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Late-glacial and Holocene vegetation and climate change at the Palü glacier, Bernina Pass, Grisons Canton, Switzerland

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Abstract. Pollen and macrofossil data from Alpe Palü, south-eastern Switzerland, are presented. On the basis of these data and the geomorphological evidence for local glacier movement, Holocene climatic oscillations and vegetation change at this upland site (1940 m asl), are reconstructed. The morainic deposits and glacial clays, as well as the pollen data from the base of the pollen profile, clearly show that the Palü glacier, after its retreat from the Cavaglia (Egesen) stade, readvanced once again shortly before the mid-Preboreal. This re-advance was considerably greater than that dating to the Little Ice Age. This early Holocene climatic event is referred to as the Palü Oscillation *(Palü-Schwankung)* and is considered to be broadly contemporaneous with the previously described Schlaten Oscillation *(Schlaten-Schwankung)* in the Austrian Alps. The reforestation of the forefield of the moraine was interrupted at least twice during this oscillation, and, compared with neighbouring sites at the same altitude, it appears to be at least 500-700 years younger, i. e. it post-dates 9400 B.P. Though the Palü Oscillation is a Holocene phenomenon, the associated vegetation changes are Late-glacial in character, e.g. *Artemisia* and Chenopodiaceae increase and *Hippophaë* is recorded. *Alnus viridis* replaces *Betula* and *Salix*, which were important in the earlier part of the Holocene, at about 5000 B.P. There is no clear evidence that forest burning is attributable to human activity. The use of *Larix*-dominated areas as pasture *(Lärchwiesen)* begins in the mid-Bronze Age. A strong decline in *Picea* (spruce) and *Larix* (larch), and an increase in Poaceae, *Plantago* and other herbs in the uppermost horizons reflect more intensive pastoral farming that began in the high Middle Ages.

Key words: Pollen analysis – Glacier readvance – Preboreal oscillation – Switzerland – Alps

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Introduction

In their efforts to study past climate, vegetation and glacier history, Swiss palynologists realised at an early stage that it was only by the simultaneous use of biostratigraphical and geomorphological methods that reliable palaeoenvironmental reconstructions could be made (Lüdi 1944; Welten 1944, 1952; Zoller 1960; Zoller et al. 1966). Some of the preliminary results presented in the two latter publications motivated G. Furrer to start a large project, at the Geographical Institute, University of Zürich, which deals with Late-Würmian and Holocene palaeoenvironments in the Grisons Canton, Swiss Alps (Furrer et al. 1984). This project included investigations at the Palü glacier (Beeler 1977; Figs. 1, 2). While mapping moraines in the vicinity of the Palü glacier, Beeler found several small bogs, the pollen analytical investigations from one of which are presented here (Alpe Palü; M3, Figs. 2, 3). In addition F. Averdieck carried out pollen analytical investigations in the bog, Galleria da Palü (M2, Figs. 2, 3) which was published in Beeler (1977). This diagram covers the last 2300 years and is important for the interpretation of the youngest parts of the diagram, Alpe Palü (M3). The base of M2 gave an early Holocene date [zone III/IV; classical zones after Firbas (1949)] which is useful for dating the last readvances of the Palü glacier (Beeler 1977). Burga (1987) published a substantial volume dealing with glacier and vegetation history of the South Raetien Alps since the Late-Würmian. This publication contains detailed geomorphological and palynological data relating to the region of the Palü glacier. Nevertheless, it seems worthwhile to publish the complete diagrams from Alpe Palü (M3), because the profile shows exceptionally well the vegetation development of an important glacier forefield at the Pleistocene/Holocene transition and also several interesting changes in the upper subalpine forests of the central Alps after the retreat of the glacier.

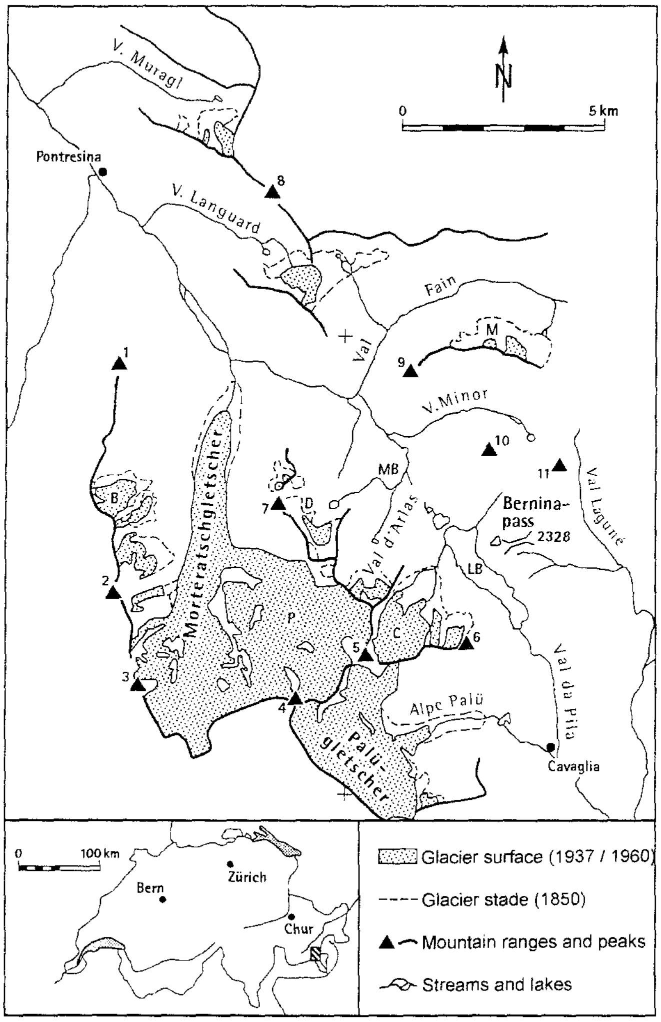

Fig. 1. Map of the Bernina Pass and surrounding region (after Beeler 1977). The area covered by the detailed map is indicated on the inset map by a solid rectangle. Abbreviations: *B*, Boval glacier; *C*, Cambrena glacier; *LB*, Lago Bianco; *M*, Minor glacier; *MB*, Munt Buottels; *P*, Pers glacier; *1*, Chalchagn; *2*, Morteratsch; *3*, Bernina; *4*, Palü; *5*, Cambrena; *6*, Sassalmason; *7*, Munt Pers; *8* Languard; *9*, Alv; *10*, Lagath; *11*, Gessi

Site description

At the site Alpe Palü, two cores, M3 1 and M3 2, were taken from 65 m east of Lagh da Palü, i.e. beside the alpine hut (Landeskarte der Schweiz 1:25 000, 1278 La Rösa; coordinates: 799.320/139.035; 1940 m asl; Figs. 2,3). The small bog lies in a flat depression surrounded by rocky outcrops and morainic deposits. Drainage is by a small wet channel between the slope of Alp Grüm and the northern rocky outcrop so that the bog was at least partly dammed by the morainic deposits lying to the east of Lagh da Palü (Beeler 1977). For the interpretation of the pollen record at the base of the diagram, it should be noted that the alluvial plain and its opening toward the steep gorge of Asciai da Palü lies below 1930 m asl. Today, the bog supports a sedge-dominated community that may be classified in the Caricetum nigrae trichophoretosum association. In a 10-m^2 relevé at the site, the following species were recorded (Braun-Blanquet cover/abundance values given in parentheses): *Carex nigra* (3), *C. panicea* (r), *Trichophorum caespitosum* (3), *Eriophorum angustifolium* (+), *Potentilla erecta* (r), *Pinguicula vulgaris* (r), *Drepanocladus exannulatus* (3) and *Calliergon stramineum* (2).

Intensive pasturing has greatly influenced the natural succession in the forefield of the Palü glacier. Outside the moraine of 1890, transitions from pioneer communities of the Epilobion fleischeri to Poion alpinae grasslands can everywhere be observed. On the older stages of the Little Ice Age (seventeenth century to 1850) in particular, initial stages of the dwarf shrub Rhododendro-Vaccinion communities have developed, but an advanced succession towards the subalpine podsol climax has not taken place. In the outermost, older parts (system 1), ericoid vegetation is better developed than in the younger parts (system 2-4; after Beeler 1977). The northern slopes of the forefield appear to be very dry. On the inside of these slopes, there are just a few small *Larix* trees, while on the north-facing parts, *Larix* trees attain a height not exceeding 5-7 m. In the southern parts of the forefield, increased soil wetness is indicated by several specimens of *Alnus viridis*, some patches of tall herbs (Adenostylion) and strongly growing *Larix* specimens on north-facing slopes.

Outside the moraines dating to the Little Ice Age, the region of Alpe Palü is more or less covered by forests where *Larix* is dominant. There are occasional specimens of *Picea abies* and *Pinus cembra* (Swiss stone pine). As a consequence of human activity over at least 3500 years, only a few remnants of the formerly closed, subalpine, coniferous forests remain. The understory of these forests consists of dwarf-shrub communities (Rhododendro-Vaccinion) at the northerly exposed slopes. On the sunny slopes, a mosaic of *Juniperus alpina* and *Festuca acuminata* forms the ground layer of the open larchwoods. *A. viridis* is rather inconspicuous and grows mainly with *Sorbus aucuparia* on the shaded slopes to the south of Acqua da Palü. Willows (*Salix* spp.) are infrequent on the forefield and in the areas adjacent to the Palü glacier. The present-day alpine timberline at Alpe Palü fluctuates between 2000 m on the slopes of the valley and ca. 2170 m on the slopes to the north of Alp Grüm. There are many indications that the climate-determined timberline in the Bernina Pass region lies between 2250-2300 m or somewhat higher (Burga 1987).

On the alluvial plain immediately in front of the subrecent moraines, a mosaic consisting of communities on gravels (Epilobion fleischeri), pastures (Poion alpinae) and wetlands (Caricion nigrae) covers the flat surface, and there are spring-associated communities (Cratoneuro-Philonotidetum seriatae) along the many water channels.

Cores, stratigraphy, radiocarbon dating and pollen analysis

Sampling, which was carried out in 1974, was particularly difficult because of the woody remains at depths 90-320 cm (details in Beeler 1977). The uppermost 3 m of peat was sampled continuously from an undisturbed peat face prepared by Beeler and collaborators by digging a pit. Below this, sampling was carried out to a depth of 650 cm using an improved Dachnowsky corer. Thus the profile consists of two parts, i.e. an upper part, Palü M3 2, 0-290 cm, and a lower part, Palü M3 1, 285-650 cm). Details of the stratigraphy and radiocarbon dating are given in Tables 1 and 2, respectively.

The pollen analytical results are presented in two diagrams, i.e. M3 1 and M3 2 (Fig. 4). The main features of the pollen profile and also macrofossil results are summarised in Table 3.

Discussion

From the Palü Oscillation "Palü-Schwankung" to reforestation (650-555 cm)

The blue silty, pollen-free silt/clay at the base (650-600 cm) indicates that the site lies immediately in front of the Palü glacier (500 m from the outer slopes of the moraine which dates to the seventeenth century). Unfortunately, the end moraines of this stade have not been identified (Beeler 1977). The glacier tongue probably lay during this period in the Asciai da Palü gorge where there was no moraine deposition. Sedimentation of fine plastic silt/clays *(Glazialton)* was only possible if the Palü glacier reached the area now covered by bog to the east of the Lagh da Palü, because even the base of the profile lies several metres higher than the surface of the alluvial plain in front of the subrecent moraines.

At ca. 600 cm (base of the diagram M3 1), pioneer plant succession started and was later interrupted and delayed by several climatic oscillations. The first pioneer phase is reflected by high percentages of *Artemisia* and Chenopodiaceae followed by a maximum of *Rumex/Oxyria*. Meanwhile, *Juniperus* achieves a peak of ca. 8%, *Hippophaë* and *Salix* are constantly present, *Larix* reaches 2% and two *Larix* leaves are recorded. Furthermore, the silt/clays are largely replaced by organic material (gyttja). This demonstrates clearly a rapid succession towards reforestation. However, this development seems to be abruptly halted by a practically pollen-free layer between 575-570 cm, where again clays and silts predominate. How far the glacier advanced during this period is not exactly known but the fine mineral matter proves that the edge of the glacier was close by and hence the vegetation around the site was strongly affected.

Above 570 cm, herbaceous communities with *Artemisia* and *Rumex/Oxyria* as well as shrub communities with *Juniperus* and *Hippophaë* regenerated. Numerous fruits of *B. pubescens* and needles of *Larix* indicate the presence of woody shrubs and trees beside the site. *P. cembra* later attains maximum representation for the profile as a whole (ca. 10-12%), immediately before the

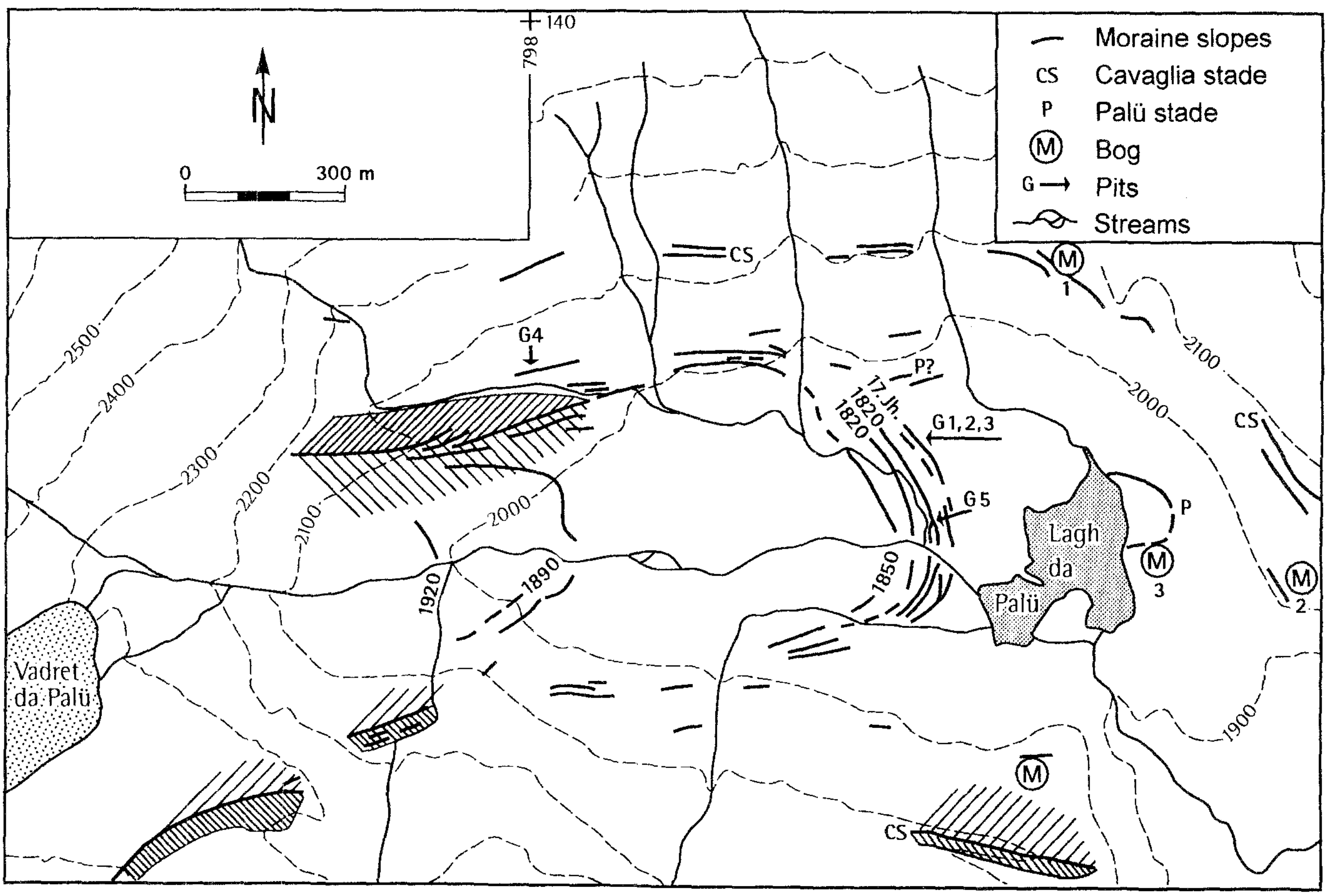

Fig. 2. Map of study area showing moraines and investigation sites. Contours are in metres

Table 1. Details of peat stratigraphy at sampling point

M3 2 (upper part)	
0 - 5	Highly decomposed sedge peat
5 - 20	Highly decomposed sedge peat
20 - 90	Highly decomposed sedge peat with some mosses
90 -107	Poorly decomposed sedge peat
107 -135	Highly decomposed sedge peat
135 -165	Poorly decomposed sedge peat
165 -185	Highly decomposed sedge peat
185 -290	Poorly decomposed sedge peat
285 -290	Sandy, poorly decomposed sedge peat
M3 1 (lower part)	
285 -325	Poorly decomposed sedge peat
325 -380	Highly decomposed sedge peat
380 -425	Highly decomposed sedge peat with many larch needles
425 -430	Poorly decomposed sedge peat
430 -500	Larch needle peat
500 -520	Highly decomposed sedge peat with layers of larch needles
520 -530	Highly decomposed sedge peat with many larch needles
530 -555	Poorly decomposed sedge peat with layers of larch needles
555 -560	Silty peat
560 -568	Gyttja with silty layers
568 -576	Gyttja
576 -578	Silty gyttja
578 -585	Sand
585 -600	Silt
600 -650	Clayey silt; sand and gravel prevented further coring

two pronounced peaks of *Artemisia*. This suggests local presence of the Swiss stone pine. As regards the *Artemisia* peaks, these coincide with increased mineral matter and the *Larix* curve behaves in the opposite manner. It seems plausible to suggest that reforestation has been delayed once again, most likely as a result of climatic oscillations.

The radiocarbon date 9460±140 B.P., which relates to the twin *Artemisia* peaks, indicates that retreat of the Palü glacier from the vicinity of bog M3 did not occur before the middle Preboreal. It is recorded in many sites that the rise of *Corylus* took place during the second half of the Preboreal and in several profiles *Artemisia* is well represented during the first part of the Preboreal. Frequently, *Artemisia* declines just before the rise of *Corylus* and often ends after *Corylus* has increased.

Though there is considerable variation in the ^{14}C dates attaching to this climatic event (Table 4), it is clear that the complex Palü Oscillation ended shortly before the middle Preboreal. On the other hand, we do not have a satisfactory date for its beginning. It is obvious that it is certainly younger than the Cavaglia stade of the Palü glacier but by how much remains an open question. The minimal age of 9690 B.P. which Beeler (1977) got at the base of bog M1, close to a lateral moraine of the Cavaglia stage (CS, Fig. 2), seems to be several centuries too young. The lack of fine glacial clay at the base of this site suggests that organic sedimentation began distinctly later than the retreat of the Palü glacier from the Cavaglia stade. Hence the date, 9690 B.P., cannot correspond with the end of the Cavaglia stade.

Beeler calculated that a depression of the snow line by 160-240 m was required for the advance of the Palü glacier to the moraines of Cavaglia. That means that the Cavaglia stade must be compared with the classical Egesen stade in Austria which happened during the Younger Dryas (ca. 10 200 B.P., Patzelt 1972, 1977). Consequently the retreat of the Palü glacier from the Cavaglia stade, the readvance to bog M3 (Palü Oscillation) and the advance and retreat in vegetation development prior to reforestation proper must have occurred during a period of, at most, 700-800 years.

According to Beeler (1977), the retreat of the Palü glacier from Cavaglia to the plain of Alpe Palü lasted at least two or three centuries. The readvance to M3 is later than the end of Younger Dryas so therefore the tripartite

Table 2. Details of conventional radiocarbon dating

Profile	^{14}C Lab. No.	Material dated	Depth (cm)	Age (B.P.)
M1	UZ-46	Gyttja (335-358)	Base	9635 ±160
M2	Ki-670	Cyperaceae peat (sandy)	100	2290 ± 65
	Hv-5041	Soil	Immediately below peat/ mineral soil interface	2390 ± 90
M3	B-2995	Cyperaceae peat	20-25	1530 ± 70
	B-2498	*Larix* root	110	3680 ±100
	B-2779a	*Picea* wood	ca. 285	4970 ± 80 *
	B-2779a2	*Picea* wood (2nd dating)	ca. 285	5010 ± 90 *
	B-2880	*Picea* wood	ca. 300	5210 ± 70 *
	B-2779i	*Picea* wood	ca. 300	6380 ± 70 **
	B-2645	Silty gyttja	560-565	9460 ±140

* Material from outer part of stem
** Material from centre of stem

Fig. 4a. Percentage pollen diagram M3 1. Curves for the main woody taxa (left side), a summary diagram (centre) and main NAP curves (right side) are shown. In each case, a total terrestrial pollen sum (excluding hydrophytes and indeterminate taxa) is used. Abbreviations: *ABI*, *Abies*; *ACE*, *Acer*; *COR*, *Corylus*; *FRX*, *Fraxinus*; *HIP*, *Hippohaë*; *JUN*, *Juniperus*; *LAR*, *Larix*; *QUE*, *Quercus*; *SAL*, *Salix*; *TIL*, *Tilia*; *ULM*, *Ulmus*; curve ∍ *Pinus cembra*: *ART*, Artemisia; *CAM*, Campanulaceae; *CAR*, Caryophyllaceae; *CHE*, Chenopodiaceae; *C.L.*, Compositae Liguliflorae; *CLT*, *Caltha*; *C.T.* Compositae Tubuliflorae; *ERI*, Ericaceae; *HYD*, *Hydrophyta*; *IND*, *Indeterminata*; *PLA*, *Plantago*; *PTM*, *Pteridium*; *RAN*, Ranunculaceae; *RUB*, Rubiaceae; *RUM*, *Rumex*; *ROS*, Rosaceae; *SAX*, *Saxifraga*; *THA*, *Thalictrum*; *UMB*, Umbelliferae; *VAR*, *Varia*, stratigraphic legend follows Fægri and Iversen 1950, for details compare Table 1

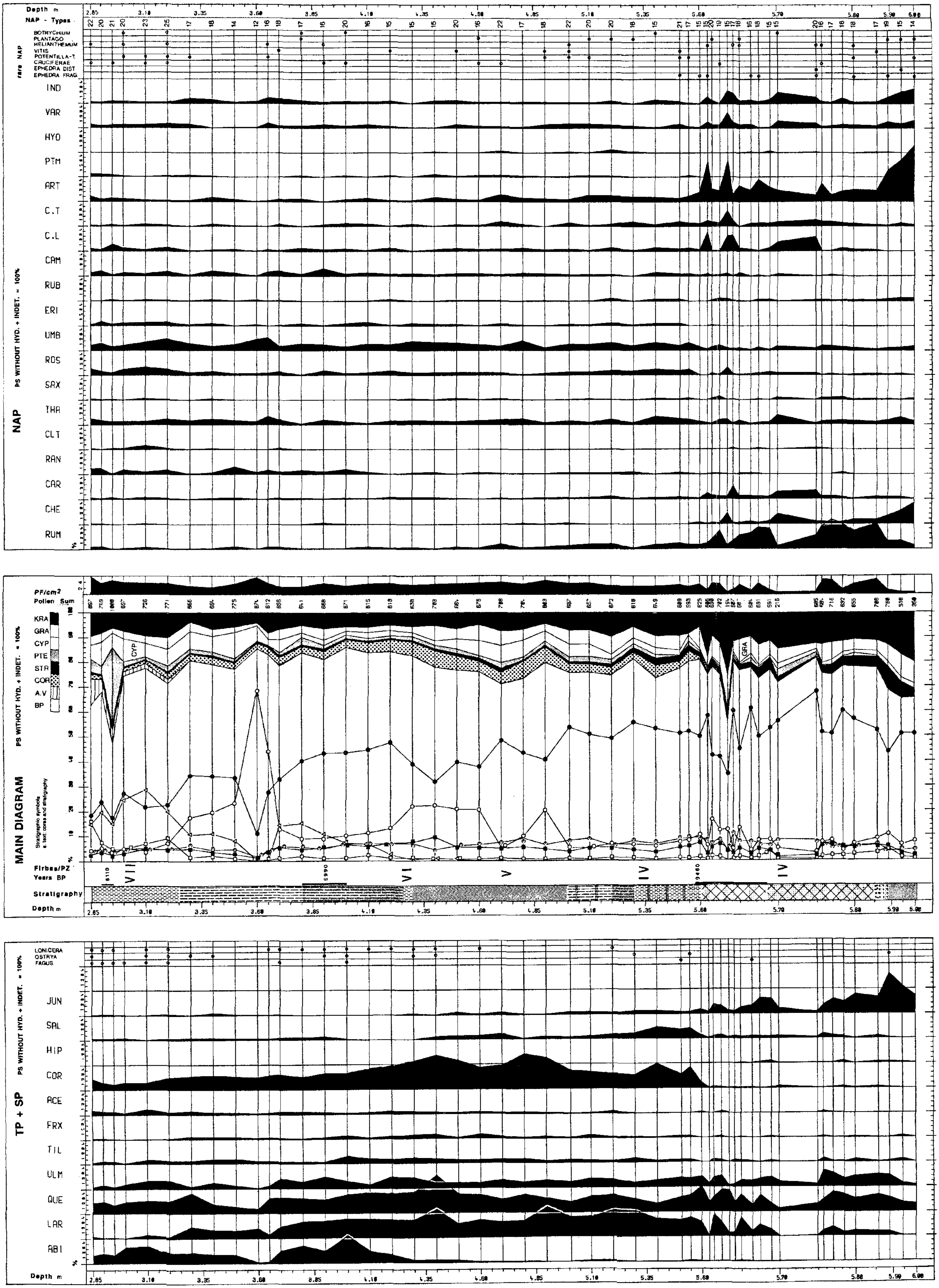

DIAGRAM M3 1

ALPE PALÜ I, GRISONS 1940m

Fig. 3. Photograph showing the bogs M1, M2 and M3 where pollen analytical investigations have been carried out (photograph by Beeler, 1977)

Palü Oscillation certainly relates to the early Holocene. It can be correlated with the Schlaten Oscillation which is recorded in the Austrian Alps by well developed moraines. On the basis of the available ^{14}C dates, it relates to the middle Preboreal (Patzelt and Bortenschlager 1973).

Burga (1987) found indications of the Palü Oscillation at two neighbouring sites:

1. Buottels where there is a NAP peak in 185 cm, and
2. Plansena where there is strong representation of *Artemisia*, Asteraceae-Cichorioideae and *Saxifraga* at 238-228 cm. On the basis of the ^{14}C date 9200±90 B.P. from 232-327 cm, the transition from silt to silty gyttja at 241 cm and the rise of *Corylus* at 230 cm, the upper boundary of the Younger Dryas may be drawn at 241 cm. A similar delay in reforestation as at Alpe Palü seems to have taken place at Plansena because of its situation close to a landslide and the accumulation of debris and gravels.

It is clear that trees and forests spread up to, or at least close to, altitudes corresponding to those of the recent timberline under the favourable conditions pertaining at the beginning of the Holocene (cf. Welten 1982a). However, Wick and Tinner (1997) suggested recently a decline of the alpine forest limit in the middle Preboreal at Gouillé Rion (Valais) and at Lago Basso (Splügen) which obviously corresponds with the Palü Oscillation. Effects of this unfavourable phase have been observed even in the lowlands south and north of the Alps (Behre 1978; Schneider and Tobolski 1985; Lotter et al. 1992). In Maloja, at a comparable altitude, the reforestation took place between 10 000-9800 B.P. (Heitz-Weniger et al. 1982). Delay in reforestation at Alpe Palü is at least 500 years. Though the Palü Oscillation is a Holocene phenomenon, the plant succession shows distinct late-glacial characteristics like the occurrence of *Ephedra*, *Hippophaë* and high percentages of *Artemisia*.

Since the middle Preboreal, the Palü glacier never again extended close to bog M3. Furthermore, no traces of moraines can be found which might have been formed during Holocene cold phases such as Venediger/Oberhalbstein, Misox/Frosnitz, Piora/Rotmoos, Löbben and Göschenen I and II [for age of these fluctuations see Burga and Perret (1998)]. Even during the Little Ice Age, the Palü glacier did not re-advance to this degree.

From reforestation to the expansion of Picea abies and Alnus viridis (560-290cm)

In Palü M3 1, the establishment of trees is especially well documented by the rapidly increasing number of *Larix* needles in the peat. Though *Pinus s/m*, i.e. *Pinus sylvestris* and/or *P. mugo* pollen, dominates the pollen record, larch was probably the dominant tree in the vicinity of the site, particularly during the time when an almost pure *Larix*-needle peat was forming (500-430 cm). The development, from an open to a closed larch forest, is clearly shown by the decline in *Salix* from relatively high representation to low values (2-3%) at the base of the *Larix*-needle peat. It should be noted, however, that in the period after human impact begins to register, *Salix* representation remains less than 0.5% from which it may be concluded that willows were much more important on the moraine forefield during the early Holocene reforestation than during the Little Ice Age.

Compared with the pollen record from Plansena (1892 m) and Aurafreida III (2140 m), the representation of *P. cembra* (≤10%) is remarkably low at Alpe Palü. According to Burga (1987), *P. cembra* increases in the early Holocene at Plansena to more than 40% and is dominant during the whole of the Boreal. In Aurafreida III, *P. cembra* is also much more frequent than at Alpe Palü. This might explain why, in the Alpe Palü profile, a sharp decline in *P. cembra*, similar to that in Aurafreida III is not recorded. This event in Aurafreida III is correlated by Burga (1987) with the cold phase of Venediger/Oberhalbstein during the early Boreal.

Of special interest is the course of the *Betula* curve. After a depression during the late Preboreal, it peaks initially to almost 20%. This feature may be comparable to the *Betula/Poaceae* maximum at 190 cm in Plansena. In M3 1, however, the corresponding depression of *P. cembra* is lacking. Consequently, it is not sure if the equivalent of the cold phase of Venediger/Oberhalbstein can be seen in the Alpe Palü profile. Later, after a short depression, the *Betula* curve again fluctuates between 12-25%. Shortly after the rise in *Picea* and *Abies,* it increases further and attains 70% (360 cm). The similarity of the *Betula* curve at Alpe Palü and Plansena cannot be ignored. In both instances, soon after the simultaneous rise of *Abies* and *Picea, Betula* also rises in Plansena to achieve almost 70%. At both sites, a sharp but short decline in all conifers corresponds with this *Betula* phase. Burga (1987) connected this *Betula* peak with the cold phase of Misox/Frosnitz which lasted from ca. 7500-6500 B.P. (cf. Zoller 1960). However, the ^{14}C date 5990±110 B.P. from 380-400 cm, i.e. just below the *Betula* maximum, is 500 years younger than the end of the cold phase of Misox/Frosnitz. This date may not, however, be

Table 3. Zonation and main features of the pollen profile

Local pollen assemblage zone (PAZ)	Classical zone*	Spectra/ depths (cm)	Main features of PAZ and macrofossil record
15: *Poaceae-Plantago*-NAP PAZ	X	0- 20	Trees + shrubs <20%. Poaceae increase to 30%, *Plantago* to 3.5%
14: *Alnus-Picea-Larix* PAZ	VIII p.p. IX p.p.	20-105	*Picea* and *Pinus s/m* decline, stomata rare. *Larix* rises to 4%; some needles. *Alnus viridis* and *A. glutinosa/incana* mostly >10%. *Pinus cembra* falls to <2%
13: *Picea-Pinus s/m-Alnus* PAZ	VIII p.p.	105-265	*Picea* dominant, also stomatal records; only a few *Pinus s/m* stomata. *A. viridis* and *A. glutinosa/incana* at 5-10%
12: *Pinus-Picea-Alnus viridis* PAZ	VII p.p.	265-295	Coniferous AP rise again. Stomata of *Pinus s/m* and *Picea*. *A. viridis* and *A. glutinosa/incana* rise. Temporary rise in *Betula*, and *Larix*<1%
11: *Pteridophyta-Pinus s/m-Picea* PAZ	VII p.p.	295-300	Rise in Pteridophyta at point where there is a layer of wood fragments and some silty material. Sharp temporary decline in *Picea, Pinus* and *Abies*
10: *Pinus s/m-Picea* PAZ	VI p.p. VII p.p.	300-350	Definitive decline of *Betula* to <5%. *Larix* declines to <2%. *Picea* rising to 30%; also stomatal records
9: *Betula* PAZ	V p.p.	350-370	*Betula* maximum (£70%), also numerous fruits of *B. pubescens*. Sharp decline of *Abies, Picea, Pinus s/m* and *Larix*
8: *Pinus s/m-Larix-Abies-Picea* PAZ	V p.p.	370-430	Needles of *Larix* plentiful and stomata of *Pinus s/m* recorded. *Abies* maximum (4-6%). *Picea* rises to more than 10%, and some stomata. Decline of *Betula*
7: *Pinus s/m-Larix-Betula-Corylus-Abies* PAZ	V p.p.	430-470	Similar to PAZ 5, but continuous curve for *Abies alba*
6: *Pinus s/m-Larix-Corylus* PAZ	V p.p.	470-480	*Betula* declines; *Larix*-needle peat; *Pinus s/m* stomata
5. *Pinus s/m-Larix-Betula-Corylus* PAZ	IV p.p. V?	480-515	Maximum of *Betula*; a few fruits of *Betula pubescens*. *Larix* maximum; more or less pure *Larix*-needle peat; also *Pinus s/m* stomata
4: *Pinus s/m-Larix-Corylus-Salix* PAZ	IV p.p.	515-557	Maximum of *Salix*, decline of *Juniperus, Rumex/Oxyria, Artemisia* and other NAP. *Betula* <5%. *Larix* recorded by numerous needles, *Pinus s/m* by stomata. Beginning of coniferous wood. Between zones 4-13, *P. cembra* reaches only 5-10%.
3: *Pinus s/m-Artemisia-Betula-Pinus cembra-Larix* PAZ	IV p.p.	557-572	*Juniperus* and *Salix* ± constantly present. *Betula* rises to >10%; *B. pubescens* fruit. *Pinus cembra* with two peaks of >10%. Needles of *Larix*. *Hippophaë* curve ceases. Second pioneer vegetation development
2: *Pinus s/m-Artemisia*-(hiatus) PAZ	IV p.p.	572-576	Very low pollen concentration. *Larix, Juniperus, Betula, Hippophaë* and most NAP poorly represented
1: *Pinus s/m-Artemisia-Juniperus* PAZ	IV p.p.	576-600	*Larix, Salix, Betula, Hippophaë* more or less constantly present. In one needle of *Larix* recorded. First pioneer communities
–	–	600-650	No pollen recorded

* Classical zones after Firbas (1949)

reliable and should be rejected (see below). Correspondence with the Misox/Frosnitz phase can be justified by the ^{14}C date 8040±120 B.P., which dates the rise of *Picea* at Selva (Burga 1987). It is therefore concluded that *Betula* peaks shortly after the rise of *Picea* at both Alpe Palü and Plansena, i.e. soon after 7500 B.P. or the zone VI/VII boundary.

Consideration should also be given to the factors giving rise to the *Betula* phase. Possible factors include a short period of unfavourable climate, human activity or avalanches. In the Alpe Palü profile, evidence of human influence is noted only in much younger horizons (see below). If it were an avalanche, wood fragments and some inorganic material might be expected in the sediment, but no traces of such were observed. On the other hand, the pteridophyte peak at 290 cm may be caused by an avalanche. The many large wood fragments between 90-320 cm indicate that many trees were broken or even uprooted and logs, trunks and roots were transported, together with some inorganic matter, onto the bog. Furthermore, the pteridophyte phase corresponds with a distinct increase in sand within the peat (285-290 cm). After this sudden death of conifers caused by a local disaster, ferns flourished for a short period until the forest regenerated. Radiocarbon dates from several pieces of *Picea* timbers from between 285-300 cm support this conclusion. Outer wood from three *Picea* stems differ only by 240 years (4970-5210 B.P.). Wood from the centre of a *Picea* trunk gave a date of 6380±70 B.P. which suggests that the tree in question was at least 1200 years old.

The period between the ^{14}C dates, 4970 and 5210 B.P., when the trees were killed, corresponds to the mid-Holocene cold phase of Piora/Rotmoos (Zoller 1960;

Fig. 4b. Percentage pollen diagram M3 2. For conventions followed see Fig. 4a

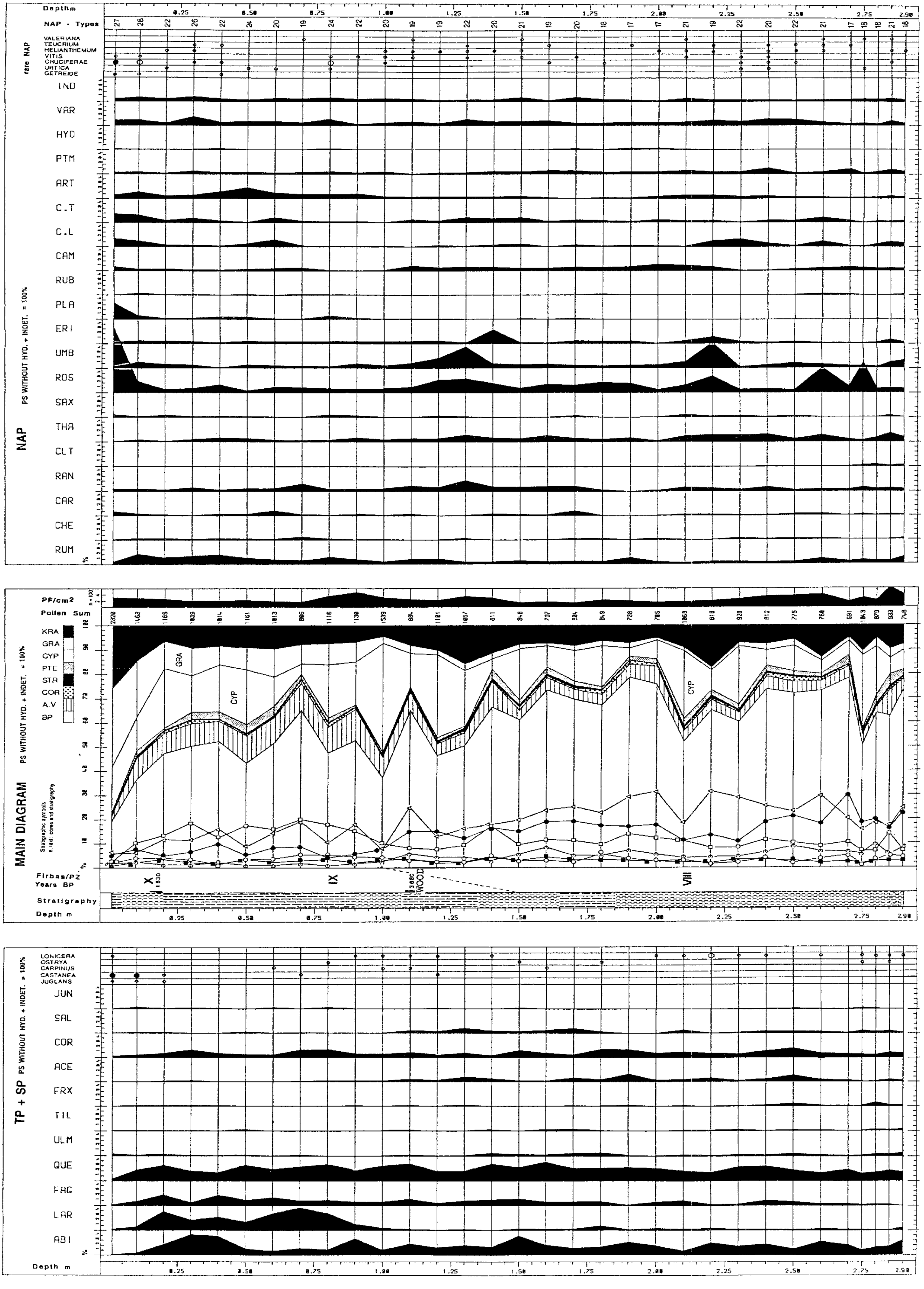

DIAGRAM M3 2

ALPE PALÜ II, Grisons 1940m

Table 4. Sites at which *Corylus* increases and *Artemisia* declines between 9200-9600 B.P. in subalpine and alpine pollen diagrams

Site	Author
Simplon (Hopschensee II, 2017 m)	Welten (1982a)
Breil/Brigels (Vorderrhein, 1520 m)	Müller (1972)
Segnes (Vorderrhein, 1880 m)	Müller (1972)
Bedrina (Leventina, 1235 m)	Küttel (1977)
Acquacalda (Lukmanier, 1730 m)	Müller (1972)
Campra (Lukmanier, 1420 m)	Müller (1972)
Sur (Oberhalbstein, 1780 m)	Heitz (1975)
Stallerberg (Oberhalbstein, 2450 m)	Heitz (1975)
Lago di Annone (Brianza, 226 m	Wick (1996)
Pian di Gembro (Aprica, 1370 m)	Zoller et al. (1977)
Selva (Poschiavo, 1892 m)	Burga (1987)
Alpe di Palü (Bernina, 1940 m)	Palü M3 1 (this publication)

Sites are listed according to geographical location from south-west to north-east

Patzelt 1972; Patzelt and Bortenschlager 1973). In several profiles, this cold phase is well marked by a strong decline in *Picea* and *A. viridis* and a substantial increase in NAP (Zoller 1960; Burga 1993; Wick and Tinner 1997; Burga and Perret 1998). But at Palü no distinct signs of a climatic change, such as increased representation of dwarf shrubs and alpine pioneer plants, were noted in the pollen record. It may be purely a coincident that the avalanche catastrophy at Alpe Palü happened during the cold phase of Piora/Rotmoos, but it is likely that avalanche frequency was considerably higher during this phase of unfavourable climate. It should also be noted that no traces of fire, such as charcoal, were noted so that it is highly unlikely that human activity was responsible.

From the expansion of Picea *and* A. viridis *to the first evidence of early human impact*

Eastwards of a line running through the valley of the Inn from Landeck to Maloja and from there south-westwards to the Valtellina, *Picea* spread during zone V (Boreal period; between ca. 8000-7500 B.P.). At sites near Alpe Palü, the spread of *Picea* also falls within this period (Table 5). At Alpe Palü, however, the rise in *Picea* to ca. 15% is almost 2000 years younger than in adjacent profiles. Even if the spread of *Picea* towards the high and glaciated Bernina massif was considerably delayed, the difference in the dates from Selva and Alpe Palü, which are only 10 km apart, cannot readily be explained. The dates from 285-290 cm and 380-400 cm are inverted so that there are no reliable dates for the rise of *Picea* nor of *A. viridis*. The spread of spruce at Selva has been dated to 8040 B.P. (Table 5) and this date, which fits fairly well with the results from adjacent sites, is probably also applicable to Alpe Palü.

Compared with the subalpine diagrams from Poschiavo and Oberengadin, later developments at Alpe Palü show some distinctive features. At most sites, *P. cembra* dominates in zones V and VI and, subsequently, *Picea* achieves higher values (much of zones VII and VIII; Keller 1930; Kleiber 1974; Heitz-Weniger et al. 1982). In the course of zones IX and X, *P. cembra* is once again dominant in the Oberengadin, mainly as a result of climatic deterioration during the later Iron Age and partly as a result of human impact, especially clearing of spruce on the better soils (Zoller and Brombacher 1984).

At Alpe Palü, *P. cembra* achieves highest representation (12%) during the reforestation phase in zone IV. Later, it never attains more than 8%. The Alpe Palü profile clearly shows that spruce took the place of larch and pines (*Pinus sylvestris* or *P. mugo*). It should be noted that, parallel to the rise of *Picea*, the peat changes gradually from predominantly consisting of *Larix* needles (515-420 cm) to sedge peat (from 380 cm upwards) in which no *Larix* needles are recorded. Also, the slow decline in *Pinus s/m* pollen from ca. 45% (410-420 cm) to less than 20% (260 cm) should be noted. This trend ends when spruce finally started to dominate. According to Brockmann-Jerosch (1907), *P. mugo* is rare on the siliceous soils in the vicinity of Alpe Palü while *P. sylvestris* does not occur in the upper valley of Poschiavo. Representation at 10-20% during the spruce phase suggests that one or both were still present in the vicinity of the Palü glacier.

It is noteworthy that *Picea* (20-30% when dominant) was distinctly less frequent at Alpe Palü than at the adjacent sites of Plansena (35-50%) and Aurafreida (30-45%) (Burga 1987). During the same period, NAP at Alpe Palü are noticeably higher (6-15%). This suggests that the forests at Alpe Palü were more open which may be due to cold katabatic winds from the Palü glacier.

As in the profiles from Pian di Gembro Aprica (Zoller et al. 1977) and Selva Poschiavo (Burga 1987), *Abies* increased together with *Picea*. There is no doubt that *Abies* penetrated far into the valley at Poschiavo where it is still present in the lower part (Brockmann-Jerosch 1907). According to Burga (1987), it is certain

Table 5. Dates for the rise in *Picea* between Oberengadin and Passo Tonale

Site (13)	Altitude	Age (B.P.)	Source
Maloja	1830	7700	Heitz-Weniger et al. 1982
St. Moritz	1850	8000	Heitz-Weniger et al. 1982
Alpe Palü (Bernina)	1940	5990	Diagram M3 1
Selva (Poschiavo)	1470	8040	Burga 1987
Pian di Cembro (Aprica, D 1973)	1360	8610-7150	Zoller et al. 1977
Pian di Cembro (Aprica, D 1975)	1360	8040-6920	Zoller et al. 1977
Passo di Tonale	1880	8200-7600	Gehrig 1997

that fir reached Selva above Poschiavo at 1470 m. In the Alpe Palü profile, two noteworthy peaks in *Abies* are recorded, the first one at 400 cm (6% in zone VI) and much later in zone IX (Roman period) a second peak (4%) is recorded. At the top of M3 1, *Abies* is less than 0.5%. Fir may therefore have reached the uppermost parts of the Poschiavo valley during zones VI or IX but, unfortunately, there are no records of stomata, needles or wood to support this contention.

Towards the end of zone VII, *A. viridis* increasingly replaces *Betula* and *Salix*. *A. viridis* achieves maximum expansion at Alpe Palü shortly after the peak in ferns at ca. 5000 B.P. High values are also recorded in several profiles at about the same time (Zoller 1960; Zoller and Kleiber 1971; Burga 1980, 1987; Wick and Tinner 1997) but, at Alpe Palü, the increase in *A. viridis* is rather subdued (generally <10%, max. 12%). This is not surprising since *A. viridis* achieves limited expansion only in the dryer parts of the central Alps (Zoller 1995).

From early human impact to modern times

Between 110-90 cm in the Alpe Palü profile, the following important changes take place in the pollen record: (1) increase of *Larix* needles in the sedge-peat and a considerable rise in *Larix* representation (from <1% to almost 5%); (2) increase in *A. viridis* to >10%; (3) a sharp decline in *Picea* and *Pinus s/m*; and, (4) noticeably higher amounts of Poaceae, *Rumex, Artemisia* and *Plantago*.

Evidently, the *Picea* and *Pinus*-dominated forests, which previously covered Alpe Palü, were replaced by pasture forests in which *Larix* was important *(Lärchwiesen)* as is recorded for the whole of the Engadine region [Il Fuorn in Welten (1982b); St. Moritz in Zoller and Brombacher (1984); Susch, Ardez and Ramosch in Zoller et al. (1996)]. *Larix* stands appear to have been widely planted in Engadine beginning in Neolithic times, i.e. since ca. 5600 B.P. The ^{14}C-dated *Larix* root at 110 cm (3680±100 B.P.) suggests that the first *Larix* stands attributable to human intervention at Alpe Palü relates to the middle Bronze Age. This agrees with the evidence from the Bernina Pass region where the oldest larch pasture at Ofenpass has been dated to shortly after 4000 B.P. (Welten 1982b). A later anthropogenic *Larix* stand at Alpe Palü is recorded in the profile M2 by F. Averdieck (Beeler 1977).

The severe forest clearances which took place during the Middle Ages can be recognized in the two uppermost horizons of diagram M3 2. The curves of all trees and shrubs, *Larix* included, decline to negligible values while Poaceae rise to >30% and *Plantago* to 3.5%. This suggests intensive pastoral activity at Alpe Palü. In the profile M2 by F. Averdieck, this most recent phase of intensive land use appears to be less well represented (see Beeler 1977, p. 207, Fig. 29). In profile M2, the expansion of juniper shrub, which today dominates in the dry parts of Alpe Palü, is clearly recorded. It is probably a recent development, at least in the immediate vicinity of site M2.

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