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# PARAGLACIAL SEDIMENTATION IN THE PIAVE VALLEY (EASTERN ALPS, ITALY): AN EXAMPLE OF FLUVIAL PROCESSES CONDITIONED BY GLACIATION

ABSTRACT: SURIAN N. & PELLEGRINI G.B., *Paraglacial sedimentation in the Piave Valley (Eastern Alps, Italy): an example of fluvial processes conditioned by glaciation.* (IT ISSN 0391-9838, 2000).

The effects of the last glaciation (Würm) on fluvial processes in an alpine basin (Piave Basin, Eastern Alps) are discussed in this paper. The Piave Basin was completely glaciated during the last glaciation which reached the maximum expansion in the Alps 18,000-20,000 years BP. On the basis of radiometric datings and archaeological data, it can be argued that the deglaciation phase, which began 15,000-16,000 years BP, was relatively rapid. During and after deglaciation a long sedimentation phase (mainly fluvial, but also lacustrine) took place in the Piave valley; this phase ended 8,000-9,000 years BP and was followed by an incision phase with formation of terraces.

Sedimentation processes characterised stream channels for a long period of time (about 5,000-6,000 years) after deglaciation. During this period (Late Glacial-Early Holocene), the rate of sediments delivered to streams was much higher than during «normal» conditions (like the present ones), whereas stream flows were likely not so different. It is therefore recognised that the influence of a glaciation on a fluvial system is not restricted to deglaciation period, but it regards a longer period during which a disequilibrium exists between sediment supply to river channels and stream power.

It is proposed that the term «paraglacial» could be used in this area and, eventually, in other alpine areas. This term is more suitable than the term «kataglacial» to describe those processes which characterised the transition from a glacial to a non glacial period.

KEY WORDS: Paraglacial processes, Würmian glaciation, Climatic changes, Piave River, Eastern Alps.

RIASSUNTO: SURIAN N. & PELLEGRINI G.B., *Sedimentazione paraglaciale nella valle del F. Piave (Alpi Orientali): un esempio di processi fluviali condizionati da una glaciazione.* (IT ISSN 0391-9838, 2000).

Vengono esaminati gli effetti dell'ultima glaciazione (Würm) sui processi fluviali di un corso d'acqua alpino, il Fiume Piave (Alpi Orientali). L'analisi di tali effetti è significativa per comprendere la risposta dei processi fluviali ad una variazione climatica, nel caso specifico la transizione da un periodo glaciale ad un periodo non-glaciale.

Il bacino del Piave fu completamente glacializzato durante l'ultima glaciazione che ebbe nelle Alpi la sua massima espansione 18.000-20.000 anni BP. Datazioni radiometriche e ritrovamenti archeologici, indicano che la fase di deglaciazione, che iniziò 15.000-16.000 anni BP, fu relativamente rapida. Con il ritiro del ghiacciaio, la valle del Piave fu interessata da una prolungata fase di aggradazione (prevalentemente fluviale, ma anche lacustre) del fondovalle, seguita da una fase di prevalente incisione. Lo studio dei terrazzi e dei conoidi in un esteso tratto della valle ha consentito di ricostruire l'evoluzione del fondovalle dal Tardiglaciale ad oggi ed ha messo in evidenza che la fase di aggradazione ha avuto termine all'inizio dell'Olocene (8.000-9.000 anni BP).

Processi di sedimentazione hanno quindi interessato i corsi d'acqua per un periodo di tempo relativamente lungo (circa 5.000-6.000 anni) dopo il ritiro dei ghiacciai da quest'area. Questa lunga fase di sedimentazione è imputabile all'elevata attività dei processi di versante, condizionata anche dalla grande diffusione di materiale facilmente erodibile (in particolare depositi glaciali) e dalla presenza di scarsa copertura vegetale sui versanti. Durante questo periodo, Tardiglaciale-inizio Olocene, la quantità di sedimenti convogliati ai corsi d'acqua era decisamente maggiore di quella che viene convogliata nelle condizioni climatiche attuali, mentre i deflussi dei corsi d'acqua, probabilmente, non differivano in modo sostanziale da quelli attuali. La presente ricerca evidenzia quindi come l'influenza di un ghiacciaio su un sistema fluviale non si limiti alla fase di deglaciazione ma interessi un periodo più lungo (ma variabile da un bacino ad un altro) durante il quale esiste nel sistema fluviale un disequilibrio tra il materiale convogliato ai corsi d'acqua e la capacità di trasporto dei corsi d'acqua stessi.

Si suggerisce che il termine «paraglaciale», già adottato in altre regioni (ad esempio Canada, Antartide, Himalaya), possa essere utilizzato in quest'area, ed eventualmente in altre aree alpine. Tale termine risulterebbe più appropiato rispetto ad altri introdotti in passato, come ad esempio quello di «cataglaciale», per descrivere la risposta dei processi geomorfologici ad un'importante variazione climatica, ed in particolare la transizione da un periodo glaciale ad uno non-glaciale.

TERMINI CHIAVE: Processi paraglaciali, Glaciazione Würmiana, Variazioni climatiche, Fiume Piave, Alpi Orientali.

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## INTRODUCTION

This paper describes the effects of the last glaciation (Würm) on fluvial processes in an alpine area. The study area is the Piave valley (Eastern Alps) which was completely glaciated during the last glaciation. In this valley, like in many other formerly glaciated valleys, sedimentation processes took place after the retreat of the glacier, followed by a phase of incision with formation of terraces. The primary objectives of this study are: (1) to reconstruct the processes that took place after the retreat of the Piave glacier, in particular defining the beginning and the end of the sedimentation phase; (2) to explain the changes in fluvial processes in terms of control variables (flows and sediment supply).

In a previous study (Surian, 1996), one of the author of this paper already expressed the need for a revision of existing models on the response of alpine streams to climatic changes (Tongiorgi & Trevisan, 1941; Trevisan, 1946). In this study the concept of «paraglacial», initially introduced by Church & Ryder (1972) and then used also by other authors (e.g. Jackson & *alii*, 1982; Brazier & *alii*, 1988; Ballantyne & Benn, 1996; Fitzsimons, 1996; Harrison & Winchester, 1997; Owen & Sharma, 1998), will be discussed to see if it may provide a valuable framework for explaining landscape response to deglaciation and Lateglacial - Holocene landscape evolution in the Italian Alps.

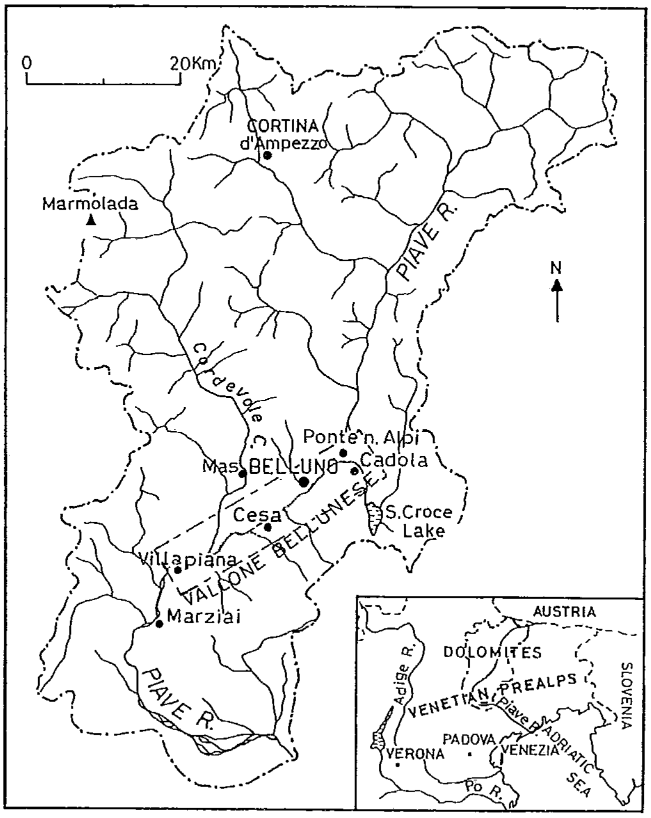


FIG. 1 - Location map of the Piave Basin and of the study area.

## GENERAL SETTING

The Piave Basin is located in the Eastern Alps (fig. 1) and has an area of 3,899 km$^2$. The basin, which belongs to the Dolomites (upper part) and to the Venetian Prealps (lower part), is mainly composed of sedimentary rocks (prevalently limestones and dolomites). In this region tectonic is active and the Venetian Prealps, in particular, are one of the most active areas of the Northeastern Italy (Zanferrari & *alii*, 1982; Slejko & *alii*, 1987). Tectonic uplift in the Piave Basin was estimated around 1 mm/year or more (Pellegrini & Zanferrari, 1980; Balestri & *alii*, 1988).

The study area is the Vallone Bellunese (fig. 1), which is a wide longitudinal valley where the sedimentation and incision phases that took place during the Lateglacial and the Holocene are well preserved. This valley belongs to the lower part of the Piave Basin and it can be seen as a transition zone between the upper part of the basin and the Venetian plain. In normal conditions, this reach of the Piave valley should fall, using the subdivision of the fluvial system proposed by Schumm (1977), in the «transfer zone» where input of sediment can equal output. In this reach the Piave River is very wide, with a braided pattern, a predominantly gravel bed and a gradient ranging between 0.003 and 0.006.

## LAST GLACIATION IN THE PIAVE VALLEY

In the Alps the last glaciation (Würm) took place between 24,000 and 16,000 years BP, and the maximum expansion of glaciers was likely between 20,000 and 18,000 years BP (Orombelli, 1983; Billard & Orombelli, 1986; Fliri, 1988). Deglaciation started 16,000-15,000 years BP as suggested by the ages of the stumps (14,765±135 and 14,370±115 years BP) found at Revine, inside the Piave moraine system (Casadoro & *alii*, 1976). Modes and times of deglaciation are not very well known, but van Husen (1989) suggests that the retreat of alpine glaciers could have been very rapid, with loss of about 50-60% of the length within 1,000-2,000 years.

During the last glaciation the Piave glacier flowed towards the Venetian Plain in two branches (fig. 2). The western branch build the Quero end moraine system, whereas the eastern one, passing through the Lapisina Valley, build the Gai and Vittorio Veneto systems. The maximum expansion of the glacier at Vittorio Veneto was recently dated around 17,670±320 years BP (Bondesan, 1999), whereas the begging of the deglaciation phase was well defined by the researches carried out at Revine (see the just mentioned ages by Casadoro & *alii*, 1976). The retreat of the Piave glacier was likely very rapid as two dates

TABLE 1 - Minimum ice-free dates from the Piave River basin and nearby locations

| Age BP | Material | Reference | Location | Comments |
|---|---|---|---|---|
| 11,910 ± 120<br>11,910 ± 160<br>12,040 ± 125<br>12,150 ± 110 | Anthropic level<br>Anthropic level<br>Anthropic level<br>Anthropic level | Broglio (1994) | Ripari Villabruna, Rosna Valley | Minimum ice-free date for the Cismon Valley |
| 13,095 ± 195<br>13,160 ± 210 | Organic matter<br>Wood | Pellegrini (in press) | Sedico (Belluno) | Minimum ice-free date for the Vallone Bellunese |
| 14,370 ± 115<br>14,765 ± 135 | Wood<br>Wood | Casadoro & *alii* (1976) | Revine (Treviso) | Minimum ice-free date for the Gai end moraine system |

(13,160±210 and 13,095±195 years BP) of lacustrine deposits in the valley floor of the Vallone Bellunese would suggest (Pellegrini, in press) (tab. 1). This old lacustrine basin, near Sedico (Belluno), is about 25 km upstream from the Quero end moraine system. As for the retreat of the glacier, other meaningful information comes from some archaeological investigations. The Epigravettian sites in Val Rosna (Broglio, 1994), dated between 12,150±110 and 11,910±110 years BP, is an evidence that this alpine area was ice-free few thousand years after the beginning of deglaciation (tab. 1). Considering all the available data it can be argue that the Vallone Bellunese was likely ice-free since 14,000-13,500 years BP (Pellegrini, in press).

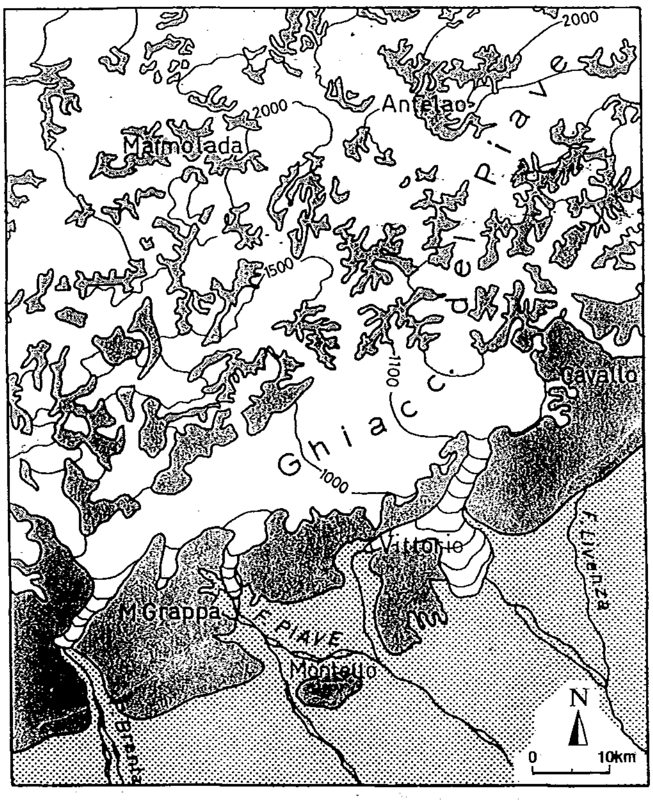


FIG. 2 - The maximum expansion of the Piave glacier during the last glaciation (after Castiglioni, 1940; slightly modified).

## EVOLUTION OF THE PIAVE VALLEY DURING THE LATEGLACIAL-HOLOCENE

Since several years the Piave valley, and particularly its middle-lower reach (between Ponte nelle Alpi and Quero), has been the object of geomorphological researches (Pellegrini, 1979; Pellegrini & Zambrano, 1979; Pellegrini, 1994; Pellegrini & Surian, 1994; Surian, 1996; Surian, 1998). The following outline of the evolution of the valley during the Lateglacial - Holocene is based on the results of all these researches and particularly on those obtained during the Research Project «The Geomorphological Map of the "Belluno" Sheet (at 1:50,000 scale)» (Pellegrini, in press) and a study on the fluvial terraces in the Vallone Bellunese (Surian, 1995).

During and after the retreat of the Würmian glacier, slope processes were very active as suggested by many landslides and valley floor sedimentation. Large landslides dammed the valley bottom at several places causing the formations of lakes and changes in the course of the Piave River (Pellegrini, 1994; Pellegrini & Surian, 1996) (see fig. 1 for location of the sites). The lake upstream from the Fadalto landslide still exists (S. Croce Lake), whereas the lake upstream from the Marziai landslide was filled during the Lateglacial. Two other large landslides are the Mt. Peron landslide (near Mas), which took place when the valley bottom was still occupied by ice, and the Cadola landslide. Numerical ages are not available for these landslides but from relative datations it can be argued that they occurred during deglaciation (surely the Mt. Peron landslide) and/or just after the retreat of the glacier, in any case during the Lateglacial. Also in the upper part of the Piave Basin, in the Cortina d'Ampezzo area, a similar situation has been reconstructed (Panizza & *alii*, 1996). In fact in this area, which was ice-free some times later than the Belluno area (1,000-2,000 years?), many landslides occurred at the boundary between Pleistocene and Holocene, around 10,000 years BP.

TABLE 2 - Dates of the end of the paraglacial sedimentation in the Vallone Bellunese

| Age BP | Material | Reference | Location | Comments |
|---|---|---|---|---|
| 8,380 ± 720 | Organic matter | Pellegrini (in press) | Lambioi (Belluno) | Ardo Creek fan |
| 8,215 ± 115 | Organic matter | Surian (1996) | | |
| 8,545 ± 115 | Organic matter | Surian (1996) | La Venegia (Belluno) | Ardo Creek fan |
| 9,800 ± 500 | Organic matter | Pellegrini (1994) | | |
| 9,460 ± 110 | Wood | Surian (1996) | Campo S. Pietro (Mel) | Terche Creek fan |
| 11,180 ± 100 | Wood | Pellegrini and Zambrano (1979) | Levego (Belluno) | Piave River terrace |

Data from drillings and geophysical investigations have been used to reconstruct the morphology of the valley bottom and the stratigraphy of the valley fill (Pellegrini & Zambrano, 1979; Pellegrini, 1994; Surian, 1995). The valley fill is generally very thick: in the Piave valley, it is about 270 m at Ponte nelle Alpi, at least 90 m at Belluno, 35-40 m at Cesa, about 100 m at Villapiana; in the Cordevole valley, it is about 130 m at Sedico. Generally the bedrock is covered by glacigenic sediments and lacustrine deposits. Formation of lakes was due not only to landslides but also to glacial excavation of the bedrock and to fan sedimentation that dammed the valley bottom. The upper part of the fill is composed by fluvial sediments.

Terraces and fans, both of the Piave River and of its main tributaries, have been studied to reconstruct fluvial processes in the Lateglacial - Holocene (Surian, 1995 and 1996). In the Vallone Bellunese, six levels of terraces of the Piave River were identified. The highest terraces of the Piave River, and those of its main tributaries, represent the end of the phase of aggradation which took place after the retreat of the glacier. According to radiometric datings, the age of the highest terraces and fans is 8,000-9,000 years BP (tab. 2). This means that in the Vallone Bellunese, which was ice-free about 13,500-14,000 years BP, aggradation of the valley floor continued after deglaciation for about 5,000-6,000 years. The lower terraces, which are commonly unpaired and have less continuity than the highest terraces, were formed during the phase of general incision which characterised the river for the rest of the Holocene (from 8,000-9,000 years BP to the present).

## DISCUSSION

As for fluvial processes, the available data allow to reconstruct the following model for the Piave valley during the Lateglacial-Holocene. A sedimentation phase took place for a long period (about 5,000-6,000 years) after the retreat of the Würmian glacier, whereas incision and terrace formation characterised the Holocene since 8,000-9,000 years BP. During the first period (sedimentation phase) the stream power (power available to transport sediment load) was less than critical power (power needed to transport sediment load), whereas in the second period (incision phase) the stream power exceeded the critical power. This means that stream power (which, according to Bull (1979), depends on stream discharge and stream slope), sediment load, or both these parameters have changed with time. Several elements, for instance the frequency of landslides and the sparse vegetation cover on the slopes (Bertoldi, 1996), support the idea that in the first period higher rates of sediment were supplied to the streams. On the other hand, much more uncertainty exists as for stream power. The analysis of the terraces pointed out that the slope of the highest terrace of the Piave River (0.0063) is greater than that of the present river (0.0046), but no palaeoflow calculations were attempted. Considering this change in channel slope and the fact that channel pattern (actually braided) has not substantially changed through time, it can be argued that, likely, changes in sediment yield played a more important part than changes in discharge as for stream dynamics during the Lateglacial-Holocene. It is possible that in an alpine river like the Piave there have not been such remarkable changes in flow regime like those that occurred in streams (for instance in the central and north of Europe or in the north of America) conditioned by retreat and melting of continental ice sheets (e.g. Starkel & *alii*, 1991).

In the past the terms «anaglacial» and «kataglacial» have been introduced (Tongiorgi & Trevisan, 1941; Trevisan, 1946) to explain the geomorphic evolution of Italian valleys and plains. These terms were supposed to explain morphological changes, i.e. aggradation and incision phases, that occur within streams as consequence of a climatic change. In this model (anaglacial-kataglacial phases), anaglacial is supposed to be a period of stream aggradation, whereas terrace formation is the main characteristic of the kataglacial phase.

The geomorphological researches carried out in the Piave valley show that the fluvial processes that occurred during the Lateglacial-Holocene can not be explained with the anaglacial-kataglacial model of Tongiorgi & Trevisan (1941). In fact, after the maximum expansion of the glacier (which represents the beginning of the kataglacial phase) there was a long period of valley floor aggradation, not of incision. Besides, the terrace formation, which occurred when non-glacial conditions were established and not just after the glacier retreat, was likely conditioned more by changes in sediment supply rather than in precipitation or stream discharge. The processes that took place after the last glaciation can be better explained assuming the occurrence of a «paraglacial» period. This term, which can be used both to refer to a period of time and to geomorphic processes, was introduced by Church & Ryder (1972) and then used by other authors (e.g. Jackson & *alii*, 1982; Brazier & *alii*, 1988; Ballantyne & Benn, 1996; Fitzsimons, 1996; Harrison & Winchester, 1997; Owen & Sharma, 1998) and in different regions (e.g. Canada, Scotland, Patagonia, Antarctica and Himalaya). In the concept of paraglacial processes great emphasis is put on the sediment yield produced during and after deglaciation, which is much higher than that produced in «normal» conditions (fig. 3). The high rates of sediment that during a paraglacial period are supplied to stream channels can be seen as an alteration of «normal» dynamics of river system. Paraglacial sedimentation lasted 5,000-6,000 years in the Piave valley (fig. 3), but duration of the paraglacial period may be scale dependent, that is smaller basins respond more rapidly to changes brought about by glacier retreat than do larger basins (Church & Slaymaker, 1989).

## CONCLUSIONS

The main results of this study are:

(1) A reconstruction of the retreat of the Würmian glacier and of the sedimentation phase that occurred during and after deglaciation was carried out in the Piave Valley. This shows that sedimentary processes, mainly fluvial but also lacustrine, prevailed in the valley for a long time (about 5,000-6,000 years) after deglaciation. This long aggradation phase is due to paraglacial processes, but also to the particular position (lower part of the drainage basin) and morphology (wide valley floor) of the study reach.

(2) During the paraglacial period the rates of sediments supplied to streams were much higher than those in «normal conditions» (like the present ones). It is likely that changes in sediment yield, rather than changes in streamflow, have driven fluvial processes (aggradation and incision phases) in the Lateglacial-Holocene period. In the future, calculation of palaeoflow could represent the next step to verify this hypothesis.

(3) Paraglacial processes provide a valuable framework for explaining landscape response to deglaciation and Lateglacial-Holocene landscape evolution in the Piave Valley. The term «paraglacial» is suggested to replace the term «kataglacial», even if paraglacial processes need to be tested in drainage basins of different sizes and with different geologic-geomorphic characteristics for a wider use of this term (for instance in the Alps). Otherwise, though in some cases models can be very useful to explain field data, it should not be forgotten that the response of a stream to a climatic change may be different from one stream to another, but also in different reaches of the same stream, due to influence of other factors, such as tectonics and sea level change.

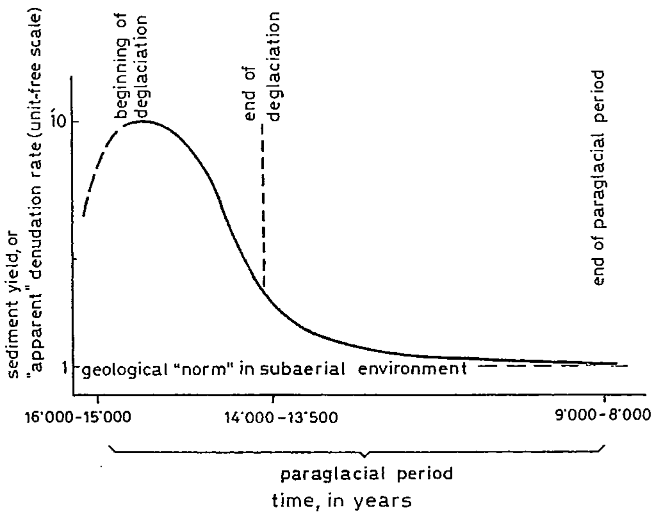


FIG. 3 - Paraglacial sedimentation in the Vallone Bellunese (modified from Church & Ryder, 1972).

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