Geogr. Fis. Dinam. Quat.,
19 (1996), 119-127, 5 figg., 1 c.

NICOLA SURIAN (*)

THE TERRACES OF THE PIAVE RIVER IN THE VALLONE BELLUNESE (EASTERN ALPS, ITALY)

ABSTRACT: SURIAN N., *The Terraces of the Piave River in the Vallone Bellunese (Eastern Alps, Italy).* (IT ISSN 0391-9838, 1996).

The terraces of the Piave River in the Vallone Bellunese (Eastern Alps) are the focus of this study: they represent the stream evolution after the last glacial period (Würm) in this region. This paper deals mainly with three topics: (1) methods and problems commonly faced in the study of fluvial terraces, (2) genesis of the terraces, and (3) geomorphic processes during the Late glacial-Holocene in this part of the alpine region.

As for methods, the fundamental value of procedures such as identification of the flood plain, determination of terrace elevation, and correlation of terraces are discussed.

In the Vallone Bellunese there are six levels of terraces of the Piave River. The highest terrace is a fill terrace: the end of the valley filling, on the basis of some numerical ages (radiocarbon and thermoluminescence datings), can be ascribed to the Early Holocene. This terrace is a climatic terrace because its formation is due to the transition from a glacial to a non glacial period. The genesis of the lower terraces is more difficult to explain. They could be complex-response terraces, or their formation could be also explained with lateral shifts during the downcutting of the river. In both cases formation of the lower terraces would not require a change of an external variable of the system (climate or tectonics).

The dynamics of the Piave River after the last Würm glaciation can be better explained if a paraglacial period is assumed. This implies a revision of previous models which referred to anaglacial and kataglacial period. Changes of sediment yield are probably much more important than changes in precipitation, in terms of both magnitude and their effects on river dynamics. A progressive reduction of sediment yield from deglaciation time to Early Holocene is the main cause of the change, from aggradation to degradation, in the modes of stream operation.

KEY WORDS: Fluvial terraces, Genesis of terraces, Paraglacial processes, Piave River, Eastern Alps.

RIASSUNTO: SURIAN N., *I terrazzi del Fiume Piave nel Vallone Bellunese (Alpi Orientali).* (IT ISSN 0391-9838, 1996).

Lo studio riguarda i terrazzi del Fiume Piave nel Vallone Bellunese (Alpi orientali); essi rappresentano l'evoluzione del corso d'acqua dopo l'ultima espansione glaciale (Würm) in questa regione. Principalmente sono stati trattati tre aspetti: (1) i metodi ed i problemi che comunemente si affrontano nello studio di terrazzi fluviali, (2) la genesi dei terrazzi esaminati, e (3) i processi geomorfologici durante il Tardiglaciale-Olocene in questo settore della regione alpina.

Per quanto riguarda gli aspetti metodologici, si è evidenziata l'importanza fondamentale di aspetti come l'identificazione della piana alluvionale, la determinazione dell'altezza dei terrazzi e la correlazione dei terrazzi.

Nel Vallone Bellunese ci sono sei livelli di terrazzi del Fiume Piave. Il terrazzo più elevato è un terrazzo deposizionale e, sulla base di alcune datazioni con il radiocarbonio e con la termoluminescenza, può essere attribuito all'Olocene antico. Si tratta di un terrazzo climatico perché la sua formazione è dovuta al passaggio da un periodo glaciale ad un periodo non glaciale. La genesi dei terrazzi inferiori è invece più difficile da spiegare. Potrebbero essere dei terrazzi di risposta complessa, oppure la loro formazione potrebbe essere spiegata con spostamenti laterali del corso d'acqua durante la sua fase d'incisione. Comunque, in entrambi i casi, la formazione di questi terrazzi minori non presuppone variazioni di una variabile esterna del sistema (clima o tettonica).

L'evoluzione del Fiume Piave dopo l'ultima glaciazione würmiana può essere spiegata assumendo l'esistenza di un periodo paraglaciale. Ciò comporta una revisione dei modelli precedenti che facevano riferimento a periodi anaglaciali e cataglaciali. Variazioni nella produzione dei sedimenti nel bacino sono probabilmente molto più significative di variazioni delle precipitazioni e dei deflussi, sia per quanto riguarda l'entità della variazione che il loro effetto sulla dinamica del corso d'acqua.

TERMINI CHIAVE: Terrazzi fluviali, Genesi dei terrazzi, Processi paraglaciali, Fiume Piave, Alpi Orientali.

INTRODUCTION

Geomorphologists have been studying fluvial terraces for a long time, since they are meaningful for understanding landscape evolution. Besides, in many situations, terraces are landforms with temporal significance that document important transitions in types or rates of fluvial processes (BULL, 1990).

This paper deals with the terraces of the Piave River in the Vallone Bellunese. Because the whole drainage basin of the river was glaciated during the last Würm expansion in the Alps, these terraces represent the stream evolution in the Late glacial-Holocene.

The main topics discussed in this paper are (1) methods

I would like to thank the Veneto Region and prof. G.B. Pellegrini who allowed me to use the results of some unpublished datings, respectively three C-14 datings and one TL dating. I appreciated the comments of prof. G.B. Pellegrini and three anonymous reviewers of this journal which improved this manuscript. This work benefited from Murst 60% Funds (Resp. Prof. G.B. Pellegrini).

(*) Dipartimento di Geologia, Paleontologia e Geofisica, Università di Padova, Via Rudena 3, 35123 Padova, Italy

and problems commonly faced in the study of fluvial terraces, (2) the genesis of the terraces in the Vallone Bellunese, and (3) geomorphic processes and fluvial dynamics during the Late glacial-Holocene in this sector of the alpine region.

In the study of fluvial terraces, some specific methodological aspects must be considered, such as identification of flood plain, terrace nomenclature, terrace correlations, relations between terrace and slope deposits, and terrace mapping (JOHNSON, 1944; FRYE & LEONARD, 1954; HOWARD, 1959; RITTER & MILES, 1973). Though it is not the aim of this paper to treat these aspects in detail, it is worthwhile to give some emphasis to the methodological problems which have a fundamental importance for a correct approach to this kind of research.

As for genesis, three main types of terraces have been recognized (BULL, 1990): climatic, tectonic, and complex response. Commonly terraces sequences have been explained as the result of climatic change or tectonic uplift, but the model of complex response for terrace formation, introduced by SCHUMM (1973), seems to be a good explanation especially for some Holocene terrace sequences. Therefore not all changes within the fluvial system are due to variations of external variables of the system (climate and geology), but can be due also to internal adjustments within the system. This means that the genesis of terraces, which represent past equilibrium or threshold conditions, is not always the consequence of changes of external variables but can be due to normal changes, e.g. phases of aggradation and degradation, in the stream.

Notwithstanding that recently general interest for fluvial processes in temperate zones during the Late glacial-Holocene has significantly increased (STARKEL & *alii*, 1991), in the Italian Alps research on this topic is still not much developed. In the past some important researches were carried out and terrace formation models were developed for alpine streams (TONGIORGI & TREVISAN, 1941; TREVISAN, 1946; GORTANI, 1950). The value of these works is unquestionable, but there is a need for a review of these ideas and models in the light of both knowledge gained by recent geomorphological research in this region and new geomorphic concepts developed in the last decades (e.g. paraglacial processes).

GENERAL SETTING OF THE STUDY AREA

The Piave River Basin

The Piave Basin is located in the eastern sector of the Alps (fig. 1). The Piave River is 222 km long and the area of its drainage basin is 3,899 km^2. The upper part of the basin belongs to the Dolomites, whereas the lower part to the Venetian Prealps. The mean elevation of the basin is 1,276 m and the highest point is the peak of Mt. Marmolada (3,342 m).

In the Piave Basin the mean annual precipitation is 1,350 mm, and the mean annual runoff is 78% (TONINI, 1968). As for the recent dynamics of the Piave River, it must be considered that the river discharges have been strongly regulated by some hydroelectric dams and diversions made during the last 60-70 years.

As for geology, the drainage basin belongs to the Southern Alps and it is mainly composed of sedimentary rocks (prevalently dolomites and limestones). In this region tectonic is active and the Belluno area in particular is one of the most active of Northeastern Italy (ZANFERRARI & *alii*, 1982; SLEJKO & *alii*, 1987). In the Piave Basin tectonic uplift is around 1 mm/year or more (PELLEGRINI & ZANFERRARI, 1980; BALESTRI & *alii*, 1988).

The study reach: the Piave River in the Vallone Bellunese

The Piave River flows for about 160 km within a mountainous area (Dolomites and Venetian Prealps) and for about 60 km on a plain (Venetian Plain). The study reach is in the middle-lower part of the mountain course and it is 35 km long (fig. 1): here the Piave River flows in a longitudinal valley commonly called in the literature the Vallone Bellunese. The valley has the same direction of a syncline (the «Belluno syncline») and its slopes are not very steep, particularly the southern slope.

The Piave River in the Vallone Bellunese has a braided pattern: the river bed is mainly composed of gravels and it is very wide (in some section more than 1 km); the average gradient of the river is 0.0046. As previously said, the river has been strongly regulated in the past and this has affected its recent dynamics (channel pattern, sediment transport, etc.).

Late Quaternary history of the area

The late Quaternary history of the Vallone Bellunese has been studied by many authors either in the past (TARAMELLI, 1883; BRÜCKNER, 1909; DAL PIAZ, 1912; CASTIGLIONI B., 1923; VENZO, 1939; SEMENZA, 1957) or recently, especially by G.B. PELLEGRINI (PELLEGRINI, 1979; PELLEGRINI & ZAMBRANO, 1979; PELLEGRINI, 1994; PELLEGRINI & SURIAN, 1994; PELLEGRINI & SURIAN, 1996a; PELLEGRINI & SURIAN, 1996b; PELLEGRINI & *alii*, 1996). During the last glaciation, which took place between 24,000 and 16,000 years B.P. in the Eastern Alps (FLIRI, 1988), the Piave Basin was completly glaciated. From the heights of the lateral moraines it can be argued that the ice was about 800 m thick in the Vallone Bellunese. Various researches have shown that during and after the retreat of the würmian glacier large landslides and aggradation of the valley bottom occured. All the large landslides took place during the würmian deglaciation and at the beginning of the Late glacial, whereas stream aggradation continued up to 8,000-10,000 years B.P. (PELLEGRINI & SURIAN, 1996a). During the Holocene the magnitude of slope processes significantly decreased, and stream downcutting and formation of terraces were the main processes.

METHODS AND DATA

A study of fluvial terraces aims to reconstruct stream dynamics in the past and, in a more general view, geomorphic evolution of a valley. In this kind of study, the importance of integrating morphological and stratigraphical approaches has been emphasized in many works (for example TRICART, 1947). In this research different kinds of data, morphological, stratigraphical, and chronological data, have been used. Besides my investigations carried out in the last years (SURIAN, 1995), this research benefited from both data available on the geomorphology and the quaternary stratigraphy of this area (PELLEGRINI & ZAMBRANO, 1979; PELLEGRINI, 1994; PELLEGRINI & SURIAN, 1994), and some unpublished data. Other important information came from the Research Project «The Geomorphological Map of the "Belluno" Sheet (scale 1:50,000)» which has been recently realized by the Veneto Region and the University of Padova (PELLEGRINI & *alii*, 1996). Presentation of data will be accompained by a discussion of some methodological aspects and problems specific to fluvial terraces.

Identification of flood plain

Fluvial terraces can be defined as remnants of former flood plains. When rivers incise their flood plains the abondoned surface which is no longer actively flooded becomes a terrace (MORISAWA, 1985). The identification of the flood plain represents the first step in studies of fluvial terraces. Only when surfaces which can be flooded have been recognized, is it possible to define other higher surfaces as terraces. The problem is: what kind of flood (for instance the mean annual flood or a flood with 100 years recurrence interval) should be considered to define the flood plain? According to some authors (e.g. DUNNE & LEOPOLD, 1978), the flood plain is a surface flooded frequently at a relatively consistent interval of 1.5 years, and a terrace, being at a higher level, is flooded less frequently. My personal opinion is that a flood plain should be considered also a surface not frequently flooded. For example using either hydrological or geomorphological methods the flood plain could be defined by those areas that have been flooded in the last 100 years. Even if the identification of such a flood plain can often be a difficult problem it is worthwhile because the distinction between flood plain and terrace is not only important for scientific purposes but also for correct environmental planning.

There are many techniques for mapping a flood plain (WOLMAN, 1971); an analysis of historical maps and a morphological analysis, on topographic maps and in the field, was carried out as it seems quite reliable to distinguish the flood plain from terraces in the study area. Because the river has been subjected to recent changes caused mainly by human interventions (dams, diversions, artificial banks, etc.), some areas which are 2-3 m higher than active channels have also been included in the flood plain. Therefore, in this kind of approach, flood plain is

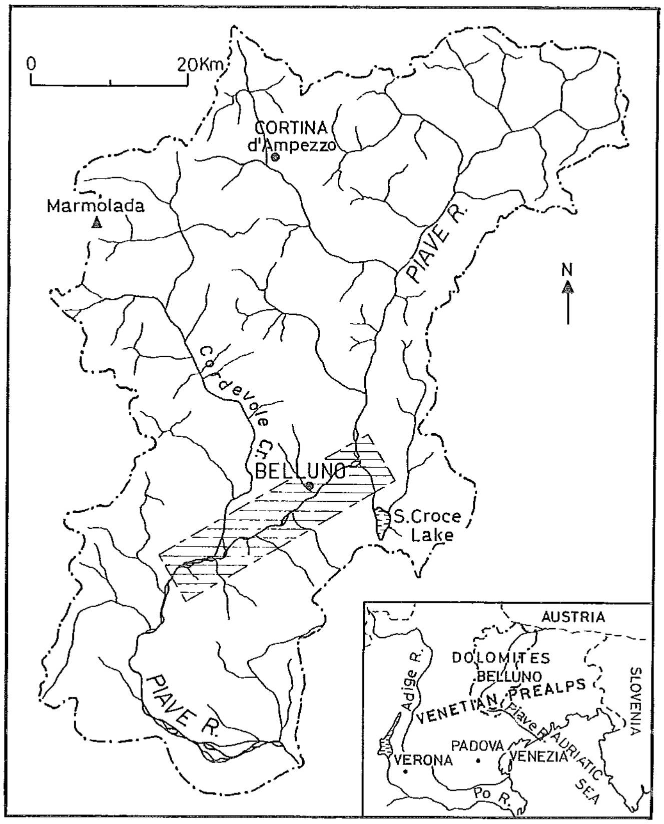

FIG. 1 - The drainage basin of the Piave River and location of the study reach.

an area that can be flooded even infrequently, whereas terraces should never be flooded in the present morphoclimatic conditions. Obviously for the Piave River some uncertainty is due to the difficulty of predicting future river dynamics which are so strongly influenced by human activities. In the Geomorphological Map the flood plain is the area with «present and recent fluvial deposits».

Terrace nomenclature

In this study terraces are not identified using a numerical system but are identified by a geographic name. Reasons why a numerical system should not be used have been exhaustively explained by HOWARD (1959). According to this author, a numerical system is confusing and difficult to apply and, moreover, it could lead to erroneous correlations, especially for more recent terrace sequences. For instance, in a region, the number of terraces can vary not only from one valley to another, but even within a valley. This is the case of the terraces of the Piave River and its tributaries in the Vallone Bellunese.

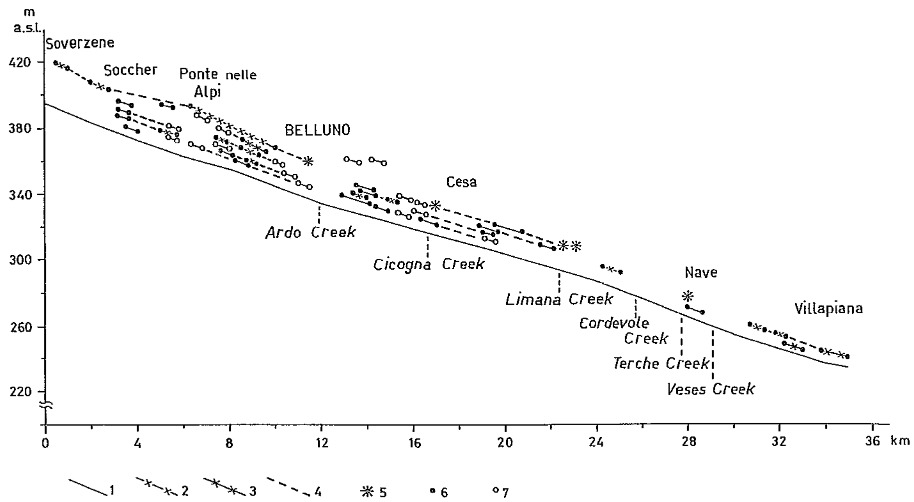

FIG. 2 - Longitudinal profile of the terraces of the Piave River in the Vallone Bellunese. 1: terrace on the left side of the valley; 2: terrace on the right side of the valley; 3: paired terrace; 4: correlated stretch; 5: elevation of the highest fans and terraces of the tributaries; 6: alluvial terrace; 7: rock-cut terrace.

Determination of terrace elevation

A correct determination of terrace elevation is essential for a rigorous study of terraces. For such a determination only the significant part of a terrace that represents a former flood plain must be considered (JOHNSON, 1944). Often this is not straightforward, mainly for two reasons: first, the morphology of ancient flood plains can be modified by depositional and erosional processes (commonly terrace surface are covered by slope deposits, colluvium, landslides, etc., or by fan deposits of tributaries); secondly, terraces are commonly relatively small landforms in low relief areas (such as the Vallone Bellunese valley floor) which are difficult to be analised. Large-scale topographic maps are needed for such an analysis. A detailed analysis of terrace morphology was carried out using a topographic map at 1:10,000 scale («Carta Tecnica Regionale») with contour interval of 5 m (in some cases of 1 m in flat areas) and by field survey. For most of the Piave River terraces, the morphological analysis allowed the identification of the portions of terrace representing the former flood plain. In a few cases slope deposits cover the whole terrace surface, and it was possible to determine only an approximate elevation.

In determining terrace elevation, an approximation of 1 m seems to be suitable for the correlation of these terraces. A more precise determination of elevations is not necessary because, as evident in a cross section, the original flood plain itself was not a perfect flat surface (COTTON, 1940; FRYE & LEONARD, 1954). On the other hand, a difference of 2-3 m between terraces could be meaningful, especially when the range of terrace heights is not very wide, which is the case in many Holocene sequences.

The terraces heights vary along the valley (fig. 2). Upstream, in the Ponte nelle Alpi-Belluno area, the highest terraces are about 30 m above the present river bed and the lowest ones 8 m; where the terraces are best preserved there are six levels of terraces. Downstream, near Busche, there are two terrace levels: 6 m and 4 m respectively above the present river bed.

Stratigraphic data

Stratigraphic data have been collected mainly by field survey. Vegetation cover is commonly very high and few natural exposures, meaningful for stratigraphic considerations, do exist. However, other useful information was provided by drillings and geophysical investigations.

The valley fill is very thick, but its thickness varies along the valley. For instance, in the Piave River valley the fill is about 270 m at Ponte nelle Alpi (geophysical investigation, see PELLEGRINI & ZAMBRANO, 1979), at least 90 m at Belluno (drillings), and about 35-40 m at Cesa (drillings and geophysical investigation). In the Cordevole Creek valley, near Sedico, the fill is about 130 m (PELLEGRINI, 1994). The upper part of all these stratigraphic sequences consists of fluvial sediments, mainly gravels, whereas in the lower part there are also, in some areas, lacustrine and glacigenic sediments.

Terraces are mainly composed of gravels, which are cemented in patches, whereas in their upper part massive silt and clay, which represent overbank deposits, were also found. The highest terraces are fill terraces, whereas the lower terraces are probably fill-cut terraces and strath (or rock-cut) terraces. Some fill-cut terraces could be also fill terraces, but I could not find evidence of other depositional sequences besides the main fill. Strath terraces were defined as those terraces in which the bedrock is covered only with a thin layer (less than 1-2 m) of gravels.

In a preliminary study no meaningful differences between soils developed on higher terraces and those on lower ones have been noticed. Therefore, unlike other regions (ROBERTSON-RINTOUL, 1986; KNUEPFER, 1988), soils seem not to be a useful tool for estimating the ages of terraces in this area.

Fans of tributaries

Two different kinds of relations between the fans of the tributaries and the terraces of the Piave River have been recognized (fig. 3): fans are superimposed to terraces or there is an interfingering contact. Such interpretation is based on the fact that some streams have not adjusted their profile to changes of the base level, whereas others have. For this reason it is assumed that only in streams which can adjust their profile to changes of the local base level, represented by the Piave River bed, the deposition took place simultaneously with deposition in the Piave River, and therefore the fan deposits of the tributaries should be interfingering with terrace deposits of the Piave River. During the downcutting of Piave River, which followed the main phase of valley bottom aggradation, these streams have trenched their old fans and, in some cases, have built younger fans at lower levels. A good example is the Rimonta Creek: there are two fans whose base levels are represented by terraces of the Piave River, and one active fan on the present flood plain of the Piave River (see the Geomorphological Map). Stratigraphical evidences of interfingering contacts between deposits of tributaries fan and deposits of the Piave River terraces were searched for but no good exposures were found.

Fans superimposed to terraces are associated to streams with a small drainage basin, a steep longitudinal profile, and, probably, characterized by debris flow processes. Obviously, the deposits of these fans could also be partially interfingered with those of the terrace but since the stream has not trenched the fan to adjust to lower base levels, fan deposition could has continued on terrace surface also during the Piave River downcutting phase.

These relations between the fans of the tributaries and the terraces of the Piave River are meaningful for chronological considerations. Fans of the main tributaries (such as the Ardo Creek, the Cicogna Creek, and so on) have the same age of the terraces on which they are superimposed, but also interfingered, whereas fans of small tributaries are likely to be more recently formed than the terraces on which they are superimposed.

At the confluence of some tributaries (such as the Cordevole Creek and the Limana Creek) in the Piave River there are terraces but no fans of tributaries. Fans, probably, did not form in these streams because there is not a distinct decrease of confinement of streamflow unlike in other tributaries of the Piave River. A decrease of streamflow confinement is a fundamental requirement for fan formation (BULL, 1977). Of course these terraces of the tributaries have the same stratigraphic and chronological meaning of the fans which have been discussed above (fig. 3, a).

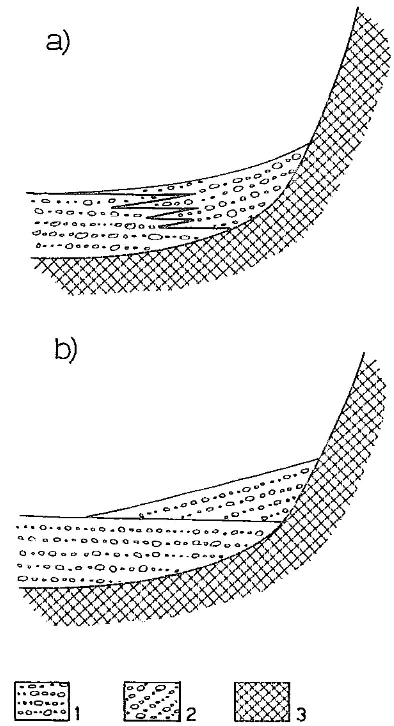

FIG. 3 - Stratigraphic relations between the terraces of the Piave River and the fans of the tributaries: a: main tributaries; b: small tributaries. 1: sediments of the Piave River; 2: sediments of the tributary; 3: bedrock. (modified from RYDER, 1971).

Chronological data

In the Belluno area several numerical ages of quaternary deposits were estimated (PELLEGRINI, 1994). In particular, as for the terraces and the evolution of the valley floor some recent radiocarbon and thermoluminescence datings were carried out.

In the distal part of the Ardo Creek fan, at La Venegia, some silty clay sediments, with organic matter, were dated with radiocarbon. Samples from two layers (3.15 m and 4.40 m respectively from the ground surface) gave these ages: 8,545±115 years B.P. (GX-18556) the upper layer, and 8,215±115 years B.P. (GX-18557) the lower layer. Results like these, with upper layers «older» than lower ones, are not uncommon in dating quaternary sediments, therefore caution should be used in considering the accuracy of these ages. This fan is correlated with the highest terrace of the Piave River (Ponte nelle Alpi-Belluno terrace), therefore these ages allow to estimate the last phase of valley filling before the river started downcutting the highest terrace.

One radiocarbon age is available for the old fan of the Terche Creek. The age of a wood, found in a sandy layer at about 6 m from the ground surface, is 9,460±110 years B.P. (GX-20131).

In alluvial deposits mainly composed of gravels it is not usual to find matter suitable for radiocarbon datings. For these reason, the thermoluminescence method has been used, even though its application to fluvial sediments, unlike other sediments (eolian and lacustrine), is probably not so reliable (FORMAN, 1989). Silty clay sediments (overbank deposits) in the upper part of the Villapiana terrace gave the following TL age: 5,000±300 years B.P. (Wa-23).

In recent years archaelogical researches has significantly increased, and so a general outline of the temporal and spatial presence of man in this mountain region is quite well established (MONDINI & VILLABRUNA, 1994; BROGLIO, 1994). As for terraces, some artifacts with an age of

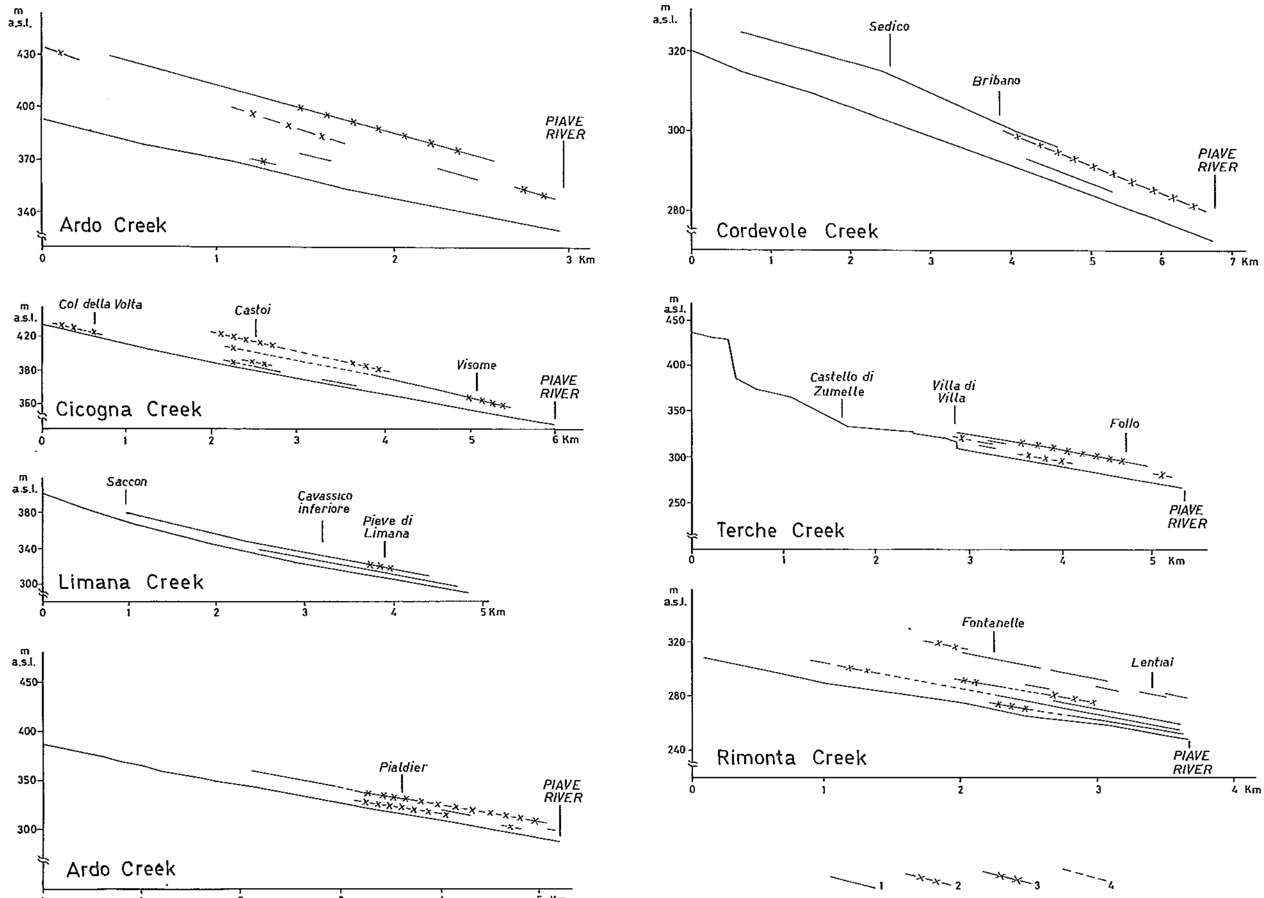

FIG. 4 - Longitudinal profiles of the main tributaries of the Piave River in the Vallone Bellunese. 1: terrace on the left side of the valley; 2: terrace on the right side of the valley; 3: paired terrace; 4: correlated stretch.

5,000-4,500 years B.P. (C. MONDINI, personal communication) were found on the highest terrace of the Piave River at Cesa. Therefore this terrace is at least 5,000-4,500 years B.P. old.

Geomorphological map

For a better understanding of valley floor evolution, a general outline of all different landforms (fluvial, glacial, slope, etc.) and of their morphological and stratigraphical relations is needed. Therefore the enclosed geomorphological map was drawn for this purpose. Prequaternary rocks are shown just as «bedrock» whereas colluvium, slope debris, and landslide deposits are all represented with the term «slope deposits». On the other hand, fluvial landforms are drawn in detail, with contour lines and elevations. A very detailed analysis is needed for the study of landforms in a valley bottom since in this way a correct mapping of terrace surfaces is possible also in those frequent situations where colluvium or fan deposits partially cover these surfaces.

Terrace correlation and longitudinal profile

Correlation is one of the most important aspects of terrace study, but it is a more difficult and delicate procedure than is generally realized (JOHNSON, 1944). Terraces are correlated both with longitudinal and transverse profiles. With longitudinal ones old profiles of the stream can be reconstructed; with transverse sections it is possible to show if terraces are paired or unpaired, which means if terraces on opposite valley slopes belong to the same level. Transverse sections are also suitable for showing stratigraphic relations between quaternary deposits and bedrock.

The fundamental requirement for correlation of terraces is an accurate determination of terrace elevations, and this issue has been already discussed. Besides, continuity of terraces along the valley is very important for reliable correlations. As it is very unlikely that the former stream profiles were exactly parallel to the present profile, terraces can not be correlated only on the basis of their elevations but their continuity must be also considered. This is especially true when a relatively long reach of a stream is studied.

Figure 2 reports the longitudinal profile of the Piave River terraces in the Vallone Bellunese. It shows paired or unpaired terraces; if they are alluvial or rock-cut terraces; and some correlations. The highest terraces or fans of the tributaries, which are correlated with the highest terraces of the Piave River, are also indicated. This allows reconstructing with good accuracy the level of the highest terraces of the Piave River where terraces are not preserved. This method was not meaningful for lower terrace levels, because they are much too discontinuous along the valleys of both the Piave River and its tributaries.

The highest terraces are the best preserved, but the correlation of these surfaces was not done all along the valley because, in some reaches, there is not enough continuity. Eventually a correlation of all the highest terraces could be attempted, but the terraces could have different ages, considering that in a 35 km long reach, adjustment of stream profile generally takes place in a certain time span.

The lower terraces don't allow meaningful correlations and terrace level reconstruction along the valley. Anyway, upstream, between Ponte nelle Alpi and Belluno, six levels have been identified, whereas four levels are found between Belluno and Limana. In the last reach of the Piave River in the Vallone Bellunese, from Limana to Busche, only one level, below the highest terrace, has been recognized.

From the graph (fig. 2) a variation in the stream gradient is evident, and this is an important feature for some considerations about the dynamics of this river. Upstream, between Ponte nelle Alpi and Belluno, the gradient of the highest terrace level is 0.0063, whereas the gradient of the present river is 0.0046.

Figure 4 shows the terraces of the main tributaries of the Piave River in the Vallone Bellunese. Only the reaches near the confluence into the Piave River are shown as in these reaches terraces are better preserved. For all these streams, except for the Cicogna Creek and the Rimonta Creek, the highest surfaces, which are terraces or fan surfaces, are correlated with the highest terraces of the Piave River. The formation of the highest surface of the Cicogna Creek and the four or five highest surfaces of the Rimonta Creek can be explained with a high base level represented by a glacier and not by the Piave River. In fact, there are no terraces of the Piave River which could be correlated with those surfaces, whereas there are glacial landforms (erosional surfaces, morainic ridges, and glacial sediments). The lower terraces of the tributaries are generally unpaired. There are only two paired terraces in the Ardo Creek valley (the Ardo Creek on the right side of the Piave River).

DISCUSSION

Considering all the available data (morphological, stratigraphical, and chronological), some ideas about the geomorphological evolution of this area and the stream dynamics during the Lateglacial-Holocene can be formulated. The valley fill indicates that after the retreat of the würmian glacier from the Vallone Bellunese a long phase of aggradation took place. This was due to the large amount of sediments available on the slopes and to the high activity of slope processes during and after the deglaciation. The main factors causing the high activity of slope processes were: the presence of unconsolidated easily erodible sediments (glacial sediments) on the slopes; slope instability caused by the retreat of a glacier which was about 800 m thick in this area (many landslides took place during this period, see for instance Pellegrini & Surian, 1996a and Pellegrini & Surian, 1996b); and a sparse vegetation cover, as indicated by pollen analysis (Bertoldi, 1996). Therefore, it can be argued that the rate of sediments delivered to streams was much higher than during nonglacial conditions like the present ones.

These processes, which characterized the transition from a glacial to a non glacial period, have also been described by Church & Ryder (1972) and by Jackson & *alii* (1982) in British Columbia (Canada). They defined these processes as «paraglacial». The interesting point stressed by the concept of paraglacial processes is that sediment yield rate is high not only during deglaciation but also for a certain period after deglaciation (fig. 5). The chronology of the valley fill of the Vallone Bellunese confirms this hypothesis. In fact, the aggradation phase after the retreat of the glacier took place in the main streams in the Lateglacial and in the first period of Holocene, the Preboreal and part of the Boreal (Pellegrini & Surian, 1996a).

Referring to stream evolution models proposed in the past (Tongiorgi & Trevisan, 1941; Trevisan, 1946), some new results have been achieved by this research. Stream aggradation occured not only in the «anaglacial» period and during deglaciation but also for a long time after deglaciation. Therefore terrace formation didn't take place in the «kataglacial» as terrace downcutting began only many thousand years after the maximum glacial expansion, which represents the beginning of «kataglacial». Probably changes in sediment yield played a more important part than changes in precipitation and discharges in the evolution of alpine streams, such as the Piave River, during the Lateglacial-Holocene.

As for the genesis, the highest terrace is a climatic terrace because its formation is essentially due to an important climatic change, the transition from a glacial period to a non glacial period. Trevisan (1946) already pointed out two important features: (1) climatic terraces in this region have decreasing heights from upstream to downstream; (2) considering a terrace level, terraces upstream are older than those downstream. This can be explained as follows.

A terrace is evidence that downcutting took place in a certain reach at a certain time. If in a reach there is downcutting, somewhere downstream there will be deposition of the material eroded upstream. For this reason, in a relatively long reach it is likely that incision doesn't occur at the same time along the reach. This is what probably happened in the Piave River in the Vallone Bellunese, and the available morphological and chronological data seem to confirm this idea. First of all, the highest terraces

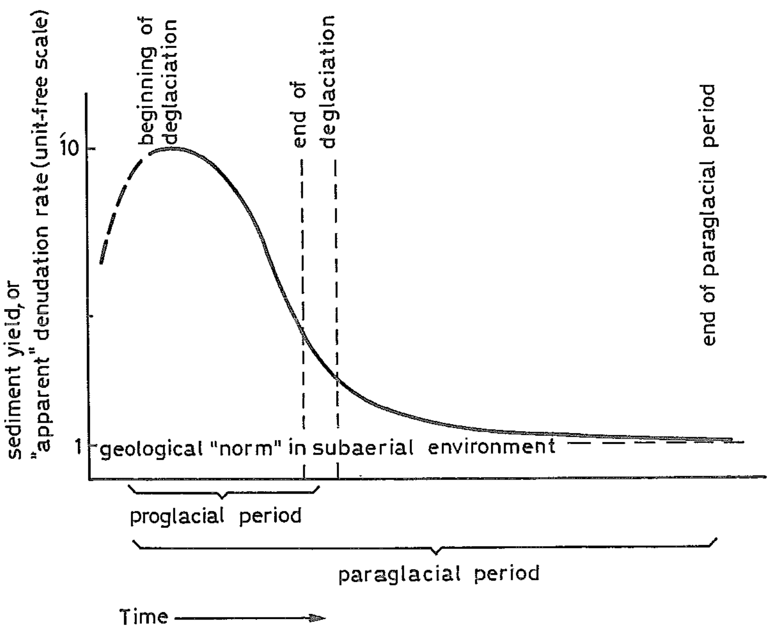

FIG. 5 - Sediment yield during a paraglacial period (after CHURCH & RYDER, 1972, slightly modified).

of the Piave River have different heights in the study reach: upstream, at Ponte nelle Alpi, the terraces are about 30 m above the present stream, whereas downstream, at Villapiana, they are about 6 m above it. Therefore the river has incised much more upstream probably because downstream incision has been partialy reduced by deposition of sediments produced by upstream downcutting. The available chronological data (C-14 and TL datings) seem to confirm that the highest terraces along the river do not have the same age. For the upstream terraces two radiocarbon ages exist (8,215±115 and 8,545±115 years B.P.), whereas a TL dating is available for the downstream terraces (5,000±300 years B.P.).

Before discussing the genesis of the lower terraces of the Piave River, something about mechanisms of terrace formation should be mentioned. Usually paired terraces are attributed to episodic incision, whereas unpaired terraces can be explained as the result of progressive incision with lateral shifts of the channel from one side to the other one of the valley floor (SCHUMM, 1977). This has important implications for stream dynamics. Formation of unpaired terraces doesn't require any variation of conditions of the system, whereas paired terraces imply that external or internal conditions of the system have changed. Paired terraces represent past equilibrium or threshold conditions. Episodic erosions mean that a geomorphic threshold has been crossed (aggradation followed by incision) or equilibrium has been reached for a certain time span (incision is not continuous).

Considering both the Piave River and its tributaries, there are few cases of paired terraces. For this reason the formation of the lower terraces could be due to a lateral shift of the stream from one side of the valley to the other. Another hypothesis is that the lower terraces represent periods of equilibrium (no net aggradation or degradation of the stream) in the general phase of incision of the river during the Holocene. In this case the terraces could be complex response terraces, therefore due to internal adjustments of the system. In fact, as shown in some studies (SCHUMM, 1973; BULL & KNUEPFER, 1987), some Holocene sequences of terraces are not due to changes of external variables of the fluvial system (climate, tectonic, and sea level).

CONCLUSIONS

As for methods, this research has confirmed the importance of integrating different approaches and techniques for the study of fluvial terraces. Additionally, the fundamental value of procedures such as identification of the flood plain, determination of terrace elevation, and correlation of terraces was shown.

In the Vallone Bellunese there are six levels of terraces of the Piave River. The highest terrace is a climatic terrace because its formation is due to a climatic change. This terrace represents a geomorphic threshold: during aggradation the stream power is less than the critical power, whereas during incision the stream power exceeds the critical power. A progressive reduction of sediment input into the stream is likely the main cause of such a change in river behavior. Stream dynamics after the last Würm glaciation in this part of the Alps can be better explained if a paraglacial period is assumed. This implies a revision of previous models which referred to anaglacial and kataglacial periods.

The genesis of lower terraces is more difficult to explain. They could be complex response terraces; in this case they would represent periods of equilibrium during the downcutting of the river. Their formation could also be explained with lateral shifts of the river. In both cases (complex response terrace or lateral shifts) the formation of the lower terraces doesn't require a change of an external variable of the system.

REFERENCES

BALESTRI L., MAGNONI G., MOZZI G., SANTANGELO R. & ZAMBON G. (1988) - *Movimenti recenti nell'Italia nord-orientale da ripetizioni di livellazioni di precisione (1952-1985).* Suppl. Geogr. Fis. Dinam. Quat., *1*, 25-30.

BERTOLDI R. (1996) - *Vegetational and climatological development during the Late Pleistocene - Early Holocene in the Vallone Bellunese (South-eastern Alps, Italy).* In: EVANS S.P., FRISIA S., BORSATO A., CITA M.B., LANZINGER M., RAVAZZI C. & SALA B. (eds.) «Late Glacial and early Holocene climatic and environmental changes in Italy» AIQUA-MTSN Conference Abstracts, Trento (Italy), 7-9 February 1996, 95.

BROGLIO A. (1994) - *La sepoltura epigravettiana del Riparo Villabruna.* Conference Proceedings «Sepolture preistoriche nelle Dolomiti e primi insediamenti storici», Belluno 19 September 1992, Fondazione G. Angelini, 59-88.

BRÜCKNER E. (1909) - *Die venezianischen Gletscher.* In: PENCK A. & BRÜCKNER E. (1909) - Die Alpen im Eiszeitalter, 3 vol., 954-1042, Tauchnitz, Lipsia.

BULL W.B. (1977) - *The alluvial fan environment.* Progr. Phys. Geogr., *1*, 222-270.

BULL W.B. (1990) - *Stream-terrace genesis: implications for soil development.* Geomorphology, *3*, 351- 367.

BULL W.B. & KNUEPFER P.L.K. (1987) - *Adjustment by the Charwell river, New Zealand, to uplift and climatic changes.* Geomorphology, *1*, 15-32.

CASTIGLIONI B. (1923) - *Le tracce glaciali del Col Visentin presso Belluno.* Atti Acc. Ven. Trent. Istr., *14*, 46-66.

CHURCH M. & RYDER J.M. (1972) - *Paraglacial sedimentation: a consideration of fluvial processes conditionated by glaciation.* Geol. Soc. Am. Bull., *83*, 3059-3072.

COTTON C.A. (1940) - *Classification and correlation of river terraces.* Journ. Geomorph., *3*, 27-37.

DAL PIAZ G. (1912) - *Studi geotettonici sulle Alpi orientali. Regione fra il Brenta e i dintorni del lago di Santa Croce.* Mem. Ist. Geol. Univ. Padova, *1*, 1-195.

DUNNE T. & LEOPOLD L.B. (1978) - *Water in environmental planning.* Freeman, New York, 818 pp.

FLIRI F. (1988) - *An outline of the middle and main Würm chronology of the Eastern Alps.* Geogr. Fis. Dinam. Quat., *11*, 117-118.

FORMAN S.L. (1989) - *Applications and limitations of thermoluminescence to date quaternary sediments.* Quat. Intern., *1*, 47-59.

FRYE J.C. & LEONARD A.R. (1954) - *Some problems of alluvial terrace mapping.* Am. Journ. Sc., *252*, 242-251.

GORTANI M. (1950) - *Gli studi sui terrazzi fluviali e marini d'Italia dal 1938 al 1948.* Boll. Soc. Geogr. It., *87*, 297-322.

HOWARD A.D. (1959) - *Numerical systems of terrace nomenclature. A critique.* Journ. Geol., *67*, 239-243.

JACKSON L.E., MACDONALD G.M. & WILSON M.C. (1982) - *Paraglacial origin for terraced river sediments in Bow Valley, Alberta.* Can. Journ. Earth Sc., *19*, 2219-2231.

JOHNSON D. (1944) - *Problems of terrace correlation.* Geol. Soc. Am. Bull., *55*, 793-818.

KNUEPFER P.L.K. (1988) - *Estimating ages of late Quaternary stream terraces from analysis of weathering rinds and soils.* Geol. Soc. Am. Bull., *100*, 1224-1236.

MONDINI C. & VILLABRUNA A. (1994) - *La ricerca preistorica nel territorio bellunese.* Conference Proceedings «Sepolture preistoriche nelle Dolomiti e primi insediamenti storici», Belluno 19 September 1992, Fondazione G. Angelini, 11-27.

MORISAWA M. (1985) - *Rivers. Form and process.* Longman, New York, 222 pp.

PELLEGRINI G.B. (1979) - *I conglomerati prewürmiani della conca di Ponte nelle Alpi.* Geogr. Fis. Dinam. Quat., *2*, 57-63.

PELLEGRINI G.B. (1994) - *L'evoluzione geomorfologica del Vallone Bellunese nel Tardiglaciale würmiano e nell'Olocene antico.* Conference Proceedings «Sepolture preistoriche nelle Dolomiti e primi insediamenti storici», Belluno 19 September 1992, Fondazione G. Angelini, 29-57.

PELLEGRINI G.B., SCARAMUZZA L., BOZZO G.P., CANEVE L., NEGRI G., SCHIAVON E., SPAGNA V., SURIAN N. & TOFFOLETTO F. (1996) - *Geomorphological Map of Italy at 1:50.000 scale: Sheet (063) Belluno - Veneto Region.* Proceedings of the First European Congress on Regional Geological Cartography and Information System, Bologna 13-16 June 1994, vol. 1, 324-325.

PELLEGRINI G.B. & SURIAN N. (1994) - *Late Pleistocene geomorphological evolution in the Vallone Bellunese, Southern Alps (Italy).* Geogr. Fis. Dinam. Quat., *17*, 67-72.

PELLEGRINI G.B. & SURIAN N. (1996a) - *Environmental changes in the late Glacial - early Holocene in the Vallone Bellunese (Eastern Alps, Italy).* In: EVANS S.P., FRISIA S., BORSATO A., CITA M.B., LANZINGER M., RAVAZZI C. & SALA B. (eds.) *«Late Glacial and early Holocene climatic and environmental changes in Italy»* AIQUA-MTSN CONFERENCE ABSTRACTS, TRENTO (ITALY), 7-9 FEBRUARY 1996, 40-42.

PELLEGRINI G.B. & SURIAN N. (1996b) - *Geomorphological study of the Fadalto landslide, Venetian Prealps, Italy.* Geomorphology, *15*, 337-350.

PELLEGRINI G.B. & ZAMBRANO R. (1979) - *Il corso del Piave a Ponte nelle Alpi nel Quaternario.* St. Trent. Sc. Nat., *56*, 69-100.

PELLEGRINI G.B. & ZANFERRARI A. (1980) - *Inquadramento strutturale ed evoluzione neotettonica dell'area compresa nei Fogli 23 Belluno, 22 Feltre (p.p.) e 24 Maniago (p.p.).* da «Contributi preliminari alla realizzazione della Carta Neotettonica d'Italia», pubbl. n. 356 del P.F.G.

RITTER D.F. & MILES C. (1973) - *Problems of stream terrace correlation and reconstruction of geomorphic history caused by colluvium.* Geogr. Ann., Ser. A, *55*, 85-91.

ROBERTSON-RINTOUL M.S.E. (1986) - *A quantitative soil-stratigraphic approach to the correlation and dating of post-glacial river terraces in Glen Feshie, Western Cairngorms.* Earth Surf. Proc. Landf., *11*, 605-617.

RYDER J.M. (1971) - *The stratigraphy and morphology of para-glacial alluvial fans in South-central British Columbia.* Can. Journ. Earth Sc., *8*, 279-298.

SCHUMM S.A. (1973) - *Geomorphic thresholds and complex response of drainage systems.* In MORISAWA M. (ed.) «Fluvial Geomorphology», Proceedings of the Fourth Annual Geomorphology Symposia Series, Binghamton, New York, 299-310.

SCHUMM S.A. (1977) - *The fluvial system.* Wiley & Sons, New York, 338 pp.

SEMENZA E. (1957) - *L'alveo sepolto del Piave a Belluno.* Atti Ist. Ven. Sc. Lett. Arti Cl. Sc. Mat. Nat., *115*, 169-181.

SLEJKO D., CARULLI G.B., CARRARO F., CASTALDINI D., CAVALLIN A., DOGLIONI C., ILICETO V., NICOLICH R., REBEZ A., SEMENZA E., ZANFERRARI A. & ZANOLLA C. (1987) - *Modello sismotettonico dell'Italia nord-orientale.* C.N.R., G.N.D.T., rend. n. 1, Trieste.

STARKEL L., GREGORY K.J. & THORNES J.B. (eds.) (1991) - *Temperate palaeohydrology. Fluvial processes in the temperate zone during the last 15.000 years.* IGCP Project 158, Wiley, 548 pp.

SURIAN N. (1995) - *I terrazzi fluviali del Vallone Bellunese (Alpi Venete).* Unpublished Ph.D. Thesis, University of Padova, 139 pp.

TARAMELLI T. (1883) - *Note illustrative alla carta geologica della provincia di Belluno.* Fusi, Pavia, 215 pp.

TONGIORGI E. & TREVISAN L. (1941) - *Discussione sulla genesi e sulla cronologia dei terrazzi e delle pianure in relazione alle variazioni climatiche.* Atti Soc. Tosc. Sc. Nat. Mem., *49*, 216-231.

TONINI M. (1968) - *Elaborazione dei dati idrologici del bacino del fiume Piave.* L'Energia Elettrica, 2, 77-95.

TREVISAN L. (1946) - *Terrazzi glaciali o terrazzi interglaciali?* Riv. Sc. Preist., *1*, 193-207.

TRICART J. (1947) - *Méthode d'étude des terrasses.* Bull. Soc. Géol. Fr., *17*, 559-575.

VENZO S. (1939) - *Osservazioni geotettoniche e geomorfologiche sul rilevamento del Foglio Belluno.* Boll. Soc. Geol. It., *58*, 433-451.

WOLMAN M.G. (1971) - *Evaluating alternative techniques of floodplain mapping.* Water Res. Research, 7, 6, 1383-1392.

ZANFERRARI A., BOLLETTINARI G., CAROBENE L., CARTON A., CARULLI G.B., CASTALDINI D., CAVALLIN A., PANIZZA M., PELLEGRINI G.B., PIANETTI F. & SAURO U. (1982) - *Evoluzione neotettonica dell'Italia nord-orientale.* Mem. Sc. Geol., *35*, 355-376.