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LOCAL GLACIERS IN THE JULIAN PREALPS (NE ITALY) DURING THE LAST GLACIAL MAXIMUM

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ABSTRACT: The prealpine range of the eastern Southern Alps includes many high-elevation (up to 1900 m) massifs, whose northern slopes contain glacial deposits. On the northern side of the Chiampon-Cuel di Lanis ridge (Julian Prealps) five different mountain moraine systems are sited; these are related to local glaciers, which were independent from the major Tagliamento Glacier during the Last Glacial Maximum (LGM). Their length was slightly more than 3 km, with lateral moraines developed along the lower part of the deep valleys. Their terminal moraines occur from 490 m to 650 m a.s.l. Clast petrography of the carbonate-rich till clearly establishes a local provenance, distinct from that of the Tagliamento catchment. Inferences from geomorphological parameters, such as elevations of the valley floor and of the lateral moraines, as well as the extent of the accumulation area, indicate a thickness of the glaciers, ranging from 130 to 230 m in the accumulation areas. Application of the Altitude x Area Balance-Ratio (AABR) formula provides an ELA estimate of 1130 to 1200 m a.s.l. This is in agreement with the atmospheric circulation models of the LGM for the Eastern Alps, which indicate an ELA depression, below 1300 m a.s.l., related to higher precipitation rates than the rest of the Alpine chain.

Keywords: Julian Prealps, LGM, glacial deposits, ELA, paleoglaciology.

1. INTRODUCTION

The prealpine sectors of the Alps provide important climatic information for the Last Glacial Maximum in the Alpine Chain, because, in those sectors, local glaciers can be distinguished from the major valley glaciers, which were directly fed from the ice caps (Kelly et al., 2004). The presence of cirque glaciers around the highest prealpine massifs during the LGM has been documented by several authors enabling estimation of the Equilibrium Line Altitude (ELA) of glaciers during the last glaciation (e.g. Carraro & Sauro, 1979; van Husen, 1997; Federici & Pappalardo, 2010; Forno et al., 2010). According to recent models (i.e., Kuhlemann et al., 2008, 2009), ELA along the southern side of the Alps is depressed in the east, descending below 1300 m a.s.l. in correspondence of the eastern Southern Alps during the peak of the LGM (around 23 ka BP). These estimates are 1200 m to 1500 m lower than Little Ice Age (LIA) values (Ivy-Ochs et al., 2008). In the studies of the local glacialism in the Venetian-Friulian Prealps, the ELA of the last glaciation was assessed at around 1400 m a.s.l. (Desio, 1926; Fuchs, 1970; Carraro & Sauro, 1979; Orombelli et al., 2004) and 1350 m for Baratto et al. (2003), about 1200 m below the Little Ice Age ELA in the Dolomites (Masini, 1998).

This paper describes the local glacial activity during the LGM in the Julian Prealps, at the southeastern margin of the Alpine Chain. This part of the chain was included in the geological survey at the scale 1:10.000 for the "Gemona del Friuli" sheet (scale 1:50.000) of the new Italian Geological Map Project (Zanferrari et al., in press). This new data enables the estimation of the ELA in this part of the chain providing new perspectives on the advance of the major glaciers, which reached the piedmont plain (Castiglioni, 2004; Monegato et al., 2007).

2. SETTING

The Julian Prealps are located in the outer sector of the Alpine Chain between the Julian Alps (Fig. 1), at the Italian-Austrian-Slovenian borders, and their junction with the northern Dinarides. The prealps do not exceed 2000 m a.s.l., reaching their maximum elevation of 1958 m a.s.l. at Plauris Mount. The Julian Prealps are characterised by a series of long ridges trending WNW-ESE. Their southern slopes are very steep, with cliffs of 1000-1300 m (Fig. 2), while northern slopes are gentler, except for steep headwalls in the highest cirques. On the southern sides very small cirques are present at the highest elevations; while on the northern sides the cirque depressions are wide and well developed (Fig. 3). The main massifs characterising the Italian side are the Chiampon-Cuel di Lanis and the Gran Monte chains, which can be considered a continuous ridge cut by the Torre valley, to the south, and the Musi chain and the Plauris-Lavara massif, to the north (Fig. 2). The two ridges are separated by the Torre valley to the east, whose drainage is included in the Isonzo River catchment, and the Venzonassa valley to the west. The Venzonassa Stream is an eastern tributary of the Tagliamento River (Fig. 2).

The distribution of the glacial deposits in the Musi chain and the Plauris-Lavara massif indicates that the local glaciers merged into the major Tagliamento-Fella glacier (Zanferrari et al., in press). This valley glacier spread out in the piedmont plain forming a wide end moraine system; several radiocarbon datings allowed to ascribe the glacial amphitheatre to the LGM (Monegato et al., 2007). Following the lateral moraines upstream along the valley, as well as paraglacial deposits related to the slope degradation, the elevation of the Taglia-

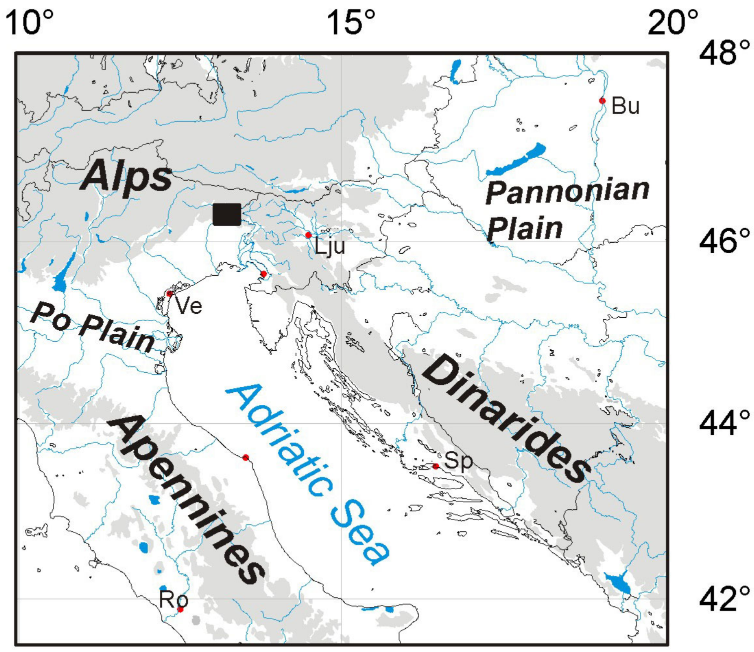

Fig. 1 - Location of the study area (black box) at the Alps/Dinarides junction grey-shaded area represents the relief above 500 m..

mento glacier sideway of the Julian Prealps was between 600-650 m a.s.l. This indicates that the ice stream hardly crept into the Venzonassa valley and not from Ledis Fork, which is at 752 m a.s.l. For these reasons, the glaciers related to the Chiampon - Cuel di Lanis and the Gran Monte chains were separated from the valley glacier and set several small end moraine systems in the lower part of the northern slopes. The glacial deposits related to the Julian Prealps were thoroughly described, for the Musi chain and the Plauris-Lavara massif, in early studies (Desio, 1926; Gortani & Desio, 1927); but the southern relieves have received only cursory attention (Feruglio, 1925, 1953). The glacial deposits were ascribed mostly to the Würmian glaciation (*sensu* Penck & Brückner, 1901-1909), while older glacial units were not recognized. Previous reconstructions of the LGM extent have indicated local glaciation in the Julian Prealps (Castiglioni, 1940; Vai & Cantelli, 2004) or a complete ice cover in the area (Venturini, 2003; Ehlers & Gibbard, 2004).

3. DISTRIBUTION OF THE GLACIAL DEPOSITS

The morphology of the northern side of the Chiampon-Cuel di Lanis ridge is characterized by five large cirques, whose headwall is represented by the crest of the ridge (Fig. 3a). These natural amphitheatres are roughly 1 km wide, with elevation ranging from 1500 m at the highest point (northern side of the Chiampon Mount) to 1400 m for the others. In this portion of the drainage, most glacial deposits are buried beneath talus. Downslope, the valleys become steeper and the glacial deposits are located along the thalweg. These deposits consist of massive matrix-supported diamicton, rich in striated sub-angular pebbles and normally consolidated. The matrix is normally silty (Fig. 4). This facies, identifiable as lodgement till, is visible in several locations from 800 m to 1100 m a.s.l., typically within stream incisions. At about 700-900 m a.s.l. the lateral moraines are clearly distinguishable in all the valleys. They are composed of matrix- to clast-supported diamicton, with a matrix of silty sand. Clasts are normally angular to sub-angular and striated. Some big boulders, up to 1 m in diameter, are present within the sediment and at the top of the moraine ridges. The moraines are typically about 30 m high; though, the ridge of Vodizza, on the eastern side of the complex towards the Torre Valley (Fig. 5), is 100 m high.

Along the central valley (locality called Bombasine), a more organized, crudely bedded diamicton can be recognized within a gorge. Meter-sized angular boulders (Fig. 6a) are embedded within this poorly consolidated deposit, which appears to be a flow-till. In this sector the glacial deposits flowed into the main Venzonassa valley, at 490 m a.s.l. The low elevation and the rough bedding of the till would suggest subacqueous processes. Nevertheless, no glacio-lacustrine facies were recognized. Westwards, the Pozzus valley is characterized by well developed end moraines (Fig. 6b), whose front is cut by the headwall erosion of the present creek; here the transition to proximal fluvio-glacial deposits crop out.

The western sector (Moeda Valley) is characterised

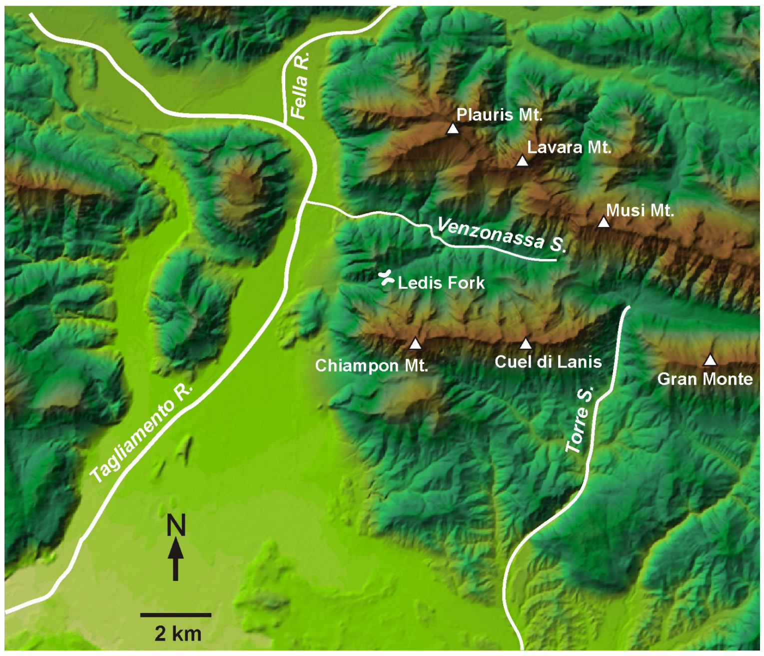

Fig. 2 - Digital Terrain Model of the Julian Prealps and the lower valley of the Tagliamento River.

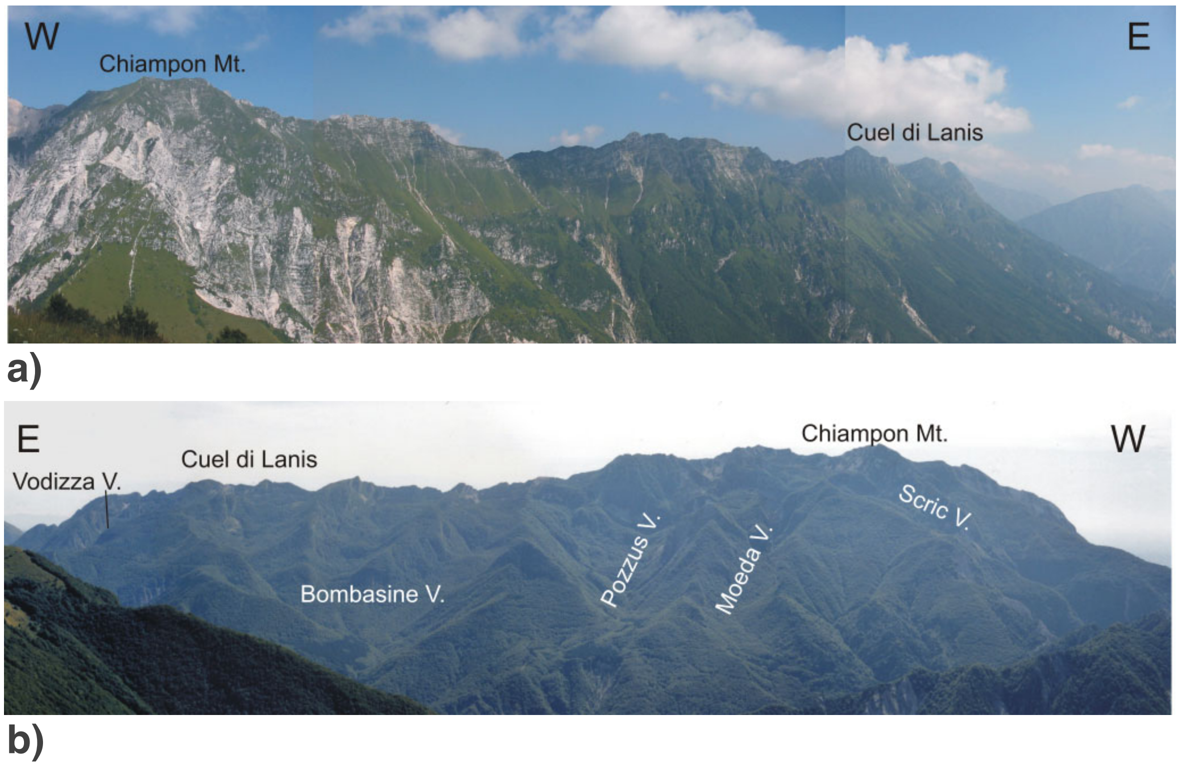

Fig. 3 - a) Picture of the southern slope of the Chiampon – Cuel di Lanis ridge from the top of Cuarnan Mount. b) Picture of the northern slope from Casera Ungarina, in which the five deep valley are evidenced.

by widespread poorly consolidated deposits. These are matrix-supported and rich in angular to sub-angular clasts, which are commonly striated. Moraines are preserved on the southern side of the valley, while to the north they are buried by talus deposits. In front of the glacial deposits matrix- to clast- supported gravels are present. Their bedding becomes increasingly more clear downstream, until crude bedding, rich in sandy matrix, appears. This deposits probably originated as fluvioglacial sediments, deposited by outwash currents in the proximal reach of the valley. It filled a palaeo-incision of Moeda Creek, which now is entrenched within the Triassic dolostones, upstream of the junction with the Venzonassa stream.

Fig. 4 - Matrix-supported till, with striated clasts, cropping out in Bombasina Vallev.

All of the outcropping glacial deposits and the related fluvioglacial sediments derive from the Chiampon-Cuel di Lanis massif. No exotic clasts from the wider Tagliamento catchment were found in these sediments. Moreover, at Ledis Fork (752 m a.s.l.) no glacial deposit related to the Tagliamento glacier are preserved, either.

Downstream, in the distal reach of the Venzonassa Valley, approximately 20 m of crudely bedded to horizontally bedded deposits are present at about 500 m a.s.l. These deposits are clast-supported, clasts are sub-angular to sub-rounded. Sandy matrix is common and fills the voids. This material must have derived from the fluvioglacial collector of the entire Chiampon-Cuel di Lanis system, upstream from the junction with the Tagliamento glacier.

A series of small circular moraines are located at about 1150 m a.s.l. in the Scric, Pozzus, and Bombasine valleys. The moraines are about 10 m high and composed of coarse clast-supported diamicton, in which most clasts are angular. The deposits are weakly consolidated and in some localities only represented by scattered blocks on the outcropping bedrock.

At higher elevation, around 1400 m a.s.l., another series of small terminal moraines are visible around the Chiampon Mount and Cuel di Lanis. These moraines are composed of angular blocks, with scarce sandy matrix.

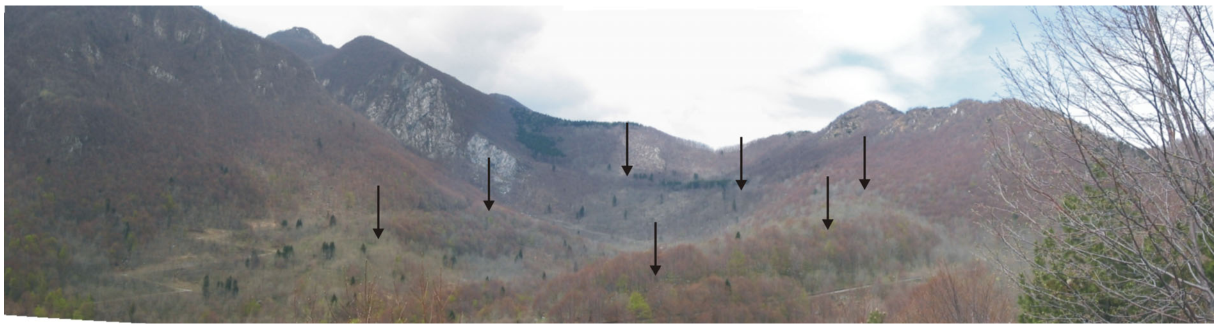

Fig. 5 - Panoramic view of the Vodizza end moraine systems, top of the ridges evidenced by black arrows.

4. PALAEOGLACIERS RECONSTRUCTION

To reconstruct the geometry of the maximum extension of the palaeoglaciers that flowed down the northern slopes of the Chiampon-Cuel di Lanis ridge, morphological parameters measured in the field, such as elevation of the valley floor and of the lateral moraines, provided key variable values for the spreadsheet equations of Benn & Hulton (2010). An average shear stress value of 100 kPa, a standard value for glacier motion on a rigid basal bedrock (Bennet & Glasser, 2009), was used for these calculations. The results point to different dynamics and geometries between these glaciers (Figs. 7-8). The western glaciers (namely: Scric, Moeda and Pozzus) have an unusual morphology in their highest portions, in which accumulation normally occurs. For these glaciers, this sector is characterised by a steep gradient above 1100-1200 m, which would normally be 1.5 to 3.5 less steep than the ablation gradient (see Carr et al., 2010 for discussion). This suggests systems dominated by avalanche accumulation below this elevation, as is found in cirque glaciers (Bennet & Glasser, 2009). The thickness of the glaciers exceeded 100 m only below this elevation. On the other hand, the eastern glaciers (Bombasine and Vodizza) show the expected gentler slope in the highest area, above 1200 m, which allowed the accumulation of ice exceeding 200 m in thickness in the Bombasina Glacier (Fig. 7). All of the calculated ice surfaces are roughly in agreement with the preserved elevation of the respective end moraine systems.

5. THE EQUILIBRIUM LINE ALTITUDE

The Equilibrium Line Altitude (ELA) is a common parameter inferred from geomorphological analysis of a glaciated basin and is useful for palaeoclimatic recostructions (e.g. Ohmura et al., 1992; Benn & Lehmkuhl, 2000). The calculation of the ELA represents a decades-long refinement of less precise methods, such as the THAR (Toe-headwall Area Ratio) or the AAR (Accumulation Area Ratio). Those methods do not take into consideration the hypsometry of the former

a)

b)

Fig. 6 - a) Organized diamicton in the lower Bombasina valley; b) lateral end-morainic ridge in the Pozzus valley.

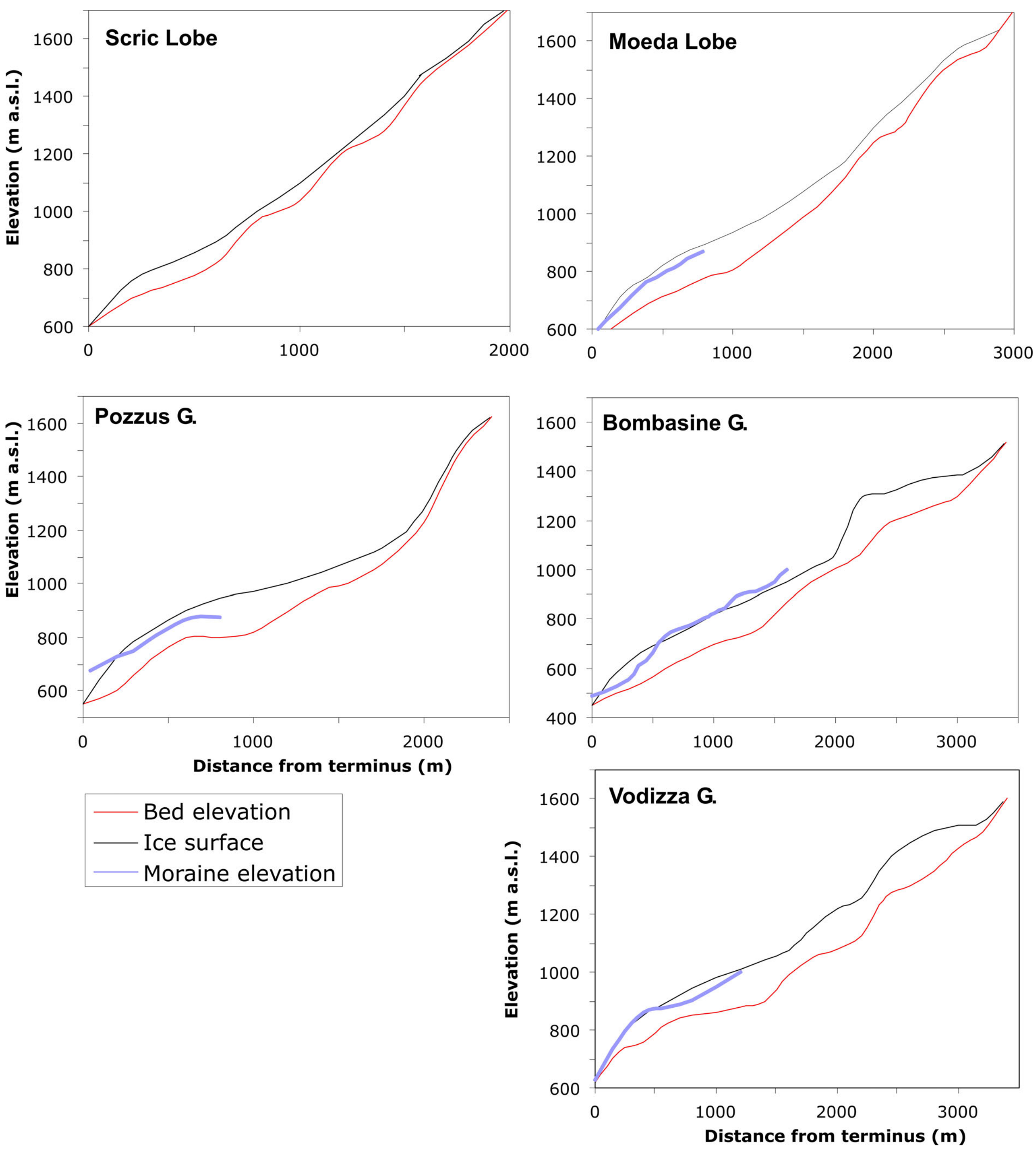

Fig. 7 - Longitudinal profiles of the palaeoglaciers calculated after Benn & Holms (2010) spreadsheet.

glaciers. This parameter was included in the calculations of the AABR (Area Altitude Balance Ratio) method (Furbish & Andrews, 1984) and tested on modern Alaskan glaciers. Subsequently spreadsheets were developed to facilitate rapid calculations (Benn & Gemmell, 1997; Osmaston, 2005) and tested for modern (Rea, 2009) and ancient glaciers (Benn & Ballantyne, 2005; Federici et al., 2012) with good results. In addition, a program was made available, recently, for reconstructing the surface profile of ancient glaciers (Benn & Hulton, 2010), which is an important advance in characterizing ancient glaciations. ELA palaeo reconstructions for long periods as the LGM have to take into account a Zero Net Balance ELA (*sensu* Rea, 2009) in equilibrium conditions, with mass balance equal to zero (Osmaston, 2005; Carr & Coleman, 2007). This hypothetical condition is essentially, but no matches with the historical studies on the present glaciers, which evidenced that the measured ELA oscillated even for some hundreds of meters in few decades (e.g., Benn & Lehmkuhl, 2000).

Using field parameters to estimate the thickness of the study glaciers, the AABR method (Osmaston, 2005; Rea, 2009) yielded an average balance ratio for this mountain ridge, that could be compared to predicted Alpine values on modern glaciers (Rea, 2009). Contour belt intervals of 100 m were used for this numerical sim-

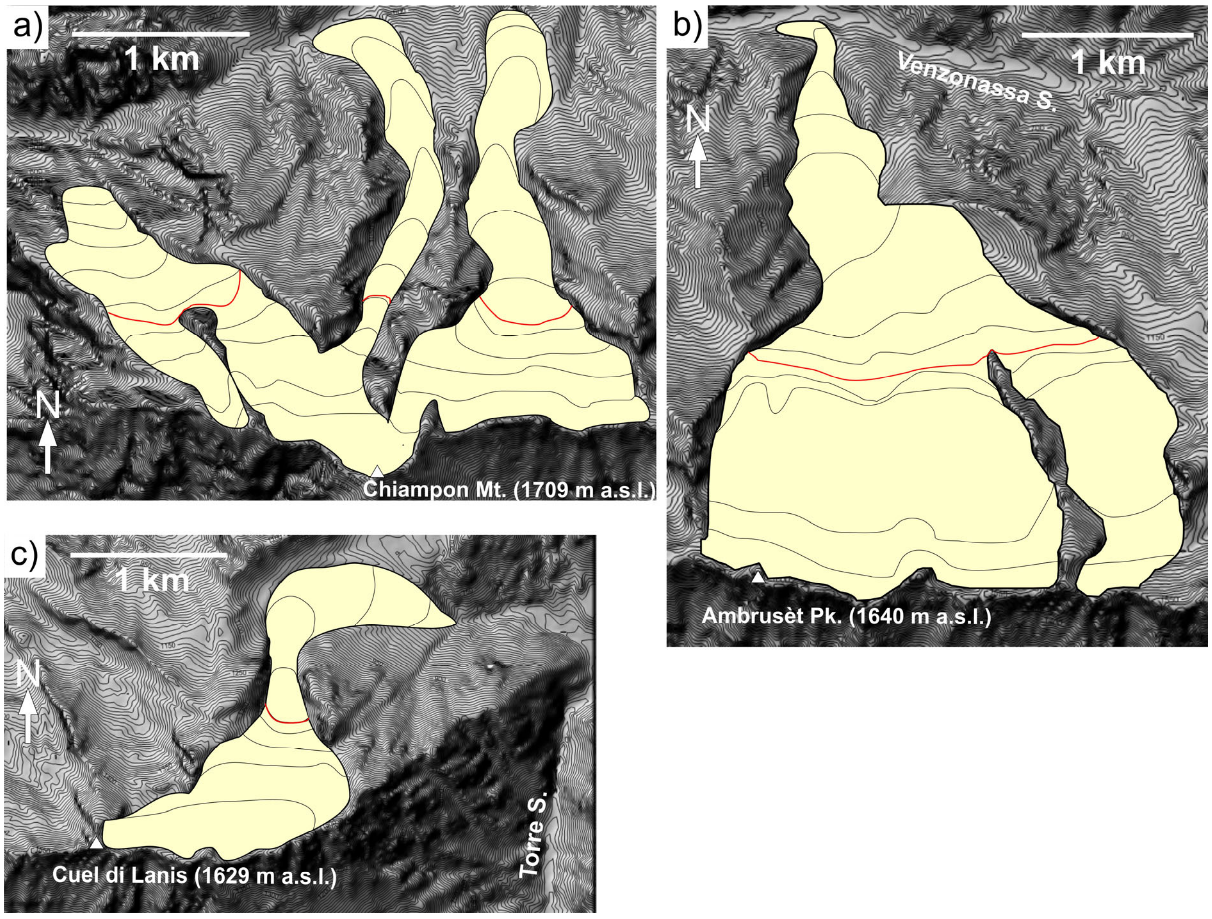

Fig. 8 - Reconstruction of the LGM palaeoglaciers; a) Pozzus and the two lobes of the Chiampon Glacier (Scric to the west and Moeda to the east); b) Bombasine; c) Vodizza. Contour line interval: 10 m, ELA is marked in red line.

ulation. The results are reported in Table 1. According to AAR method, the values of Scric-Moeda and Pozzus paleoglaciers are slightly lower than those calculated for the Alpine region (Rea, 2009; Federici et al., 2012). Moreover, also AABR ratios are slightly lower than the 1,91 average of modern Alpine glaciers (Rea, 2009).

In the study area, the eastern glaciers (Vodizza and Bombasine) had an estimated steady-state LGM-ELA around 1130-1180 m a.s.l., which is related to the wider and less steep accumulation areas, respectively of 1.026 and 3.166 km^2. Here, the thickness of the glacier reached 230 m, the highest value for the system. The central Pozzus palaeoglacier had a different morphology, with the highest gradient in the accumulation area reaching 35° (Fig. 7). It is noteworthy that this glacier reached a greater thickness (from 800 m to 1000 m a.s.l.) corresponding to the change in the width of the valley, suggesting a different mechanism of accumulation than the eastern glaciers. For this glacier, the calculated ELA is about 1145 m a.s.l.

The western paleoglaciers, originated in the common accumulation area of the Chiampon Mount and were separated into two lobes, the Moeda and Scric lobes (Fig. 8). For this system the thickest portion of the glacier reached 100 m. The eastern Moeda lobe flowed down a steep upper valley and, as in the Pozzus Valley, thickest ice occurred downvalley, from 800 m to 1000 m a.s.l. The Scric lobe was quite thin, and no terminal moraine system was preserved. Again, the ELA results are depressed to about 1190 m a.s.l., as in the Mt. Chiampon glacier as a whole.

The ELA for the internal moraine systems, which extended down to about 1150 m a.s.l., was calculated for the Moeda and Scric lobes and for Pozzus and Bombasine cirques (Fig. 9a). The values are similar for the latter two, around 1375 m a.s.l., but slightly higher (1442 m) for the Chiampon cirque. Values for comparable moraine systems in Vodizza valley and the central cirque of Bombasine were discarded for the lack of well-defined frontal moraines. Concerning the highest cirque moraines, located above 1300 m on the northern side of the two most elevated peaks, the Chiampon and Cuel di Lanis (Fig. 9b), the calculated ELAs are respectively of 1530 m and 1478 m a.s.l.

6. DISCUSSION

6.1 Palaeomorphology of the Venzonassa Valley and the Chiampon-Cuel di Lanis Massif during the LGM

The valleys of the eastern Southern Alps were invaded by widespread valley glaciers during the LGM. The front of these ice tongues formed a piedmont lobe in the case of the Tagliamento glacier (Monegato et al.,

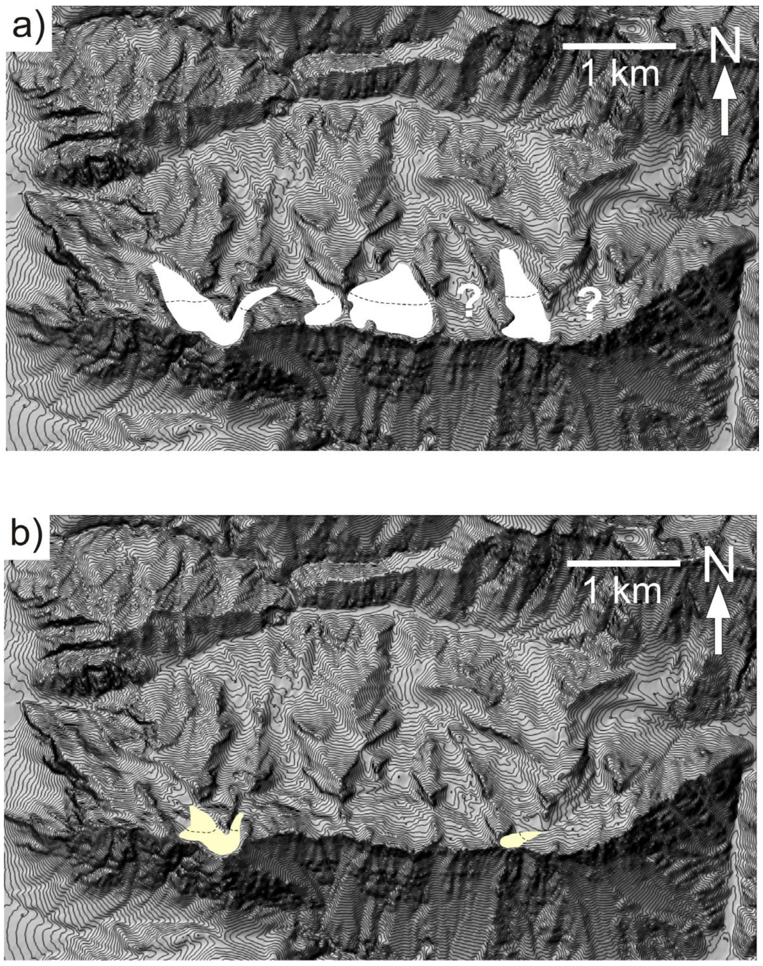

Fig. 9 - Reconstruction of the Late Glacial cirque glaciers: a) Late Glacial 1; b) Late Glacial 2. The ELA is in dashed line.

2007) and the Sava glacier (Bavec & Verbič, 2011), while the Isonzo glacier was confined within the catchment (Bavec et al., 2004). Other minor catchments had only short glaciers or cirque glaciers (Vai & Cantelli, 2004), as was the case in the Venzonassa and Torre valleys. The location of the lateral moraines and periglacial deposits of the Tagliamento glacier during the maximum advance indicates that the maximum elevation reached at the valley outlet was 500 m a.s.l. (Monegato et al., 2007), while in the lowest reach of the valley, from Venzone to Gemona del Friuli, the maximum elevation was of about 650 m a.s.l. (Fig. 10). Apparently, the Ledis Fork was not reached by the Tagliamento glacier, as no glacial deposits occur there. The Tagliamento glacier likely dammed the outlet of the Venzonassa Valley. No evidences of lacustrine sediments, related to an ice-dammed lake, have been recognized; however, the blockage of the outlet appears to have triggered alluvial sedimentation along the Venzonassa Valley, from the glacier front to the lowest reach. The Venzonassa Stream collected the meltwater from three different glaciers, flowing down the central portion of the Chiampon-Cuel di Lanis massif (Fig. 10). These tongues reached elevations of 620 m (Moeda lobe), 660 m (Pozzus) and 490 m a.s.l. (Bombasine). On the western side, the Scric lobe, flowing down from the Chiampon, is not represented by preserved frontal moraines. If it flowed down to 600 m a.s.l., it merged into the Tagliamento glacier, but no traces of this junction have been recognized. Possibly, it stopped at higher elevation, where the bedrock makes several steps, in which may have produced seracs. On the eastern side of the massif, the Vodizza tongue flowed down along the northeastern side of the Cuel di Lanis and curved toward the east into the Torre Valley, abandoning a high lateral-frontal moraine at 630 m a.s.l. (Figs. 5, 8). Only the Bombasine glacier, having a wider accumulation zone, reached an elevation below 600 m a.s.l., corresponding to the maximum elevation of the fluvioglacial deposits in the Venzonassa Valley. This relationship suggests that a rapid accumulation of fluvioglacial deposits took place during the advance of the Tagliamento glacier, which dammed the Venzonassa Valley. The long-lasting residence of the Tagliamento glacier in the lower reach of the valley, about 10 ka according to Monegato et al. (2007), may have created an ice-dammed lake in the lower reach. At the same time, the high accumulation rate of coarse deposits in the western Venzonassa Valley prevented the establishment of a stable lake in its inner reaches. In the Bombasine sector no fluvioglacial deposits are present. Nevetheless, thick bedded diamicton, interpreted as waterlain till, is widespread in the lower reach of the deep valley. The terminal moraines of the studied paleoglaciers have smaller internal ridges, which suggest phases of oscillation of the glacier tongues before their retreat. At the collapse of the Tagliamento glacier at about 18 ka, the equilibrium of the Venzonassa Stream changed and the incision of the present gorge took place. The withdrawal included some advancing pulses, represented by stadial frontal moraines located at about 1200 m and at 1400 m a.s.l.; however, chronological data to support an attribution to one of the Alpine Late Glacial stadials (Ivy-Ochs et al., 2008; Favilli et al., 2009) are lacking. For these stadial phases (namely Late Glacial 1 and 2, Tab. 1) ELAs respectively of 1375-1442 m (Fig. 9a) and 1478-1530 m a.s.l. (Fig. 9b) were calculated. A more reliable chronological analysis of these late-glacial pulses may be possible once there is a more complete investigation of late-glacial systems in the Carnian-Julian Alps, which have only attracted a few reconnaissance studies around the highest mountains (Venturini, 2003), whereas it is outlined in the contiguous Piave catchment (Baratto et al., 2003; Pellegrini et al., 2005).

6.2 The ELA depression in the southeastern Prealps

Palaeoclimatic analysis of the LGM has produced several models both for atmospheric circulation during the climate extremes in the Alpine area (Florineth & Schluchter, 2000; Kuhlemann et al., 2008; Pini et al., 2010) and for palaeoenvironmental evolution of the eastern southern Alps (Vai & Cantelli, 2004; Pini et al., 2010; Monegato et al., 2011); though all these models invoke a southerly airflow from the Mediterranean Sea as moisture source. For the Julian Prealps, no estimates of the LIA ELA are available, though for the Julian Alps (Mt. Canin, 19 km to the northeast) a value of about 2190 m a.s.l. has been established. The difference between LGM and the present ELA of the area has been estimated at about 1400 m (Kuhlemann et al., 2008). Hence, the values of the LGM-ELA values below 1200 m, reported here, suggest a depression of about 1000 m below a possible LIA analogue. It is noteworthy that the ELA depression for Gschnitz age moraines in this sector of the Alps was evaluated at 900-1000 m (Tintor, 2005), which in absolute elevation means that during the LGM, the ELA of this sector of the Alps was around 1000 m a.s.l. However, morphological factors should also be considered for this very low estimation, and perhaps ELA values of the small glaciers of the Prealps may not be extended to the major glaciers. Further work is need for a better resolution of the ELA in the inner sector of the Julian Alps. In the Julian Prealps accumulation areas occur below high and vertical northern cliffs; this fact induces snow mass movements (snowblow and avalanching) below the cliffs and at lower elevations. Moreover, the high precipitation rate of the Julian Prealps, one of the highest in the Alpine region (Janža, in press), also points to fast ice accumulation and transport. This is in agreement with the high calculated balance ratio, which suggests a unsteady regime for these ice tongues, similar to those of wet areas like the West Coast of North America (Rea, 2009). Considering the low elevation of the ablation areas, from 500 to 1000 m a.s.l., and the mean summer temperature (~8°) calculated for the LGM in the northeastern Italy (Pini et al., 2010), the glaciers of the Julian Prealps were probably very unstable, prone to surge movements and/or fluvioglacial outburst. The major glaciers may have been similarly affected, since the Tagliamento glacier had one of the lowest ice-fronts of the Alps, at 150 m a.s.l., consistent with a very depressed ELA (Kerschner & Ivy-Ochs, 2008) for the eastern southern Alps during the LGM.

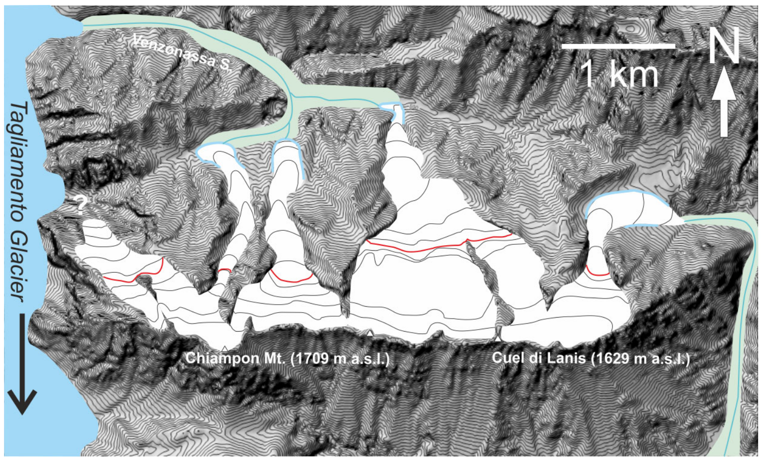

Fig. 10 - Palaeogeographic sketch of the Julian Prealps during the LGM and the relationship between the glacier systems of the Chiampon – Cuel di Lanis ridge (in white) and the major Tagliamento Glacier (blue). End moraines are represented in thick sky-blue lines, outwash valley fill is in green, ELA is marked in red line.

7. CONCLUSIONS

The Julian Prealps are a peculiar sector of the Alpine chain, in which, in spite of their low maximum elevations, local glacial deposits are extensively preserved on northern slopes, down to till 500 m a.s.l. The northern side of the Chiampon-Cuel di Lanis ridge (Julian Prealps) shows five different end moraine systems re-

Name	Scric	Moeda	Pozzus	Bombasine	Vodizza
Catchment	Tagliamento	Venzonassa	Venzonassa	Venzonassa	Torre
Glacier lenght (m)	2000	3000	2400	3400	3400
elevation of the end moraine (m a.s.l.)	unknown	600	690	490	620
Maximum headwall elevation (m a.s.l.)	1709	1714	1679	1640	1628
Surface of the accumulation area (Km2)	1,076		0,950	2,891	1,019
Surface of the ablation area (Km2)	0,989		0,720	1,390	0,702
Total	2,065		1,670	4,281	1,721
AAR	0,52		0,57	0,68	0,59
AABR	1,18		1,74	4,33	2,11
ELA LGM	1190		1145	1128	1182
ELA Late Glacial 1	1450		1373	1377	?
ELA Late Glacial 2	1530			1478	

Tab. 1 - Synthesis of the physical characters of the studied glacial systems and results of calculated ELA and ratios.

lated to local glaciers, up to 3.4 km long, which were independent from the major Tagliamento Glacier during the Last Glacial Maximum (LGM). The elevations of the frontal moraines range from 490 m to 650 m a.s.l. Clast petrography, of the predominantly limestone detrital assemblages, establishes a distinctly different provenance from that of the Tagliamento glacial deposits. The Tagliamento glacier did not flow into the Venzonassa valley, so the local glaciers were free to spread with independent dynamics. Geomorphological parameters, such as elevation of the valley floor and of the lateral moraines, the extent of the accumulation area and the contour belt areas crossing the glaciers, support estimates of ice thickness, ranging from 130 to 230 m in the accumulation areas. These parameters also yield the Altitude x Area Balance-Ratio (AABR) ELA values ranging from 1130 m to 1200 m a.s.l., which are values in rough agreement with the ELA depression modelled for the eastern southern Alps below 1300 m a.s.l., but perhaps not ascribable to the major glaciers. These findings are consistent with the atmospheric circulation models of the LGM for the Eastern Alps, which indicate higher precipitation rates, controlled by southerly airflow, than the rest of the chain.

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