Il Quaternario
Italian Journal of Quaternary Sciences
***15**(2), 2002, 187-208*

LATE HOLOCENE ENVIRONMENTAL EVOLUTION OF THE UPPER VALLE DEL GALLO (CENTRAL ALPS): AN INTERDISCIPLINARY STUDY

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ABSTRACT
Through an interdisciplinary study based on the application of geomorphological, stratigraphic, dendrochronological, pedological and phytosociological methods, the late Holocene environmental evolution of the valley bottom of the upper Valle del Gallo (upper Valtellina / upper Valle dello Spöl, Central Italian Alps), an area high in the mountains characterized by a strong environmental dynamism, has been reconstructed. The geomorphological survey and some stratigraphic sections prove that the studied area was occupied, probably from the Late-glacial period, by a lacustrine basin. Laminites, microturbidites, fluvial, deltaic and debris flow deposits formed by the progradation of the surrounding fans deposited in the lake and buried it before the Middle Holocene, originating a flat primitive valley bottom. This original surface was subsequently carved by the regressive erosion of the main river and its tributaries which isolated, especially since the Middle Ages, numerous surfaces from the more recent debris flow activity. Some fans were partially dismantled while in some depressed sectors a succession of silty deposits formed by sheetfloods accumulated. The adaptation and the reaction of the arboreal vegetation to the debris flow activity allowed us to apply dendrogeomorphological techniques thanks to which some events were dated and the recent morphologic evolution of one of the fans reconstructed. The ecological succession takes place on two types of carbonatic substratum characterising the study area: sandy gravel deriving from debris flows, silt and fine sands deriving from sheetfloods. The soils and vegetation of the upper Valle del Gallo are generally scarcely developed. The vegetation is dominated by *Pinus montana* forests at various degrees of evolution, following pioneer communities in which the pine plays a key role. The pedological study shows that pine forests develop on Leptosols, poor and dry grounds rich in rock fragments of the fans, only locally susceptible of evolving into Cambisols. These surfaces are frequently buried by debris flows that cover the grounds thus inducing regressive stages in the vegetational series. Yet trees often survive these events since they are able to heal their scars, straighten themselves up and to develop adventitious roots from the buried base of the stems and branches. On the contrary Fluvisols develop on sheetfloods silty deposits, where peculiar herbaceous communities predominate, adapted to a light periodic burial that does not kill the vegetation. Last but not least must have been the influence of the anthropic deforestation, that has probably contributed in a considerable way to the present landscape setting.

SOMMARIO
Evoluzione ambientale tardo-olocenica dell'alta Valle del Gallo (Alpi Centrali): uno studio interdisciplinare. *Mediante uno studio interdisciplinare basato sull'impiego di metodi geomorfologici, stratigrafici, dendrocronologici, pedologici e fitosociologici, è stata ricostruita l'evoluzione ambientale tardo-olocenica del fondovalle dell'alta Valle del Gallo (alta Valtellina/alta Valle dello Spöl - SO), un'area d'alta montagna contraddistinta da un'elevata dinamicità ambientale. Il rilevamento geomorfologico e alcune sezioni stratigrafiche documentano che l'area studiata era occupata, probabilmente a partire dal Tardiglaciale, da un bacino lacustre. In esso si sono depositate laminiti, microtorbiditi, depositi deltizi, fluviali e di debris flows derivati dalla progradazione dei conoidi circostanti, che hanno interrato il lago prima della metà dell'Olocene, dando origine ad un primitivo fondovalle pianeggiante. Questa originaria superficie è stata successivamente intagliata dall'erosione regressiva del torrente principale e dei suoi affluenti, che ha isolato, soprattutto a partire dal Medioevo, diverse superfici dall'attività più recente dei debris flows. Alcuni conoidi sono stati parzialmente smantellati, mentre in alcuni settori depressi si è accumulata una successione di depositi limosi derivati da processi di sheetflood. Gli adattamenti e la reazione della vegetazione arborea all'attività dei debris flows hanno consentito l'impiego di tecniche dendrogeomorfologiche mediante cui sono stati datati alcuni eventi ed è stata ricostruita l'evoluzione morfologica recente di uno dei conoidi. Sui due tipi di substrato carbonatico che caratterizzano l'area di studio, ghiaie sabbiose derivanti da debris flows, limi e sabbie fini derivanti da sheetfloods, ha luogo la successione ecologica. I suoli e la vegetazione dell'alta Valle del Gallo sono, in generale, scarsamente evoluti. La vegetazione è dominata da pinete a* Pinus montana *con gradi diversi di evoluzione, che seguono aggruppamenti pionieri in cui il pino gioca un ruolo chiave. Lo studio pedologico indica che le pinete si sviluppano su suoli poveri, scheletrici e asciutti di conoide, i Leptosols, solo localmente suscettibili di evolvere verso i Cambisols. Frequentemente queste superfici vengono sepolte da colate di detrito che ricoprono i suoli e inducono stadi regressivi nella serie vegetazionale. Tuttavia, spesso gli alberi sopravvivono a questi eventi poiché sono in grado di rimarginare le cicatrici, raddrizzarsi e sviluppare radici avventizie dalla base sepolta dei fusti e dei rami. Sui depositi limosi di sheetfloods, invece, si sviluppano Fluvisols e prevalgono peculiari aggruppamenti erbacei adattati ad un leggero seppellimento periodico che non uccide la vegetazione. Non meno importante deve essere stata, infine, l'influenza del disboscamento antropico, che ha probabilmente contribuito in modo notevole all'assetto del paesaggio attuale.*

Keywords: Alluvial fans, Debris flows, Holocene stratigraphy, Dendrogeomorphology, Mountain pine, Alpine soils, Vegetation.

Parole chiave: Conoidi alluvionali, Debris flows, Stratigrafia olocenica, Dendrogeomorfologia, Pino montano, Suoli alpini, Vegetazione.

1. INTRODUCTION

This report deals with the late Holocene environmental evolution of the upper *Valle del Gallo* (upper Valtellina / upper Valle dello Spöl, Central Italian Alps). This area high in the mountains shows a peculiar landscape characterized by a strong dynamic of the slopes, by the aggradation of fans mostly originated by debris flows and by a hydrographic network which is progressively deepening. The upper Valle del Gallo is particularly suitable to study the frequency and the effects of some geomorphologic processes strictly associated with the atmospheric dynamics, especially with precipitation, on the environment. The reaction of vegetation to such a rapid geodynamics and to a specific bedrock geochemistry (carbonates) allowed us to analyse the ecological interactions between geomorphic and sedimentary processes, the soil evolution and the factors determining it (climate, human influence, etc.). Moreover, this interdisciplinary research intends to promote the conservation and the enhancement of this area located between two wide protected areas, the *Stelvio National Park* and the *Swiss National Park*, showing at present a scant human presence.

2. STUDY AREA

The *Valle del Gallo* is situated on the Northeast extremity of the Lombardy (Northern Italy), in the *Stelvio National Park*, (Fig. 1). The studied area extends from *Passo di Fraele* (1952 m) to *Ponte di Pra Grata* (1864 m) (Fig. 1), and is entirely included in the carbonatic succession of the Norian age related to the Quattervals Nappe, except for some klippen belonging to the Scarl-Umbrail System forming some mountain tops (Pozzi & Giorcelli, 1960; Bonsignore *et al.*, 1969; Berra, 1994).

As showed by the analysis of the data (Santilli, 2000) from the meteorological station in Cancano (AEM Milano, 1948 m a.s.l., see Fig. 1), the climate of the upper Valle del Gallo corresponds to the Alpine continental one (Fig. 2). The average annual precipitation are scarce (822 mm), but, due to the altitude, the potential evapotranspiration is rather limited (428 mm). The soil water balance shows a small deficit in July. The carbonatic bedrock, the diffuse cover of coarse detrital sediments and the soils features reduce the available water capacity; consequently some aridity problems can occur during dry years.

Due to the high altitude of the surrounding mountains (up to 3180 m), wide portions of the slopes are beyond the tree limit and are without vegetative cover. Hence the climate is favourable for a strong weathering which can produce large quantities of debris that, accumulating on the slopes, are susceptible of moving due to the frequent heavy summer storms.

As regards vegetation, the studied area is included in the upper Subalpine Belt and is dominated by monospecific *Pinus montana* forests. *Pinus montana* in the

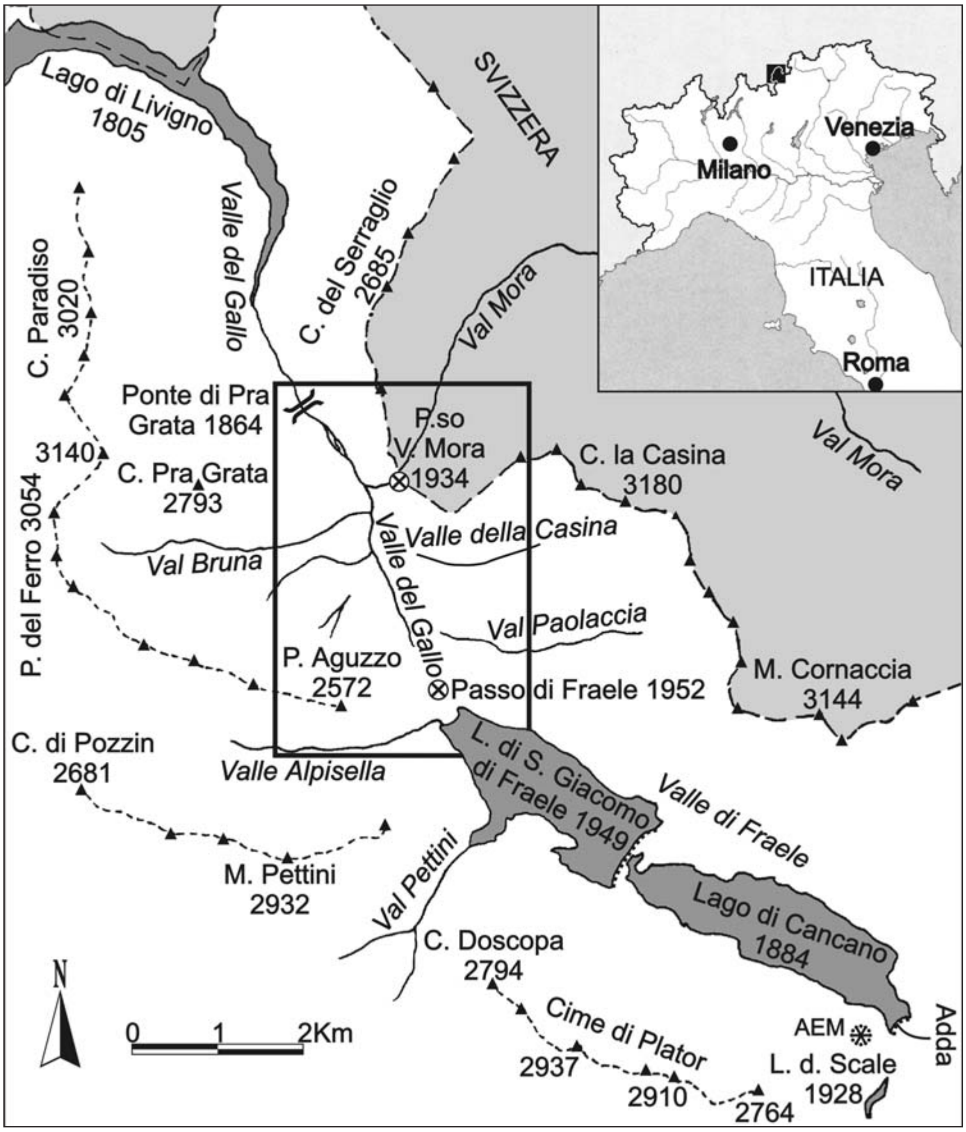

Fig. 1 - Location, hydrography and orography of the studied area. The *Valle del Gallo* covers the area northward the *Passo di Fraele* and belongs to the hydrographic basin of the Black Sea (through the Danube). The box shows the area represented in Fig. 5.

Ubicazione, idrografia e orografia dell'area studiata. La Valle del Gallo *si estende a Nord del Passo di Fraele e appartiene al bacino idrografico del Mar Nero (attraverso il Danubio). Il riquadro mostra l'area rappresentata in Fig. 5.*

broadest sense of the word (*Pinus mugo* aggregate, according to Minghetti, 1997; *Pinus* of the *mugo* group according to Pignatti, 1982; see also: Hess *et al*., 1967; Gaussen *et al*., 1993) includes two main species: *Pinus mugo* Turra 1764, having a dwarf habitus, which prefers carbonate substrata and grows in the Eastern Alps and in the Carpathian, and *Pinus uncinata* DC. in Lam & DC. 1805, having an arborescent habitus, which prefers siliceous substrata and grows in the Western Alps and in the Pyrenees. Moreover they are different for several morphological features such as the cone shape or the needle anatomy. Nevertheless, they frequently originate intermediate or hybrid forms hard to be taxonomically located. Mountain pines of the Valle del Gallo have a prevalent arborescent habitus (see Fig. 3), but even if this feature seems to be proper to *Pinus uncinata* DC., its geographical and ecological location is similar to that of *Pinus mugo* Turra, thus in the present study the generic definition of “mountain pine” is preferred.

The valley was subject to an intense anthropic exploitation for the presence of rich iron deposits that surface on its slopes. The mining activity, documented from 1272 to 1875, helped the development of a prosperous industry, that brought about the building of roads, structures and furnaces for the mineral fusion (Agostoni,1923; Leoni, 1953a-b; Zazzi, 1982). The furnaces were fed with coal produced in the several charcoal pits which are still disseminated all over the valley; the wood was obtained by felling the mountain pines and removing their stumps. The intense deforestation has probably had a great influence on the recent evolution of the soil and vegetation.

The bibliography available on the natural history of the Valle del Gallo is rather limited. General geomorphological information was provided by Giorcelli (in Pozzi & Giorcelli, 1960) and by Saibene (1973). These authors pointed out a series of erosive cycles of the Neogene-

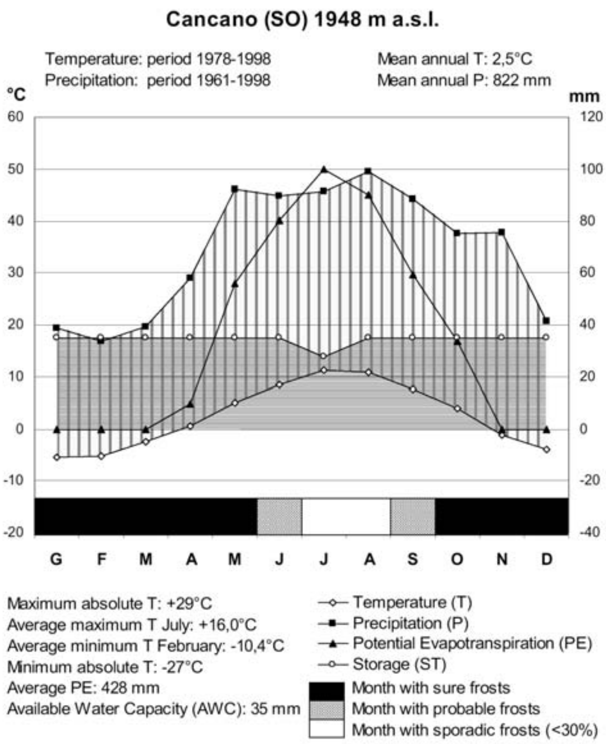

Fig. 2 - Ombrothermic diagram by Walter & Lieth and soil water balance according to Thornthwaite on the basis of the data of the meteorological station in Cancano (AEM Milano, see Fig. 1). The temperature and precipitation course shows the absence of an aridity period (P>2T) and a continental-like pluviometric system; the soil water balance shows a little deficit in July. The AWC calculated (35 mm) refers to a skeletal soil representative of the fan.

Diagramma ombrotermico di Walter & Lieth e del bilancio idrico del suolo secondo Thornthwaite in base ai dati della stazione meteorologica di Cancano (AEM Milano, cfr. Fig. 1): gli andamenti delle temperature e delle precipitazioni indicano l’assenza di un periodo di aridità (P>2T) ed un regime pluviometrico di tipo continentale; il bilancio idrico del suolo mostra un piccolo deficit nel mese di luglio. L’AWC calcolata (35 mm) si riferisce ad un suolo scheletrico rappresentativo dei conoidi.

Fig. 3 - Remarkable scar on the stem of a mountain pine hit by a debris flow in 1959. The development of compression wood contributes to the trunk straightening, following its inclination. The box represents a stem section showing compression wood (darker in the lower part) and a corrasion scar (in the upper part); both of them date back to 1986. (photos by Santilli).

Grossa cicatrice sul fusto di un pino montano investito da una colata di detrito risalente al 1959. Lo sviluppo di legno di compressione coadiuva il raddrizzamento del tronco successivo alla sua inclinazione. Il riquadro raffigura una sezione di fusto mostrante legno di compressione (più scuro in basso) e una cicatrice d’abrasione (in alto); entrambi risalgono al 1986 (foto Santilli).

Quaternary mainly caused by glaciations. Glacial erosion on the main valleys promoted a regressive erosion and fluvial captures which modified the ancient hydrography. Useful information on vegetation is available in Furrer (1914), Furrer & Longa (1915), Braun Blanquet *et al.* (1954), Giacomini & Pignatti (1955), Pirola & Di Benedetto (1959), Giacomini (1960), Pirola (1973), Pedrotti *et al.* (1974), Minghetti (1996).

3. MATERIALS AND METHODS

The environmental setting of the upper Valle del Gallo was deduced from the integration of a detailed geomorphological survey with photointerpretation (photograms no. 11-12-13, stripe 55, flight TEM 1 Regione Lombardia 1981, and no. 2571-2572, flight Alifoto 1975), and with stratigraphic, dendrochronological, pedological and vegetational studies. A general research was carried out on the whole valley sector and a more detailed study on the *Valle della Casina fan*, one of the lateral valleys. Moreover some historic information was provided by some photographs dating back to the end of the 19th century, and by a map of the land register of 1844 “Mappa del Comune Censuario di Valle di Dentro”.

Seventeen stratigraphic sections were described. Some buried layers rich in organic matter and a charred wood were dated through radiocarbon. The definition of stratigraphic units is the one used by the International Stratigraphic Code (Salvador, 1994).

Some debris flows of the Valle della Casina fan were dated using dendrogeomorphological techniques (e.g. see: Alestalo, 1971; Shroder, 1980; Heikkinen, 1994; Strunk, 1995) applied to mountain pines. More than two hundred increment cores were extracted from damaged *Pinus montana*, along the Valle della Casina fan channels and some cross-sections of stems and branches were made. The trees showed *corrasion scars* and/or *compression wood* on slanting stems, both caused by the impact of debris carried by water on the stems (Fig. 3). The *compression wood* is produced by conifers in order to bring the stem back to its vertical position whenever its orientation is altered. The scars and the year of appearance of the compression wood were dated. Owing to the fact that the trees were usually heavily damaged, the ring recognition and counting on many samples were often difficult. Finally only 53 trees were useful for dating purposes. Some historical data together with daily precipitation recorded at the meteorological station in Cancano (after 1961) confirmed some episodes which had been dated, even if it is not so easy to correlate the occurrence of the debris flows with precipitation (e.g. see: Govi *et al.*, 1985; Polloni *et al.*, 1991; Govi *et al.*, 1994; Flageollet *et al.*, 1999; Van Asch *et al.* 1999).

Thirty-two pedological profiles have been dug. For each horizon the color, the roots, the skeleton, the structure, the texture, the boundaries and the effervescence to HCl have been considered (according to Sanesi, 1977). The analysis carried out in laboratory, on the fine earth, sifted at 2 mm, determined the organic carbon (oxidation with bichromate potassium), the pH (soil/water ratio 1:2.5), the total carbonates (gas-volumetric method) and the apparent texture (by smoothing with an Esenwein’s pipette) (according to the Osservatorio Nazionale Pedologico, 1994). Soils have been classified according to the *World Reference Base for Soil Resources* taxonomic system (ISSS-ISRIC-FAO, 1998).

Vegetation has been studied by using the phytosociological method of the Zurich-Montpellier school (Braun-Blanquet & Jenny, 1926; Braun-Blanquet, 1964). Thirty-eight relevés have been processed by using the Braun-Blanquet cover-abundance scale modified by Pignatti (1952), in areas considered homogeneous from a geomorphological point of view. *UPGMA* has been used as clustering method to carry out the cluster analysis. A first analysis has been performed with the chord distance index using the cover values of the species transformed into numerical values (Van der Maarel, 1979). The following one has been carried out by using

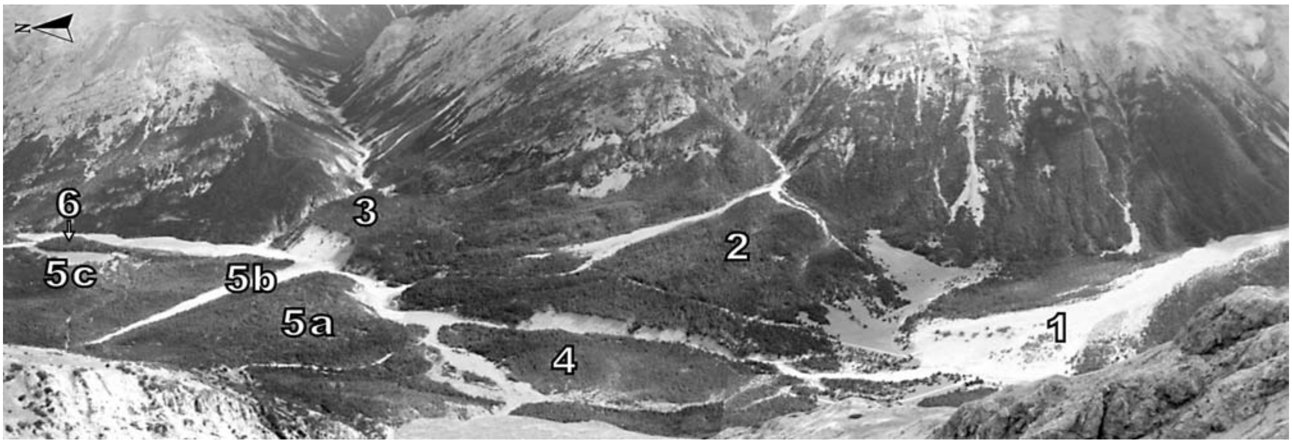

Fig. 4 - Panoramic photo of the upper Valle del Gallo (see Fig. 5): Val Paolaccia fan (1), Valle della Casina fan (2), Val Mora fan (3), “Valle del Pizzo Aguzzo” fan (4; actually, the valley does not have any place-name), inactive fan (5a-5c) and active fan (5b) of Val Bruna, moraine (6) (photo by Santilli).

Panoramica dell’alta Valle del Gallo (cfr. Fig. 5): conoide della Val Paolaccia (1), conoide della Valle della Casina (2), conoide della Val Mora (3), conoide della “Valle del Pizzo Aguzzo” (4; in realtà la valle è priva di toponimo), conoide inattivo (5a-5c) e conoide attivo (5b) della Val Bruna, morena (6) (foto Santilli).

the Jaccard coefficient and the data relevant to the species presence/absence. Sporadic species have been excluded from the clustering processing. The floristic nomenclature is the one used by Pignatti (1982).

4. RESULTS

4.1. Geomorphologic survey

Debris flow fans with a complex structure most of which are coalescent and come from both the valley sides occupy the upper *Valle del Gallo*. (Fig. 4-5). Creeks, often active only during heavy rains, sink on the eastern slope of the fans near their apexes. On the contrary, on the western slope they partially flow on their respective fan surface before sinking. This mirrors the northward/northward-eastward dipping of the strata (Saibene, 1973).

At the valley head the *Val Paolaccia* fan completely occupies the valley bottom (1 in Fig. 4-5) originating the *Passo di Fraele*. The *Valle della Casina* (2) and the *Val Mora* fans (3) extend on the eastern valley side

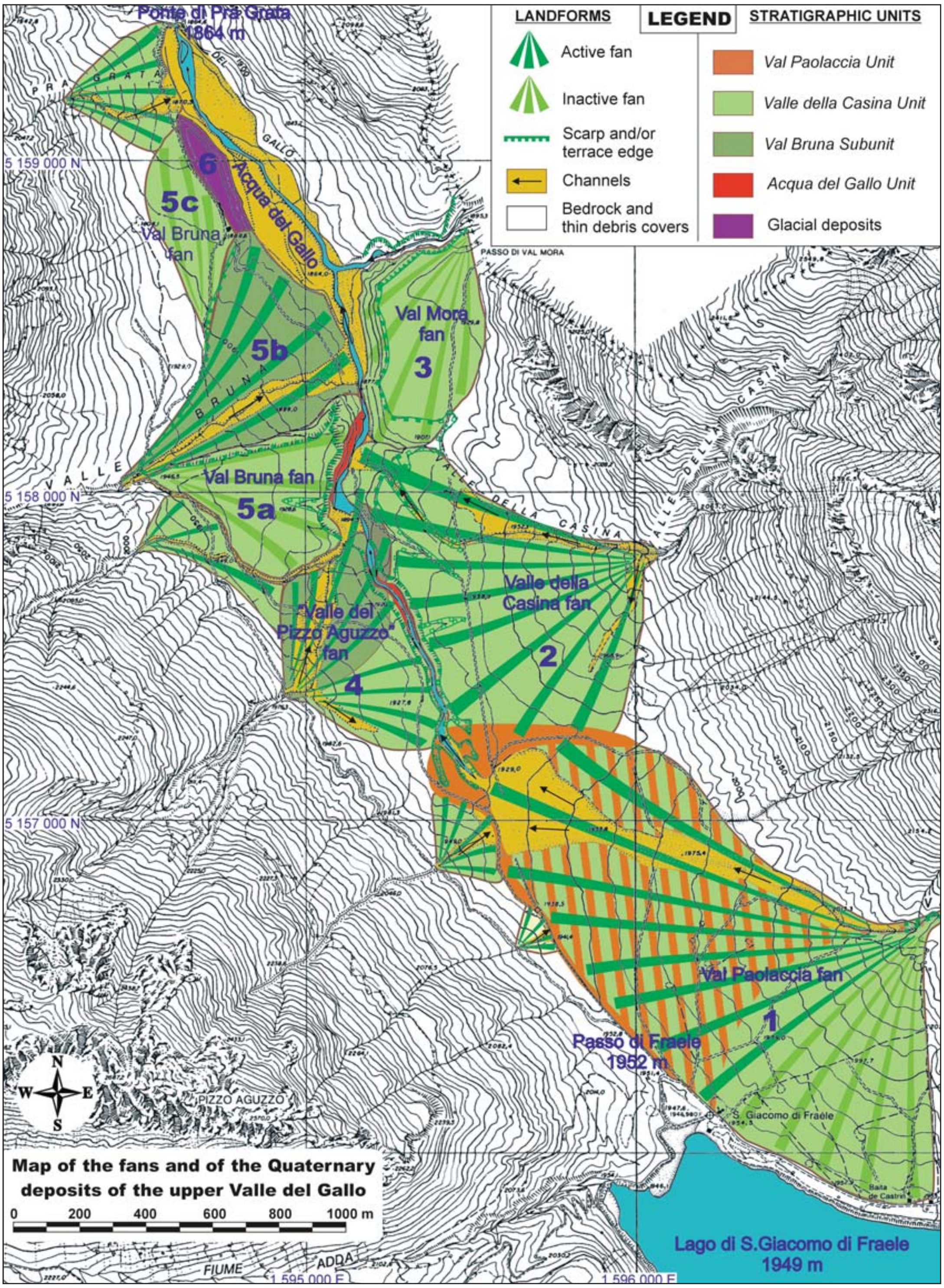

Fig. 5 - Map of the fans and of the Quaternary deposits of the upper Valle del Gallo (see Fig. 4) (from the Regional Technical Map 1:10.000 sections N° D1b3 "Lago di Livigno Sud" and N° D1c3 "S. Giacomo di Fraele", realisation 1980-83; coordinates are in the Gauss-Boaga system).

Carta dei conoidi e dei depositi quaternari dell'alta Valle del Gallo (cfr. Fig. 4) (dalla Carta Tecnica Regionale 1:10.000, sezioni N° D1b3 "Lago di Livigno Sud" e N° D1c3 "S. Giacomo di Fraele", realizzazione 1980-83; le coordinate sono nel sistema Gauss-Boaga).

while the "*Valle del Pizzo Aguzzo*" (4) and the *Val Bruna* ones occupy the western slope (5). The latter is composed of a central active portion (5b), a southern inactive part (5a) and a northern one (5c) located westwards of a hillock (6). According to Giorcelli (in Pozzi & Giorcelli, 1960) this hillock is a moraine deposited during the Gschnitz stadium (early Late-glacial). The Val Mora fan and the southern part of the Val Bruna one (5a) are now inactive surfaces bordered by scarps, up to 50-m high, facing the Val Bruna, Val Mora and Valle del Gallo the respective rivers of which flow at lower altitudes. These surfaces are considered (according to Martina, 1954) as the remains of an ancient flat valley bottom successively dissected by Acqua del Gallo, the river of the main valley, and its tributaries; other edges of the same valley bottom are represented by some small parts of the Valle della Casina and "Valle del Pizzo Aguzzo" fans.

Near the Val Paolaccia fan, the river Acqua del Gallo carves silty deposits (see par. 4.2.3.). The border of terraces formed by the crack has a winding shape which is more evident down the valley and represents an area where erosion gives birth to small incisions separated by crests (see Fig. 8).

The Valle della Casina fan (Figs. 4-5-6) extends nearly for 1 km between an altitude of 2020 and 1885 m a.s.l. There is a *main channel* (A in Fig. 6) near the northern margin; it is normally dry and marked by terraces separating other channels and inter-channel zones with *Pinus montana* forests. A part of the channel is edged by a high debris terrace (D). Downhill the Val Mora road (1935 m) the channel still carves the fan until it forms a ten-meter deep scarp before flowing into *Acqua del Gallo*. Two *secondary channels* (B) and (C) originate from the main channel (A). Channels (A) and (B) border a zone with a discontinuous vegetation and dwarf and damaged trees (E). Nearby there is another zone covered with a taller and thicker forest (F). Channel (G) originates from the secondary channel (C). Finally, at the fan-toe a few meter above the creek Acqua del Gallo a terrace (H) exists.

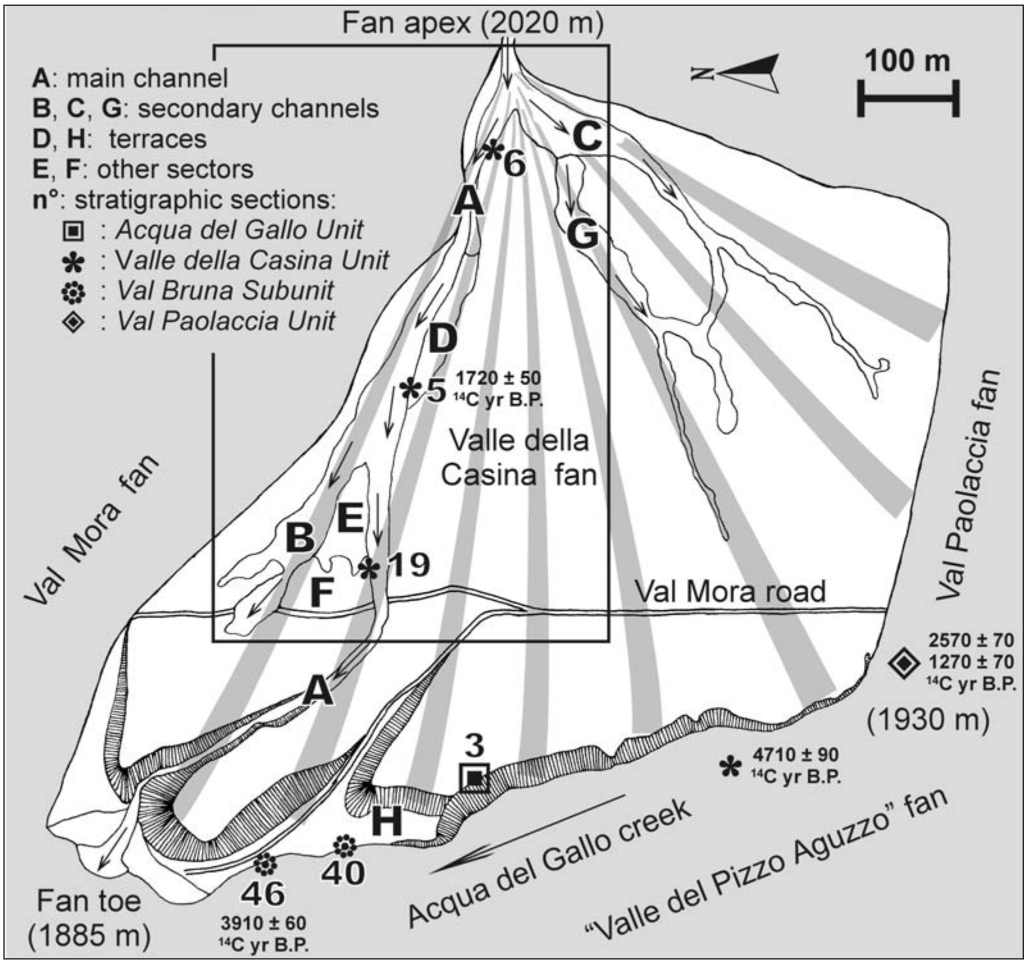

Fig. 6 - Morphological sketch map of the Valle della Casina fan. The box shows the area represented in Fig. 11.

Schema morfologico del conoide della Valle della Casina. Il riquadro mostra l'area rappresentata in Fig. 11.

4.2. Quaternary stratigraphy

The quaternary deposits cropping out on the valley bottom of the upper Valle del Gallo have been assigned to three lithostratigraphic units, the names of which derive from specific localities: the *Acqua del Gallo Unit*, the *Valle della Casina Unit* and the *Val Paolaccia Unit* (Fig. 5).

4.2.1. Acqua del Gallo Unit

DESCRIPTION AND INTERPRETATION. The *Acqua del Gallo Unit* is a carbonatic clay sedimentary succession with a coarsening-upward sequence (Fig. 7). The lower part is formed by massive grey clays; the middle part by horizontally laminated clays alternating between levels of silty clays and fine sands in fining-upwards laminas. Deposits are interpreted as decanted laminites and microturbidites deposited in a lacustrine environment. The uppermost part of the succession alternates between graded and well-sorted sands, silt and silty clays. The succession is clast free. Plant remains and macrofossils were not observed.

THICKNESS. The maximum visible thickness is 8 m (section 3; Figs. 5-6-7); the estimated thickness is at least 35 m, between 1885 and 1920.

NAME. Its name comes from the creek that carved it and exposed the succession.

LATERAL EXTENT AND RELATIONS WITH THE OTHER

STRATIGRAPHIC UNITS. Boreholes carried out by AEM Milano at the Passo di Fraele (Giorcelli in Pozzi & Giorcelli, 1960) and the exposed sections along the river bed of Acqua del Gallo allow us to identify these lacustrine deposits for more than 2 km from the inactive fan of Val Bruna (5a in Figs. 4-5) to Passo di Fraele. The uppermost part of the *Acqua del Gallo Unit* is interdigitated with alluvial deposits included in the *Valle della Casina Unit.*

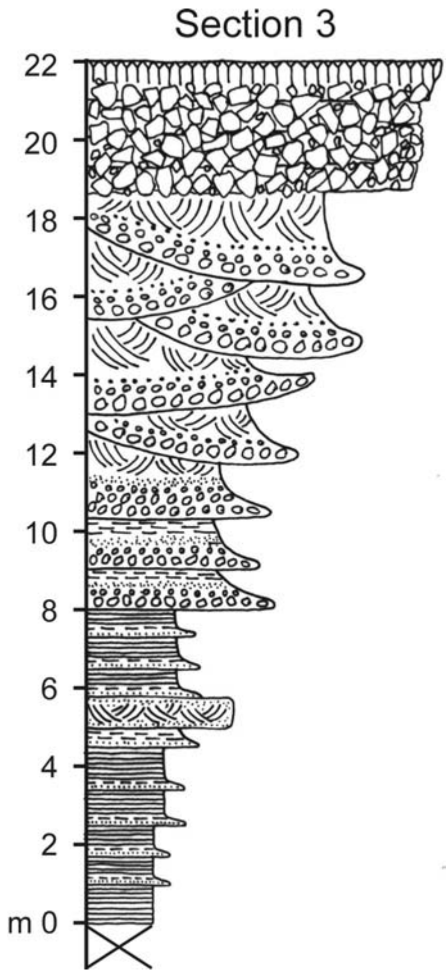

Fig. 7 - Section 3 of the *Acqua del Gallo Unit* (see Appendix I)
*Sezione 3 dell'*Unità dell'Acqua del Gallo *(cfr. Appendice I).*

TYPE SECTION. Section 3 (Fig. 7; Appendix I); coordinates: 46° 34' 00'' N, 10° 14' 40'' E.

AGE. No direct dating is available for this unit. Considering its stratigraphic position, it is older than 4710 ± 90 ^{14}C yr B.P. (Tab. 1; see par. 4.2.2.).

PREVIOUS STUDIES. Giorcelli (in Pozzi & Giorcelli, 1960) mentions a paleolake originated by the erosion processes of the last glacial cycle that caused the formation of a watershed in the upper Valle del Gallo, and by the obstruction of the Val Paolaccia fan at the Passo di Fraele.

4.2.2. Valle della Casina Unit

DESCRIPTION AND INTERPRETATION. This unit (Fig. 5) is made up of several interdigitated bodies of gravelly deposits expanding on the valley bottom at the base of tributary valleys. Each element is composed of lenticular successions, scantily stratified, of clast-supported gravel beds with sandy matrix, occasionally separated by well-sorted sandy-silty levels. Both fine fraction and clasts are carbonatic but locally are siliceous erratic, metamorphic clasts and iron ores. Clasts have a subangular or subrounded shape, are chaotic or have a weak stratification, with sands and a high primary porosity. Buried soils are common; brownish silty horizons rich in coal are sporadically embedded. The entire succession is markedly inclined towards the valley bottom and distinctly finingdownward. It can be considered as a series of wedge-shaped and coalescent debris flow fans. The uppermost part of section 3 (*Acqua del Gallo Unit*) shows the progradation of a fan covering gravelly and sandy alluvial deposits. The latter differ from the debris flow deposits because they are organized in channel bars, are better sorted, graded and partially stratified. They are included in the *Valle della Casina Unit.*

NAME. The present study analyses in detail the fan of Valle della Casina.

BOUNDARIES AND RELATIONS WITH THE OTHER STRATI-

GEOCHRON LABORATORY NUMBER	SAMPLE TYPE	CONVENTIONAL AGE ^{14}C years BP (^{13}C corrected)	SD	CALIBRATED AGE BP (Stuiver et al., 1998) max cal age (cal age intercepts) min cal age	δ $^{13}C_{PDB}$
GX-26488	Charcoal dispersed in sediment (see fig. 5)	4710 ± 90	1σ	5590 (5466, 5347, 5333) 5320	– 25.1 ‰
			2σ	5610 (5466, 5347, 5333) 5090	
GX-26487	Soil (section 39)	1270 ± 70	1σ	1290 (1231, 1204, 1182) 1090	– 24.8 ‰
			2σ	1310 (1231, 1204, 1182) 1010	
GX-26489	Soil (section 49)	2570 ± 70	1σ	2750 (2740) 2510	– 24.2 ‰
			2σ	2780 (2740) 2360	
GX-25989	Charred wood (section 5)	1720 ± 50	1σ	1710 (1687, 1675, 1612) 1550	– 23.8 ‰
			2σ	1730 (1687, 1675, 1612) 1520	
GX-28747	Soil (section 46)	3910 ± 60	1σ	4420 (4406, 4365, 4363) 4240	– 24.6 ‰
			2σ	4520 (4406, 4365, 4363) 4150	

Table 1 - Radiocarbon dating.

Date ^{14}C.

GRAPHIC UNITS. The exposed upper surfaces are characterized by an active aggradation or by the development of Leptosols (locally Cambisols) (see par. 4.4.). The basal part of the unit is interdigitated with lacustrine deposits of the *Acqua del Gallo Unit*. Some fans are interrupted by river downcuttings, between which the *Val Bruna Subunit* (see further on) is embanked. A depressed sector in the southern part is covered by the *Val Paolaccia Unit*. The contact surface is marked by a buried Leptosol, locally eroded (see Fig. 10 and par. 4.2.3.).

AGE. A thin layer rich in coal at the "Valle del Pizzo Aguzzo" fan-toe (see Fig. 6) was dated 4710 ± 90 ^{14}C yr B.P. (Tab. 1). A buried charred wood embedded in silty, reddish horizons rich in coal and partly pedogenized between gravelly layers in the upper part of the Valle della Casina fan (section 5 in Fig. 6) was dated 1720 ± 50 ^{14}C yr B.P. (Tab. 1). Some recent surfaces (since the end of the 19th century) were dated through dendrogeomorphology.

PREVIOUS STUDIES. These fans were mentioned by Martina (1954), Borgonovo (1955) and Giorcelli (in Pozzi & Giorcelli, 1960).

SELECTED SECTIONS. No. 5 (coordinates: 46° 34' 10'' N, 10° 15' 00'' E; Appendix I), 6 (46° 34' 00'' N, 10° 15' 10'' E) and 19 (46° 34' 10'' N, 10° 14' 50'' E) (Fig. 6).

SUBUNITS. The deposits embanked in the *Valle della Casina Unit* and separated from the latter by an erosional surface were assigned to the *Val Bruna Subunit.* The latter includes the active part of the Val Bruna fan (from which the name derives - 5b in Fig. 5) and the northern sector of the "Valle del Pizzo Aguzzo" fan (Fig. 5). The terrace (H) (Fig. 6; see Fig. 13) of the Valle della Casina fan is considered as a part of the "Valle del Pizzo Aguzzo" fan separated by the erosion activity of the creek Acqua del Gallo. Sections 40 and 46 (Fig. 6; see Fig. 13), coordinates 46° 34' 10'' N, 10° 14' 40'' E, are representative of this subunit. The buried soil included in section 46 was dated 3910 ± 60 ^{14}C yr B.P. (Tab. 1).

4.2.3. Val Paolaccia Unit

DESCRIPTION AND INTERPRETATION. The *Val Paolaccia Unit* (Fig. 8) is formed by a succession of centimetric layers made up of an undulating stratification of massive and well-sorted carbonatic silts and fine sands up to more than 4-m thick and totally clast-free. Coal fragments are locally common, dispersed, concentrated in pockets or related to pedoturbations. Pedogenized horizons and pedoturbations can only be found in the uppermost part (see section 2 in Fig. 9 and Appendix I). The structure of this succession suggests that it was formed in a terrestrial environment. The fine grain size, the good selection and the massive structure indicate that each layer resulted from the accumulation of single sheetfloods. These processes occur when dilute mixtures of water and sediments flow as traction currents spreading on the fan surface (Bull, 1972; Nichols, 1999). They cause a thin burial which does not kill the vegetation (see par. 4.5.3.), which promptly reacts by developing new roots and emerging stems. This also explains the common pedoturbation associated with the pedogenized horizons observed in the upper part of the succession.

NAME. These sheetflood deposits come from the Val Paolaccia (Figs. 5- 8).

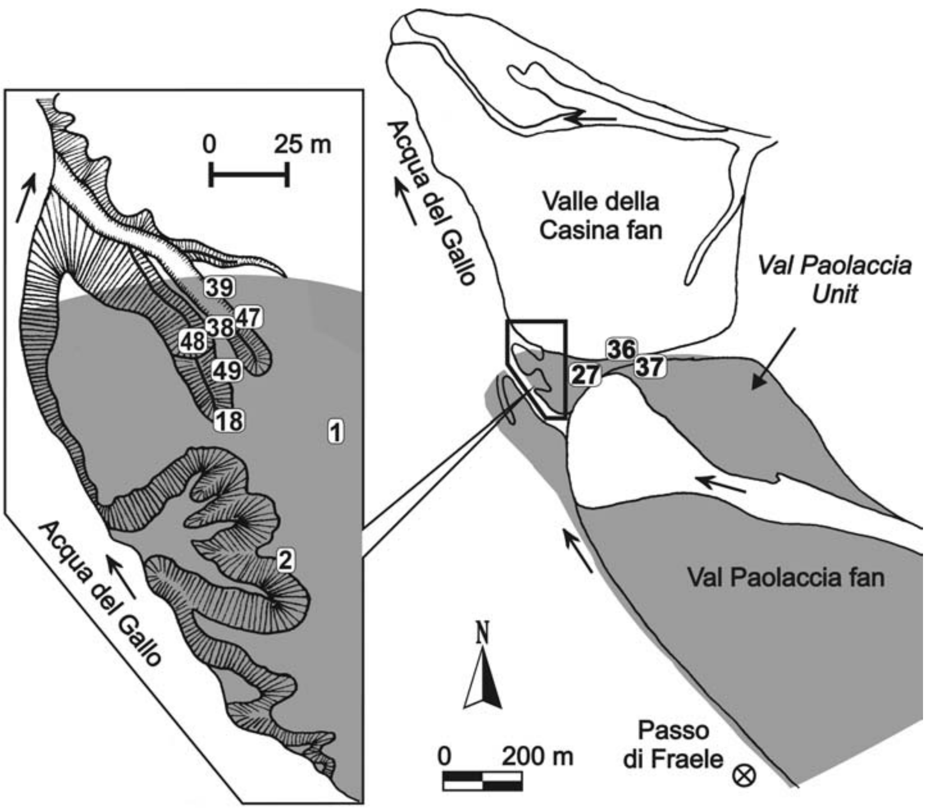

Fig. 8 - *Val Paolaccia Unit*: location, extent, erosion morphologies (in the box) and location of the stratigraphic sections (numbers).

Unità della Val Paolaccia: *localizzazione, estensione, morfologie d'erosione (nel riquadro) e ubicazione delle sezioni stratigrafiche (numeri).*

<u>Lateral extent, thickness and relations with the other stratigraphic units</u>. The unit is interdigitated with the gravel deposits forming the Val Paolaccia fan and covers with an *onlap* contact the depressed sectors around it. These fine deposits can also be found on the fan surface where they locally bury the soil and vegetation with a layer up to 10-15-cm thick. Some thicker successions have been observed in wide natural downcuttings in the north-west sector of the unit. Sections 39 and 49 show the contact with the *Valle della Casina Unit* marked by a buried Leptosol (locally eroded) (Figs. 8-9-10).

<u>Selected sections</u>. No. 39, 49, 2 (coordinates: 46° 33' 50'' N, 10° 14' 50'' E; Figs. 8-9-10; Appendix I).

<u>Age</u>. The tops of horizon A of the soil lying on the upper surface of the *Valle della Casina Unit* and buried under the *Val Paolaccia Unit* provided two dates (Figs. 6-9-10, Tab. 1). We think that the difference between these dates, respectively 1270 ± 70 ^{14}C yr B.P. (section 39) and 2570 ± 70 ^{14}C yr B.P. (section 49) depends on the different time of burial, which is related to their altitudinal position: the soil at a lower altitude was buried earlier. Therefore, the difference observed in the ages provides a rough estimation of the average sedimentation rate (0.6 mm/yr).

4.2.4. Deposits of unsettled stratigraphic position

Some blocks of monogenic clast-supported conglomerates, locally passing to medium sandstone, were found along the river bed of Acqua del Gallo. Clasts are carbonatic and the red or grey matrix is scarce. The provenance of this material is unknown. Surveys carried out by the AEM Milano at the Passo di Fraele detected conglomerate layers embedded in the gravel. Moreover a conglomerate layer a few centimetre thick is embedded in the sequence of clay, gravel and sands along the escarpment of the Val Bruna fan.

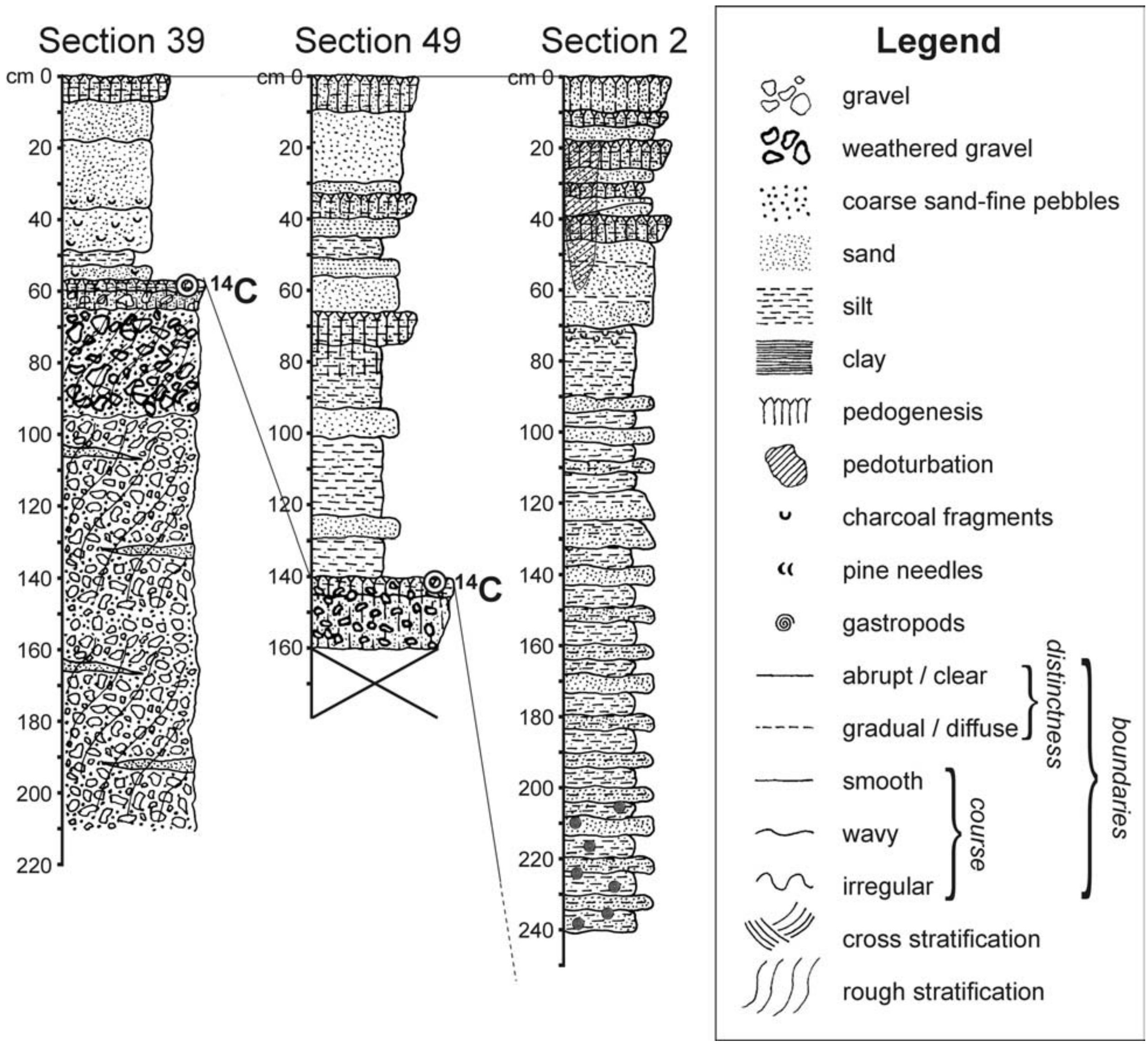

Fig. 9 - Stratigraphic sections of the *Val Paolaccia Unit* coming into contact with the *Valle della Casina Unit* (see Appendix I).

*Sezioni stratigrafiche dell'*Unità della Val Paolaccia *al contatto con l'*Unità della Valle della Casina *(cfr. Appendice I).*

4.3. Dendrochronology of debris flows

The dendrogeomorphological study concerns the most recent history of the Valle della Casina fan. The integration of the historical, meteorological and dendrochronological data allowed us to reconstruct the following chronological sequence of debris flows in the Valle della Casina (Fig. 11) (Santilli & Pelfini, 2002).

The oldest dated debris flow occurred at the end of the 19th century: five trees in area (F) showed compression wood events dating back to 1888.

Two close dates obtained by analysing eleven trees located in channel (B), area (F) and terrace (D) are 1927-1929. This could be considered as a single episode.

Between 1936 and 1941 four damaged trees in areas (E) and (F) were sampled. Two scars dating back respectively to 1936 and 1941, point out that probably different debris flows were responsible for them.

A tree located in the secondary channel (B) was damaged in 1953. This debris flow can be connected to a flood, which occurred after heavy rain between 12th and 13th August (Borgonovo, 1955).

Clear scars on three trees located in the secondary channels (B) and (C) witness an event that took place in 1959 (see Fig. 3).

The damage on a tree located in area (F) jutting out in the main channel (A) witness a debris flow in 1964 (see sample (c) in Fig. 5). Heavy rain occurred on June 2nd (34.2 mm) and October 8th (42.8 mm).

A flood which occurred in 1978 left traces everywhere; twenty-one damaged trees, in the main channel (A), in the secondary channels (B) and (G), and on the terrace (D), were sampled. This event is witnessed by the aerial photographs: the secondary channel (G) does not appear in 1975 whereas it is present in 1981 photos. Heavy rain was recorded on May 21st-22nd (57.3 mm), June 24th (58.2 mm) and July 4th-6th (84.7 mm).

Nine damaged trees located in the main channel (A), in the margin of area (F) and in the upper part of the terrace (D) witness an event occurred in 1986. Intense precipitation took place on August 19th (43,8 mm).

Finally a debris flow in 1992 is documented by five trees located in the main channel (A) and on terrace (D). This event coincides with a general flood of the whole upper Valtellina, that caused a lot of damage especially near Bormio, where 74 mm of rain fell in 2.5 hours on July 22nd (Mortara *et al.* 1994); the station in Cancano recorded 40.8 mm on July 23rd, but heavy rain also fell on June 19th-20th (67.2 mm) and on October 6th (39.4 mm).

4.4. Soil types

Four soil reference groups have been identified: Leptosols, Cambisols, Fluvisols and Regosols.

<u>Leptosols</u>. They are shallow scarcely developed soils, with an (A)C or AC profile. They develop on sandy-matrix carbonate gravel (e.g. *Valle della Casina Unit*) and belong to the most represented group including four different types of soil.

<u>1. Calcari-Hyperskeletic Leptosols</u>. They are made up of coarse pebbles superficial layers (AC or CA) under which fine material accumulates. The layer, which may contain a significant amount of organic matter, is very modest and discontinuous. It lacks in structure and its skeleton is mainly made up of gravel with a sandy texture matrix. Its colors are usually light (hue 2,5Y), the effervescence is quite strong and the pH is definitely basic.

<u>2. Calcaric Leptosols</u>. Horizon O (Oi + Oe) is 3-4-cm thick; horizon A is 10-cm thick and can assume dark colors. Its structure is scarcely developed, its texture is silt loam or sandy loam, its organic carbon content is of 29-35 g/kg. The amount of carbonates is high (676-757 g/kg), therefore its reaction is basic, too (pH 7.6-8.0).

<u>3. Calcari-Humic Leptosols</u>. Horizon O (Oi + Oe) is 2-4-cm thick; horizon A is usually about 10-cm thick, has dark colors (often 10YR 2/2), a weakly or moderately marked fine or medium granular structure, is rich in rock fragments, has a sandy loam texture, a very light or null effervescence, a pH of 7.4-7.9, a 51-97-g/kg organic carbon content and a variable total carbonate content (61-595 g/kg).

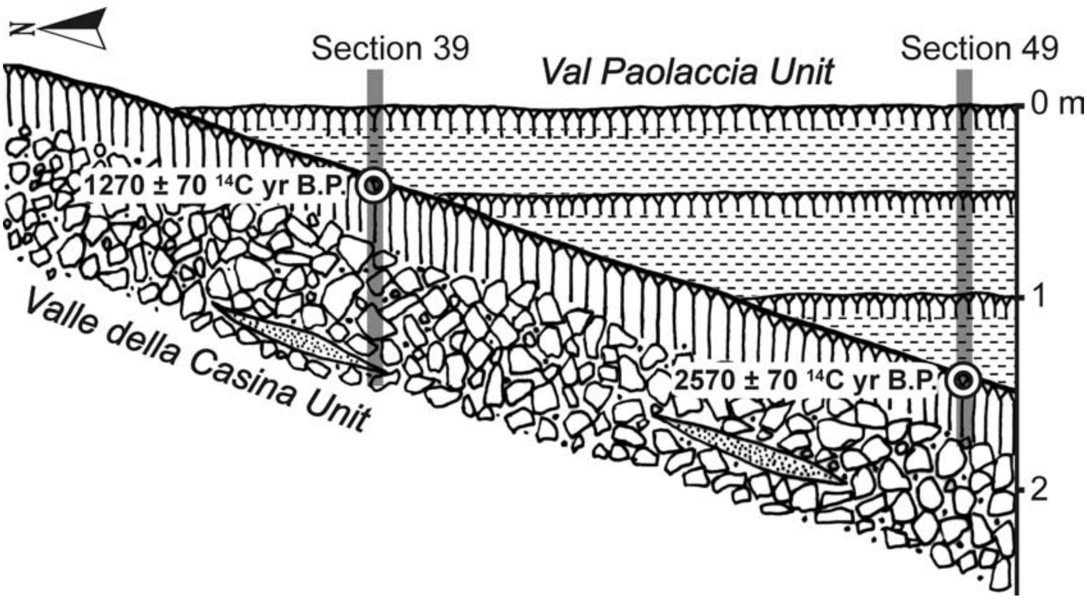

Fig. 10 - Stratigraphic scheme of the north-western sector of the *Val Paolaccia Unit.*

*Schema stratigrafico del settore nordoccidentale dell'*Unità della Val Paolaccia.

4. Humi-Rendzic Leptosols (Calcaric). Horizon O (Oi + Oe; which is sometimes totally absent, and sometimes includes also Oa) can be up to 4-cm thick; horizon A, which can sometimes be divided into two subhorizons having the characters of the mollic epipedon, is usually 10-25-cm thick, has a dark color (10YR 2/1-2/2), a weakly or moderately marked fine or medium granular structure, is rich in rock fragments, has a mostly sandy loam texture, a pH varying from 7.0 to 7.9 (seldom lower than 7.0), a very variable total carbonate content (0-569 g/kg) and a 12-130-g/kg organic carbon content. A subordinate fraction of parent material is locally siliceous (see par. 4.2.2), what reduces the carbonate content in lower horizons.

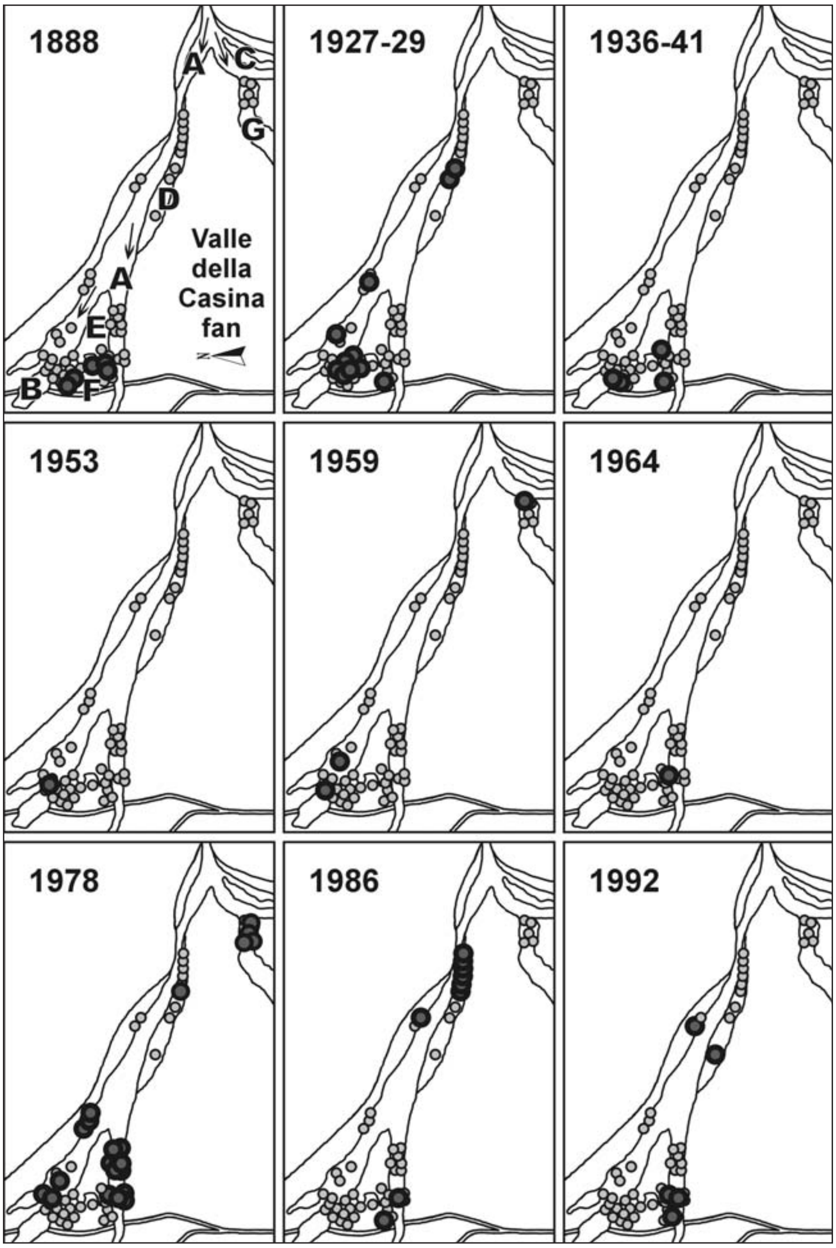

Fig. 11 - Dating of debris flows: event-response yearly maps pointing out the position of the sampled trees used for dating purposes; the black circles indicate the specimens in which event years (corrasion scars or first developing compression wood) relevant to the same episode were identified. The box is showed in fig. 6.

Datazione dei debris flows: mappe annuali evento-risposta mostranti la posizione degli alberi campionati utilizzati per le datazioni; i cerchi neri indicano gli individui in cui sono stati identificati anni caratteristici relativi ad uno stesso episodio (cicatrici d'abrasione o inizio dello sviluppo di legno di compressione). L'area è mostrata in fig. 6.

CAMBISOLS. They are moderately developed soils, with an ABC profile and a cambic B horizon (Bw). Cambisols develop on carbonate gravel, with a local subordinate siliceous fraction. These soils are little represented, and only one type of them exists.

Skeleti-Calcaric Cambisols. Horizon O (Oi + Oe) is 1-2-cm thick; horizon A is not more than 10-cm thick, does not have very dark colors (10YR 3/2-4/3), contains few or normal rock fragments, has a moderately marked fine or medium granular structure, a sandy loam or silty loam texture, a weak or null effervescence, a variable total carbonate content (10-559 g/kg), an organic carbon content between 33 and 75 g/kg and a pH of 6.7-7.8. Horizon Bw is about 15-cm thick, is brown (10YR 3/3-3/4), has a moderately marked medium granular structure, a loamy, sandy loam or silty loam texture, a variable effervescence, a total carbonate content between 108 and 601 g/kg, a pH of 7.8-8.0 and a 18-36 g/kg organic carbon content.

FLUVISOLS. These soils have an (A)C or AC profile, and sheetflood sediments are periodically brought to them determining the stratification of the parent material and an irregular content of organic matter along the profile. Fluvisols are only located on silty deposits without rock fragments in the *Val Paolaccia Unit*.

Calcaric Fluvisols. Horizon O (Oi and/or Oe) has little importance (0-2 cm) and can also be absent; topsoils (A horizon) have very variable characteristics: their thickness is between 2 and 25 cm, they have light (2,5Y 5/2) to dark (10YR 2/2) colors, a moderate to strong effervescence, a pH of 7.5-8.3, a very scarce decarbonatation (549-946 g/kg $CaCO_3$, whereas the $CaCO_3$ content in the parent material is only slightly higher) and a 4-80 g/kg organic carbon content. The pedogenesis is always weak, and the dynamic characteristics of the deposits give rise to buried horizons, which can be distinguished by a weak structure and by a little accumulation of organic matter.

REGOSOLS. Soils with a limited development not belonging to other soil groups.

Anthropic Regosols. These soils develop on little level areas for the charcoal production which are very widespread in this zone. The topsoil is made up of a black layer of pure charcoal, about 20-cm thick, that can be divided into two levels: the upper one differs from the lower one in a more acid reaction (respectively pH 5.7 and pH 7.1) and in a weak structure granted by the roots.

Many Leptosols and Cambisols show some traces of surface erosion causing a partial lack in vegetation and emerging roots on a remarkably wide surface.

4.5. Plant communities

Three main groups of relevés have been identified through the chord distance analysis: pioneer lithophilous communities, mountain pine-dominated woods and scrubs, and grasslands. A further distinction has been made through the presence/absence analysis.

4.5.1. Pioneer lithophilous communities (Tab. 2)

A sparse herbaceous layer, locally associated with a thin layer of young/small pines characterizes these communities. The cover values never exceed 20-30% and are sometimes lower than 5%, according to the age and the stability of the surface. The average number of species per relevé is 18. The moss layer has a negligible cover value while lichens lack. These communities are characterized by the constant presence of *Hieracium staticifolium*, as well as of *Pinus montana* and of many lithophilous and basiphilous species such as *Trisetum distichophyllum*, *Saxifraga caesia* and *Athamanta cretensis*. Other species are sporadically present and are sometimes linked to peculiar local parameters such as a higher humidity (e.g. *Saxifraga aizoides*).

These communities belong to the association *Athamanto-Trisetetum distichophylli* (Jenny-Lips 1930) Lippert 1966 (class *Thlaspietea rotundifolii* Br.-Bl. 1926 *et al.* 1948, order *Thlaspietalia rotundifolii* Br.-Bl. in Br.-Bl. & Jenny 1926 em Seib 1977, alliance *Petasition paradoxi* Zollitsch 1966). The importance of *Pinus montana* in this pioneer vegetation, which is instead usually found only in the most advanced stages of the association (Pirola & Di Benedetto, 1959), must be stressed.

Pioneer litophylous communities	
N. of relevés	**10**
N. of species	**18**
Hieracium staticifolium	100
Pinus montana	100
Campanula cochleariifolia	90
Biscutella laevigata	80
Kernera saxatilis	80
Saxifraga caesia	80
Trisetum distichophyllum	70
Silene vulgaris glareosa	60
Polygala alpestris	60
Dryas octopetala	60
Carex humilis	60
Athamanta cretensis	60
Festuca quadriflora	60
Leontodon hispidus	50
Saxifraga aizoides	50
Poa cenisia	50
Gypsophila repens	40
Carex ornithopoda	40

Table 2 - Synoptic table of the pioneer lithophilous communities. This table (see also tab. 3-4) shows the percentage frequencies of the most widespread species in the relevés, except in those represented by one single relevé, where the cover values are directly reported.

Tabella sinottica delle comunità pioniere litofile. Questo tipo di tabella (cfr. anche tab. 3-4) mostra le frequenze percentuali delle specie più diffuse nei rilievi, eccetto nelle tipologie con un solo rilievo, dove sono direttamente riportati i valori di copertura.

4.5.2. Mountain pine woods and scrubs (Tab. 3)

Pinus montana woods and scrubs dominate the vegetation of the upper Valle del Gallo. The vegetative cover is nearly complete, even if in pioneer or degraded stages it can reach low values (<50%). The arboreal layer, where present, has a mean cover value of 60% and is 4 to 8-m high, while the shrubby layer (locally including *Juniperus nana*) has a mean cover value of 35% and is 0.3 to 3-m high. The herbaceous layer is well developed and reaches a cover value of about 70%. Both mosses and lichens reach a cover value of 15-20%. These communities share in general xerophitic and heliophilous characteristics and seem quite homogeneous. Nevertheless, some different aspects can be observed. The syntaxonomic treatment of pinewoods is difficult because of the uncertain taxonomy of the pine itself. According to Minghetti (1996), all the sampled communities should be included in the class Erico-*Pinetea Horvat* 1959, order *Erico-Pinetalia* Horvat 1959, alliance *Erico-Pinion mugo* Leibungut 1948.

CAREX HUMILIS AND *SESLERIA VARIA*-DOMINATED PINEWOODS. These groupings are joined together by some exclusive or preferred species like *Polygala chamaebuxus*, *Calamagrostis varia* and *Daphne striata*, and by high cover values of *Erica carnea*, *Carex humilis* and *Sesleria varia*. Two main situations can be identified.

1. Pinewoods on stabilized substrata. They are characterized by a wider cover of arboreal layer, by some species indicating that the soil has started to acidify (*Moneses uniflora* and *Hieracium tenuiflorum*) and by an accumulation of organic matter. According to the tree layer and *Erica carnea* cover, the presence and abundance of *Vaccinium vitis-idaea* and the average number of species, four different degrees of evolution can be identified:

- *Low degree of evolution*. Young pinewoods or scrubs, having a scanty arboreal and *Erica carnea* cover. The average number of species is 32.
- *Intermediate degree of evolution*. A thicker tree layer, a wider heather cover and a greater average number of species (35) characterize it. A group of differential

Pine woods	*Carex humilis* and *Sesleria varia* -dominated		*Rhododendron hirsutum* -dominated	Pine scrubs on scree
	On stabilized soils	Regresive stages		
N. of relevés	**9**	**3**	**1**	**5**
N. of species	**32**	**40**	**17**	**29**
Carex sempervirens	67	.	.	.
Festuca quadriflora	44	.	.	.
Corallorhiza trifida	44	.	.	.
Thymus polytricus	.	100	.	.
Senecio abrotanifolius	.	67	.	.
Carlina acaulis	.	67	.	.
Crepis alpestris	.	67	.	.
Carex caryophyllea	.	33	.	.
Minuartia verna	.	33	.	.
Ranunculus gr. montanus	56	100	.	.
Calamagrostis varia	44	100	.	.
Polygala chamaebuxus	89	100	.	.
Leucanthemum vulgare vulgare	56	100	.	.
Hippocrepis comosa	56	100	.	.
Lotus alpinus	89	100	.	.
Cirsium acaule	78	100	.	.
Juniperus nana	44	100	.	.
Homogyne alpina	67	67	.	.
Polygala alpestris	67	67	.	.
Campanula scheuchzeri	67	67	.	.
Festuca nigrescens	56	67	.	.
Anthyllis vulneraria alpestris	44	67	.	.
Leontodon autumnalis	67	33	.	.
Melampyrum pratense	89	67	+	.
Vaccinium vitis-idaea	56	67	+	.
Rhododendron hirsutum	.	.	4	.
Arctostaphylos alpinus	.	.	+	.
Tofieldia calyculata	.	.	+	.
Saxifraga caesia	.	.	.	100
Hieracium staticifolium	.	.	.	80
Campanula cochleariifolia	.	.	.	80
Athamanta cretensis	.	.	.	60
Silene vulgaris glareosa	.	.	.	40
Carex mucronata	.	.	.	40
Salix waldsteniana	.	.	.	40
Epipactis atropurpurea	.	.	.	40
Carex firma	.	.	.	40
Pinus montana	100	100	4	100
Carex humilis	78	100	+	100
Carex digitata	89	67	1	100
Carex ornithopoda	78	67	+	100
Erica carnea	100	100	4	80
Sesleria varia	100	100	+	80
Daphne striata	100	100	.	80
Leontodon hispidus	.	100	.	80
Dryas octopetala	78	.	+	80
Orthilia secunda	.	.	1	80
Antennaria dioica	56	100	.	60
Hieracium sylvaticum	56	100	.	60
Carex ericetorum	.	67	+	60
Hieracium tenuiflorum	78	.	r	60
Moneses uniflora	89	.	.	60
Aster bellidiastrum	78	100	.	40
Euphrasia salisburgensis	.	100	.	40
Biscutella laevigata	78	67	.	40
Galium anisophyllum	.	67	.	40
Taraxacum officinale	.	67	.	40
Carex alba	100	67	+	.
Hieracium bifidum X cirrhitum	.	.	r	.

Table 3 - Synoptic table of the mountain pine woods and scrubs. The synoptic tables point out only the main communities and not those belonging to an inferior rank which are instead relevant as concerns the dynamic aspects.

Tabella sinottica dei boschi e degli arbusteti a pino montano. Le tabelle sinottiche evidenziano solo le comunità principali e non quelle di rango inferiore, che sono invece importanti per gli aspetti dinamici.

species, some of which are linked to grasslands, is present; the main species distinguishing this community from the previous one is *Vaccinium vitis-idaea*.

– *Cowberry-dominated*. It is characterized by the dominance of *Vaccinium vitis-idaea* and by a lower average number of species (26).

2. Regressive stages due to the soil erosion: the marked soil erosion causes a reduction in the arboreal cover to the advantage of the shrubby one. Near the typical species of pinewoods grow more heliophilous species linked to thinner communities like *Carlina acaulis, Senecio abrotanifolius* and *Thymus polytrichus.* The average number of species rises to 40.

All these communities are similar to the association *Erico carneae-Pinetum prostratae* Zöttl 1951, with a particular reference to the subassociation *caricetosum humilis* Br.-Bl. 1939

RHODODENDRON HIRSUTUM-DOMINATED PINEWOOD. It is really different for the dominant role of *Rhododendron hirsutum* in the shrubby layer, for the scanty cover of *Vaccinium vitis-idaea* and for the low floristic richness (17 species) mainly due to the disappearance of the most thermophilous species. The herbaceous layer is sparse and dominated by heather only. This kind of vegetation can only be found on slopes facing northward and can be ascribed to the association *Rhododendro hirsuti-Pinetum prostratae* Zöttl 1951.

PINEWOODS GROWING ON SCREES. The presence of lithophilous species make these coenoses similar to the pioneer herbaceous ones growing on early developed soils. Two kinds of pinewoods can grow on screes: one is characterized by scrubby pines growing on young surfaces, and the other one represents a former pinewood buried by low energy debris flows. These communities have an uncertain syntaxonomic treatment and can be considered as a transition between *Athamanto-Trisetetum* and primary stages of *Erico-Pinetum*.

4.5.3.Grasslands (Tab. 4)

Grasslands are very rich in species (the average number of species per relevé is 52). The herbaceous layer is almost continuous but often not very thick, probably because of the low cover value of grasses (mainly *Festuca nigrescens* and *Sesleria varia*) compared to the rosette-shaped plants (*Plantago alpina*, *Cirsium acaule* and *Carlina acaulis*). Grasslands include the most acidophilous and the least xerophilous communities in the studied area and can be all regarded as pastures. Although all the grasslands share a high cover value of *Sesleria varia*, two main communities, growing on different substrata, can be distinguished; some transition stages can also be observed.

POA ALPINA AND *FESTUCA NIGRESCENS* GRASSLANDS. These communities grow on fan gravelly deposits and are the richest in species (up to 68 per relevé). Grasses and sedges (*Sesleria varia, Poa alpina, Festuca nigrescens, Carex sempervirens* and

Grasslands	***Poa alpina* and *Festuca nigrescens* grasslands**	***Cirsium acaule* and *Plantago alpina* grasslands**	***Carex flacca* regressive stage**	**Pine settling over grasslands**
N. of relevés	**4**	**2**	**1**	**1**
N. of species	**60**	**36**	**51**	**45**
Hippocrepis comosa	100	.	.	+
Agrostis stolonifera	100	.	.	.
Hieracium pilosella	100	.	.	.
Thymus polytricus	100	.	.	.
Thalictrum alpinum	100	.	.	+
Elyna myosuroides	100	.	+	.
Euphrasia salisburgensis	100	.	.	.
Anthyllis vulneraria alpestris	100	.	.	.
Senecio abrotanifolius	100	.	.	.
Carlina acaulis	100	.	.	.
Viola rupestris	100	.	.	.
Luzula multiflora	100	.	.	.
Carex ericetorum	75	.	.	r
Festuca quadriflora	75	.	.	+
Scabiosa lucida	75	.	.	.
Avenella flexuosa	75	.	.	.
Erigeron uniflorus	75	.	.	.
Plantago media	75	.	.	.
Minuartia verna	75	.	.	.
Aster alpinus	75	.	.	.
Leontodon autumnalis	75	.	.	.
Crepis alpestris	75	.	.	.
Euphrasia rostkoviana	50	.	.	.
Potentilla aurea	50	.	.	.
Euphrasia minima	50	.	.	.
Leucanthemum heterophyllum	50	.	.	.
Botrychium lunaria	50	.	.	.
Phyteuma orbiculare	50	.	.	.
Gentianella campestris	.	100	.	.
Prunella vulgaris	.	100	.	.
Carum carvi	.	100	.	.
Salix retusa	.	50	.	.
Taraxacum officinale	100	100	.	.
Crepis aurea	50	100	.	.
Hieracium auricola	50	50	.	.
Saxifraga caesia	.	.	r	.
Salix glabra	.	.	+	.
Salix waldsteniana	.	.	+	.
Gymnadenia conopsea	.	.	+	.
Kobresia simpliciuscula	.	.	+	.
Salix reticulata	.	.	+	.
Vicia cracca	.	.	+	.
Tussilago farfara	.	.	+	.
Trichophorum pumilum	.	.	+	.
Hieracium sylvaticum	.	.	+	.
Leontopodium alpinum	.	.	r	.
Plantago alpina	.	100	1	.
Carex caryophyllea	.	50	+	.
Pedicularis verticillata	.	.	.	1
Erica carnea	.	.	.	1
Carex ornithopoda	.	.	.	+
Carex digitata	.	.	.	+
Hieracium tenuiflorum	.	.	.	r
Moneses uniflora	.	.	.	r
Bartsia alpina	.	.	.	r
Festuca puccinellii	.	.	.	+
Koeleria eriostachya	.	.	.	r
Homogyne alpina	.	.	.	+
Dryas octopetala	.	.	+	+
Juniperus nana	.	.	r	+
Pinguicola alpina	.	.	+	+
Pinus montana	.	.	1	3
Equisetum variegatum	.	50	+	+
Gentiana clusii	.	50	+	+
Carex flacca	.	100	2	+
Gymnadenia odoratissima	.	100	.	+
Tofieldia calyculata	.	50	+	+
Festuca nigrescens	100	100	1	1
Lotus alpinus	100	100	1	+
Cirsium acaule	100	100	1	+
Ranunculus gr. montanus	100	100	+	+
Campanula scheuchzeri	100	100	+	+
Galium anisophyllum	100	100	+	+
Briza media	100	100	r	.
Trifolium pratense nivale	100	100	+	.
Trifolium pratense pratense	100	100	+	.
Trifolium thalii	100	100	+	.
Sesleria varia	75	100	1	1
Achillea millefolium	75	100	+	.
Polygonum viviparum	75	100	+	+
Primula farinosa	75	100	+	+
Parnassia palustris	75	100	r	+
Leucanthemum vulgare vulgare	50	100	+	r
Potentilla erecta	50	100	+	+
Carex sempervirens	100	.	1	2
Poa alpina	100	.	+	1
Selaginella selaginoides	75	.	+	+
Aster bellidiastrum	75	.	1	1
Thesium alpinum	75	.	r	+
Polygala alpestris	75	.	+	+
Antennaria dioica	100	50	+	+
Gentiana verna	75	.	+	+
Helianthemum oelandicum	75	.	+	.
Salix serpillyfolia	75	50	1	1
Carex capillaris	75	50	+	.
Deschampsia caespitosa	75	50	+	.
Leontodon hispidus	75	50	.	+

Table 4 - Synoptic table of the grasslands. Even though *Androsace chamaejasmae* is widespread it is not present in the table because of its premature disappearance during the vegetative season.

Tabella sinottica dei pascoli. Nonostante la diffusa presenza, Androsace chamaejasmae *non compare nella tabella per via della sua precoce scomparsa durante la stagione vegetativa.*

Elyna myosuroides) have very high cover values. Some species (e.g. *Luzula multiflora, Elyna myosuroides* and *Avenella flexuosa*) show a soil acidification and/or an accumulation of organic matter. These coenoses can be included in the class *Seslerietea albicantis* Oberd. 1978 corr. Oberd. 1990 (Mucina *et al.*, 1993) and probably be referred to *Seslerieto-Sempervíretum* Br.-Bl. 1926 (alliance *Seslerion coeruleae* Br.-Bl. in Br.-Bl. & Jenny 1926). However, species belonging to different syntaxa (in particular the acidophilous taxa) can also be present thus making the syntaxonomic and synecological treatments difficult.

CIRSIUM ACAULE AND *PLANTAGO ALPINA* GRASSLANDS. These communities grow on the silty deposits in the *Val Paolaccia Unit*, have a lower floristic richness (30-40 species per relevé) and a less continuous structure, where grasses and sedges play a less important role. The dominant or significant species are *Cirsium acaule, Carex flacca* and *Plantago alpina*. The syntaxonomic classification is very difficult in this case, too.

Carex flacca regressive stage. Where the erosion prevails (see Fig. 8) grassland species are replaced by other species as *Tussilago farfara* and *Carex flacca*, which become dominant.

PINE SETTLED OVER GRASSLANDS. Even if these communities share many species with the grasslands of silty deposits, the sparse tree layer allows the pine wood species as *Erica carnea* to grow and causes the majority of the heliophilous grassland species to disappear.

5. ENVIRONMENTAL EVOLUTION OF THE UPPER VALLE DEL GALLO

5.1. Holocene evolution of the valley bottom

The oldest sediments cropping out on the valley bottom are lacustrine deposits belonging to the *Acqua del Gallo Unit*. The paleolake was buried by a coarsening-upward succession of clays, microturbidites, alluvial and deltaic deposits transported by the fans prograding from the tributary valleys (Fig. 12). The basin had already dried up before the middle Holocene (e.g. before 4710 ± 90 ^{14}C yr B.P.). This phase caused the formation of an ancient flat valley bottom (belonging to the *Valle della Casina Unit*) now representing inactive portions of some fans (Fig. 5; see par. 4.1); its southern part dates back at least to the Iron Age (2570 ± 70 ^{14}C yr B.P.), but it is probably much older (e.g. before 3910 ± 60 ^{14}C yr B.P.).

Later, the northern and southern sectors of the upper Valle del Gallo had a different evolution.

After eroding the northward lacustrine threshold, creek Acqua del Gallo started an intense regressive erosion process which at first affected the northern sector of the valley (Fig. 12). This caused the formation of deep gorges (up to 50 m) in the fans of Val Mora and Valle della Casina (and locally in the bedrock), and the dismantling of wide portions of the fans of Val Bruna and “Valle del Pizzo Aguzzo”, what isolated some still existing parts of the original valley bottom (Fig. 5; see par. 4.1). Yet a series of important flooding phases temporary interrupted the erosion process at least since the Copper Age (3910 ± 60 ^{14}C yr B.P.) as testified by the *Val Bruna Subunit* which is embanked in the valley bottom (Figs. 5-12-13). The subunit is intercalated by buried soils documenting that it formed in successive stages, separated by significant phases of stability and some changes in the erosion direction of creek Acqua del Gallo (see terrace (H) in Fig. 13).

The southern sector of the studied area (Fig. 12) was not dissected by erosion until recent years. For this reason, a thick succession of fine deposits originated by sheetfloods (*Val Paolaccia Unit*) accumulated among the coalescent fans of Valle della Casina, “Valle del

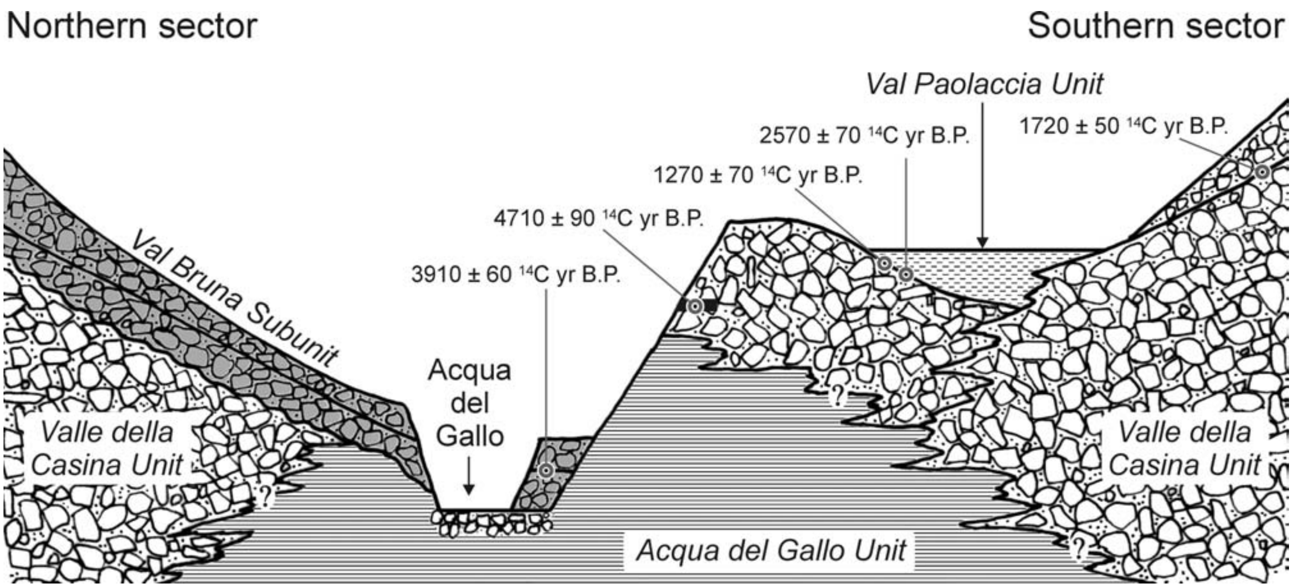

Fig. 12 - Stratigraphic relations of the upper Valle del Gallo. An ideal profile was used to show the different units at the same time.

Schema dei rapporti stratigrafici dell’alta Valle del Gallo. È stato impiegato un profilo ideale per mostrare contemporaneamente le diverse unità.

Pizzo Aguzzo" and Val Paolaccia. Depositional events, which were originally very frequent, prevented the settlement of vegetation (see section 2 in Fig. 9 and Appendix I; see par. 4.2.3).

Meanwhile, the regressive erosion extended southward along the river bed of Acqua del Gallo isolating distal portions of some fans (e.g. under the Val Mora road for the Valle della Casina fan). In the Middle Ages (1270 ± 70 ^{14}C yr B.P.) it reached the *Val Paolaccia Unit*, favouring the drainage and the reduction of the sedimentation rate. Therefore Fluvisols started to develop together with a kind of vegetation suitable to adapt to frequent burials (*Cirsium acaule* and *Plantago alpina* grasslands) the features of which show the persistence of vegetation during aggradation.

Only some parts of the fan surfaces were affected by these changes in the sedimentary activity and in the vegetation. Other portions of the fans were still under an active aggradation. The formation of the middle part of the Valle della Casina fan went on at a high rate, at least till the late Roman Age (1720 ± 50 ^{14}C yr B.P.; Fig. 14, Tab. 1), when a phase of morphologic stability caused the formation of a soil (buried soil in section 5, Figs. 6-14). Since the Middle Ages, debris flows were instead mostly localized close to the fan apex (see buried soils in section 6, Figs. 6-14; see par. 5.2) and along the main channel (A in Fig. 6), its ramification (B, C, G) and the adjoining sectors (E, F, D), while its most distal part was isolated by the downcutting formed by the main channel, under the Val Mora road.

Therefore, on the whole, since the Middle Ages, the regressive erosion of the valley bottom is responsible for the general stabilization of many surfaces, since debris flows which were locally canalised can no more spread on the entire fan surface.

5.2. Recent evolution of the Valle della Casina fan

The dendrochronological reconstruction of the debris flow sequence in the Valle della Casina (Fig. 11) begins at the end of the 19th century because of the young age of the trees. The presence of young forests (100-200 years old) is probably due to the drastic deforestation which occurred over past centuries. The most ancient dated event happened in 1888 and involved area (F) besides the channels and area (E) (Fig. 15), where it covered a part of the fan surface currently exposed downhill. Later debris flows (in 1927-29 and in 1936-41) interested this area only marginally (Fig. 15). The most recent episodes were mostly confined to the main channel (A), where they affected the margin of area (F), and to the secondary channels (B) and (C). The 1978 debris flow represents the most intense episode during which a new channel developed (G in Fig. 6). The event, which occurred in 1986, formed the upper part of the terrace (D) (see Fig. 14).

The main channel (A) of the Valle della Casina fan constitutes the course of normal drainage, with a maximum capacity able to contain the smaller flows (e.g. 1964 and 1992), the traces of which (damaged trees and terraces) are only visible along the margins. Below Val Mora road, scarps border the main channel so in the lower part of the fan the flows do not have any direct effect outside the river bed and can reach the river Acqua del Gallo. When the flows exceed the maximum flow rate in the main channel, the secondary channels

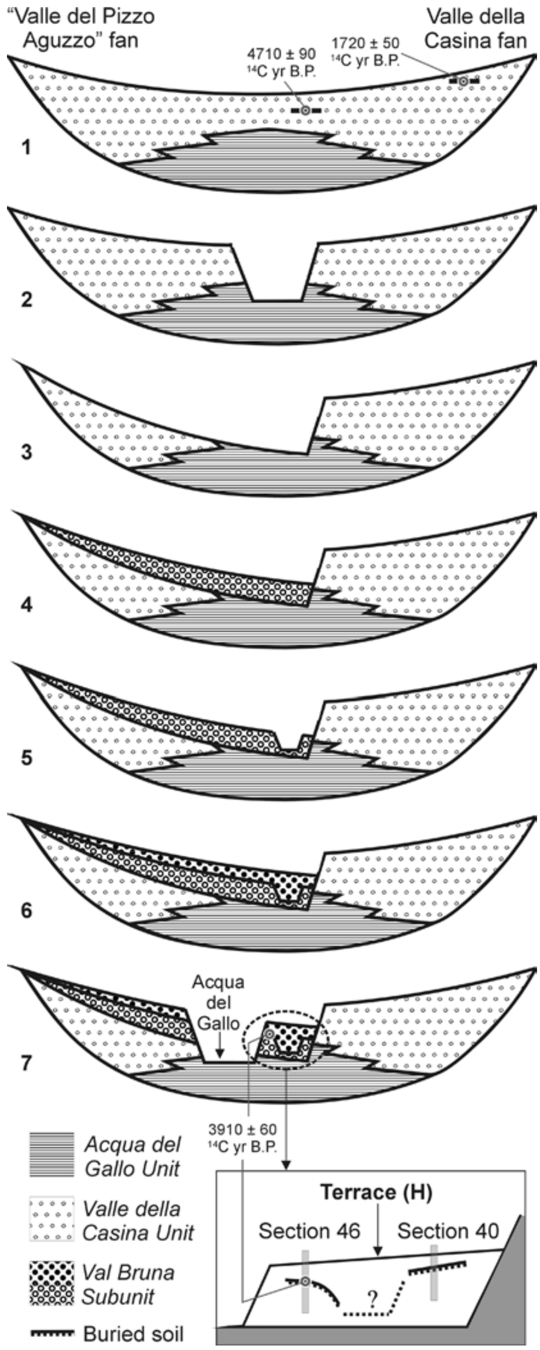

Fig. 13 - Hypothetical succession of events that originated the *Val Bruna Subunit* and the terrace (H): 1) ancient post-lacustrine valley bottom; 2) first downcutting phase by the river Acqua del Gallo; 3) dismantlement of a part of the "Valle del Pizzo Aguzzo"fan; 4) formation of a new portion of the "Valle del Pizzo Aguzzo" fan; 5) second downcutting phase by the river Acqua del Gallo; 6) new flooding on the "Valle del Pizzo Aguzzo" fan; 7) present downcutting by the river Acqua del Gallo and separation of the terrace (H).

Ipotetica successione di eventi che avrebbe dato origine alla Sottounità della Val Bruna *e al terrazzo (H): 1) antico fondovalle post-lacustre; 2) prima fase di incisione da parte dell'Acqua del Gallo; 3) smantellamento di parte del conoide della "Valle del Pizzo Aguzzo"; 4) costruzione di una nuova porzione del conoide della "Valle del Pizzo Aguzzo"; 5) seconda fase di incisione da parte dell'Acqua del Gallo; 6) nuova fase di alluvionamento del conoide della "Valle del Pizzo Aguzzo"; 7) incisione attuale dell'Acqua del Gallo e separazione del terrazzo (H).*

(B) and (C) are involved. Trees slacken these lateral flows that can spread to larger surfaces, hence they do not reach the river Acqua del Gallo (e.g. 1927-29, 1953, 1959 and 1978). Exceptional flows can sometimes form new courses when they exceed also the maximum flow rate of the secondary channels. In 1978 channel (G) originated in this way. The subsequent restoration of the main channel banks made the lateral channels inactive again.

5.3. Relations between soil and vegetation and dynamic of the ecological succession

Soils and vegetation of the upper Valle del Gallo are, in general, scarcely developed. This is probably due to five principal causes: the relatively recent age of those areas subjected to pedogenesis; the periodic burial affecting some areas; the climatic restriction due to low temperature and scanty rainfall; the effects of human deforestation during the last millennium; the extent of areas subjected to an intense soil erosion.

The relations between plant communities and soils allow us to make some considerations. Pioneer litophilous communities grow only on Calcari-Hyperskeletic Leptosols. Pinewoods do not show soil more developed than Leptosols, even at their most advanced stages. The stage characterized by the presence of cowberry on the *Carex humilis* and *Sesleria varia*-dominated pinewoods occurs on Humi-Rendzic Leptosols (Calcaric); these soils locally grow under less developed vegetation together with Calcaric and Calcari-Humic Leptosols. The presence of a Cambisol under a regressive stage of the *Carex humilis* and *Sesleria varia*-dominated pinewood suggests that pinewoods growing on Skeleti-Calcaric Cambisols are the most developed situation found on the fans (a higher evolution degree concerning the woody vegetation can be found only locally on the slopes, out of the fans).

Grasslands show a close relation between plant communities and soil typologies. For example *Cirsium acaule* and *Plantago alpina* grasslands only occur on Calcaric Fluvisols while *Poa alpina* and *Festuca nigrescens* grasslands develop only on Leptosols or locally on Cambisols with a moderate degree of decarbonatation as suggested by the presence of some acidophilous species (see par. 4.5.3.).

It is now possible to outline the dynamic succession of soil and vegetation. Surfaces formed by different sedimentation and erosion processes are progressively colonized by vegetation and are subjected to pedogenesis as they become sufficiently stable. The ecological succession occurs on two kinds of substrate, both carbonatic, different in the grain size and originated by two sedimentary processes: gravel with a sandy matrix deriving from debris flows (*Valle della Casina Unit*); silts and fine sands without skeleton deriving from sheetfloods (*Val Paolaccia Unit*). A third subordinate kind of parent material is constituted by coal masses from charcoal pits.

The dynamic succession on a gravelly substrate (Fig. 16) starts with plant communities collected in the *Athamanto-Trisetetum* grown on Calcari-Hyperskeletic Leptosols. Under geomorphological stability, a pine scrub settles and discontinuous mosaic-like horizons O and A grow up connected with pioneer vegetation. The further soil evolution involves an increase in the fine fraction and the development of a thin horizon A (Calcaric Leptosols). When the mass of organic matter and the decarbonatation become significant, soils pass to a stage of Calcari-Humic Leptosols, existing until a mollic horizon develops (Humi-Rendzic Leptosols (Calcaric)). Locally a Bw horizon sometimes evolving

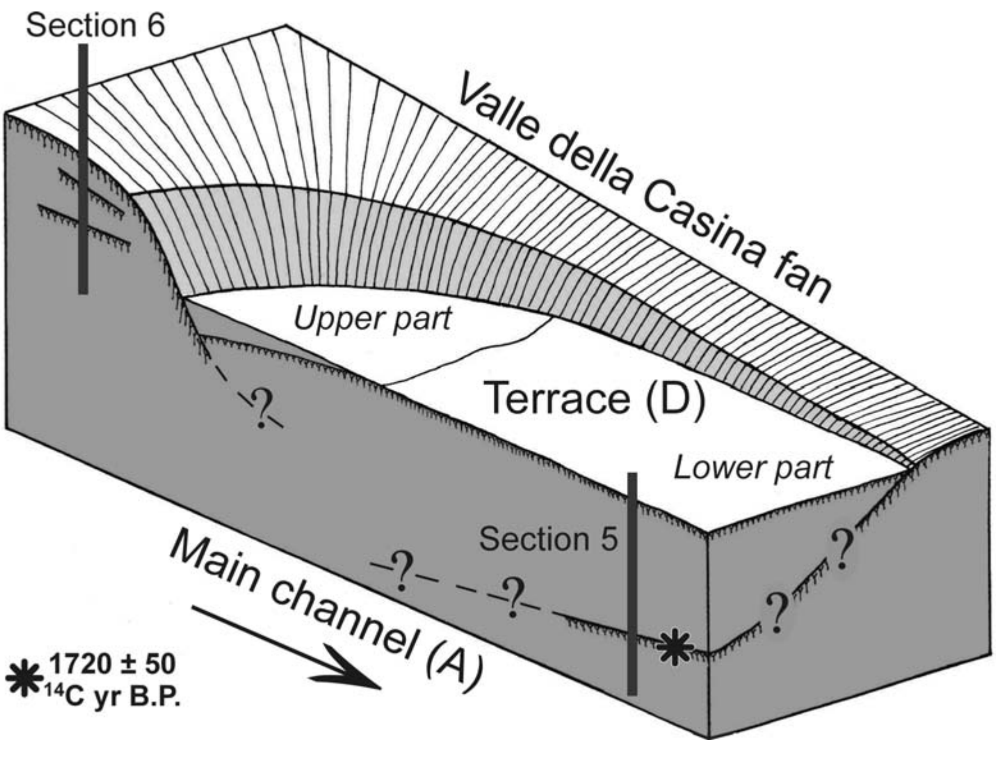

Fig. 14 - Block-diagram of the hydrographic left side of the main channel (A in fig. 6) of the Valle della Casina fan showing the position of sections 5 and 6 and of the buried charred wood (star) dated 1720 ± 50 ^{14}C yr B.P. (Tab. 1).

Block-diagramma del lato sinistro idrografico del canale principale (A in Fig. 6) del conoide della Valle della Casina che mostra la posizione delle sezioni 5 e 6 e del tronco carbonizzato sepolto (asterisco) datato 1720 ± 50 anni ^{14}C B.P. (Tab. 1).

into a cambic horizon (Skeleti-Calcaric Cambisols), can originate. At the same time the development of vegetation brings about an increase in the number of species and in the ground cover until *Carex humilis* and *Sesleria varia*-dominated pinewoods develop, where the first acidophilous species appear. The progressive acidification of the upper horizons causes an increase in the acidophilous species, the decrease in the basiphilous ones and an increase in the tree layer and in the *Erica carnea* cover, until the species richness decreases to the advantage of *Vaccinium vitis-idaea* (the cowberry-dominated stage). The latter is the most developed stage of vegetation found, which probably took place after a few hundred years. The *Rhododendron hirsutum*-dominated pinewood is mainly limited to the northward exposure.

All the remaining vegetation typologies represent regressive stages or secondary vegetation. The burial caused by debris flows brings the pine-forest back to *Athamanto-Trisetetum* with a tree layer; this is probably susceptible to a rapid development due to the litter supplied by the tree cover. The surface soil erosion makes the succession regress to less developed stages because of the removal of the upper horizons and the progressive crop out of parent material; the pine-forest is thinned out and the number of heliophilous species increases. On the contrary grasslands are to be considered as secondary vegetation deriving from pine-forests deforestation.

The ecological succession on a silty substrate (Fig. 16) is periodically interrupted by centimetric burials caused by sheetfloods. However, the soil evolution is connected to the frequency of burial episodes, depending on the closeness of the downflow direction. Soils are Calcaric Fluvisols, periodically rejuvenated, without a meaningful decarbonation and an organic matter accumulation. The vegetation dynamics stops to a stage of blocked evolution (*Cirsium acaule* and *Plantago alpina* grasslands). The morphological attributes of the dominating species indicate that this community seems to "float" on a substrate in periodic aggradation; in fact *Carex flacca* is a stoloniferous plant while *Plantago alpina* and *Cirsium acaule* develop tap-roots up to 50-cm long. This reaction of the vegetation causes the common radical pedoturbation. On the contrary, where erosion is intense, substitution communities prevail (*Carex flacca* regressive stage).

Whenever grasslands disappear *Pinus montana* forms a tree layer again.

6. CONCLUSION

During the Holocene, the upper Valle del Gallo experienced a series of intense transformations that progressively and quickly transformed the environmental setting that became established after the retreat of the würmian glaciers. Complex and still unclear erosive and depositional cycles of glacial origin formed thresholds that originated a lake, although this is a pass zone, where outflows should therefore have been facilitated. Environments originally poor or without vegetation, supplied an ideal substrate for the weathering and denudation processes of the slopes, originating huge amounts of debris that water could easily mobilize and transport to the lacustrine basin. Its width and depth favoured a pelagic terrigenous sedimentation, than in a few thousand years progressively evolved into an alluvial and deltaic environment characterized by shallow water and finally a terrestrial environment dominated by fans mostly formed by debris flow processes. Vegetation adapted finding a balance with the environmental dynamics, characterized by a high instability of the slopes causing erosion and covering processes that often determine ecological situations with a blocked or slowed down evolution. The valley setting was finally modified by human action.

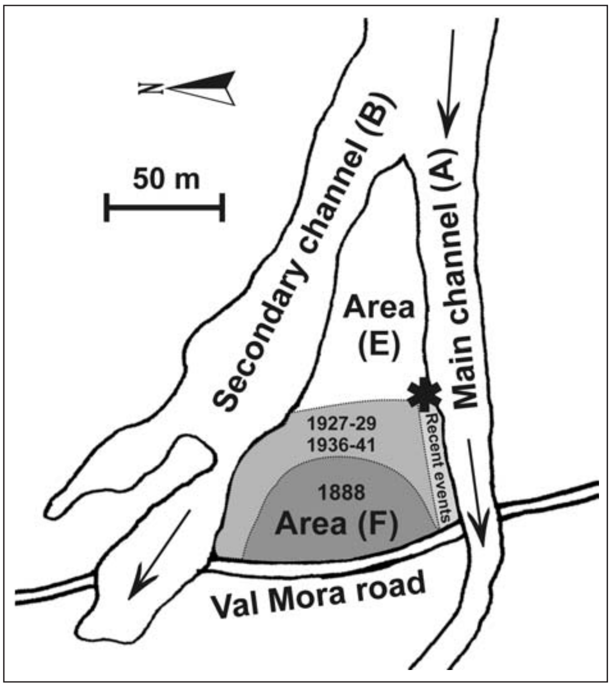

Fig. 15 - Scheme showing area (F) and the different age sections composing it. Below this area a buried soil (section 19 in Fig. 6) and a buried stump in position of life were found (star) (Santilli & Pelfini, 2002).

Schema mostrante l'area (F) e le porzioni di differente età che la costituiscono. Sotto quest'area è stato inoltre trovato un suolo sepolto (sezione 19 in Fig. 6) e un tronco sepolto in posizione di vita (asterisco) (Santilli & Pelfini, 2002).

Because of the complexity and the interaction of the various ecological components, the study of this kind of environment necessarily demanded an interdisciplinary approach. The several methods used span various temporal intervals and space scales and have different resolution power, but each of them contributed in an effective way to explain every single aspect of the environmental evolution of the examined territory, allowing the final integration and synergy of the different results obtained. This route forms in a more and more detailed way for the recent times: the geomorphological and stratigraphic researches, allowed us to reconstruct the main evolutionary stages of the whole territory during the Holocene and to identify some factors controlling the ecological successions; the study of the soils and vegetation has allowed us to clarify the relations existing between the various environmental components and the adaptations to the dynamics of the geomorphological and sedimentary processes occurred during relatively recent times; finally, the dendrogeomorphological study has allowed us to know the precise dating and the extent of every single debris flow that, starting from the end of the 19th century, affected one of the fans.

The environmental complexity of the upper Valle del Gallo must be deepened further on. In spite of the great amount of data and information collected up to now, new stratigraphic sections, especially relevant to the lacustrine succession, would be necessary since they could clarify the valley evolution starting from the Late-glacial period and the influence of the successive alternate phases of climatic deterioration and improvement; further surveys should concern the taxonomic position of the mountain pine, the widespread superficial erosion of pinewoods and the important role of the anthropic influence, which has been up to now only partially documented.

We want to emphasize the importance of an integrated approach of different disciplines to the studies on the environment. The efforts necessary to carry out interdisciplinary studies often must be restricted to small areas; however starting from local events it is possible to make comparisons and to extrapolate results that can refer to bigger areas or be applied on a regional scale.

Researches carried out up to now constitute therefore a good starting point for the study of the peculiar environment of the Vale del Gallo, to which an elevated naturalistic value to be preserved and exploited is acknowledged.

The research has been carried out with the co-financing of MURST-COFIN 40%-1999 - project: Movimenti di massa come indicatori di cambiamenti climatici dal Tardiglaciale ad oggi. National responsible Prof. M. Panizza, local responsible Prof. G. Orombelli.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. G. Orombelli of the University of Milano-Bicocca, for the critical revision of the manuscript, the *Parco Nazionale dello Stelvio* for authorising researches in its territory and *AEM Milano* for supplying the climatic data.

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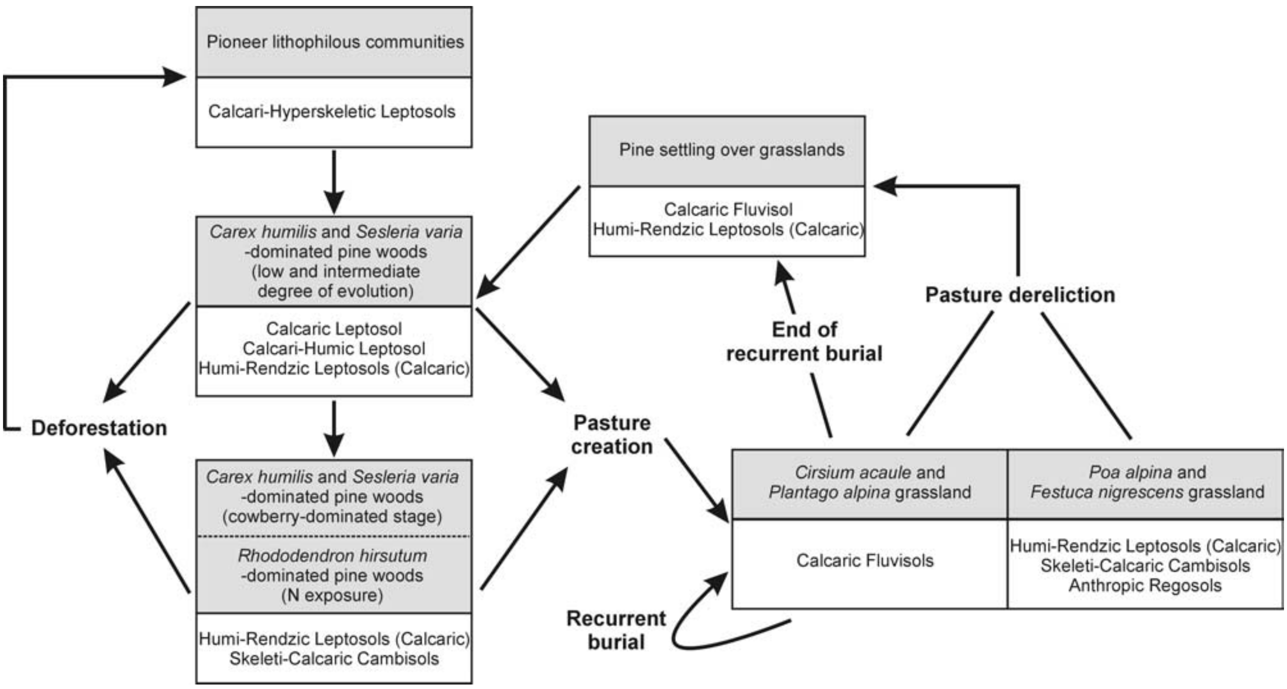

Fig. 16 - Vegetation and soil dynamic in the upper Valle del Gallo (Regosols are not represented since they belong to point-shaped soils of anthropic origin not connected to the other typologies).

Dinamica della vegetazione e del suolo in alta Valle del Gallo (sono stati tralasciati i Regosols, poiché legati a situazioni puntiformi di origine antropica non relazionate con le altre tipologie).

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APPENDIX I (DESCRIPTION OF THE STRATIGRAPHIC SECTIONS)

Section 3 - Acqua del Gallo Unit (Fig.7). From the bottom upwards:

0-2,5 m: grey (2,5Y 5/1) and brown (10YR 5,5/3) clayey deposits with a flat parallel lamination, made of thin massive clay laminas, less than 1-mm to 3-mm thick, alternating with subordinate silty clay and silt levels. Very fine grey and well sorted sand laminas are widespread too;

2,5-4,5 m: deposits mostly clayey and laminated, yellow reddish and analogous to the previous ones, but showing on average thicker laminas. Locally deposits loose this flat parallel lamination and sediments assume a "mottled" aspect due to the different colors according to the grain size

4,5-5 m: centimetric layers with a flat parallel lamination mainly composed of brown clay laminas and subordinate intercalations of silt and very fine grey sands;

5-5,8 m: dark grey sand layer, the structure of which alternates between middle-sized and fine sands in a wavy parallel lamination, with subordinate millimetric grey-brown silty levels. In the upper part a layer with a low-angle cross lamination can be observed, then assuming a climbing style and gradually reconstituting the wavy parallel lamination and then again the flat parallel one;

5,8-8 m: laminated deposits mostly clayey, brown reddish, with subordinate intercalations of very fine sands 2,5Y 5/2;

8-12 m: in this layer the first gravel levels can be found. These deposits tend to have a normal gradation layer, some-centimetres to 1-2-decimetres thick. Each layer is composed at its base of variable thickness centimetric levels of fine and middle-sized gravel with loose centimetric clasts in clear contact, often of erosive type, on the underlying finer sediments; towards the top the layer structure gradually passes to grey middle-sized and fine sands, to silt and brown reddish silty clay, in a wavy subparallel lamination at intervals little evident;

12-15,5 m: centimetric alternations of fine sands, middle-sized sands, gravelly sands and gravel with subordinate silty levels that, quantitatively, tend to reduce towards the top;

15,5-18,5 m: unselected gravelly and clast-supported sediments alternated with lens and intercalations of sands and silt sometimes containing gravel with matrix support (sometimes reddish). A rough stratification, locally passing to a cross stratification, can be observed;

18,5-22 m: proceeding towards the top unselected gravel sediments with a clastic support without sedimentary structures gradually become prevalent. At the top of the scarp there is a soil (Humi-Rendzic Leptosols (Calcaric)).

Section 39 - Val Paolaccia Unit (Fig. 9) - Sequence of silt and sand deposits lacking in skeleton, organised in little differentiated sedimentary sublevels and laying upon a buried soil developed on the underlying gravel.

+1-0, 0-1 cm: horizon O (Oi + Oe);

1-7 cm: horizon A, light grey 2,5Y 5/2, with a silty loam texture and a little marked fine granular structure; numerous plant remains, many thin and middle-sized roots, a clear wavy boundary, and a high effervescence. Analytical data: pH 7,8, organic C 24,8 g/kg;

7-18 cm: horizon C composed of massive grey sands, 2,5Y 5/2, with brown variegations,10YR 4/2, woody subhorizontal roots up to 1 cm in diameter;

18-37 cm: middle-sized to fine sands as above, well selected, but with a dark brown tonality and a clear wavy boundary; little coal fragments are widespread at the base;

37-49 cm: middle-sized grey sands with thin discontinuous brown lens including coal fragments; coal remains are scattered inside the level, too;

49-53 cm: yellow-ochre sandy silt; clear boundary;

53-57 cm: middle-sized to fine brown-grey sands with an evanescent lamination and a clear lightly wavy boundary; sparse coal fragments;

57-60 cm: horizon Ab, brown 10YR 3/2, with a poor skeleton, a well marked fine granular- polyedric subangular structure, a silty loam texture, thin and middle-sized common roots, a wavy abrupt boundary and a high effervescence. Analytical data: pH 8,0, organic C 34,3 g/kg. This buried soil dates back to 1270 ± 70 ^{14}C yr B.P. (Tab. 1);

60-65 cm: horizon C_1' composed of incoherent gravel with clasts up to 10 cm with the support of a sandy middle-sized to coarse matrix and fine gravel, grey brown 10YR 5/3, with very thin common roots, a gradual wavy boundary, a high effervescence and unaltered or only lightly altered pebbles;

65-95 cm: rough stratified gravel alternating between clastic support and matrix support up to 10 cm big, with a coarse sandy matrix, subangular pebbles, sometimes subrounded. The horizon shows a reddish matrix and reddish patinas on pebbles that at some levels form rather wide pellicles. Roots are absent.

95-250 cm: fine gravel with matrix support alternating with sand lens lightly altered; in this case too the matrix of the gravelly levels shows reddish patinas that harden the sediment.

Section 49 - Val Paolaccia Unit (Fig. 9) - Sequence of sandy and silty deposits lacking in skeleton, organised in sedimentary differentiated sublevels and laying upon a buried soil developed on the underlying gravel.

0-10 cm: horizon A, dark brown, having a weakly marked fine granular structure, a sandy loam texture, abundant roots and a clear wavy boundary;

10-30 cm: bioturbated massive fine sands, light grey with ochre tones, 2,5Y 5/2;

30-33 cm: grey middle-sized to fine sands;

33-40 cm: yellowish silty fine sands, 2,5Y 5/2, having a weakly marked fine polyedric subangular structure and sparse thin roots;

40-45 cm: middle-sized laminated and well selected sands, 2,5Y 4/2;

45-51 cm: sandy silt with fine sand, brown-yellowish, 2,5Y 5/3;

51-56 cm: middle-sized to fine laminated yellowish sands, 2,5Y 5/2;

56-66 cm: massive fine sands with a weakly marked lamellar structure, grey, 2,5Y 4/2, with sparse roots and a clear boundary;

66-75 cm: fine sand sandy silt, yellow-brown, 10YR 5/3, having a moderately marked middle polyedric-lamellar structure;

75-93 cm: yellowish fine sand sandy silt, 2,5Y 5/3, having a weakly marked polyedric-lamellar structure;

93-101 cm: grey middle-sized sands, 2,5Y 4/2;

101-123 cm: weakly sandy silt with fine sand, with colors zoned between yellow and yellow-brown, and a very weakly marked lamellar structure;

123-129 cm: middle-sized grey sands; clear boundary;

129-140 cm: yellow-brown weakly sandy silt with fine sand, a weakly marked lamellar structure and a clear boundary;

140-145 cm: horizon Ab 10YR 4/3, with a well marked middle polyedric angular structure, a clayey silty loam texture, a high effervescence, a poor skeleton on the surface, more abundant at the base of the horizon, where it gradually passes to the underlying horizon. Analytical data: pH 8,0, organic C 28,5 g/kg. This buried soil dates back to 2570 ± 70 14C yr B.P. (Tab. 1);

145-160 cm: altered gravel in a sandy matrix 10YR 5/4 altered too; patinated pebbles altered on the surface, patinas having the same color as the soil, little marked fine granular structure.

Section 2 - Val Paolaccia Unit (Fig. 9) - Sequence entirely composed of sandy and silty fine deposits, without skeleton, organised in sedimentary sublevels. The first 90 cm differ from the remaining part because of the presence of buried horizons and organic matter.

0-10 cm: horizon AC little pedogenized composed of grey massive fine sands, 10YR 5/1,5, with very poor roots and a wavy boundary;

10-14 cm: horizon Ab composed of silty sands 10YR 4/2, having a moderately marked middle-sized to fine polyedric structure and thin sparse roots;

14-18 cm: massive grey fine sands 10YR 5/1; clear wavy boundary;

18-26 cm: horizon Ab' composed of fine silty sands 10YR 4/2, with brown variegations explainable as the result of radical bioturbations; well marked middle-sized to fine polyedric structure, with sparse roots, sometimes woody too, with a subhorizontal course, an irregular boundary with pedoturbation of biological origin going down to the underlying levels (up to 60 cm);

26-30 cm: massive grey fine sands as above, 10YR5/1, with a light wavy boundary;

30-34 cm: horizon Ab'' composed of lightly silty fine sands 10YR 4,5/2, with a weakly marked middle-sized to fine polyedric structure and a lightly wavy boundary;

34-39 cm: lens of grey sand as above, 10YR 5/1;

39-46 cm: horizon Ab''' composed of fine silty sands 10YR 4,5/2, with a weakly marked medium-sized granular structure and a clear wavy boundary; presence of partially decomposed needles;

46-70 cm: grey massive fine sands, alternating with fine silty-sandy ochre levels, subhorizontal and lightly wavy; clear boundary;

70-90 cm: ochre-yellowish massive sandy silt 2,5YR 5/3, with variegations composed of small but long empty spaces sometimes filled with decomposing dark roots; in the upper part a dark brown level rich in very little coal fragments (71-72 cm) and an ochre level with sporadic millimetric coal fragments (72-77 cm) can be observed;

90-400 cm: yellowish sandy silt alternating with subordinate centimetric levels of mainly massive grey silty fine sands, with little clear-cut lamination; locally (about 130 cm) there are laminas with a normal gradation. It is a monotone succession, totally lacking in organic elements. Pedogenized buried horizons have not been identified. Between 200 and 400 cm sparse little shells of gastropods can be found.

Ms. ricevuto il 23 ottobre 2001
Testo definitivo ricevuto il 10 settembre 2002

Ms. received: October 23, 2001
Final text received: September 10, 2002