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HOLOCENE VEGETATION DEVELOPMENT AND HUMAN IMPACT IN THE CENTRAL ALPS: THE "PIAN VENEZIA" PALAEOBOTANICAL RECORD (TRENTO, ITALY)

A. Speranza [1,5] **- C. Ravazzi** [1,2] **- C. Baroni** [3] **- A. Carton** [4] **- B. Van Geel** [5] **- H. Mommersteeg** [5]
[1]Dip.to di Scienze dell'Ambiente e del Territorio, Università di Milano, Milano, Italy
[2]CNR - Centro Geodinamica Alpina e Quaternaria, Università di Milano, Milano, Italy
[3]Dip.to di Scienze della Terra, C.N.R.-C.S. per la Geologia Strutturale e Dinamica dell'Appennino, Università di Pisa, Pisa, Italy
[4]Dip.to di Scienze della Terra, Università di Torino, Torino, Italy
[5]Hugo de Vries-Laboratorium, University of Amsterdam, Amsterdam, The Netherlands

RIASSUNTO - *Evoluzione della vegetazione e impatto antropico durante l'Olocene nelle Alpi Centrali. La successione paleobotanica della torbiera di Pian Venezia (Trento, Italia)* - Il Quaternario *Italian Journal of Quaternary Sciences,* **9**(2), 1996, 737-744 - In questo articolo vengono presentati i risultati preliminari delle analisi paleobotaniche condotte sulla torbiera di Pian Venezia (2270 m s.l.m., Val di Peio, Alpi italiane orientali). Lo scopo della ricerca è la ricostruzione dell'evoluzione olocenica della vegetazione in un ambiente ad elevata altitudine, presso il limite del bosco. Sulla successione di torba sono state ottenute 6 date ^{14}C. La sedimentazione organica è iniziata in una fase avanzata del Preboreale ed è continuata fino al presente. La successione pollinica di Pian Venezia ha registrato numerosi eventi vegetazionali che hanno caratterizzato la storia della vegetazione nell'Olocene. Nel tardo Preboreale una prateria alpina con arbusti (*Salix* e *Alnus*) è presente nelle vicinanze della torbiera, mentre persistono aree con vegetazione discontinua pioniera, come indicata dalla presenza di granuli di *Androsace* ed *Oxyria. Picea* compare con curva continua circa 8.900 anni BP e subisce un brusco aumento circa 8.700 anni BP, allorchè l'abete rosso raggiunge l'alta Val di Peio. Durante l'Atlantico medio e superiore, la presenza nella torba di aghi e stomi di cembro e di larice nonchè di semi di cembro indicano che il bosco circondava la torbiera. *Fagus* e di *Abies* compaiono rispettivamente circa 6.500 e 6.000-5.500 anni BP. Due importanti fasi di impatto antropico sono evidenti: la prima (4.000 - 3.000 anni BP) può essere attribuita al tardo Neolitico, la seconda (che inizia circa 2.200 anni BP) al periodo romano. Nei livelli datati a quest'ultima fase compaiono spore di *Podospora* e *Sporormiella,* funghi coprofili, il che suggerisce l'estensione del pascolo nel Pian Venezia.

ABSTRACT - *Holocene vegetation evolution and human impact in the Central Alps: the "Pian Venezia" paleobotanical record (Trento, Italy)* - Il Quaternario *Italian Journal of Quaternary Sciences,* **9**(2), 1996, 737-744 - The preliminary results of palaeobotanical analyses carried out on the peat-bog of Pian Venezia at the altitude of 2270 m a.s.l. in Val di Peio (Eastern Italian Alps), are presented in this paper. The aim of this work is the reconstruction of the vegetation development in a high altitude environment. Six radiocarbon dates provide a time control between 9,2 ka BP and the present time. The peat accumulation started during the Preboreal and is assumed to have been continuous up to the present. The Pian Venezia pollen succession illustrates the main Holocene vegetational events. In the late Preboreal an alpine meadow with shrubs grew close to the peat-bog, whereas other areas were still with no vegetation. The first *Picea* pollen grains are recorded by a continuous curve at about 8.9 ka BP; the *Picea* curve shows a sharp increase at 8.7 ka BP, when this tree was present in the upper Val di Peio. During the middle and late Atlantic the presence of macroremains of *Pinus cembra* and *Larix* (needles, stomata and seeds) in the peat indicates that the forest line surrounded the bog. *Fagus* and *Abies* are recorded at about 6.5 and 6-5.5 ka BP, respectively. Two phases of human impact were recorded; the first, dating to 4 - 3 ka BP, may be attributed to the Late Neolithic; the second, which begun at about 2,2 ka BP, can be attributed to the Roman period. During this latter phase, the occurrence of spores of *Podospora* and *Sporormiella,* which are coprophilous fungi, suggests that at that time the Pian Venezia plain was used as a pasture.

Keywords: Holocene, vegetation history, peat-bog, pollen analysis, Ortles - Cevedale Group, Central Alps, NE Italy
Parole chiave: Olocene, storia vegetazionale, torbiera, analisi pollinica, Gruppo dell'Ortles - Cevedale, Alpi centrali, Italia nor-orientale

1. INTRODUCTION

The Pian Venezia mire develops at 2,270 m a.s.l. and is located within the Ortles-Cevedale mountain-group at the head of Val di Pejo (fig. 1), a lateral valley of the northern side of Val di Sole (Italian Central Alps). The site lies within the territory of the Stelvio National Park at about 2,200 m a.s.l., just below the front of "Vedretta di La Mare", identified with the n° I/4L00102517 in the World Glacier Inventory. The mire developed on the smooth edge of a *riegel,* about 100 m to the N of the step edge. The bedrock is covered by scattered glacial deposits and by a Late Glacial moraine deposited by Vedretta di La Mare (Fig. 1).

A palaeobotanical investigation, targeted to the reconstruction of the Holocene vegetational history of a high altitude alpine site, was carried out on the Pian Venezia mire deposits.

Among the mires present in the area, the Pian Venezia mire was chosen for the investigation because of its particular position with respect to glacial deposits, and because the mire is not supplied by important streams. Peat

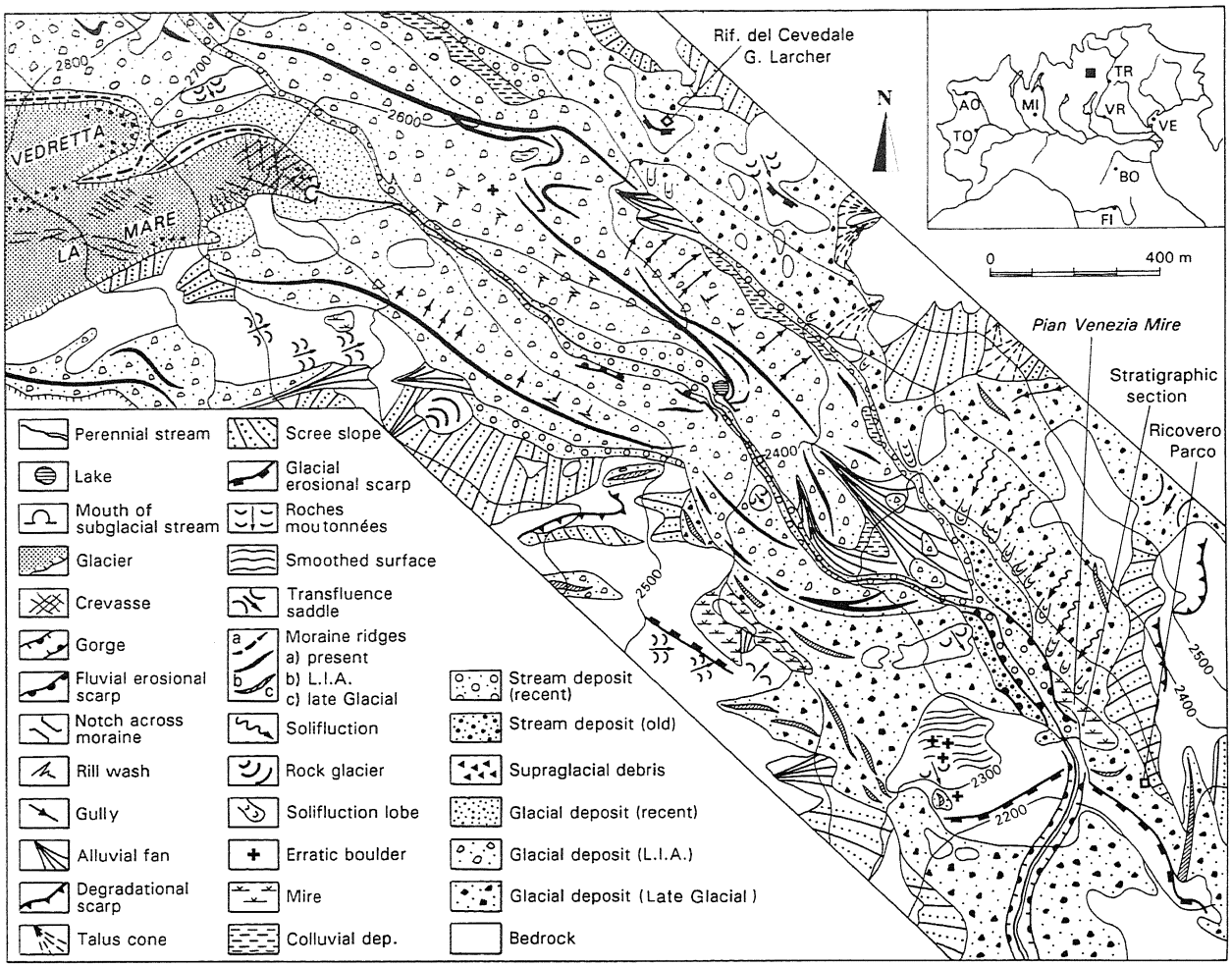

Fig. 1 - Geomorphological sketch of the Pian Venezia area (upper Val di Pejo, Central Alps), redrawn with modifications from GNGFG-CNR (1986). The location of in the Pian Venezia mire section is shown by a solid square in the inset.

Schizzo geomorfologico della zona di Pian Venezia (alta Val di Pejo, Alpi centrali), ridisegnata e modificata da GNGFG-CNR (1986). In evidenza l'ubicazione della torbiera e della sezione descritta nel testo.

accumulation probably commenced in the Preboreal and continued, with scarce clastic material input, up to the present-day.

The present work describes the section studied at Pian Venezia, presents six new radiocarbon dates (see Table 1), and reports the preliminary results obtained from the analysis of pollen and other microfossils, focusing on the lower part of the record of early Holocene age.

Previous studies on the Pian Venezia peat-moss were carried out in 1983 by Paganelli *et al.* (in GNGFG-CNR, 1986) in the course of a geomorphological field-work organized by the "Gruppo Nazionale di Geografia Fisica e Geomorfologia" of the Italian National Research Council (C.N.R.). A section of the Pian Venezia peat deposits was sampled, described and radiocarbon dated. The base of the sequence (2.2 m) yielded the age of 9,130 ± 320 ^{14}C yr BP. In 1992, Baroni & Carton made a new trench (1.5x1.5 m) opened in the area at 2,270 m a.s.l., and described and sampled a sequence 180 cm deep. This research was carried out in the framework of studies on Holocene glacier variations in the Adamello-Presanella and Ortles Cevedale groups.

At present, the central, depressed part of Pian Venezia is a fen, with dominance of *Carex fusca* (*Caricetum fuscae*) and patches of *Eriophorum angustifolium*. It is surrounded by a gently sloping minerotrophic bog with *Trichophorum alpinum* and several alpine grasses, like *Phleum alpinum, Nardus stricta, Avenula versicolor, Festuca rubra* (*Hygronardetum* and *Festucetum halleri nardetosum* occupy the drained parts of the peat bog). The mire is supplied upslope by small springs, surfacing at the base of debris fans, characterized by stands of *Saxifraga stellaris, Phylonotis sspp., Montia fontana* and *Epilobium selenifolium* (*Montio-Cardaminetea*). Outside

Table 1 - ^{14}C datings.
Datazioni ^{14}C.

Depth (cm)	Age	Lab. number	Material processed
37-38	4280 ± 120 BP	GX-19720	peat
52-53	6735 ± 105 BP	GX-19728	peat
60	7630 ± 135 BP	GX-19727	wood
109-110	8905 ± 115 BP	GX-19726	peat
110	9215 ± 125 BP	GX-19724	wood
112-111	9180 ± 170 BP	GX-19725	bulk material
115	8185 ± 110 BP	GX-19723	roots

Table 2. - Calibration of the ^{14}C datings (CAL 20, Groningen University).

Datazioni ^{14}C calibrate (CAL 20, Groningen University).

Radiocarbon Age (BP)	Calibrated datings (calendar years BC) 1σ (68.3% confidence level)
4280 ± 120	3080 cal BC - 3070 cal BC 3040 cal BC - 2860 cal BC 2820 cal BC - 2660 cal BC 2640 cal BC - 2630 cal BC
6735 ± 105	5690 cal BC - 5560 cal BC 5555 cal BC - 5520 cal BC
7630 ± 135	6590 cal BC - 6580 cal BC 6560 cal BC - 6350 cal BC 6330 cal BC - 6300 cal BC 6280 cal BC - 6240 cal BC
8905 ± 115	8070 cal BC - 8060 cal BC 8050 cal BC - 7880 cal BC 7810 cal BC - 7710 cal BC
9180 ± 170	8400 cal BC - 8370 cal BC 8350 cal BC - 8040 cal BC
9215 ± 125	8390 cal BC - 8380 cal BC 8350 cal BC - 8090 cal BC

the mire, the vegetation is that typical of alpine meadows with patches of *Rhododendron ferrugineum* and *Juniperus nana*. Juvenile individuals of *Pinus cembra* and *Larix* occur, especially on slopes facing south and on rocks. According to a recent survey in upper Val di Peio (Rota, 1996), the present-day limit of the *Pinus cembra* forest is located at about 2,370 m a.s.l. on steep slopes facing S, SSW and SW. In the same conditions, isolated trees may reach up to 2,450 m a.s.l. The altitude of forest and tree-lines is the highest estimated for the whole Trentino Province (Pro-vincia Autonoma di Trento, 1992).

2. GEOMORPHOLOGICAL SETTING

The Pian Venezia mire developed on the edge of a *riegel* that marks the boundary of the head of Noce Bianco valley, a wide glacial trough eroded by Vedretta di La Mare. The glacier is presently nested in the upper part of the valley head. Widespread glacial and periglacial deposits, talus slopes, debris cones and other slope deposits (GNGFG-CNR, 1986; Fig. 1) cover the area. Holocene and Late Glacial moraines outcrop close to the mire. In particular, the Holocene moraines lie only 400 m to the NW of the mire. They are a complex of accretional, superimposed moraines, characterized by different degrees of weathering and soil evolution (Orombelli in GNGFG-CNR, 1986). Field data (geomorphology, lichenometry, soil depth) and cartography data show that these moraines mark the maximum position reached by Vedretta di La Mare during the Little Ice Age, which coincides with the most advanced Holocene position. At present, the glacier front rests at about 1800 m back from this maximum position.

The Late Glacial moraine ridges of the area are less prominent than Holocene moraines and their profiles are more gently rounded. The best developed Late Glacial

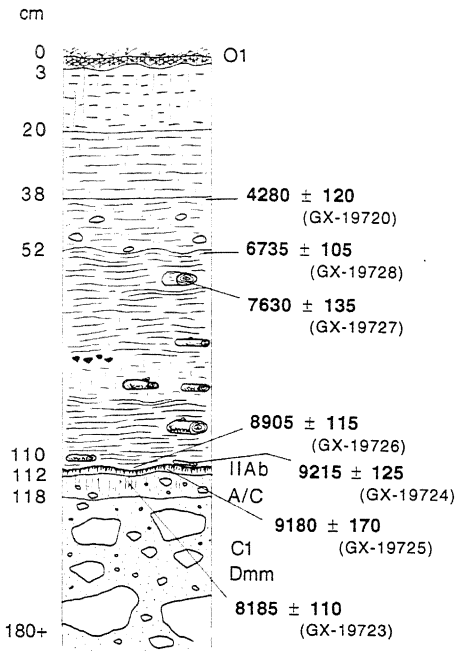

Fig. 2 - Section of the Pian Venezia peat sequence and position of the radiocarbon dates (see detailed description in the text).

La sezione torbosa di Pian Venezia e la posizione delle date ^{14}C (v. descrizione dettagliata nel testo).

moraines are to be found to the SW of the Holocene moraines system (Fig. 1). At the opposite side of the valley, the corrisponding moraine ridges are less marked due to the steepness of the slope. A Late Glacial position for Vedretta di La Mare within the Pian Venezia area is indicated by the moraine ridge deposited to the SE of the mire. Therefore, the Pian Venezia mire lies within the Late Glacial moraines and outside the L.I.A. moraines.

3. THE STRATIGRAPHIC SECTION

A 1.5 m wide, 1.8 m deep, and about 3 m long trench was excavated in the Pian Venezia area, at about 2270 m a.s.l. The section shows a 122 cm thick sequence of organic deposits (Fig. 2). The base of the deposits consists of massive diamicton (ablation till), covered by 6 cm of sandy silt and a thin hydromorphic soil lying at the top. The succession is capped by the vegetation which forms peat. The peat succession does not show any abrupt boundary and is assumed to have been continuous up to the present. A set of six conventional ^{14}C datings on bulk material or on wood has been carried out (Table 1). The dates have been calibrated by means of the program CAL 20, the upgraded version of Cal 15, by the Centre for Isotope Research of the University of Groningen (Van der Plicht, 1993) (Table 2).

Macrofossil analysis has shown that the peat mainly consists of *Carex sp.* rootlets, whereas *Sphagnum* only appears in some levels at different depths.

At the base of the peat succession, a thin hydromorphic soil between 112 cm and 110 cm, yields two ^{14}C dates: 9180 ± 170 BP (bulk sample), 9215 ± 125 BP (wood). The base of the peat overlying the soil

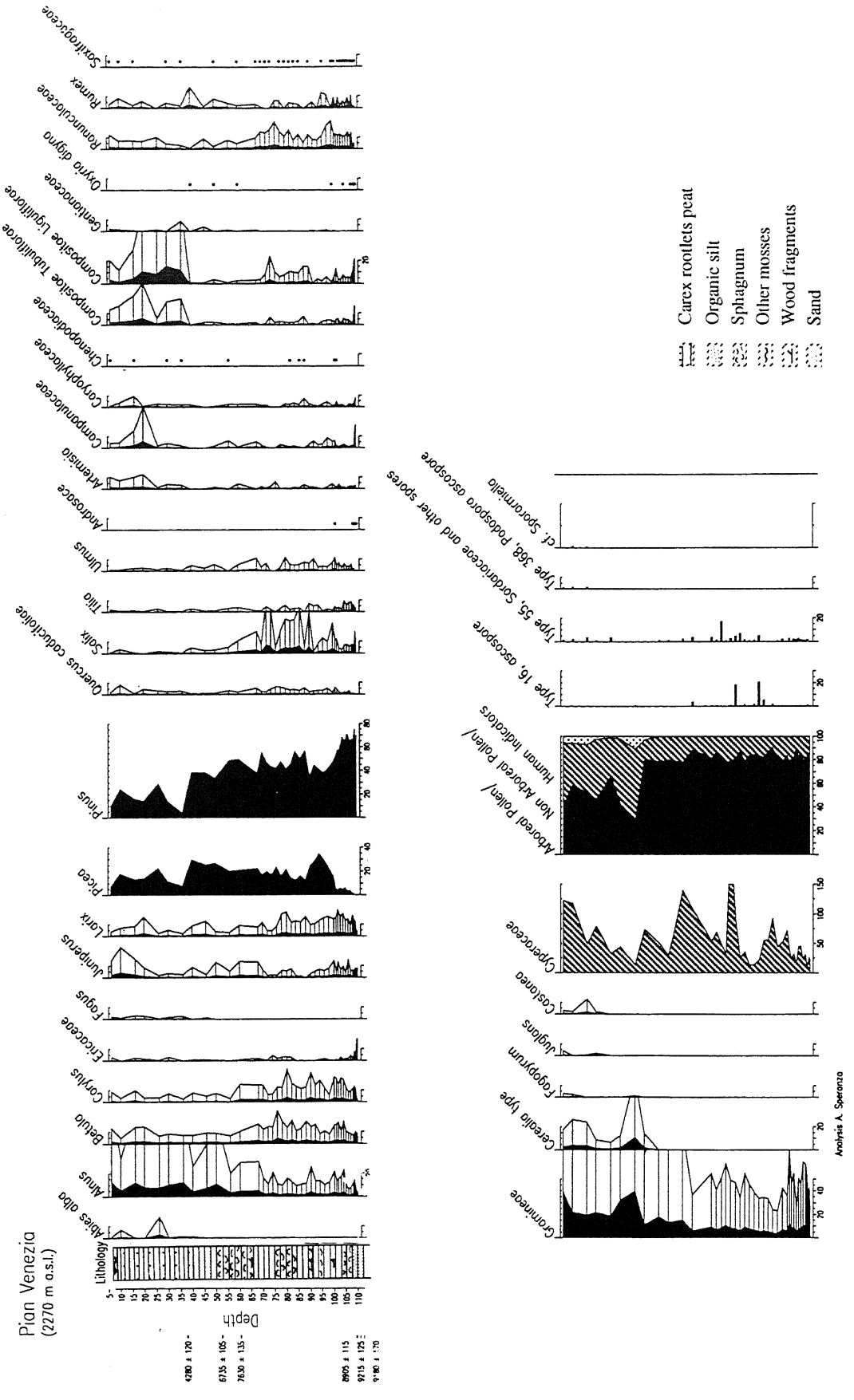

Fig. 3 - Simplified percentage pollen diagram. Cyperaceae are excluded from the pollen sum.
Diagramma pollinico semplificato. Le Cyperaceae sono escluse dalla somma pollinica.

dates back to 8905 ± 115 years BP.

Interpolation between these dates, and other available datings at depth of 55 cm (7630 ± 135 yr BP), 52 cm (6735 ± 105 yr BP) and 40 cm (4280 ± 120 yr BP), provides a time control over the whole section.

The detailed description of the deposits is as follows (from the top) (Fig. 2):

– from 0 to 3 cm: loose leeves and organic debris, discontinuous, wavy clear boundary;

– from 3 to 20 cm: dark greyish brown (10 YR 3/3) peat with prevalent *Carex* rootlets, feltrous structure moderately developed, mineral fraction absent, gradual boundary;

– from 20 to 38 cm: dark greyish brown (10 YR 3/2) silty peat, feltrous structure moderately developed, medium platy weakly developed, lineary clear boundary. A sample at the base of this layer supplied the age of 4280 ± 120 ^{14}C BP (GX-19720).

– from 38 to 52 cm: dark brown (10YR 3-2/2) peat with vegetal debris, small pebbles, feltrous and medium platy structures moderately developed, wavy clear boundary;

– from 52 to 110 cm: brown (7.5 YR 4/4) *Carex* peat, clear vegetal debris and wood fragments, particularly concetrated at 60, 77, 100 and 110 cm depth, lenses of silty peat 1-2 cm thick are locally present, charcoals remains at 80 cm depth, medium platy structure moderately developed, feltrous structure inside the platy aggregates, wavy sharp boundary. Three samples for radiocarbon dates have been collected within this layer: the first sample on peat material at the top of the horizon (52-53 cm) yielded the age of 6735 ± 105 ^{14}C yr BP (GX-19728); the second sample, collected at the base (109-110 cm), yielded 8905 ± 115 ^{14}C yr BP (GX-19726); the third sample, a wood fragment (*Larix decidua,* 60 cm depth), gave the age of 7630 ± 135 ^{14}C yr BP (GX-19727);

– from 110 to 112 cm: Ab horizon, peaty silt (10 YR 4/1) with small pebbles and wood fragments, beetle remains, discontinuous, fine platy weakly developed; wavy clear boundary. A sample at the base of the layer yielded the age of 9180 ± 170 ^{14}C yr BP (GX-19725). A wood sample from the same layer (within the soil just above the other sample) has been dated 9215 ± 125 ^{14}C yr BP (GX-19724);

– from 112 to 118 cm: A/C horizon, sandy silt with pebbles, feltrous roots concentrated at the base of pebbles, indistinct boundary. A sample of root yielded the age of 8185 ± 110 ^{14}C yr BP (GX-19723); fine blocky weakly developed;

– from 118 to 180+ cm: C1 horizon (5 Y 5/1), matrix-supported diamict, gray, massive (ablation till); lower boundary not reached.

4. POLLEN AND MACROFOSSIL ANALYSIS

Forty-one samples for pollen analysis have been processed with the method reported in Moore *et al.* (1991). The minimum pollen sum is of 400 grains. Identification and nomenclature refer to Moore *et al.* (1991), Punt *et al.* (1976-1991) and to the reference collections of CNR in Milano and Hugo de Vries Laboratory in Amsterdam.

On the basis of macrofossil analysis, we have considered the role of *taxa* in the mire; the aim was to define which *taxa* have to be considered local, and to exclude them from the pollen sum.

Cyperaceae are mainly local, as indicated by the fact that their rootlets are the major component of the material. Therefore, their pollen has been excluded from the pollen sum. Some species of other *taxa* such as Gramineae, Compositae, Ranunculaceae — which are widespread in alpine meadows — were possibly present in the mire. Nevertheless, these *taxa* have been included in the pollen sum, as the macrofossil analysis has not demonstrated their presence in the peat-forming vegetation.

5. VEGETATION DEVELOPMENT

5.1 Late Preboreal and Boreal

The analysis of the organic silt at the base of the section shows a percentage predominance of *Pinus* and a relative abundance of *Salix,* Ericaceae, *Betula, Juniperus, Alnus* and *Corylus.* At about 9200 BP the area around the site was characterized by an open vegetation dominated by herbaceous plants, such as Gramineae, Compositae Tubuliflorae and Liguliflorae, Caryophyllaceae and Campanulaceae, with shrubs of *Salix, Alnus incana/glutinosa* type, Ericaceae and *Juniperus.* The significant occurrence of pioneering *taxa* on moraines, such as *Oxyria* and *Androsace,* suggests that spots around the mire were still only partially covered by vegetation. Just over the silty base (about 9000 BP), a decrease of pioneer herbaceous *taxa* is recorded in correspondence with the start of *Carex* peat accumulation. An increase is observed in *Larix* percentage, whereas *Betula* and *Pinus* remain constant.

Although the presence of trees is not demonstrated by remains in the peat bog, the occurrence of *Larix* on the slopes at the altitude of the peat bog is supported by its continuous curve, moderate percentage (3%) and concentration (1000-2000 pollen grains/g). Similar values commonly indicate larch stands to be very close to the site because, in contrast with other conifer pollen (*e.g. Pinus*), *Larix* pollen is seldom transported over long distances and, therefore, has low background values (Ammann & Wick, 1994). Consequently, we infer that the dynamic tree limit was above Pian Venezia at 9000 BP, at least on sunny slopes. The shapes of *Larix* and *Juniperus* pollen curves correlate well from the base of the diagram, suggesting the development of an open forest with dwarf-shrub heath dominated by *Juniperus nana* and *Larix decidua.* The establishment of *Larix-Pinus* woodlands up to 2200-2300 m a.s.l. during the Preboreal is documented by several palaeobotanical investigations in Tyrol (Seiwald, 1980; Oeggl & Wahlmüller, 1992).

A shrubby hygrophilous vegetation with *Salix* and several tall herbs, belonging to Umbelliferae (like *Peucedanum*), Ranunculaceae and Compositae, expanded around the mire and partly replaced the open alpine vegetation at the end of the Boreal. At the same time, a decrease of *Juniperus* is recorded, with respect to both percentage and concentration values. These consistent evidences suggest general conditions of high humidity with an in-

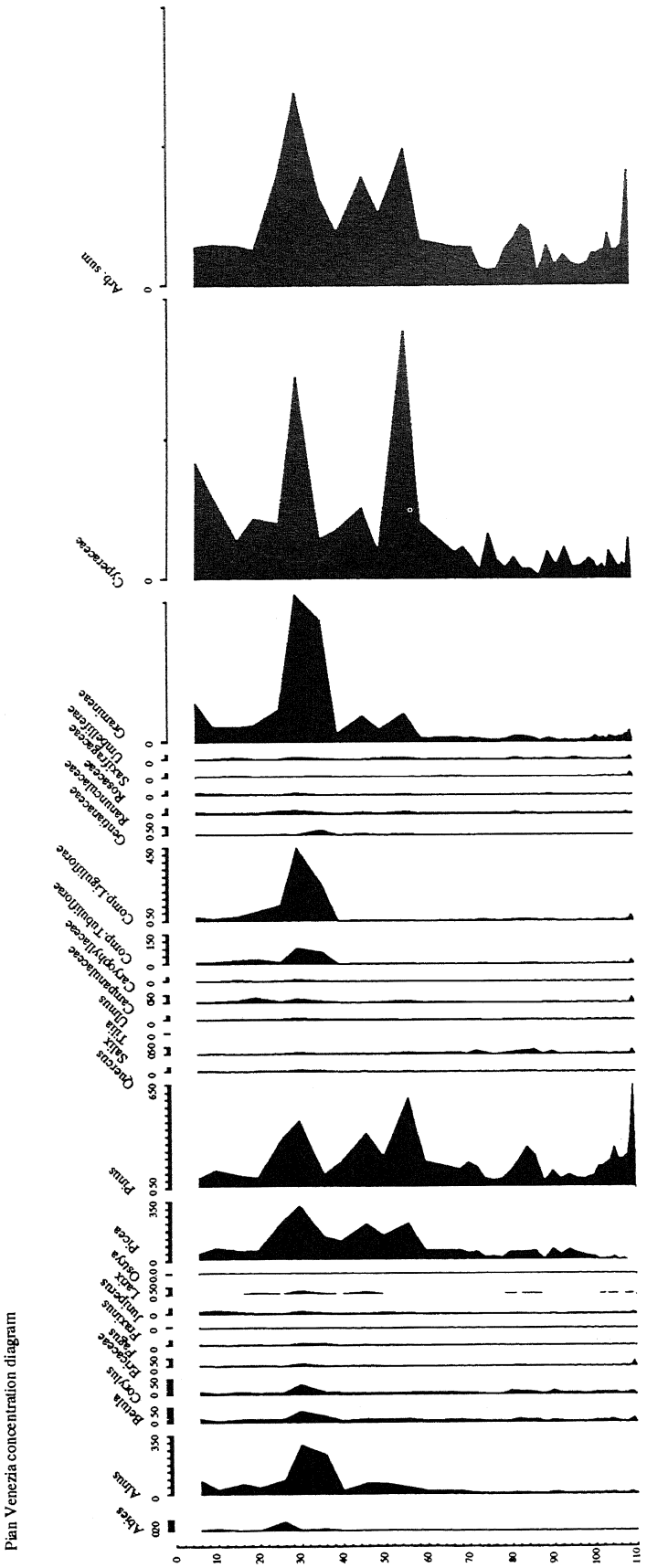

Fig. 4 - Selected concentration curves; the concentration values of each *taxon* have been divided by 100.
Curve di concentrazione selezionate; i valori di concentrazione di ogni taxon *sono stati divisi per 100.*

creased competition of subalpine tall forbs and hygrophilous shrubs (vegetation belonging to the class *Betulo-Adenostyletea*) *vs.* xerophilous vegetation with dominance of conifers (*Vaccinio-Piceetea*). The climatic conditions linked to such late Boreal evolution will be discussed in the next section.

5.2 Immigration and early Holocene history of *Picea*

The presence of *Picea excelsa* is documented for the catchment area from 8900 BP and for Val di Peio from 8700 years BP (interpolated ages), when the pollen curve shows a sharp increase. On the opposite, *Pinus* (Fig. 3 and 4) decreases. These data are in agreement with the appearence of this tree in Val Sugana (Trento) just before 8900 ± 130 BP (Forcellona diagram in Kral, 1980). After a maximum expansion at about 8500 BP, a sensible retreat of *Picea* occurs in the percentage curve between 92 and 70 cm (8450-7900 years BP, interpolated ages). A similar depression of *Picea* percentages has been observed in Austrian Alps, where a *Picea* belt established before 9000 years BP, as a result of the Venediger climate deterioration (Patzelt & Bortenschlager, 1973; Bortenschlager, 1992). The concentration curve of *Picea* in the Pian Venezia record (Fig. 4), however, shows a different pattern, with a marked decrease only between 78 and 72 cm (8100-7950 BP, interpolated ages). Between 95 and 80 cm, decreasing *Picea* percentages are mainly the consequence of increasing concentration curves for long distance transported pollen, like *Pinus* and *Corylus.* This situation may be explained as follows. The transport of *Picea* pollen grains is influenced by changes in the height of vegetation belts more than that of *Pinus* pollen grains. *Pinus* was at the forest limit and its pollen grains were free to move with the wind upvalley, whereas *Picea* was settled at slightly lower altitudes and was separated from the mire by the *Pinus* forest belt,

which acted as a screen blocking part of the *Picea* pollen grains from being transported upvalley.

For these reasons, we think that the observed development of the pollen curves in the Late Boreal is due to the opposition between i) the local-extralocal and ii) the long distance components of pollen assemblage. Correlation with climate oscillations described in the same time interval («Venediger», Patzelt & Bortenschlager, 1973; «Schams», Burga, 1980; 1988) seems to be premature.

5.3 The Atlantic

With the beginning of the Atlantic, a progressive expansion of a subalpine belt dominated by *Alnus viridis* is shown by percentage and concentration curves. The *Picea* curve is slowly but constantly increasing and the *Pinus* curve shows a decrease up to 5000 BP (interpolated age). The occurrence of sporadic grains of *Plantago,* and the increase of *Gentiana* at 45 cm (about 5500 BP), indicate a possible disturbance by grazing.

During the middle and late Atlantic period trees expand around the site, as indicated by needles and *Pinus cembra* and *Larix* stomata and seeds of *Pinus cembra* occurring in the samples of that period. A forest expansion in the Atlantic is also recorded in other alpine sites (*e.g.* Burga, 1988; Pott *et al.*, 1995; Bauerochse, 1996).

The present-day composition of the tree flora is achieved with the arrival of *Fagus* at about 6500 BP, and of *Abies* at about 6000-5500 BP.

5.4 Subboreal, Subatlantic and human impact

A sharp decrease in arboreal pollen occurring shortly after 4280 BP (calibrated datings in Table 2) indicates that deforestation has been intense in the upper Val di Peio since the Late Neolithic. Two distinct phases of human impact have been recognised: the first lasted between ca. 4200 and ca. 3000 BP, the second from ca. 2200 BP up till recent.

At about 4200 BP, the start of the first phase is recorded through an abrupt decline (from ca. 80% to ca. 30% of the pollen sum) of tree pollen (*Pinus* and *Picea*), an increase of herbs and shrubs acting as pioneer of pastures (*Alnus viridis, Juniperus nana*) and the presence of *Cerealia* type pollen. In other alpine sites, an important human umpact pressure on the subalpine forest can be dated to the beginning of Bronze Age (Lago Basso and Lago Grande; Wick, 1994). In the Pian Venezia record, the evidence of this human impact is very clear, probably due to the favourable topographic conditions of the site, which offers a large plain to be exploited. In this respect, one should remember that the Pian Venezia plain was certainly larger before of the Little Ice Age glacier advance, which covered part of pastures with large amount of ablation till.

Between 3000 and 2200 BP (interpolated ages) human activity decreases. The antrophogenic indicators decrease and arboreal pollen increases.

At ca. 2200 BP the second human impact phase starts. It is characterised by the pattern of AP decrease and NAP increase, and by an increase of *Cerealia* type. The appearance of *Juglans regia* and *Castanea sativa* pollen grains is in agreement with their spreading at the beginning of the of the Roman influence and colonisation period in Northern Italy, about 2nd Century BC (Schneider-Drescher, 1994). The occurrence of *Fagopyrum* in the upper part of this interval indicates that the second human impact phase includes Medieval times (Zoller, 1960).

6. ANALYSIS OF ADDITIONAL MICROFOSSILS

In the analysed material, apart from pollen and macrofossils, also other microfossil types (mainly fungi) are present (Van Geel *et al.*, 1978; 1989; Van Geel, 1996). These microfossils were taken into consideration to find additional information for the reconstruction of environmental conditions in a restricted area around the mire. The material examined is not very rich in microfossils, possibly due to the relative cold conditions prevailing at the site. These conditions favour slow rates of decomposition and might have influenced the diversity of fungal communities in a negative way.

Spores of fungi that play a role in the decomposition of organic material, like Type 55, are prevalent and were observed in the whole succession from the base to the levels with the first signs of human impact. The occurrence of ascospores of Type 16 (Van Geel, 1978) seems to correlate with the presence of *Sphagnum* in the peat deposit.

A decrease in the diversity of Types seems to coincide with the beginning of human influence in the area. In the second human impact phase, the presence of spores of *Podospora* and *Sporormiella,* coprophilous fungi, indicate that Pian Venezia was used as pasture field at that time (Van Geel *et al.*, 1981; Lundqvist, 1972; Davis, 1987).

At present, we are studying in detail the upper 50 cm of the section, with the aim of characterising the patterns of human activity.

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