AUSTRIAN JOURNAL OF EARTH SCIENCES
[MITTEILUNGEN DER ÖSTERREICHISCHEN GEOLOGISCHEN GESELLSCHAFT]

AN INTERNATIONAL JOURNAL OF THE AUSTRIAN GEOLOGICAL SOCIETY
VOLUME 97 2004 2005

Joachim KUHLEMANN, Wolfgang FRISCH, Balázs. SZÉKELY, István DUNKL,
Martin DANIŠÍK & Ingrid. KRUMREI:
Würmian maximum glaciation in Corsica 68 - 81

EDITING: Grasemann Bernhard, Wagreich Michael
PUBLISCHER: Österreichische Geologische Gesellschaft
Neulinggasse 38, A-1031 Wien
TYPESETTER: Irnberger Norbert, www.irnberger.net
Copy-Shop Urban, Bahnstraße 26a, 2130 Mistelbach
PRINTER: Holzhausen Druck & Medien GmbH
Holzhausenplatz 1, 1140 Wien
ISSN 0251-7493

Austrian Journal of Earth Sciences | Volume 97 | 68 - 81 | Vienna | 2005

Würmian maximum glaciation in Corsica

J. KUHLEMANN, W. FRISCH, B. SZÉKELY, I. DUNKL, M. DANIŠÍK & I. KRUMREI

Institute of Geosciences, University of Tübingen, D-72076 Tübingen, Sigwartstr. 10, Germany

KEYWORDS

Pleistocene
glaciation
Würmian
Corsica
LGM
ELA

Abstract

Investigation of glacial deposits and trimlines in Corsica enabled us to provide a new reconstruction of the maximum extent of glaciers during the (early) Würmian and to estimate the ancient equilibrium line altitude (ELA) pattern. The ELA was lowered to ca. 1400 m above sea-level (a.s.l.) north and northwest of the main drainage divide, to ca. 1500 m a.s.l. in the center, and to 1750 m a.s.l. in the drier northeastern center (Niolo) and the warmer southwest of the island. Lowering of the ELA by 1300 m during the Würmian maximum glaciation is equivalent to a mean annual temperature drop of ca. 8°C as compared to recent times. The central and northern mountains of Corsica were strongly glaciated in the Würmian, with glaciers up to 14 km long, protruding to altitudes as low as 500 m a.s.l. Relics of high-altitude paleosurfaces display a high sensitivity to ELA fluctuations and a remarkable potential for self-amplifying accumulation of relatively large plateau glaciers.

Eine Studie glazialer Ablagerungen und Schliffkanten auf Korsika ergab eine neue Rekonstruktion der Maximalvorstöße der Gletscher im (frühen) Würm und ließ eine Schätzung der Gleichgewichtslinien-Verteilung zu. Die Gleichgewichtslinie war im Norden und Nordwesten bis auf ca. 1400 m ü.NN., in der Mitte der Insel auf 1500 m ü.NN. und im trockenen nordöstlichen Zentralteil (Niolo) bzw. im Südwesten der Insel auf nur 1750 m ü.NN. abgesenkt. Eine Absenkung der Gleichgewichtslinie gegenüber der Gegenwart um 1300m während der maximalen Würm-Vergletscherung entspricht einer Absenkung der Jahresdurchschnitts-Temperatur um ca. 8° C. Die zentralen und nördlichen Gebirgsanteile Korsikas waren im Würm stark vergletschert und wiesen Gletscher bis zu 14 km Länge auf, die bis in Tallagen von 500 m ü.NN. vorstießen. Relikte von hochgelegenen Altflächen weisen eine hohe Sensitivität für Schwankungen der ELA und ein bemerkenswertes Potential für selbstverstärkende Akkumulation von relativ großen Plateaugletschern auf.

1. Introduction

During maximum Würmian glaciation the mountain ranges of Corsica looked much like the presently glaciated parts of the European Alps (Conchon, 1986). Although Corsica is presently free of permanent ice, small patches of snow frequently survive the summer in the highest massifs (Klaer, 1956), indicating that a minor drop of average temperatures, like that during the Little Ice Age (LIA) may have created niche glaciers at high elevations in NE-exposed cirques.

Owing to its altitude up to 2700 m a.s.l., its latitude at 42° N, and its position in the western Mediterranean basin, Corsica provides important constraints on Würmian temperature gradients across Europe (e.g., Klaer, 1956; Messerli, 1967). Modelling of the Würmian climate indicates frequent high pressure and dryness in central Europe and a southward shift of northwest Mediterranean Genoa-type cyclones (CLIMAP, 1976; COHMAP Members, 1988). As a result, the Central Alps received more precipitation from the S than from the N (Florineth & Schlüchter, 1998, 2000), whereas the distribution of precipitation is almost symmetric today (Frei & Schär, 1998). The main drainage divide of Corsica formed a N-S oriented obstacle to the Genoa cyclone storm tracks and thus represents a key site for Pleistocene climate reconstructions of the western Mediterranean. The former distribution and altitude range of Würmian glaciers in Corsica can be used to constrain the equilibrium line altitude (ELA) during the Würmian maximum glaciation, which in turn provides insights into regional precipitation and wind patterns.

2. Present climate, geology and morphology in Corsica

The present climate in Corsica is characterized by subtropic Mediterranean-type conditions (Gamisans, 1991) with dry and warm summers (May to September) and oceanic-type temperate, wet winters (October-April). Mean annual precipitation is largely controlled by elevation and increases from 600 mm/a near the coast to more than 1500 mm/a in the mountains (Bruno et al., 2001). The northeastern parts of the mountain range are somewhat drier than the central and southern parts. The extent of snow fields in late summer indicates that the cirques exposed towards the N to NE typically contain most snow. Remnants of firn frequently outlast the summer.

Steep mountainous relief and altitudes exceeding 2000 m a.s.l. characterise the granite-dominated so-called Variscan Corsica, which comprises the greater part of the island (Rossi & Cocherie, 1991). Alpine Corsica in the northeast, dominated by Mesozoic ophiolites and phyllites, rises up to an altitude of 1767 m a.s.l. It remained unglaciated during the Würmian (Klaer, 1956).

A widely spaced fault pattern determines the SW-NE oriented deep valleys of Variscan Corsica (Fig. 1). This fault pattern preformed during Permian transtensional movements (Durand-Delga et al., 1978) and was reactivated several times, especially during sinistral displacement in the course of Early Miocene rotation of Corsica (Carmignani et al., 1995). Less important fault systems are E-W and NW-SE oriented. Nevertheless, in several regions of rugged relief these subordinate faults force the headwaters into strictly aligned narrow canyons. All tectonic lineaments represent zones of weakness that predetermine the glacier network and the aspect of single glaciers. Except of fault zones, differences in erodibility are of minor importance, since unsheared calcalkaline granites are most widespread.

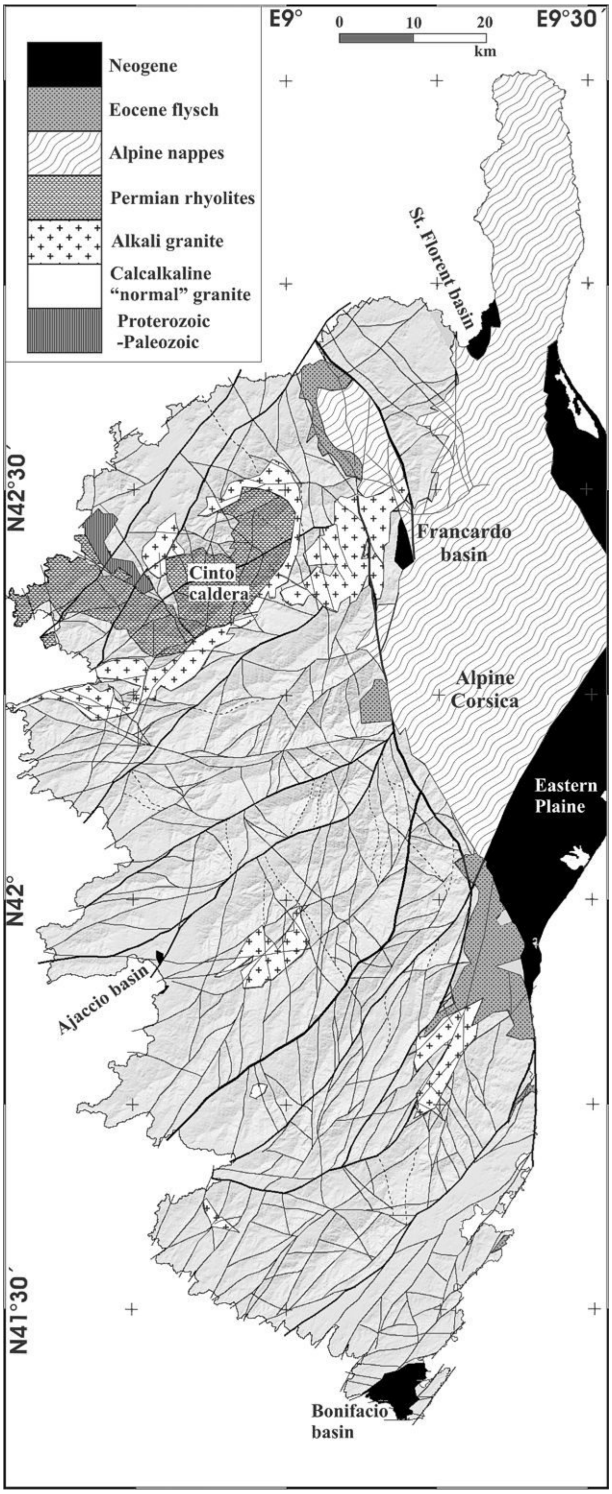

Figure 1: Tectonostratigraphic sketch map of Corsica, displaying tectonic lines and major lithologic units.

Meso- and microscale relief in the higher mountains widely mirrors glacial impact, independent from differences in lithology (Fig. 1, 2). Qualitative observations of cirques and U-shaped valleys have been made by Klaer (1956), Rondeau (1961) and Conchon (1975). However, no systematic mapping of nunataks, trimlines, and roche moutonnée has yet been performed. Glacial striae are frequent, although generally strongly weathered.

The macrorelief of Variscan Corsica is characterised by a general increase in altitude from S to N. The main drainage divide is located E of the central axis of Variscan Corsica in the southern part and W of it in the northern part of the island (Fig. 2). Northern Corsica thus displays a relief contrast with steep slopes and river gradients in the W, and moderate slopes with frequent remnants of paleosurfaces in the E. Constraints on the genesis and age of paleosurfaces in Variscan Corsica, first described by Rondeau (1961), are yet unknown. For the purpose of this paper only the high-elevated paleosurface, which is called "summit surface" later on, is of interest.

The summit surface forms hilly flats in the southern half of Corsica, which have been tilted as individual blocks by up to 30°. Along the drainage divide, the summit surface is found between 800m a.s.l. in the southern extremity and 2200 m a.s.l. in the Renoso Massif. Isolated castle- or cone-shaped hills are frequently observed in less weatherable granite areas. The largest continuous summit surface in the south is the Cuscione Plateau W of Mte. Incudine at ca. 1600 m a.s.l. In the northern half of Corsica the summit surface is largely destroyed by erosion, except for the high Tavignano region where an upland relief between 1600 m and 2300 m a.s.l. is found (Fig. 2). The relief in this region has already been strongly modified by glacial erosion, mainly along the gentle Tavignano valley.

A younger paleosurface, called "piedmont paleosurface", is found ca. 500 m below the summit surface in the south of Corsica (300 to 900 m a.s.l., tilted to the SW) and up to 1500 m below the summit surface in the north of Corsica (900-1100 m a.s.l.). The piedmont paleosurface is younger than the summit surface, since the former sealed faults which had tilted and offset the latter paleosurface.

3. Chronostratigraphy of Würmian glaciations

The Pleistocene, mainly Würmian deposits in Corsica have been studied by Klaer (1956) and Rondeau (1961), and intensively by Conchon (1975, 1976, 1977, 1978, 1979, 1985, 1986, 1988, 1989). Their results are summarized in a 1:250000 geological overview map (Rossi et al., 1980), and in several 1:50000 geological map sheets published over the last decades (e.g., Amaudric du Chaffaut et al., 1985; Orsini et al., 1990; Rossi et al., 1995). Detailed documentation has focused on the regional extent of Würmian moraines, phases of stagnation during late Pleistocene glacial retreat, and formation of glacio-fluvial deposits and terraces (Conchon & Gauthier, 1977; Conchon, 1975, 1976, 1977, 1979, 1985, 1986, 1988, 1989). The occurrences of

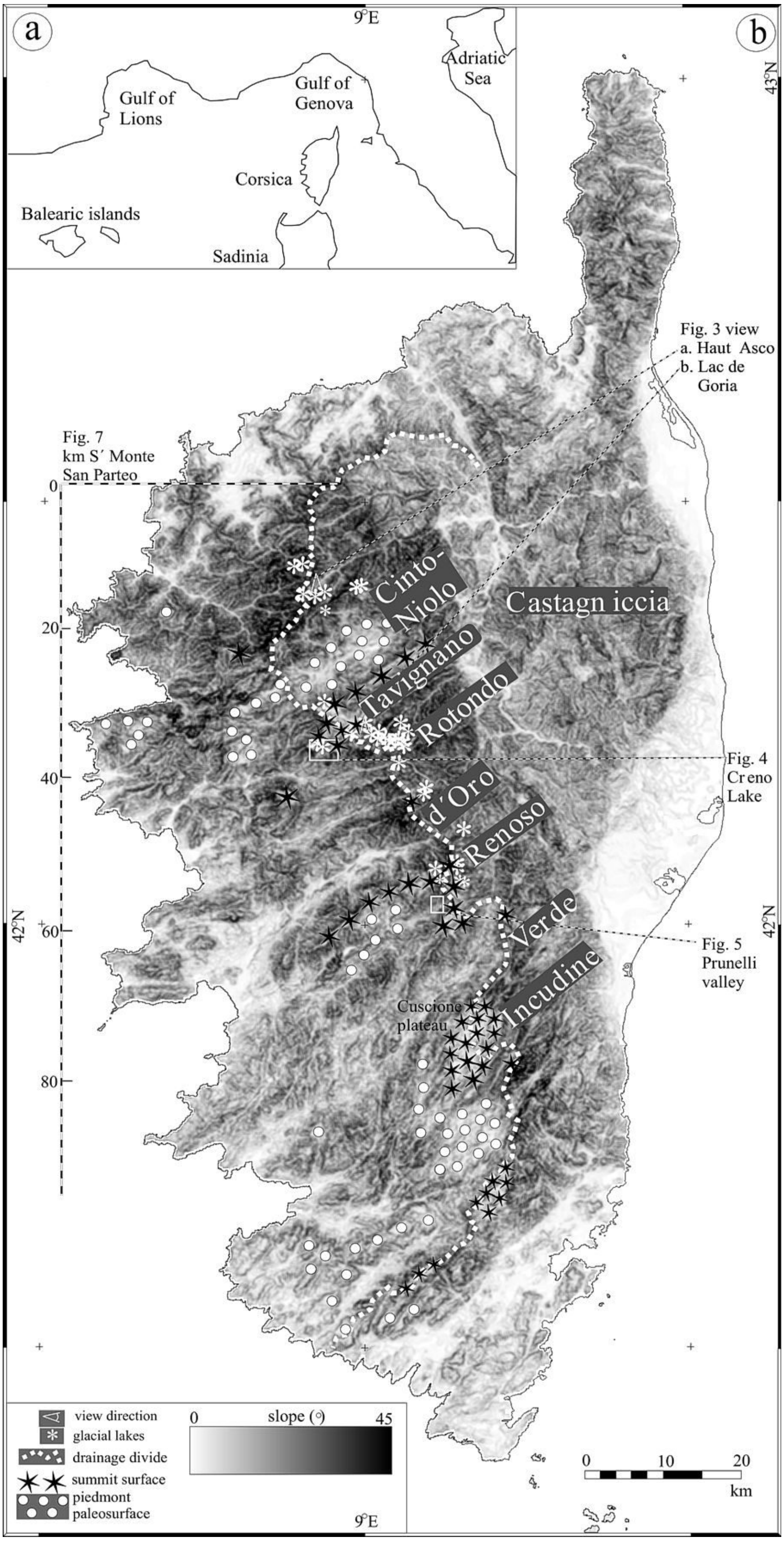

Figure 2: (a) Geographic position of Corsica in the western Mediterranean and (b) derivative of a Digital Elevation Model of Corsica, showing the distribution of the standard deviation of the slope angle. Light colors display low relief slopes associated with a low standard deviation whereas dark colors display steep slopes. Note light colors close to the drainage divide which indicate preservation of paleosurfaces. Two generations are distinguished: an older, higher uplifted „summit surface“ (black stars) and a younger „piedmont paleosurface“ (open circles). Locations of view points (Fig. 3), detail maps (Fig. 4, 5).

moraines noted in these publications are partly contradictory and therefore require re-evaluation. Complete lack of chronostratigraphy of moraine deposits is a major problem in Corsica.

The best chronostratigraphic clue available at present are the Creno Lake sediments (see Fig. 4), which have been cored down to about 7 m depth into presumably glacial pebbles and sand without plant remains (Reille et al., 1997). This debris is covered by late glacial grey clay, dated by ^{14}C Accelerator Mass Spectrometry (AMS) at ca. 15 ka BP, followed up-section by an organic-rich 6.5 m thick late Pleistocene and Holocene gyttja succession, due to swamps along the margins of the lake and forest in the entire catchment (Reille et al., 1997). The age of the deposits strongly suggests that the glacial basin was filled by ice during the Late Würmian (Last Glacial Maximum; LGM, 24-18 ka, oxygen isotope stage (OIS) 2), because otherwise it should contain older deposits with organic remains of interstadial periods within OIS 3. Trimlines, a latero-frontal moraine and relics of lateral moraines in the Zoicu valley (Fig. 4) are related to a continuous glacier surface which enabled transfluence to the isolated glacial basin of Creno Lake (see below). Thus, it is inferred that the level of glaciation testified by these glacial landforms was reached during the LGM. The same level may have been reached during older glacial advances within the Würmian, too.

4. Methods

Fieldwork and studies of 1:25000 topographic maps and satellite images enabled us to distinguish trimlines and other glacial landforms. Observations have been evaluated and compared with published data on glacial and fluvioglacial deposits (Bieda et al., 1977; Conchon & Gauthier, 1977; Conchon, 1975, 1976, 1977, 1979, 1985, 1986, 1988, 1989) in the field.

Occurrences of concave overdeepened valleys and cirques (glacial basins), as indicated by ancient and former lakes now filled with late Pleistocene and Holocene debris, have been compiled. These glacial basins are often arranged in stair cases (Conchon, 1976). The glacial basins have been parametrised by altitude, latitude, aspect, size, and elongation.

Würmian frontal moraines of many large glaciers are poorly preserved. In some places with poor outcrop conditions moraine deposits are doubtful, because they are difficult to separate from glaciofluvial deposits formed in front of glacier tongues (see Conchon & Gauthier, 1977). The trimlines and the moraine limits define highstands of the Würmian glaciation (OIS 4 to OIS 2). Poorly preserved relics of higher trimlines originating from pre-Würmian glaciations have been observed, which were discriminated from Würmian trimlines by their missing geometric relation to Würmian moraine deposits.

The Würmian trimlines and maximum till limits have been used to reconstruct elevation isolines of the maximum Würmian glacier surfaces (Fig. 4, see location in Figs. 2). It is tentatively assumed that the Würmian trimlines and maximum till limits are of the same age and that this maximum level of glaciation was reached several times during the Würmian (see below).

The reconstruction of the glacier surfaces enabled us to estimate the ice thickness and the volume of the glaciers by planimetry. According to Porter (2001), the mean altitude between the trimlines of the highest cirques and the frontal moraines can be used as a first approximation of the ELA. The size of the the ablation area (1/3 to 1/2) relative to accumulation area (1/2 to 2/3) of a glacier (accumulation area ratio-method; AAR) is a more accurate estimate of the ELA (Porter 2001), but it depends on the hypsometry of the glacier surface and debris cover of the tongue. For a typical hypsometry of Würmian glaciers on Corsica, we chose an AAR of 0.6, according to modern glaciated regions of similar relief in the Alps (Wilhelm, 1975). As an exception, the ELA of avalanche-fed glaciers and hanging glaciers is commonly far below the climatic snow line (Wilhelm, 1975) and is therefore not considered for the reconstruction of Würmian climate setting. Although poorly constrained, small niche glaciers have been included in the Würmian ice cover map for the sake of completeness (see Fig. 5). Their distribution correlates with the inferred ELA and depends also on local relief, aspect, and wind-driven snow accumulation.

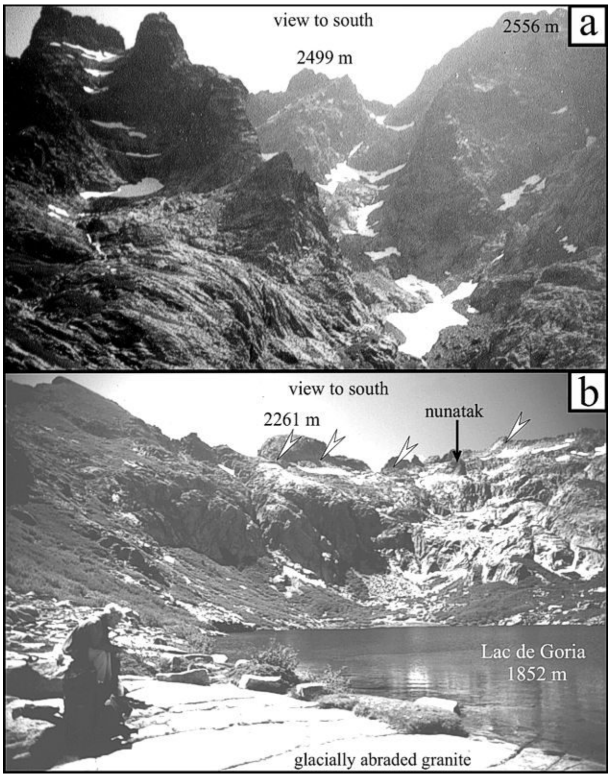

Figure 3a-b: Glacial valleys, lakes and trimlines in Corsica. Trimlines are marked by arrows.

5. Results and local implications

Evidence of several Würmian glacial advances of roughly

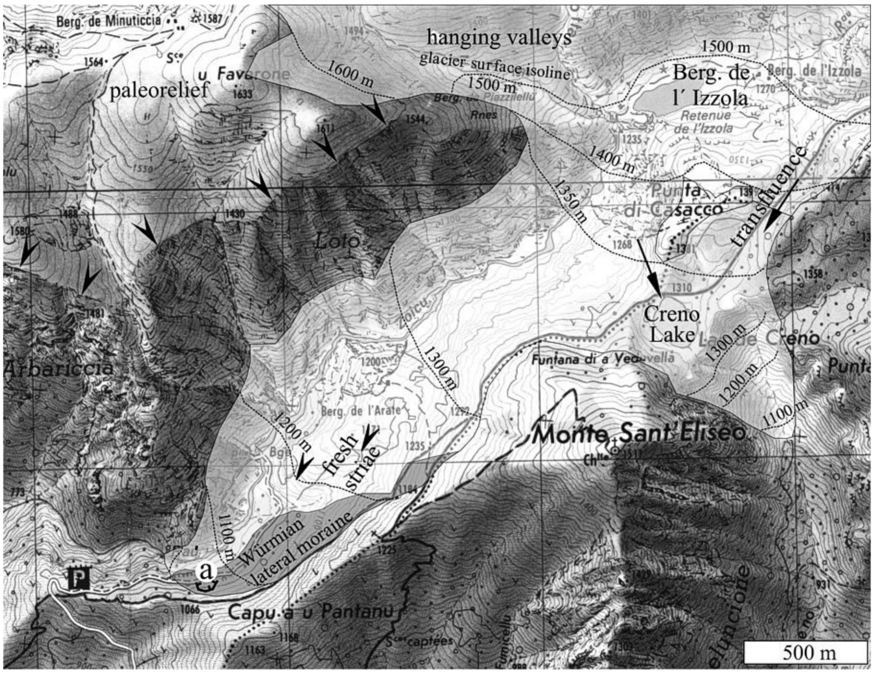

Figure 4: Detailed map of the Zoicu valley on the western slope of Haut Tavignano, based on the 1:25000 map IGN 4251 OT. White transparent cover shows the maximum Würmian glacier surface of the western outlet tongue of the Tavignano icefield. At point (a) within the latero-frontal moraine at the end of the Würmian glacier, a fresh open pit exposes brownish oxidised moraine material, containing rhyolite pebbles with perfectly preserved glacial striae. Transfluence from the Zoicu glacier to the small catchment of the Creno Lake is shown by arrows. The former lake at Bergerie de l´Izzola, now dry and filled with coarse gravel, exposes a debris cone from the N overlying former swampy meadows.

similar extent has been detected in the Prunelli valley, where a succession of 4 latero-frontal moraine crests is preserved (Fig. 5, for location see Fig. 2). The youngest moraine is about 25° steep on the outer flank and more than 40° steep on the inner flank and the outwash on the crest is very limited. In contrast, the crests of the outer moraine generations are progressively flatter, due to solifluction and increasing age. The preserved geometry suggests that the ancient glacier tongue became progressively narrower but longer as debris accumulated internally between the younging latero-frontal moraines. The surface of the glacier tongue, however, seems to have covered a roughly similar area during the 4 recognized glacier advances. According to AAR calculation this geometry implies an almost identical ELA during the 4 constrained Würmian glacier advances, since modification of topography by glacial erosion within several 10,000 years in the granitic bedrock of Corsica is concentrated at the floor of the U-shaped valley which keeps the area size of the maximum glacier surface almost unchanged.

Exceptionally good preservation of the geometry of the latero-frontal moraines is favoured by the special local setting in an abruptly widening U-shaped valley offering sufficient space for deposition. Good preservation of the latero-frontal moraines has also been supported by a glacial lake 4 km upvalley, which buffered extreme runoff and stored potentially erosive material.

Creno Lake (Fig. 4) represents a key site not only for chronostratigraphy but also for ice flow dynamics and ELA calculations. The 13 m deep glacial basin is located as low as 1310 m a.s.l. and is surrounded by forest, which suppresses erosion. It has a hilly catchment of only 0.15 km² size with a rivulet to the N, and a fairly steep rocky slope of 0.04 km² size to the S. To the S, the highest point of the catchment at 1420 m a.s.l. is located on the flank of Monte Sant´ Eliseo (1511 m a.s.l.). It is extremely unlikely that a glacial basin of the size and depth of Creno Lake could have formed by glacial excavation supplied by these local catchments only, even if glaciations of the catchment had successively recurred during the Pleistocene. Moreover, the hypsometry of the catchment would imply a local ELA at 1350 m a.s.l. in easterly exposition. If such ELA position was real, the glacier tongue of the Zoicu valley N of Creno Lake would have been far more extended than displayed in Fig. 3. The only reasonable explanation for the overdeepening of Creno Lake is transfluence of ice from the Zoicu valley across a wide gentle saddle. Roche moutonnée and excavation of grabens along faults suggest that this transfluence occurred also from NE to SW along a small plateau separating the two catchments (Fig. 4).

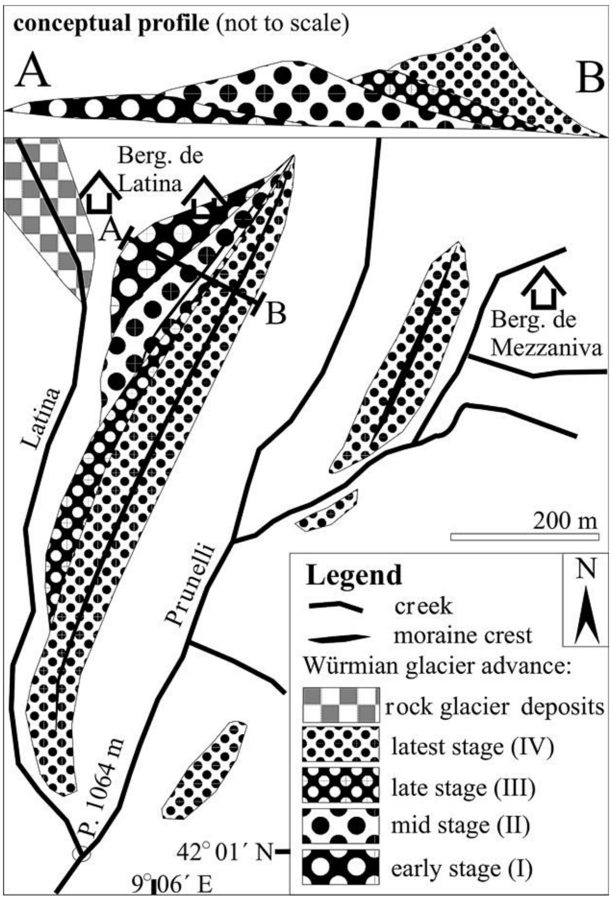

Figure 5: Sketch map and schematic profile of the Würmian latero-frontal moraine succession in the Prunelli valley.

Transfluence as described for the Zoicu valley to Creno lake occurred also in the Mte. Renoso massif, where paleosurface remnants are frequently found at altitudes between 2300 and 1600 m a.s.l. (Fig. 6d). In the Mte. d´Oro massif (Fig. 6c), transfluence occurred from the Agnone glacier to the SW across Vizzavona Pass which in the particular local topographic setting indicates relatively high accumulation of snow on this glacier and on the southwestern flanks of the Mte. d´Oro massif. We interpret this by means of drift snow accumulation and local turbulence leeward of the main drainage divide. In the center of Variscan Corsica, between the Tavignano region and the Chaîne de Verde, glaciers joined with those from neighbouring massifs in the passes, forming ice-stream networks.

In certain places of extremely rugged relief, avalanche-fed canyon glaciers dominated. These were located in the E- to N-exposed canyons in the SE of the island, W- to N-exposed canyons in the NW of the island, and in S-exposed canyons of the western satellite peaks of the Mte. d´Oro massif. The south-exposed „Glacier de Busso" in the latter massif (Bruno et al. 2001), which completely melted a few years ago, testifies of the relevance of such type of glaciers.

5.1 Latitude-dependence of Würmian glaciers

A plot of the maximum and minimum altitude of glaciers versus latitude (41° 50´ N to 42° 32´ N, Fig. 2) mirrors the southward decrease of topography and the incised passes and adjacent large valleys (Fig. 7a). We selected the northernmost prominent peak of the main drainage divide (Mte. San Parteo, 1680 m a.s.l.) as a local reference point of the latitudinal cross section (see Fig. 1).

Glacier length, ice thickness and ice volume show roughly similar patterns (Fig. 7b-d). The Tavignano icefield and glaciers of the Rotondo massif display maxima for all three parameters, although the upper Tavignano region is 400 to 300 m lower than the Cinto and Rotondo massifs, respectively. The Cinto massif,

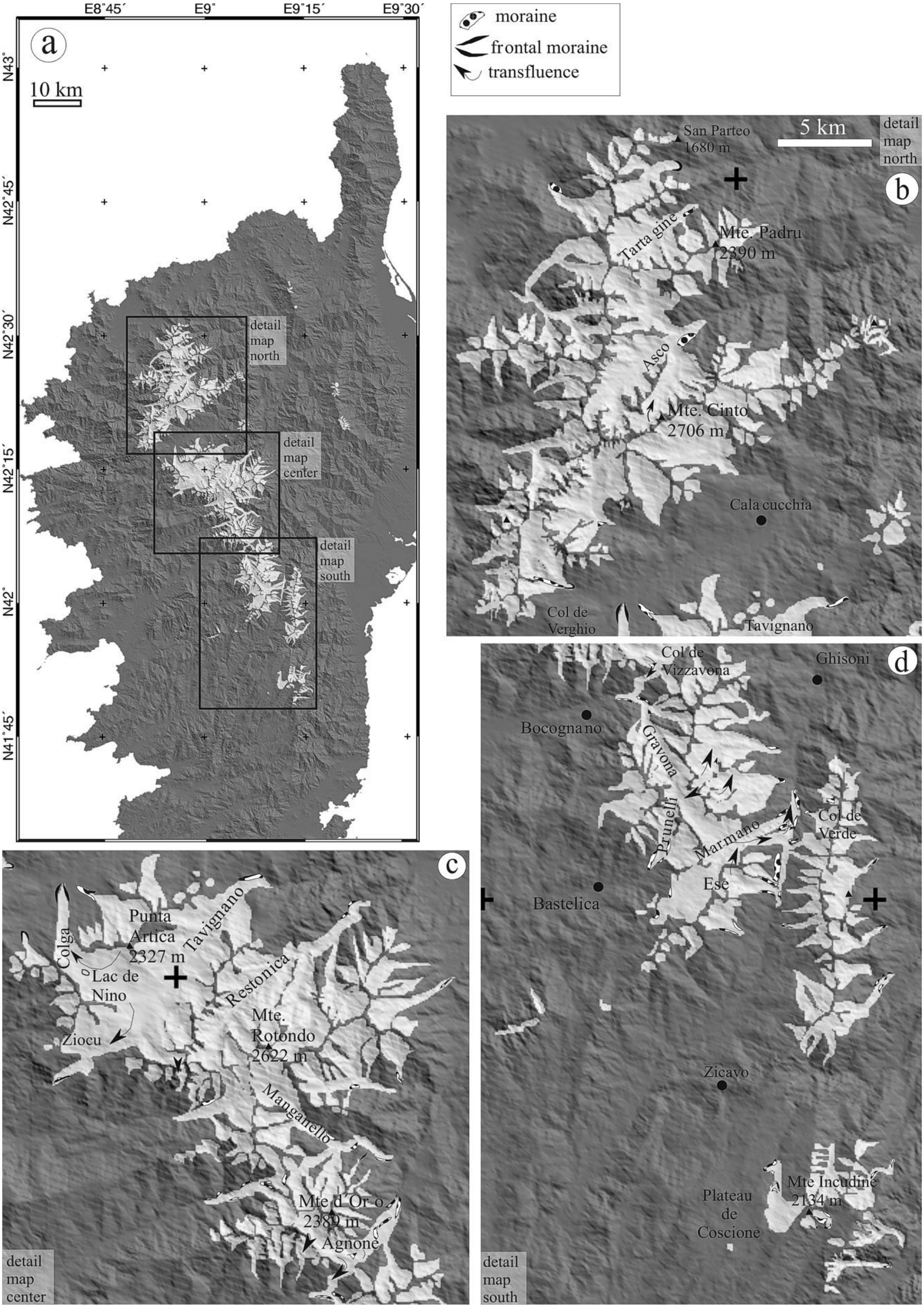

Figure 6a-d: Distribution of glaciers during Würmian maximum in Corsica, the regional maps including moraines mapped during fieldwork and according to references (see text). Locations of inferred transfluence and sites of potential major avalanche supply are indicated.

despite of its high altitude, hosts only a single outstanding large glacier (Asco valley). The Cuscione Plateau in the south almost lacks traces of Würmian glaciation despite of its altitude, which exceeds 1500 m a.s.l. in most parts and should thus be sensitive to glaciation. This indicates that during the Würmian there was a steep temperature gradient across this plateau.

Low altitudes of both the glacier tongues (Fig. 7a) and ELA (Fig.7f) indicate an ELA-depression in the center of the island. Here, the ELA is located below 1500 m a.s.l., and rises towards both the NE and S of the island. The calculated mean ELA (1530 m a.s.l.) is slightly lower than the calculated mean snow line (1575 m a.s.l.), due to supply from avalanches and drift snow (Fig. 7f). The ELA of glaciers in steep and narrow canyons is significantly lower than the bulk.

Comparison of several parameters versus latitude indicates the following (Fig. 7):

1) Despite the high topography in the northern part (Mte. Cinto region), except for the northwestern flank, Würmian glacier thickness, volume and length are smaller than in the Tavignano-Rotondo region. This may indicate lower annual precipitation and higher temperatures in this region. Such a climatic pattern is similar to the present one, which displays less than 1350 mm/a at Mte. Cinto and close to 1500 mm/a at Mte. Rotondo and Mte Renoso (see Bruno et al. 2001).
2) The strong accumulation of ice in the upper Tavignano region is probably not the result of a regionally enhanced precipitation or lower temperatures. Rather it reflects the vast catchment size of the Miocene paleosurface close to and above the ELA, self-amplification during accumulation of ice due to the raising ice surface, and the local climatic positive feedback (albedo, infrared radiation, preservation of low winter temperatures in the ice).

5.2 Aspect of Würmian glaciers

Crossplots of several parameters versus aspect of glacier flow also display some local climatic trends (Fig. 8). Latitude vs. aspect shows no preference, which eliminates this as a potential variable (Fig. 8a).

If we consider aspect vs. ice volume, ice thickness or glacier length (Fig. 8b-d), there is a weak preference for NE aspect, whereas W to NW aspects display a minimum. The preference of NE aspect is expected because of higher sun irradiation per surface unit on S dipping surfaces. Melting of snow and ice is more effective in the afternoon than in the morning due to the temperature delay of ca. 3 hours to insolation, resulting from the heat capacity of air, soil, and especially of ice (Wilhelm, 1975). Thus, a minimum of ice volume, ice thickness and glacier length may be expected in SW aspect, but not in W to NW aspects. The main reason for this feature in Corsica is the relative rareness of valleys of W to NW aspects except of NW Corsica, owing to the fault-controlled preference of SW and NE aspects and the steepness of such valleys. The surprisingly high ice thicknesses and glacier lengths in SE aspect result from the high average altitude of corresponding valleys in the northern half of the profile (Rotondo to Cinto) east of the main drainage divide.

The Würmian ice distribution with respect to aspect matches with the recent typical distribution of snow fields in late spring, as observed during field work and by study of satellite images.

The elevations of snow line and ELA (Fig. 8e-f) display no significant variations with aspect, although a higher altitude would be expected in S to SW aspects. We argue that this is caused by dominant advection of moisture from S to SW during the Würmian, similar to the recent setting. Relatively high amounts of snow probably accummulated leeward of the main drainage divide above the ELA and windward of moderate slopes of high mountains east of the main drainage divide.

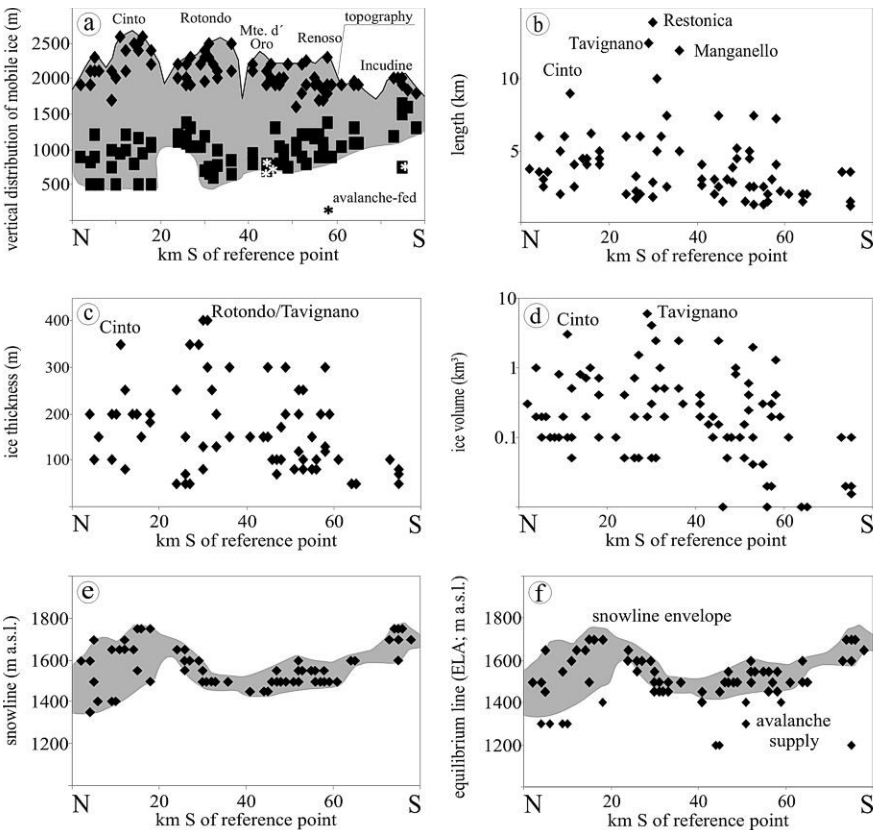

Figure 7 a-f: Crossplot of latitude south of the northernmost glaciated peak (Monte San Parteo, 1680 m) vs. key parameters of Corsica glaciers; (a) maximum (rhombs) and minimum (squares) altitude of glaciers; (b) length of glaciers according to the flow tracks of ice particles; (c) ice thickness, (d) single glacier ice volume; (e) snow line altitude; (f) equilibrium line altitude (ELA).

5.3 Aspect and altitude of glacial basins

The distribution of glacial basins (Fig. 9) supports the interpretations above, but indicates some additional regional differentiation, partly controlled by relief. In Fig. 9b-f the glacial basins of 5 regions have been differentiated according to altitude and aspect.

The Incudine massif (see Fig. 2) lacks glacial basins, and the Chaîne Verde comprises a single small one. In contrast, glacial basins formed in the center of Variscan Corsica even in areas of lower ice thickness as compared to Würmian glaciers of the Incudine massif and the Chaîne Verde. In the N (Cinto massif, Fig. 9b), there is only one group of glacial basins exposed between N and SE aspects typically at altitudes above the ELA, with 2 outliers slightly below the local ELA (1700 m a.s.l.). In the upper Tavignano region, except for 3 outliers ca. 300 m below the local ELA (1550 m a.s.l.), the glacial basins are concentrated in the N-facing steep flanks at the southern margin of the catchment, where no paleosurfaces are preserved. Lac de Nino formed from glacier flow from the southwestern flank of Punta Artica (highest peak in the catchment) upvalley towards the NW and N, spilling over a pass down into the Niolo (Colga valley). In terms of volume, this example probably represents the most important transfluence of the Tavignano icefield and of entire Corsica. A small pond NW of Lac de Creno (Fig. 4) at 1180 m a.s.l. represents the minimum elevation of a glacial pond of Corsica (Gauthier et al., 1983).

The Renoso massif displays 3 groups of glacial basins: the typical NE to E sector, a S aspect and a W aspect. All groups are tightly clustered, which is partly due to several staircases of overdeepened valley sections. This pattern is largely structurally controlled and reflects also the fact that the Renoso massif displays paleosurfaces and high-elevated valleys of similar extent on the opposite flanks of the drainage divide. Whereas fluvial and glacial erosion deeply incised the valleys, ridges suffered low periglacial overprint and erosion.

In the Mte. d´Oro massif, a setting similar to that of the Rotondo massif is observed (Fig. 8e), although the number of glacial basins is smaller due to the smaller size of the massif. The SE-exposed glacial basins belong to the large Agnone glacier. In the Mte. d´Oro and Mte. Renoso massifs (Fig. 8e, f), few glacial basins have formed at altitudes slightly below the ELA.

The Rotondo massif contains the highest and largest cirques, as well as more and deeper lakes than any other massif of Corsica (Fig. 9d). The glacial basins of the Rotondo massif form

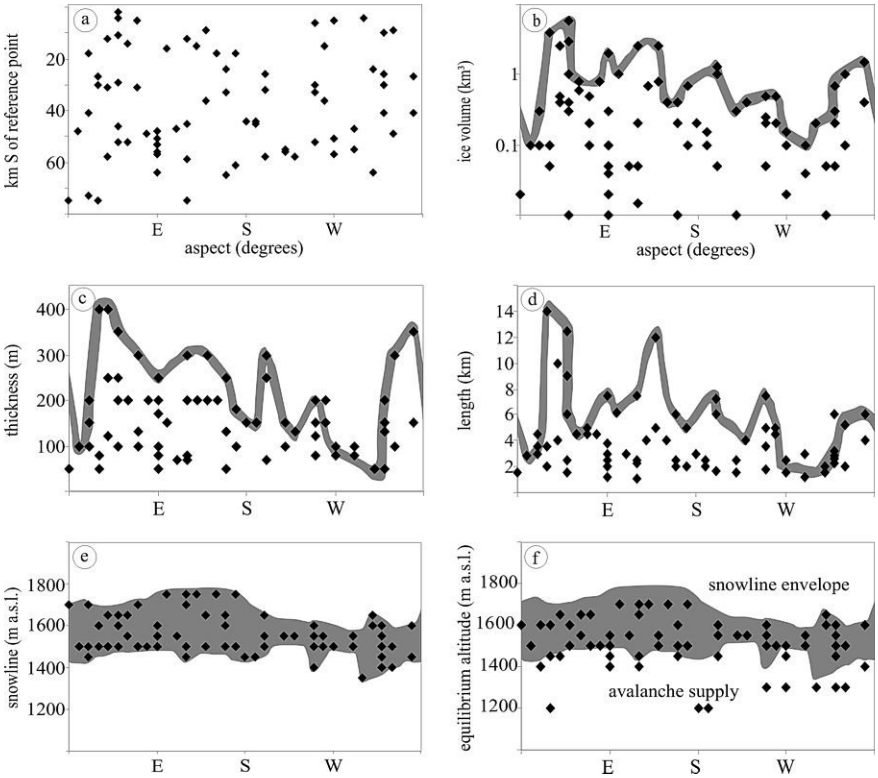

Figure 8 a-f: Crossplot of aspect direction vs. key parameters of Corsica glaciers; (a) latitude as expressed by distance south of Monte San Parteo (see Fig. 1, 4); (b) single glacier ice volume; (c) ice thickness; (d) length of glaciers according to the flow tracks of ice particles; (e) snow line altitude; (f) equilibrium line altitude (ELA).

Massif N to S	valley/ glacier	max. alt. (m)	min. alt (m)	ELA (m)	thickn. max. (m)	length (m)	vol. (km^3)
Mte. Grosso	Tartagine	2100	820	1500	200	6	1
Mte. Cinto	Erco	2600	950	1750	150	6,2	1
	Stranciacone	2600	950	1600	350	9	3
P. Artica	Nino-Colga	2300	1050	1600	350	6	1,5
	Tavignano	2200	1030	1600	350	12,5	6
Mte. Rotondo	Restonica	2400	500	1450	400	14	4
	Pozzolo	2500	750	1450	400	10	2,5
	Verjello	2200	600	1450	250	6	1
	Manganello	2500	650	1500	300	12	2,5
Mte d´ Oro	Agnone	2200	780	1450	300	7,5	2,5
Mte. Renoso	Gravona	2200	750	1500	300	5,2	1
	Prunelli	2300	900	1550	300	7,2	1,3
	Pozzi-Marmano	2250	800	1550	250	7,5	2
Chaîne de Verde	Nursoli	1800	900	1450	120	4	0,4
Mte. Incudine	Tremoli	2000	1180	1600	100	3,5	0,1

Table 1: Parameters of Würmian glaciers in Corsica from N to S, including maximum and minimum altitude, ELA, inferred maximum thickness, length and volume.

one large cluster exposed to the NE sector, another smaller but tight cluster is exposed to the S. Most of the latter glacial basins belong to the long Manganello glacier, which created numerous basins in the highly elevated source regions despite of its minor ice thickness. High rates of drift snow accumulation, southerly aspect, and a relatively steep dip of the hanging valleys may have supported fast flow of the Manganello glacier.

The largest and most elongated glacial basins display no preferred aspect (Fig. 10a) and scatter around 1800 m in settings of low valley gradients, well above the ELA (Fig. 10b). Shallwo and localized overdeepening below the ELA occurs in few long valleys of low gradient (Restonica, Manganello, Agnone; Fig. 6c).

Würmian glaciers reached 14km in length, rooted primarly in high cirques (1800 - 2400 m a.s.l.; Tab.1), but were also fed by avalanches and drift snow (Fig. 7, 8a-d). The length and distribution of Würmian glaciers in Corsica is not much different to the present Swiss Alps (Herren et al. 2001). The exceptionally large glacier of Grand Aletsch in the Bernese Alps (23 km long, up to 800 m thick; Herren et al. 2001) had no equivalent in Corsica.

The total volume of ice on Corsica during the Würmian is estimated to be 46 km^3. It was concentrated in the Rotondo massif (12 km^3), Tavignano region (9 km^3), Renoso massif (8 km^3) and Cinto massif (8 km^3). 13 of the 71 Würmian glaciers had an ice volume of more than 1 km^3.

5.4 The amplifying role of paleorelief for glaciations in Corsica

A steep relief is unfavourable for hosting glaciers, as steep flanks above the ELA tend to cause accumulation of ice at altitudes far below the ELA where melting efficiency increases drastically. In contrast, high-elevated hilly paleosurfaces above the ELA offer ideal conditions for accumulation of ice to form large glaciers.

One large icefield, which is superordinating relief and resembles a plateau glacier (see Benn & Evans, 1998), existed in the upper Tavignano region in the central part of the island (Fig. 11). The total volume of this icefield, including its 3 outlet tongues, was about 8 km^3. In the source region, a high-elevated paleosurface is preserved around 2000 m, whereas the wide valley floor, which represents a glacially modified paleosurface, is located between 1750 m and 1500 m a.s.l., still largely above the Würmian ELA. The icefield built up sufficient thickness to enable extensive transfluence over local divides and the main drainage divide. Transfluence probably triggered catchment cannibalism in the southeastern headwaters of the Zoicu creek (Fig. 11), which according to the paleosurface remnants was a tributary to the Tavignano prior to Pleistocene glaciations. In the long-term perspective of geomorphic change, the headwaters of the Tavignano will once be a tributary to the Zoicu catchment since the gradient of the Zoicu creek is steeper than that of the Tavignano river.

An important mechanism is the positive feedback of paleo-surfaces in the critical range of the ELA. Once a paleosurface becomes covered with permanent ice, albedo and radiation in the infrared spectrum will enhance local cooling and the raising ice surface will buffer the ice body against minor fluctuations of the ELA. Moreover, the increasing elevation of the ice body would increase precipitation and thus enhance accumulation of ice. This positive feedback explains the strong accumulation of ice in the Haut Tavignano region.

Other paleosurface remnants at critical elevations above the Würmian ELA are found in the Renoso massif. In particular the Ese valley in the S of the Renoso massif is very sensitive to fluctuations of the ELA, since the mountain tops are less than 2000 m a.s.l. high and too flat to allow relevant ice accumulation. In the upper Ese valley (1850 and 1700 m a.s.l.), the self-amplified growth of an ice body would be limited by increasing wind drift near the flat mountain tops which transported snow across the main drainage divide to the lee side. The upper Marmano valley N of the Ese plateau benefited from this drift snow. Since the upper Marmano valley floor also rises above the ELA, ice accumulation is more efficiently self-amplifing than on the Ese plateau.

Large parts of the Cuscione plateau (Fig. 2) are situated above 1600 m a.s.l.. The plateau is flanked by ridges rising 100 to 500 m above the plateau. It provides excellent morphologic conditions for a self-amplifying plateau glacier, if the ELA would drop to 1600 m a.s.l. in this region. However, the altitude of the local ELA during the coldest Würmian periods was around 1700 m a.s.l. During coldest pre-Würmian glacial periods the Cuscione plateau was probably glaciated. The strong local gradient of the Würmian ELA east of the Cuscione plateau and the Incudine massif may be interpreted as shielding by frequent fog in this region (see Bruno et al., 2001).

6. Regional Würmian climatic implications in Corsica

Würmian ELA estimates in Corsica display a depression in the center of the island (Fig. 7e, 12) around the lowest pass across the main drainage divide (Vizzavona pass, 1163 m a.s.l.). The deep Gravona valley southwest of Vizzavona pass keeps a wide and gentle character below 600 m a.s.l. in only 5 km distance from the pass. It funnels approaching clouds, which break through Vizzavona pass without development of foehn effects within the next few km east of the pass, causing precipitation on both sides of the drainage divide. Fairly wet and cool climate conditions east of Vizzavona pass are indicated by the montane vegetation belt reaching down to unusually low altitude. East of Vizzavona pass, the Würmian 1500 m ELA isoline extends to the S and the N, possibly as a result of the missing or weak foehn effect (Fig. 12).

gauching station	altitude (m a.s.l.)	pp (mm/a)	exposure to W wind
Calacuccia	820	850	leeward
Evisa	850	1250	windward
Bocognano	670	1280	windward
Bastelica	800	1320	windward

Table 2: Annual precipitation of mid-elevation gauging stations in Corsica.

In contrast, in northern Corsica the minimum of the ELA was located west and north of the divide, where clouds approaching from north-westerly directions were forced to release precipitation. This pattern is in line with a typical leeward rise of the ELA in the range of 300 m in the spatial scale of 50 km (e.g., from the margin towards the dry interior of the Alps; Wilhelm, 1975). At present, the wide Niolo valley displays reduced precipitation to the east (Tab. 2; after Bruno et al., 2001), partly as a result of foehn effects. Advection of moisture from the east to the northern center of Corsica is hampered by 1000 to 1700 m high N-S trending drainage divide in the Castagniccia (Fig. 2), which appears to have hosted small niche glaciers during coldest periods (Fig. 12). The wide and fairly high Niolo valley (above 800 m a.s.l.) appears to favour the development of local high air pressure which tends to hinder clouds to spill over the drainage divide. Instead, damed clouds approaching from the SW rather spill over the slightly higher drainage divide further to the S in the Tavignano catchment. Large valleys in northern Corsica generally show a higher Würmian ELA on the south-facing flanks due to more effective insolation and less precipitation.

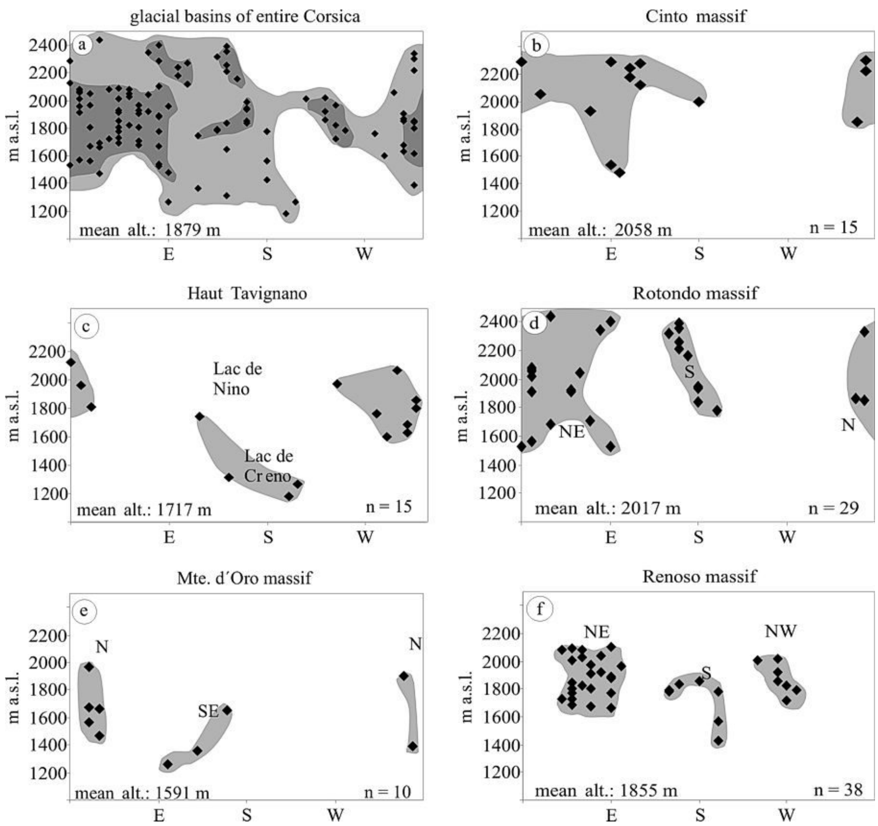

Figure 9 a-f: Altitudes of glacial lakes or former, now filled lakes (glacial basins) plotted vs. aspect. (a) Entire Corsica, splitting in different regions from N (b) to S (f).

Strong gradients of the ELA isoline pattern are inferred in the northwest and in the south. In southern Corsica, west of Mte. Incudine, the ELA is relatively high (Fig. 6d, 12), whereas NE and E of Mte. Incudine glaciers have formed at relatively low altitudes in deeply incised valleys, fed by drift snow and avalanches. These valleys are recently protected from insolation by frequent fog in autumn and winter (Bruno et al., 2001), probably as an effect of cool upwelling water SE offshore Corsica and strong and early generation of clouds moving inland in the course of summer land-sea circulation.

7. Difference of Würmian maximum and Holocene ELA

There is no recent permanent ice in Corsica and thus the ELA of 3000 m was just estimated (Wilhelm, 1975). We have discovered a small fresh moraine crest of a niche glacier at 2400 m a.s.l. on the north face of Mte. Rotondo (2622 m) in the center of the island. The moraine is crested by boulders as large as 10 m. The glacial basin, about 30 m wide, is partly filled by a gentle fan of granite grains, sand, and mud. The slope above this glacial basin is largely built of boulders but includes also fresh roche moutonnée. Except for the largest boulders, the slope and the lowest 5 to 8 m at the foot of rock walls in the rear of this glacial basin are free of lichen (*Rhizocarpon geographica*), which indicates that this area is free of snow for less than 95 days per year (Innes 1985). The largest boulders of the moraine crest show some *Rhizocarpon geographica* of less than 3 cm in diameter. According to standard lichenometric interpretation (e.g., Bull & Brandon 1998) we assume that this moraine crest has formed during the late Little Ice Age (LIA). This implies a local ELA at 2450 m a.s.l. during the late LIA in parts of the Rotondo massif. Similar observations in the southern center of Corsica (Mte. d´Oro and Mte. Renoso massifs) indicate an ELA as low as

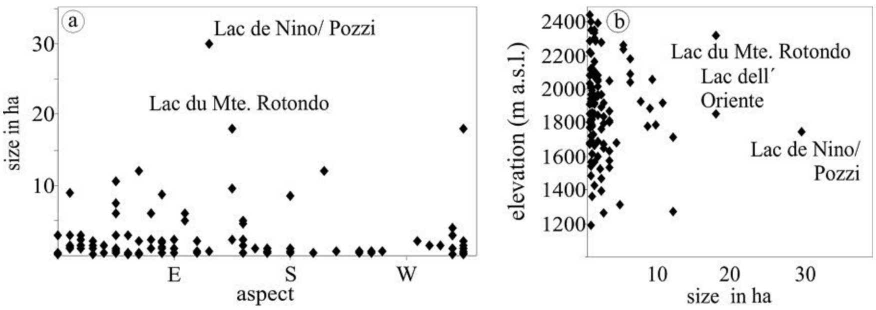

Figure 10 a-b: (a) Crossplots of size of glacial depressions vs. elongation aspect; (b) elevation vs. size altitude; (c) crossplot of elongation (length/ width) vs. aspect and (d) elevation vs. elongation (length/ width).

2200 m a.s.l. during an earlier, even cooler period of the Little Ice Age in NE exposition in places where a strong supply of drift snow is likely.

This local evidence enables to estimate the hypothetic elevation of the actual ELA by comparison with the Alps. A 300 m rise of the Lower Grindelwald Glacier tongue in the Swiss Alps since late LIA (Holzhauser & Zumbühl 1996) implies a rise of the ELA by 150 m. Lowering of the Swiss Alpine ELA by 150 m in the late LIA implies an average temperature decrease of ca. 0.9°C, if a lapse rate of ca. 0.6° C/100 m is assumed (see Porter, 2001). This matches with borehole temperature measured in the Greenland ice sheet (Dahl-Jensen et al., 1998) and the LIA average temperature decrease of the entire northern hemisphere (Jones et al., 2001). In Corsica, a 150 m rise of the ELA since the late LIA would imply an actual ELA of 2400-2600 m a.s.l. in steep N to NE cirques. We estimate an actual ELA-average in the range of about 2700 to 3000 m in Corsica.

8. Discussion

The interpretation of the poorly preserved glacial deposits in Corsica is difficult due to lack of chronostratigraphic data. According to Conchon (1977), moraines older than Würmian are extremely rare.

Conchon (1985, 1989) interprets large boulders of glacial origin at 600 m a.s.l. in the narrow Restonica valley as pre-Würmian deposits, based on weathering patterns and erosion of the till matrix. We found larger spots of glacial tills with minor outwash at 600 m a.s.l., and small spots of till upvalley within short distance at a level of 15 m above the Restonica river, increasing in volume, thickness and freshness upvalley to 800 m a.s.l. Conchon (1985, 1989) interprets deposits above 800 m a.s.l. as Würmian moraines, whereas we find a continuous degradation downvalley to 600 m a.s.l., which we interpret as older Würmian tills. In the narrow Restonica valley, it is in fact difficult to discriminate between surficially reworked thick till remains at 600 m a.s.l. and seemingly reworked till remnants, but possibly glaciofluvial deposits at 530 m a.s.l., which include outwashed giant boulders. In other valleys, such as the Prunelli, which host better preserved remnants of pre-Würmian moraines, these are easily distinguishable according to their geometric relation to trimlines high above the Würmian one.

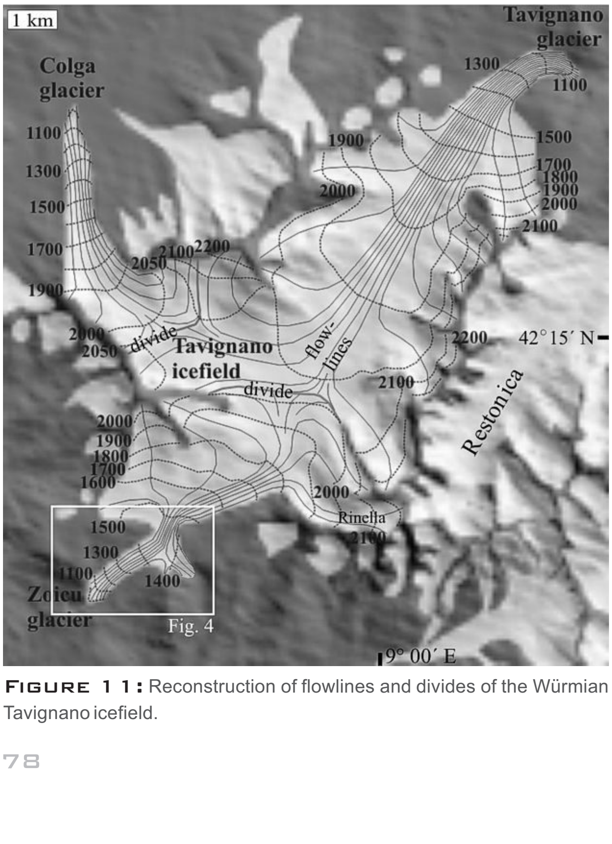

Figure 11: Reconstruction of flowlines and divides of the Würmian Tavignano icefield.

Our observations in entire Corsica yielded a wide range from fresh to strongly weathered outcrops of Würmian moraines. Some moraines, e.g. in the Gravona valley at 930 m a.s.l., show excellent preservation, grey matrix, and lack of weathering of components. Such fresh moraines were found to be pelite-rich, exposed to the N and almost saturated with water. Outcrops of south-exposed moraines with dry and sandy matrix were found to be yellowish to slightly brownish, and the components were partly weathered. Relative dating of moraines on the base of pebble weathering, as attempted by Conchon (1976, 1985), Bieda et al. (1977) and Conchon & Gauthier (1977), has been found to be largely biassed by the local setting and the outcrop conditions. Based on observations on numerous new exposures from road constructions, we interpret the different degree of weathering of matrix and pebbles in these deposits mainly as a result of local variability of thickness, water saturation, porosity, and exposure.

Between 70 ka and 21 ka, climate in the northern hemisphere, as recorded by oxygen isotopes of marine plankton and ice cores in Greenland, shows abrupt, short-lived warming and cooling events (Dansgaard et al., 1993). Minimum temperatures between 70 and 65 ka (Early Würmian, OIS 4) are in the same range as between 46 and 21 ka (Jouzel, 1999). According to Cacho et al. (2002), high-resolution alkenone data suggest that maximum cooling in the western Mediterranean is contemporaneous and causually linked with northern hemispheric glacier surges, known as Heinrich events. The coldest events in the western Mediterranean occurred at 67 ka, 39 ka, 30 ka, and 24 ka (Cacho et al., 2002). In western-central Europe, maximum glacier advances are recently noted by Florineth & Schlüchter (2000) at 67 ka (Alps), 56 ka (Massif Central), 46-39 ka (Pyrenees), 39 ka (Vosges), and 21 ka (Alps). Except for the Alps, the LGM glaciers according to Florineth & Schlüchter (2000) have protruded less far than earlier cold phases during the Würmian in western Europe, in contrast to the general northern hemispheric trend. Nevertheless, Reille & Andrieu (1995) report oldest late glacial blue clays in northern Pyreneean glacial piedmont lakes and basins, dated at 20 ka and younger, leaving the question open why no deposits have formed in these basins between 45 ka (38 ka in their paper) and 20 ka in front of a retreating glacier (see also Hérail et al., 1986).

We assume that the maximum extent of Würmian glaciers on Corsica occurred during one of these discrete short-term cold periods and that the glacier extent during the coldest Heinrich events between 70 ka and 21 ka was close to the maximum. Our

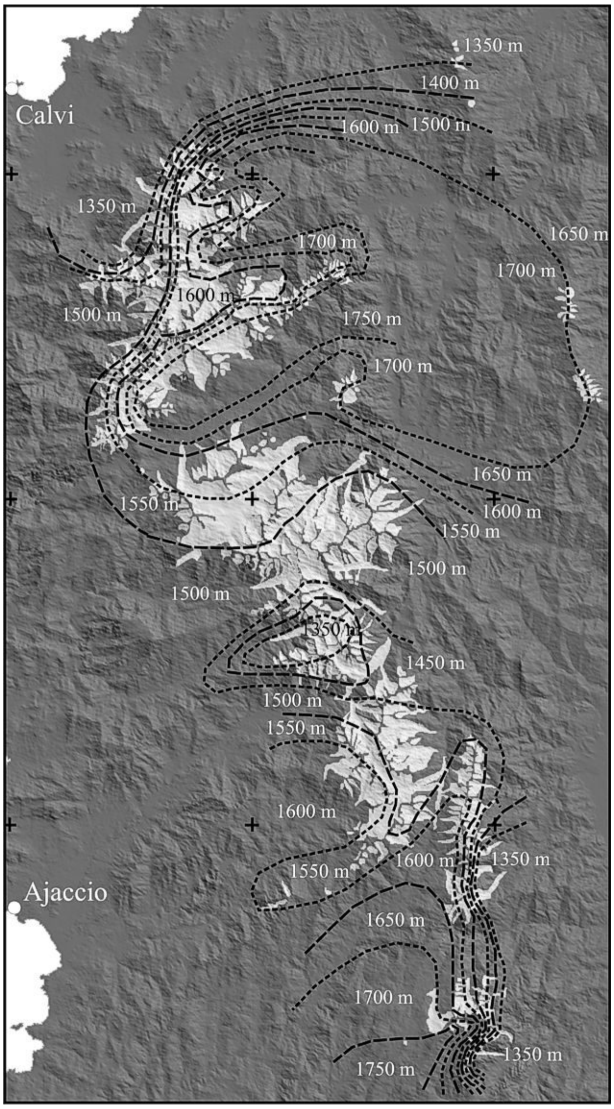

Figure 12: Estimated isolines of Würmian ELA in m a.s.l.

observations in the Prunelli valley (Fig. 5) suggest 4 events of Würmian maximum glacier extent, the last of which reached minimum altitude in this particular valley. If considering the depositional age and setting of the Creno glacial basin (Fig. 4), this maximum glacier extent (minimum altitude) in the Prunelli valley most likely formed during the LGM.

Our results show that the average elevation of the Würmian ELA in Corsica (ca. 1500 m a.s.l.) is lower than previous estimates of about 1800 m (Klaer, 1956) and 1700 m a.s.l. (Conchon, 1978, 1988). This difference may partly result from different calculation techniques, but it is also caused by slightly different interpretations of depositional environment (glacial moraines vs. glaciofluvial deposits), depending on the outcrop quality and potential modification of deposits during glacial retreat. Even if the tongues of the larger glaciers would have ended at ca. 200 m a.s.l. higher elevation during the strongest of the 6 potential Würmian glacier advances as compared to the others, as it is likely in case of the large Restonica glacier, this could mean an ELA range of about 100 m. The Restonica glacier potentially was more sensitive to changes of preciptation and snow accumulation than other glaciers in Corsica, since it displays an extremely large catchment above the ELA as compared to the long and narrow glacier tongue.

Keeping this robustness of ELA-based paleotemperature estimates in mind, a comparison with paleoclimate data acquired from the ocean record promises important constraints on the regional late Pleistocene paleoclimate in the western Mediterranean. Maximum lowering of the Würmian equilibrium line elevation (ELA) by 1200 to 1400 m indicates that mean annual temperatures (MAT) were lowered by ca. 8°C, in line with the marine record of OIS 4 to 2 (Cacho et al., 2002).

The technique of constructing ancient snow lines and ELA by the AAR method is only one, but probably the best, of several approaches (see Porter 2001). However, if a certain approach is applied consequently, the gradients and thus the distribution pattern found should provide reliable information independent from particularities of the method applied.

9. Conclusions

Our mapping of the Würmian maximum glacier cover in Corsica revealed a larger extent than it was previously assumed. Glacier tongues reached elevations as low as 600, perhaps 530 m a.s.l. The elevation of the Würmian ELA displays a minimum in the island center. Funneling of clouds by SW-NE oriented valleys and local topographic and climatic effects are held responsible for a lower ELA in the center than in the NE of Corsica. High-altitude valleys of a glacially modified Miocene paleorelief played an important role for self-amplifying accumulation of large icefields.

Acknowledgements

This study has been supported by a special Baden-Württemberg government grant with technical periphery and commercial remote sensing data. Support for field work has been granted by the German Science Foundation (DFG) in the course of a project dedicated to Cenozoic relief evolution. The manuscript strongly benefited from remarks by Desmond Patterson, who also improved the language. Detailed comments by Odette Conchon on an early version of the paper were very helpful. Constructive reviews especially of Christian Schlüchter, again Odette Conchon, and finally by Markus Fiebig are gratefully acknowledged.

References

Amaudric du Chaffaut, S., Bonin, B., Caron, J.M., Conchon, O. and Rossi, P., 1985. Càrte Géol. France (1/50000), feuille Venaco (1114). BRGM, Orleans.

Benn, D.I. and Evans, D.J.A., 1998. Glaciers and glaciation. Arnold, London, 734 pp.

Bieda, S., Conchon, O., and Icole, M., 1977. Attempted correlation of Quaternary deposits in two regions, Corsica and the Pyrenees, using pebble weathering. I.G.C.P. Project 24, Quaternary glaciations in the Northern Hemisphere, Report 4, 67-71, Prague.

Bruno, C., Dupré, G, Giorgetti, G., Giorgetti, J.P. and Alesandri, J., 2001. Chì tempu face? Méteorologie, climat et microclimates de la Corse. CNDP-CRDP de Corse/ Méteo France, Ajaccio, France, 82 pp.

Bull, W.B. and Brandon, M.T., 1998. Lichen dating of earthquake-generated regional rockfall events, Southern Alps, New Zealand. Geological Society of America Bulletin 110/1, 60-84.

Cacho, I., Grimalt, J.O., and Canals, M., 2002. Response of the western Mediterranean Sea to rapid climatic variability during the last 50,000 years: a molecular biomarker approach. Journal of Marine Systems 33-34, 253-272.

Carmignani, L., Decandia, F.A., Disperati, L., Fantozzi, P.L., Lazzarotto, A., Liotta, D. and Oggiano, G., 1995. Relationships between the Tertiary structural evolution of the Sardinia-Corsica-Provencal Domain and the Northern Apennines. In: A.H.F. Robertson and M. Grasso (Editors), Later Tertiary-Quaternary Mediterranean tectonics and paleo-environments. Terra Nova, 7/2,128-137.

CLIMAP Project, 1976. The surface of the ice-age. Earth Science 191, 1131-1136.

COHMAP Members, 1988. Climate changes of the last 18,000 years: Observations and model simulations. Science, 241, 1043-1052.

Conchon, O., 1975. Les formations quaternaires de type continental en Corse orientale. PhD Thesis, University of Paris VI, Vol. I : Observations et interprétations, 514 pp., Vol. II : Documents annexés, 244 pp.

Conchon, O., 1976. Quaternary glaciations in Corsica. I.G.C.P. project 24, Quaternary glaciations in the Northern Hemisphere, Report 3, 250-255, Prague.

Conchon, O., 1977. Les glaciations quaternaires dans le Centre-Sud de la Corse; Comparaison avec la Corse du Nord et les régions periméditerranéennes. Bulletin Societé Géologique de France, 19/5, 1041-1045.

Conchon, O., 1978. Quaternary studies in Corsica (France), Quaternary Research, 9/1, 41-53.

Conchon, O., 1979. Maximum extension of Wurm glaciation around the western Mediterranean. In: V. Sibrava and F. Shotton (Editors), Quaternary glaciations in the Northern Hemisphere, IGCP Project 24/ 5, 77-88.

Conchon, O., 1985. Nouvelles observations sur les formations glaciaires quaternaires en Corse. Bulletin de l´ Association Française pour l´étude du Quaternaire, 1, 5-11.

Conchon, O., 1986. Quaternary glaciations in Corsica. In: V. Sibrava, D.Q. Bowen and G.M. Richmond (Editors), Quaternary glaciations in the Northern Hemisphere. Quaternary Science Reviews, 5, 429-432.

Conchon, O., 1988. Paléogeographie et paléoclimatologie de la Corse au Quaternaire; chronologie des événements. Bulletin Societé Géologique de France, Huitième Serie, 4/ 4, 587-594.

Conchon, O. 1989. Dynamique et chronologie du détrisme quaternaire en Corse, domaine Méditerranéen montagnard et littoral. Bulletin de l´ Association Française pour l´étude du Quaternaire, 4, 201-211.

Conchon, O. and Gauthier, A., 1977. Les formations quaternaires du massif du Monte Renoso (Corse), BRGM Section 1, Géologie de la France, 4, 277-283.

Dahl-Jensen, D., Mosegaard, K., Gundestrup, N., Clow, G.D., Johnsen, S.J., Hansen, A.W. and Balling, N., 1998. Past temperatures directly from the Greenland Ice sheet, Science, 282, 268-271.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjornsdottir, A.E., Jouzel, J. and Bond, G., 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. Nature, 364/6434, 218-220.

Durand-Delga, M. et al., 1978. Corse – Guides géologiques régionaux, Masson éd. Paris, 208 pp.

Florineth, U. and Schlüchter, C., 1998. Reconstruction the Last Glacial Maximum (WÜRMIAN) ice surface geometry and flowlines of the Central Swiss Alps, Eclogae Geologicae Helvetiae, 91, 391-407.

Florineth, D. and Schlüchter, C. 2000. Alpine evidence for atmospheric circulation patterns in Europe during the Last Glacial Maximum, Quaternary Research, 54, 295-308.

Frei, C. and Schär, C., 1998. A precipitation climatology of the Alps from high-resolution rain-gauge observations, International Journal of Climatology, 18, 873-900.

Gamisans, J. 1991. La végétation de la Corse in Compléments au Prodrome de la Flore Corse, Annexe 2. Conservatoire et Jardin botaniques, 391 pp., Genève.

Gauthier, A., Roché, B. and Frisoni, G.F., 1983. Contribution à la connaissance des lacs d´ altitude de la Corse, 265 pp., Parc régional de la Corse, Ajaccio.

Hérail, G., Hubschman, J. and Jalut, G., 1986. Quaternary glaciation in the French Pyrenees. In: V. Sibrava, D.Q. Bowen and G.M. Richmond (Editors), Quaternary glaciations in the Northern Hemisphere, Quaternary Science Reviews, 5, 397-402.

Herren, E., Hoelzle, M. and Maisch, M., 2001. The Swiss Glaciers 1997/98 and 1998/99. Glaciological Report No. 119/120, 86 pp., Glaciol. Comm. Swiss Academy of Science and Laboratory of Hydraulics, Hydrology and Glaciology, ETH Zürich.

Holzhauser, H., and Zumbühl, H.J., 1996. To the history of the Lower Grindelwald Glacier during the last 2800 years – palaeosols, fossil wood and historical oictorial records – new results. Zeitschrift für Geomorphologie, Supplementband104, 95-127, Stuttgart.

Innes, J.L., 1985. A standard Rhizocarpon nomenclature for lichenometry. Boreas, 14/1, 83-85.

Jones, P.D., Osborn, T.J. and Briffa, K.R., 2001. The evolution of climate over the last Millenium. Science, 292, 662-666.

Jouzel, J., 1999. Calibrating the isotopic paleothermometer. Science, 286, 910-911.

Klaer, W., 1956. Verwitterungsformen im Granit auf Korsika.- Petermanns geographische Mitteilungen, Ergänzungsheft, 261, 146 pp.

Messerli, B., 1967. Die eiszeitliche und gegenwärtige Vergletscherung im Mittelmeergebiet, Geographica Helvetica, 22, 105-228.

Orsini, J.B., Michon, G., Laporte, D., Vellutini, P., Fumey-Humbert, F., Conchon, O. and Gauthier, A. 1990. Carte géol. France (1/50 000), Feuille Calvi (1105). BRGM, Orléans.

Porter, S.C., 2001. Snow line depression in the tropics during the last glaciation, Quaternary Science Reviews, 20/10, 1067-1091.

Reille, M. and Andrieu, V., 1995. The late Pleistocene and Holocene in the Lourdes Basin, Western Pyrénées, France: new pollen analytical and chronological data. Vegetation History and Archeobotany, 4, 1-21 (Springer).

Reille, M., Gamisans, J., de Beaulieu, J.-L. and Andrieu, V., 1997. The late-glacial at lac de Creno (Corsica, France), a key site in the western Mediterranean basin, New Phytologist, 135, 547-559.

Rondeau, A., 1961. Recherches géomorphologiques en Corse (la part de la téctonique et de l'érosion differentielle dans le relief de l'ile), Librairie Armand Colin, 586 pp., Paris.

Rossi, P. and Cocherie, A., 1991. Genesis of a Variscan batholith; field, petrological and mineralogical evidence from the Corsica-Sardinia batholith, In: R. Freeman, M. Huch, and S. Mueller (Editors), The European Geotraverse, Part 7, Tectonophysics, 195, 319-346.

Rossi, P., Rouire, J. and Durand-Delga, M., 1980. Carte Géologique de la France, A 1/250 000, Corse, sheet 44/45, Notice explicative de la feuille, 80 pp., BRGM, Orléans.

Rossi, P., Durand-Delga, M., Caron, J.M., Guieu, G., Conchon, O., Libourel, G., Loye-Pilot, M.D., Oll, J.J., Pequignot, G., Potdevin, J.L., Lieuf, M., Rodriguez, G., Sedan, O., Vellutini, P.J. and Rouire, J., 1995. Càrte Géol. France (1/50000), feuille Corte (1110), BRGM, Orléans.

Wilhelm, F., 1975. Schnee- und Gletscherkunde. 434 pp. De Gruyter, Berlin, New York.

Received: 1. March 2004
Accepted: 21. April 2004

J. KUHLEMANN, W. FRISCH, B. SZÉKELY, I. DUNKL, M. DANIŠIK & I. KRUMREI
Institute of Geosciences, University of Tübingen, D-72076 Tübingen, Sigwartstr. 10, Germany