calculated present-day ELA lies between 2772 m and 3154 m for the glaciers and between 2644 m and 2801 m for the *glacierets* (although it is not correct to use the term «equilibrium line» for *glacierets*). The mean altitude of the ELA results to be 2867 m. If only real glaciers are considered (and *glacierets* excluded) the mean ELA altitude is 2915 m. During the Little Ice Age, the ELA was located between 2751 m and 2914 m. Mean altitude is 2778 m. If *glacierets* are not taken into consideration, mean ELA altitude for the Little Ice Age was 2779 m. Therefore, the difference between the two calculated mean values for present-day and Little Ice Age amounts to 136 m, if only glaciers are considered. As for each single glacier, the ELA fluctuated between a minimum value of 77 m and a maximum one of 117 m, with the exception of: Vitelli Gl., which shows a value of 402 m, Cristallo W Gl. (20 m) and two *glacierets* with depressed equilibrium line altitudes. The lowering of the ELA may be related to the present locations of *glacierets* in the most depressed part of the cirque, which is entirely set in the ablation zone below the real equilibrium line, whereas during the Little Ice Age the glacier had a greater areal extension and thickness. Consequently, by calculating the ELA of a *glacieret* it is possible to observe a depression from the Little Ice Age to the present (tab. 1a). Fig. 3a and 3b show the hypsographic curves for two glaciers located in Vitelli Valley.

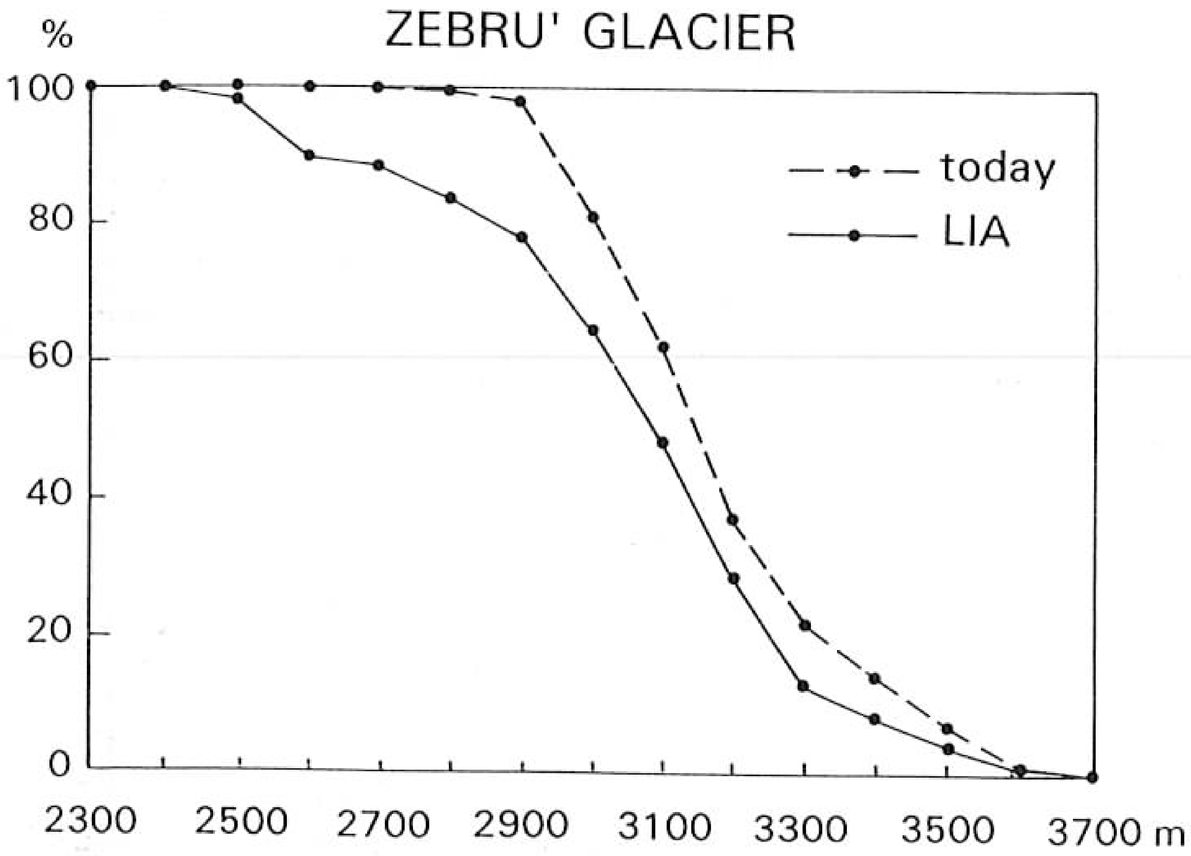
In Zebrù Valley (fig. 4) the present ELA lies between 2867 m (2833 m if the Camosci *glacieret* is taken into consideration) and 3116 m. Mean ELA is 2986 m (2967 if considering Camosci *glacieret*). The ELA shows marked differences as a function to the exposition. ELA in glaciers with S orientation lies at about 3101 m (with the exception of Camosci Gl.). ELA of glaciers with N orientation lies at about 2901 m, a higher elevation than that recorded in Vitelli Valley. In southern Norway, LIESTØL (1967; in

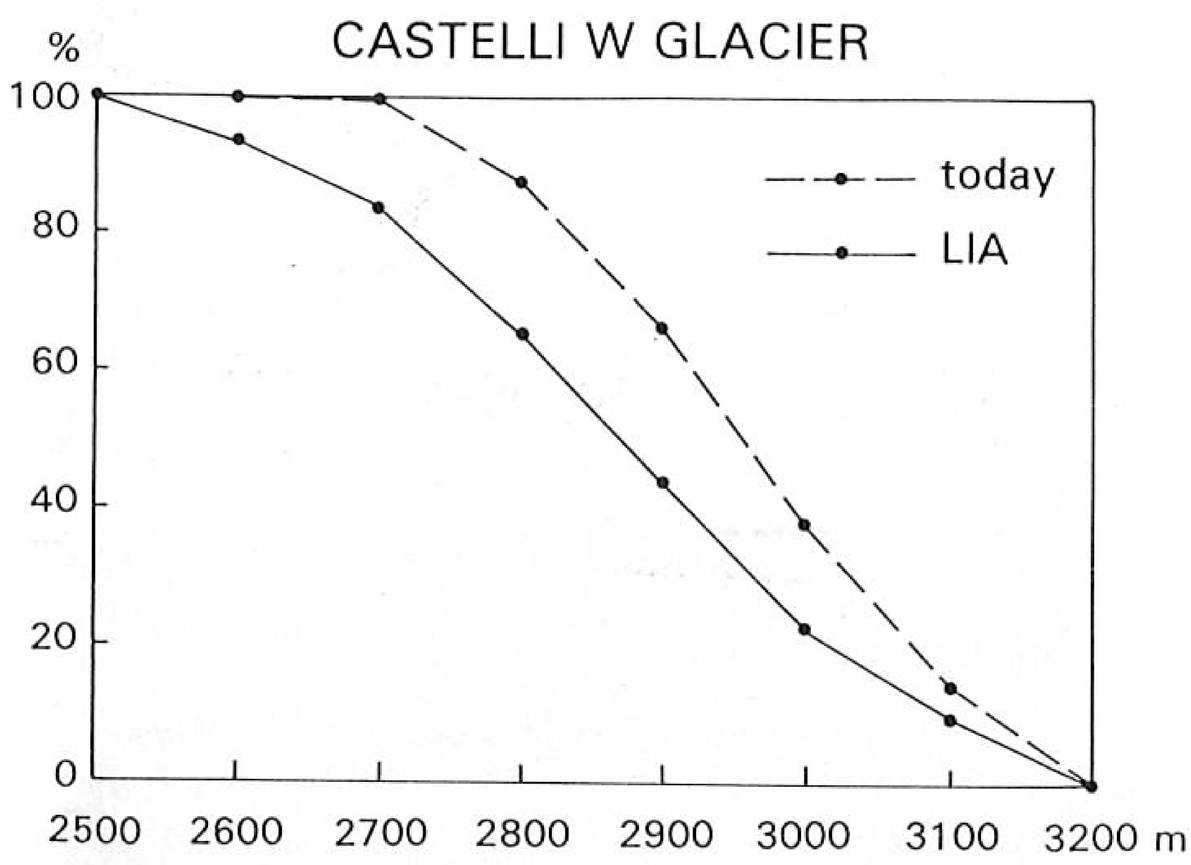
FIG. 4 - Zebrù Valley: glaciers located on the left slope of the valley viewed from Cristallo (photo Pelfini, 1989). In the photo Castelli Glaciers and Montagna Vecchia Glacier are shown.

DAHL & NESJE, 1992) estimates a 50 m-difference between the ELA of glaciers with N and that of glaciers with S orientations (tab. 1b).

According to DESIO (1973), in the Ortles-Cevedale Group the average values for each orientation in 1944, when the snowline was calculated to be at 3050 m are shown in tab. 2a. The average values for each orientation in 1961, when related to 3050 m are shown in tab. 2b. During the Little Ice Age the ELA was located between 2795 m and 3038 m, with a mean of 2895 m (if present-day *glacierets* are not considered).

The ELA records a mean upward shift of about 91 m (Camosci Gl. not being considered). As for each single glacier, the upward shift of the ELA varies from a mini-





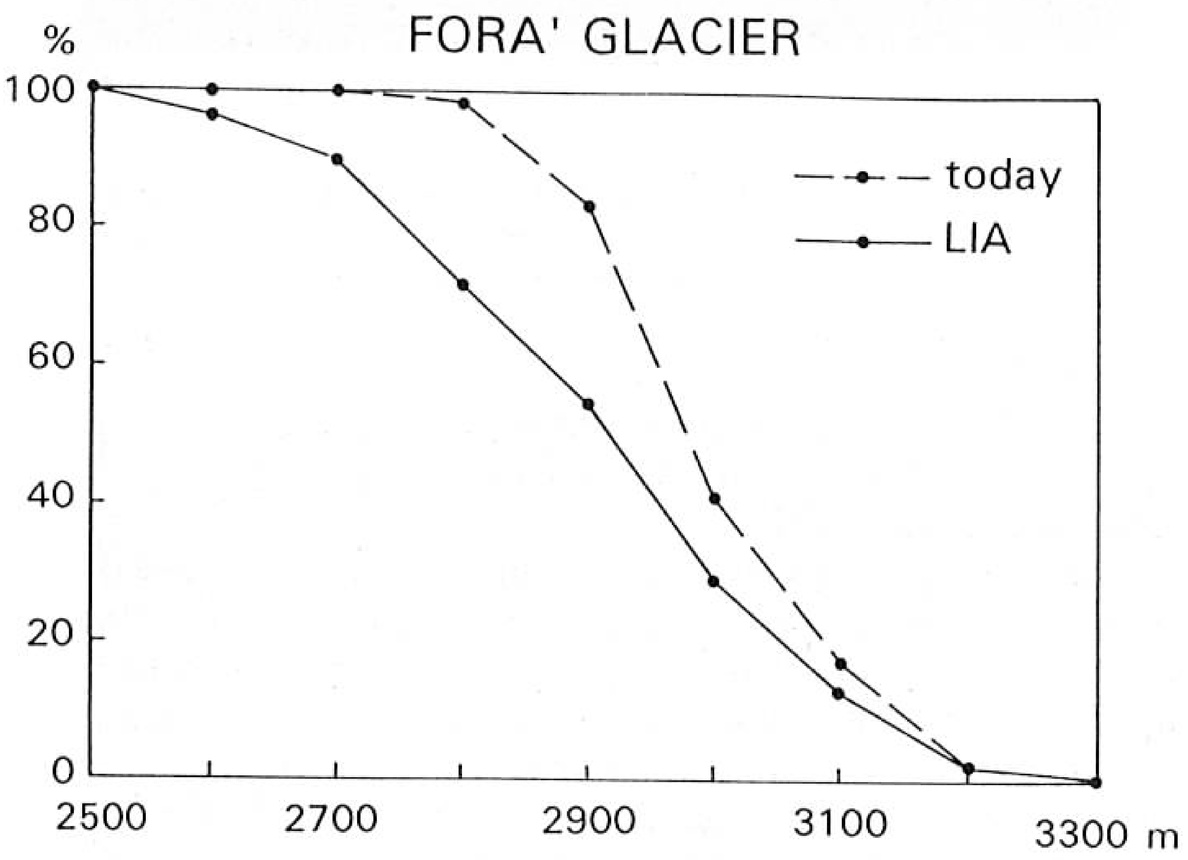


FIG. 5 - Hypsographic curves for Zebrù Gl. (5a), Castelli W Gl. (5b) and Forà Gl. (5c).

mum of 61 m for Montagna Vecchia Gl. to a maximum of 106 m for Castelli E Gl.

Fig. 5a-b-c shows the hypsographic curves for Zebrù, Castelli W and Forà Glaciers.

On the southern slope of Valfurva there are only *glacierets*. Present-day ELA varies between 3042 and 3133 m, with a mean of 3081 m. During the Little Ice Age mean ELA altitude was 3057 m. Therefore, the upward shift should be 24 m. However, if only glaciers with positive values in the third column are considered, the mean present-day ELA is 3106 m. These same glaciers showed a mean ELA of 2991 m during the Little Ice Age. Consequently, the ELA upward shift is 115 m (tab. 1c).

In Cedèch Valley present-day ELA varies between 3074 m and 3218 m with a mean of 3136 m. During the Little Ice Age the head of the valley was completely covered by ice and the ELA was about 2943 m. The difference between the two calculated values is 193 m (tab. 1d). The greater upward shift of the ELA is recorded at Cedèch Gl., characterized by a well developed W tongue (fig. 6).

The two glaciers of the Rosole Valley show a S orientation. Present-day mean ELA is set at 3070 m, whereas that of the Little Ice Age was 3014 m. The difference fluctuation amounts to 56 m (tab. 1e).

Glaciers in Forni Valley are anomalous. Forni Gl. (fig. 7) ELA is now set at 3010 m. During the Little Ice Age the ELA was at 2923 m. The recorded upward shift of the ELA is thus 87 m (fig. 8). Palòn della Mare Gl., which recently broke off Forni Gl., shows an ELA upward shift of 293 m. However, this datum is not reliable because of the dramatic change of the morphologic setting. The ELA was unexpectedly higher for San Giacomo E Gl. during the Little Ice Age. Present-day mean altitude for all the glaciers is 2991 m (3027 if S. Giacomo E Gl. is excluded). In the Little Ice Age the ELA was set at 2894 m. Thus, the upward shift is 133 m. Palòn della Mare Gl., characterized by S orientation, shows the highest ELA (tab. 1f).

In Gavia Valley only the first three glaciers (tab. 1g) are located in the main valley, while the other four are in Dosegù Valley, a right tributary. The present-day ELA varies between 2853 m and 3166 m, with a mean of 2979 m when considering all the glaciers. Mean value lowers to 2897 m for glaciers with N orientation. Mean ELA for the other glaciers is 3115 m (fig. 9). During the Little Ice Age maximum expansion, the altitude of the ELA varied between 2849 m and 3016 m, with a mean of 2921 m. If glaciers with unreliable values are not taken into consideration (Lago Bianco and Sforzellina NE), present-day ELA mean value is about 3011 m, and Little Ice Age mean value was 2919. Consequently, the upward shift for Gavia Valley glaciers is 92 m.

ELA UPWARD SHIFT IN THE ORTLES-CEVEDALE GROUP GLACIERS

Evaluation of the real ELA fluctuations for glaciers cohalescing and entirely covered valley heads is extremely difficult. Cohalescing glaciers, in fact, acted as indipendent

FIG. 6 - Cedèch Valley: the two tongues of Cedèch Glacier from the trail to Casati Hut (photo Pelfini, 1983)

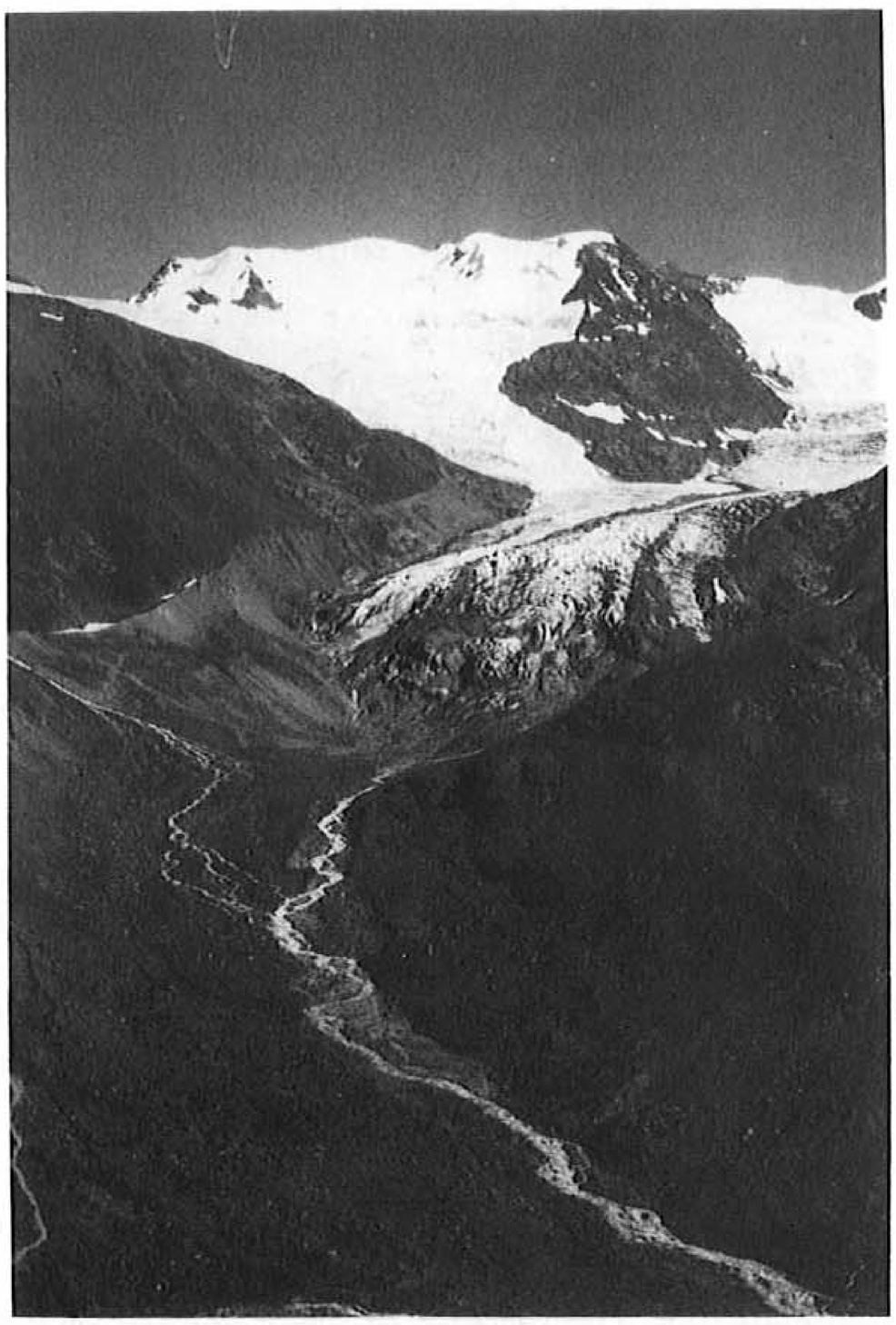


FIG. 7 - Forni Glacier, 1988 (photo Pelfini).

units, the extension of which is not well known. Consequently, the altitude of the ELA during the Little Ice Age was calculated by considering formerly cohalescing glaciers as a single unit. This approximation may introduce a few errors in the calculus and, therefore, only mean values are reliable.

The following data represent mean upward shift of the ELA for different valleys. Glaciers with depressed values were not taken into consideration:

Vitelli	Zebru	Valfurva	Cedèch	Rosole	Forni	Gavia
136m	91m	115m	193m	56m	133m	92m

The calculated mean value of ELA upward shift is 117 m, when considering different valleys. If single glaciers are taken into account, and those with depressed values excluded, the obtained mean upward shift value is 118 m. To eliminate sources of errors in the evaluation of the ELA mean upward shift from Little Ice Age to present, values far off the mean were excluded (i.e. values of over 200 m or less than 50 m). Consequently, the mean value results 102 m, which is consistent with the mean 100 m upward shift observed in several regions of the Alps (100-150 m according to GROSS & *alii* 1977).

Glaciers characterized by ELA variations far off the mean are the following: Vitelli Gl. (about 402 m), a valley glacier with W orientation; Palòn della Mare Gl. (about 293 m), a cirque glacier with SW orientation; Pasquale S Gl. (274 m), a cirque glacier with W-SW orientation; Dosegù Gl. (about 229 m), a valley glacier with SW orientation; and Cedèch Gl. (about 226 m), a valley glacier with W orientation. These are wide glaciers with long tongues and wide accumulation basins, with the exception of both Palòn della Mare Gl., which broke off Forni Gl. a few years ago, and Pasquale S Gl., which is connected with Cevedale Gl. Most of these glaciers show a W and SW orientation and, during the Little Ice Age, were connected

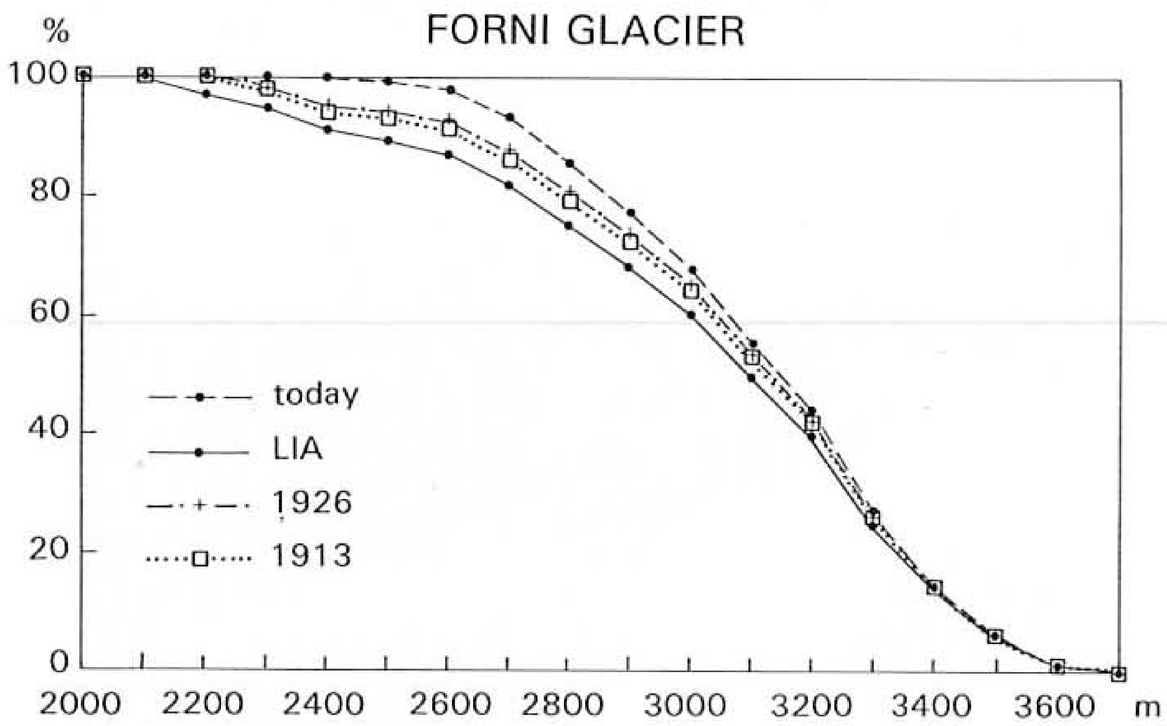


FIG. 8 - Hypsographic curves for Forni Glacier: during the LIA, 1913-14, 1926 and today. 1913-14 and 1926 correspond to two different Forni Gl. advances documented by dated moraines.

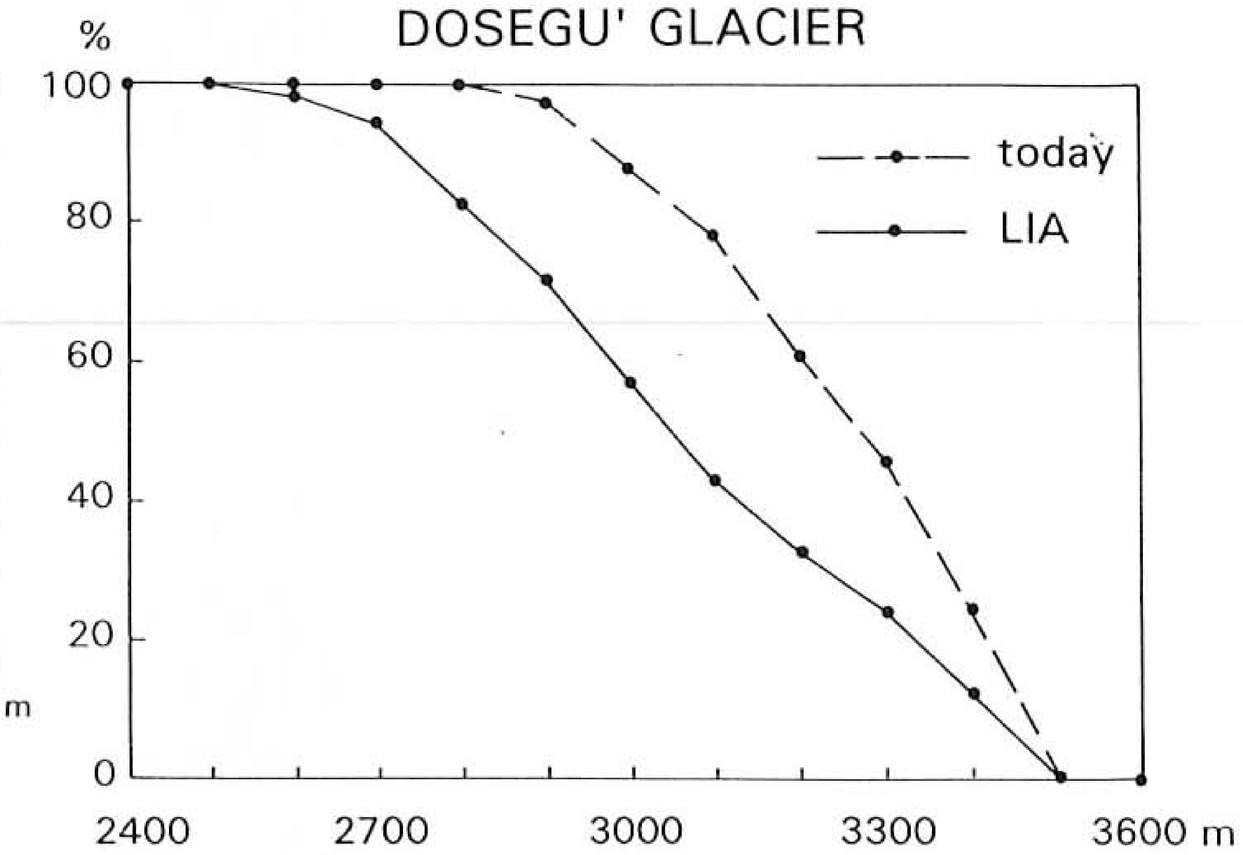


FIG. 9 - Hypsographic curves for Dosegù Glacier.

with other glaciers. To obtain more reliable values it would be necessary to calculate the Little Ice Age ELA for each studied glacier by reconstructing the tongue limits and disregarding contacts with adjacent glaciers.

ELA variations amount to less than 50 m in the following glaciers: Passo del Dosegù Gl. (about 9m), a cirque glacier with NW orientation, W Cristallo Gl. (about 20 m), a cirque glacier with N orientation, Col della Mare Gl. (Col di Lamare Gl. in: PELFINI, 1992) (about 38 m), a valley glacier with SW orientation. These cirque glaciers show a N component. Col della Mare glacier is an exception. It is characterized by a tongue with SW orientation, but its accumulation basin has a NW orientation.

The following glaciers show ELA upward shifts consistent with mean values: Crapinelìn Gl. (101 m), Central Cristallo Gl. (103m), E Castelli Gl. (106 m) and Castelli W Gl. (105 m). These are all well-developed cirque glaciers, characterized by amphitheatre-shaped valley heads which act as a barrier against solar radiation. Orientation of these glaciers is to the N. The aforementioned data indicate that:

Glaciers response to climatic fluctuations is influenced by several factors. Only by averaging the results it is possible to hinder local effects and reliable results can be obtained. Great valley glaciers, which were part of wide glaciated areas during the Little Ice Age, are characterized by a conspicuous upward shift of the equilibrium line altitude. These glaciers underwater several retreat phases and breakage of ice cover. RICHTER (1888) calculated the altitude of snowline above 2900 m, in the Ortles-Cevedale Group (DESIO, 1973). According to DESIO (1973) the snowline has raised 50 m between 1888 and 1944 and at least 9 m from 1944 to 1961.

In conclusion, glaciers of Ortles-Cevedale Group record an average ELA upward shift from the Little Ice Age to present of 102 m.

VARIATIONS OF THE TEMPERATURE FROM THE LITTLE ICE AGE TO PRESENT

The variations of the annual mean temperature and July mean monthly temperature from the Little Ice Age to present were evaluated by multiplying the ELA upward shift mean values (in meters) times the mean annual lapse rate (0.51°C/100 m) calculated by BELLONI & PELFINI (1985) in Lombardy and the July monthly lapse rate (0.63°C/100 m).

It is known that glacial snout variations and hence ELA variations depend on both summer temperatures and winter precipitations. As secular series of climatic data (temperature and precipitation) are not available, a tentative to extrapolate palaeoclimatic informations has been done, through a semplification of the problem, using the vertical mean annual lapse rate.

In any way the comparison of climatic and snout variation data (BELLONI & *alii* 1985) shows that in the Ortles Cevedale Group the summer temperature is the prevaling forcing parameter. The increase in mean annual temperature is 0.52°C. This value is consistent with temperature variations calculated for the whole surface of the Earth (GRIBBIN, 1988). The increase in July mean monthly temperature results to be 0.64°C.

TABLE 2 - ELA: a) average values for each orientation in 1944; b) average values for each orientation in 1961 (according to Desio, 1973).

a)

N	NNE	NE	ENE	E	ESE	SE	SSE
-110	-108	-83	-91	92	95	70	201
S	SSW	SW	WSW	W	WNW	NW	NNW
63	—	87	55	83	14	-40	-16

b)

N	NNE	NE	ENE	E	ESE	SE	SSE
-108	-83	-121	-38	72	67	159	67
S	SSW	SW	WSW	W	WNW	NW	NNW
186	205	125	—	48	-8	-38	11

CONCLUSIONS

Glaciers located in the Lombardy part of Ortles-Cevedale Group underwent conspicuous surface area reduction (at least 46%-47%) from the Little Ice Age to the present. This phenomenon is particularly intense for relatively small glaciers. Between the Holocene maximum expansion and the present, the ELA shifted upwards of about 102 m. This figure is consistent with values observed in other alpine areas. 102 m altitude variation corresponds to an annual mean temperature increase of about 0.52°C and to a July monthly mean temperature of about 0.64 °C. However, during this time span, several climatic changes towards colder conditions occurred. As a consequence, alpine glaciers advanced and the ELA was depressed. During warm phases following the colder periods, the ELA shifted upwards. The calculated total upward shift of the ELA is thus the result of a series of receding steps characterized by different receding rates.

On the basis of the calculated upward shift ELA values for each glacier, it is possible suppose the time interval necessary to cause the complete disappearance of glaciers in the Ortles-Cevedale Group (provided present-day warm climatic trend persists).

By hypothesizing a continuous upward shift, at a constant rate, of the equilibrium line altitude, the time when the ELA will coincide with the maximum altitude of the glacier itself (as reported in I.G.M maps) was determined. By that time, that glacier will not have an accumulation basin and is bound to die. At present the real ELA is higher than the maximum altitude of many alpine glaciers, expecially in the Central Alps. However, oversemplification of the problems involved is needed. In fact:

— the Holocene maximum expansion did not occur at the same time for all the glaciers,
— errors may affect the calculated Little Ice Age glaciated areas and ELA values,
— calculus is based on single glacier variations, not on mean values.

On the basis of the aforementioned semplification, over 50% of the glaciers present in the Ortles-Cevedale Group (Lombardy sector) will disappear during the next 200 years.

These results were obtained by considering the observed constant tendency towards an increase of annual mean temperature of 0.5°C per 120 years. Recent studies carried out by the World Meteorologic Organization forecast a temperature increase of 0.3°C in ten years, corresponding to an increase of 3°C by the end of next century, if nothing is done to lower CO^2 input in the atmosphere. If this is the case, ice melting would take place at a much faster rate, and the ELA could shift upwards of 500-600 m in a century. Consequently, almost all the glacier could disappear by the end of XXI century.

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