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THE DEMONTE TERRACE IN THE STURA VALLEY (MARITIME ALPS) BETWEEN CLIMATIC CHANGES AND TECTONIC MOVEMENTS

ABSTRACT: CAPITANI M. & MARRUCCI M., *The Demonte terrace in the Stura Valley (Maritime Alps) between climatic changes and tectonic movements*. (IT ISSN 1724-4757, 2008).

The lower part of the Stura valley, which from the Maritime Alps flows into the Cuneo plain, is characterized by several orders of fluvial terraces.

This paper discusses the genesis and the subsequent erosion of the third order terrace (Demonte terrace) in relation to climatic changes due to succession of glacial and interglacial phases and to tectonic movements that have involved the study area.

In order to understand the mechanisms that led to the aggradation of the Demonte terrace, the relations between this surface and the glacial deposits located in Stura Valley have been analysed. Stratigraphic relations and recent datings have identified the study surface as having a climatic genesis, temporally set in a typical paraglacial period, in particular in the passage from the last glacial period to the interglacial.

As regards the incision of the Demonte terrace, longitudinal profiles of the terraces of the Stura Valley and the geometric relations between the Demonte terrace and the upper and the lower terraces have shown that the erosion of this surface cannot be exclusively due to climatic evolution, but are due above all to the tectonic movements that have acted on this area of the Maritime Alps.

The tectonic activity that mainly influenced the fluvial pattern of the Stura di Demonte river is due to both the up-lifting of the Argentera massive and to the subsidence of the Cuneo plain. In particular the hydrographic disruption related to the capture of the Tanaro river due to the combined activity of anticlines, synclines and direct faults located in the Cuneo plain, is likely to have been responsible for the regressive mechanism that led to the progressive lowering of the Stura river base level. This is shown by the divergence of the terraces lower than third order.

KEY WORDS: Terraces, Climate, Tectonics, Stura Valley, Maritime Alps.

RIASSUNTO: CAPITANI M. & MARRUCCI M., *Il terrazzo di Demonte in Valle Stura (Alpi Marittime) fra cambiamenti climatici e movimenti tettonici*. (IT ISSN 1724-4757, 2008).

La Bassa Valle Stura che dalle Alpi Marittime sbocca nella Pianura Padana sud-occidentale, è caratterizzata da vari ordini di terrazzi fluviali.

Viene qui analizzata la genesi e la successiva erosione del terrazzo di 3° ordine (terrazzo di Demonte) in relazione ai cambiamenti climatici im-

putabili all'alternarsi di fasi glaciali e interglaciali e ai movimenti tettonici che hanno interessato l'area in esame.

Per comprendere i meccanismi che hanno portato all'aggradazione del terrazzo di Demonte sono state analizzate, in particolare, le relazioni tra questa superficie e i depositi glaciali presenti nella Valle Stura. I rapporti stratigrafici e le recenti datazioni hanno consentito di attribuire alla superficie in questione una genesi prevalentemente climatica collocandola temporalmente in un periodo tipicamente paraglacial, più precisamente nel passaggio dall'ultimo Glaciale all'Interglaciale.

Per quanto concerne l'incisione del terrazzo di Demonte, i profili longitudinali dei terrazzi presenti nell'area e i rapporti geometrici che il terrazzo di Demonte presenta con quelli di ordini superiori ed inferiori, hanno mostrato che il forte abbassamento del livello di base della Stura non può essere imputato esclusivamente ad un'evoluzione climatica ma soprattutto ai movimenti tettonici che hanno agito in questo settore delle Alpi Marittime. L'attività tettonica che ha influito maggiormente nell'evoluzione fluviale della Stura di Demonte è legata prevalentemente al sollevamento del Massiccio dell'Argentera e alla subsidenza della piana cuneese. In particolar modo lo sconvolgimento idrografico connesso con l'evento di cattura del fiume Tanaro indotto dall'attività combinata di sinclinali, anticlinali e faglie dirette localizzate nella piana cuneese, sarebbe responsabile del meccanismo di tipo regressivo che ha condotto al progressivo abbassamento del livello di base del collettore principale della Valle Stura, testimoniato dalla divergenza dei terrazzi di ordine inferiore al 3°.

TERMINI CHIAVE: Terrazzi, Clima, Tettonica, Valle Stura, Alpi Marittime.

INTRODUCTION

The lower Stura Valley which from the Maritime Alps flows out into the south-western Cuneo Plain, is characterized by several orders of fluvial terraces. From Demonte as far as Borgo San Dalmazzo downvalley, there is both a progressive increase in the number of terraces and also a considerable increase in the height of the slopes that separate them from the present valley bottom. To be precise, whilst above Festiona there is a single order of terraces, which progressively links with the alluvial plain by means of slopes never higher than 15 metres, going towards Borgo San Dalmazzo there is a greater number of terraces,

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separated from one another by slopes which are sometimes higher than 20 metres. In particular, we can see three main orders of terraced surfaces (1st, 2nd and 3rd order), and besides this at a lower altitude with respect to the 3rd order terrace, there is a discontinuous distribution of smaller terraces which indicate alternating phases of vertical incision and periods of standstill and deposition in the morphological evolution that has brought about the present level of the flood plain.

In order to identify the genesis and evolution of the terraces of the Stura valley it was decided to start from a detailed study of the 3rd order terrace because this is the largest and best preserved, it being more or less continuous throughout the lower valley. This surface is known as the Demonte terrace, in agreement with the naming rules suggested by Howard (1959), using as reference a place name in order to avoid misunderstanding in the sections in which the terrace has a different relative height, even if references are occasionally made to numerical naming.

Until now very few Authors have been interested in the study of the fluvial terraces of the Western Alps, and the area between the Middle and Lower Stura Valley of Demonte is lacking in detailed geomorphological studies.

There are several important research works carried out in this area that we can list. Sacco, at the end of the 1800s, studied the flood terraces of the Stura of Demonte. Ognibeni & Venzo (1951), whose research concerned the planning of a dam, never actually built, close to the village of Moiola. Gabert (1962), who, in his general treatise on the western plains of the Po, also took into consideration the morainic amphitheatre of Gaiola in the lower Stura Valley. Last but not least, we have the notes regarding the Quaternary, in the illustrative Notes of the Geological Map of the Argentera Massif published by Malaroda & *alii* (1970), and on the geomorphology of the Arma Valley (Spagnolo, 2007).

We must also not forget the importance of some work carried out in surrounding areas, like that on the Cuneo Plain by Biancotti (1975, 1977, 1979 a-b) and finally the short summary specifically on the terraces of the lower Stura Valley by Capitani & Federici (in Federici, 2007), prepared for an International Congress (12th Belgium-France-Italy-Romania Geomorphological Meeting «Climatic change and related landscapes», Savona 26-29 settembre 2007).

THE DEMONTE TERRACE

Morphological characteristics

The terrace extends from a height of about 740 metres just above the village of Demonte to the area of Ponte di Vignolo, at a height of around 625 metres. This terraced surface has the appearance of a series of narrow strips rising above the slopes of both hydrographic left and right (with the exception of the sector between Demonte and the Podio hill). In the middle-terminal section, from Gaiola as far as the opening onto the Cuneo plain, it is made up of wider and better preserved terraces. It is likely that this

distribution of surfaces is an indication of the different lithological arrangement of the territory within which the river Stura was embanked during its incision phase. In particular, in the sector above the Stura, given the presence of easily erodible gravelly deposits, it has been able to act freely varying its position and eroding laterally extensive parts of the Demonte terrace, as shown by the present width of the flood plain. On the other hand, downvalley a similar evolution was possible only up until the main catchment drain of the valley cut down into the rocky basement close to the village of Roccasparvera at a height of about 635 metres. The presence of the pre-Quaternary rocky basement has brought about the formation of several terraced surfaces which have a configuration typical of the *fillstrath terraces* of Howard (1958) or Bull's *fill-cut terraces* (1990).

Moving downvalley there is a significant variation in the height with which the third order terrace (Demonte terrace) rises with respect to the present flood plain, showing a diverging trend. In particular the terrace, near Fessione, is about 15 metres higher than the river bed of the Stura, whilst at the end of the valley the difference in height is more than 30 metres. The slope has a mean gradient of about 0.0065.

An additional element of the morphology of the Demonte terrace is the group of small lakes of Rialpo, immersed in their alluvium and generated through a karstic process brought about by the presence of Subriannais Carniole under the same alluvial deposits (Marrucci, 2008).

Depositional arrangement

The deposits typical of the terrace are made up exclusively of gravels with a medium to high roundness, which range from sub-rounded to well rounded, and with a high mean sphericity index (0.81).

The maximum particle sizes of the gravels, which range between about 20-25 cm near the village of Ospedalieri, from about 15 to 20 cm near Ponte di Vignolo, where there is prevalence of finer 7-8 cm sized particles, generally show very little variation in maximum particle size.

The sequence used to describe the depositional arrangement of the Demonte terrace can be seen on the fluvial erosion scarp which below Demonte runs along the side of the main road near Tetti Cavalier. The 15-20 metre-long section is typical of a medium-proximal portion of the terrace.

Here the gravels are lithologically typical of the deposits outcropping in the hydrographic basin of the Stura Valley, although crystalline lithotypes are prevalent, and they show a clear stratification that varies from flat-parallel (prevalent) to concave cross-bedding at a middle-scale. The main lithofacies are the Gm, Gt, Gp, Sh of Miall (1985) (fig. 1). The Gm facies can be associated with the development, following surge flow events, of longitudinal bars. On the other hand, the Gp, Gt and Sh can be considered as representing respectively the frontal growth of previous bar nuclei, of small canal infilling and finally of episodes of planar flow and not bottom-channelled deposition (Miall, 1977; Paronuzzi, 1988).

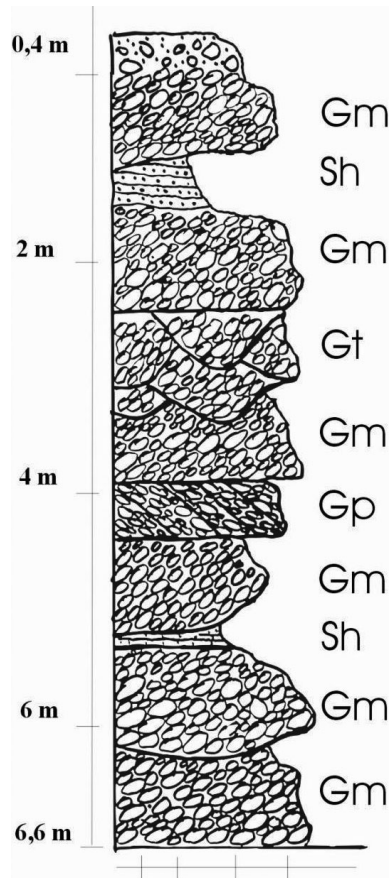


FIG. 1 - Stratigraphic column of the third order terrace.

A similar sequence showing a vertical repetition of identical depositional facies, where from bottom to top there are no substantial particle size variations apart from a limited cementation at the roof, constitutes a typically aggrading succession of a fluvial system with intertwining channels, with low sinuosity index and prevalent bottom load, typical of braided rivers (model 2 of Miall, 1985).

As regards the degree of alteration of the gravels, there are sandy matrixes, often in large quantities inside the gravel interstices, characterized both by low amounts of clay and by coloration which in the first 60-75 cm of soil depth goes from brown-red, typical of the first 10-15 cm of soil, to a grey-yellow in the remaining 50-60 cm. The single elements of the alluvial deposit, aside from a calcareous patina in the deepest part, show no signs of alteration.

Along the scarps close to Roccasparvera the Demonte terrace deposits change basewards (at about 10-15 metres) to coarse deposits typical of sequences belonging to higher order terraces. This could indicate that the incision of the second order terrace continued to a height greater than the present level of the Stura. In this case the Demonte terrace would appear to have a geometry typical of Howard's Fill Terraces, that is representative of an initial phase typified by prevailing vertical corrosion, and a successive phase of predominantly fluvial aggradation.

GENESIS OF THE DEMONTE TERRACE

Aggradation phase

In order to understand the mechanisms governing the aggradation of the Demonte terrace it is useful to analyse the relations between this surface and the glacial deposits in the Stura Valley and in particular the residual morainic frontal deposits, an expression of phases of advance and standstill of the glacial tongues which came downvalley in cold periods.

Above the village of Demonte there are residual forms of various barrier moraines. These can be attributed, on the basis of their location and deposit characteristics, to three different complexes that can be found respectively close to the villages of Festiona, Gaiola and Castellan. In particular, the degree of alteration of these deposits seems to increase in a downvalley direction, where the deposits appear more altered and washed away.

Whilst the oldest terraces, of first and second order, show connecting surfaces with the complexes of Gaiola and Castellan, making it likely that they were the result of proglacial deposition that will not be discussed here, the third order terrace has a clear contact with the morainic deposits of Festiona.

This type of relation between the two deposits clearly indicates deposition of this terrace alluvial sequence after the formation of the morainic arch, which is partially buried.

Dating recently carried out with cosmogenic nucleides (at the laboratory of Earth and Atmospheric Science Department of Purdue University in Lafayette (Indiana, USA) (Capitani & Federici, in Federici, 2007) gives a Late-glacial age (15505 ± 1109 years BP) to these morainic deposits. The aggradation of the Demonte terrace is therefore likely to have occurred during the passage from the last Glacial to the Interglacial. To be more precise, the deposition of the sequence probably began during the initial phase of deglaciation, lasting throughout the period of glacial retreat and probably beyond, step by step as the glacial prevalence was substituted by the fluvial regime.

From data in the literature, especially from the work of Surian (1996) and Surian & Pellegrini (2000) on the terraces of the River Piave, we can deduce that the aggradation phase of the Demonte terrace could be typical of a paraglacial period. Processes associated with denudation of the valley slopes acted with great intensity in moving large amounts of solid load to the main catchment drain of the valley and brought about the partial filling of the valley.

The great availability of easily erodible material coming mostly from the break-up of glacial deposits that became unstable in the new fluvial regime, together with scarce vegetation cover, played a crucial role in the accumulation of sediments.

The establishment of these conditions is shown also by the characteristics of some cones of the Stura Valley which, on the basis of their morphological features, in a recent note by Capitani & *alii* (in Federici, 2007) were classified as paraglacial cones.

The paraglacial attribution of the Demonte terrace is also shown by the stratigraphic relations of these cones with the terrace. In correspondence with the fluvial erosion scarp which from Ospedaliere as far as Tetti Maigre borders the Demonte terrace, there are zones of both deposits associated with the paraglacial cones and also areas on the other hand where there appear sandy-gravelly deposits referable to the activity of the Stura (fig. 2). The depositional geometry is, in fact, that typical of an aggradation of the paraglacial cones and the terrace at the same time, also by means of the transportation of glacial material on the slopes of the middle valley.

Erosion phase

Whilst the aggradation phase of the Demonte terrace seems relatively easy to interpret and is linked essentially to climatic factors, it is more complicated to explain the causes and various stages that characterised the erosion of the palaeo-plain up to the present profile. In order to understand fully the factors that conditioned the incision of the Demonte terrace we must examine the longitudinal profiles of the terraces in the area, and also the geometric relations that the Demonte terrace has with higher and lower orders.

The longitudinal profiles of the first, second and third order terraces have a converging trend (fig. 3). In particular, whilst those of first and second order having very similar gradients tend to converge according to a low angle of incidence, the Demonte terrace, having a lower gradient

than the other two, has a higher angle of incidence. The relations between glacial depositional and standing phases can at first sight suggest, in agreement with Trevisan's (1949) and Nesci & Savelli's (1986; 1990 a, b; 1991 a, b) models, an Anaglacial (aggradation) and Cataglacial (incision) origin for these terraces. However, the strong lowering of the base level of the Stura cannot be attributed exclusively to a climatic evolution of the valley, since in an alpine sector like the Maritime Alps we cannot ignore the effects of regional tectonics that are still active today, and which in the past are likely to have varied between moments of greater or lesser activity.

The absence of data regarding the rate of tectonic uplift of the Argentera Massif does not allow detailed quantification of the extent to which the neotectonics has really influenced the fluvial evolution of the valley. Of particular interest however is the fact that starting from the Upper Oligocene the Italian side of the Argentera Massif underwent a different rate of exhumation compared with the French side, which from a mean of about 0.33 mm/year progressively increased (fig. 4) and reached in the Upper Pliocene-Lower Pleistocene a mean value of about 1.1-1.4 mm/year (Bogdanoff & *alii*, 1997; Bigot & *alii*, 2000; Bogdanoff & *alii* 2000). Exhumation rate does not completely coincide with that of tectonic uplift and so in general cannot be used as clear evidence of uplift of an area (England & Molnar, 1990; Gilchrist & Summerfield, 1991; Stuwe & Bar, 1998). However, the morphological differences noted by Ribolini (1999, 2000) between the Italian and French sectors, relative to the Argentera Massif, indicating how the south-eastern part underwent greater tectonic uplift than that of the French side, could suggest a certain correlation between rate of exhumation and tectonic uplift.

Recent studies on the focal mechanisms in the sector of the Maritime Alps (Madeddu & *alii*, 1996), confirming how the study area is still today subject to transpressive tectonic activity, can indicate how the generalised uplift of the Argentera Massif might have acted, in the recent evolution of the study area, superimposed on the main climatic phases that have taken place from the Middle-Upper Pleistocene until today. We must also take into account the tectonic events that have influenced the south-western sector of the Cuneo plain, from the Middle Pleistocene to the present time. According to Biancotti (1977; 1979 a, b), in fact, in the Cuneo plain the events that determined the evolution of both the isolated terraces of Salmour, Pianfei, Eula, Isola and Roracco, and also of the sectors at the end of the Po and Maira valleys, are connected with the direct synclinal, anticlinal and fault activity which have acted since the Middle Pleistocene and which in part continue to influence the current evolutive trends of the main hydrographic aspects of this plain. It is precisely the combined activity of these tectonic elements which is likely to have played, according to Biancotti, since the Middle-Lower Pleistocene, a crucial role in conditioning for example the evolution of the Tanaro river, causing a progressive shift of the talweg towards sectors located more to the east of the Po Plain, to the point of inducing, after the last glacial pe-



FIG. 2 - Contact between massive deposits and gravelly-sandy lenses of Paleo-Stura.

FIG. 3 - Longitudinal profiles of the main fluvial terraces in Stura valley.

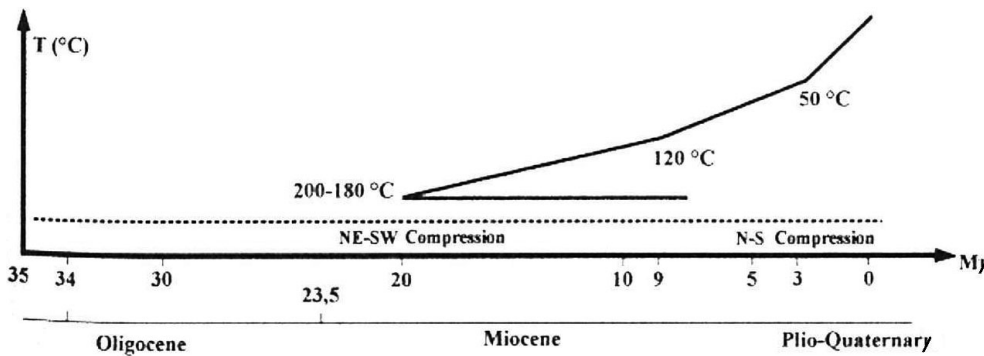
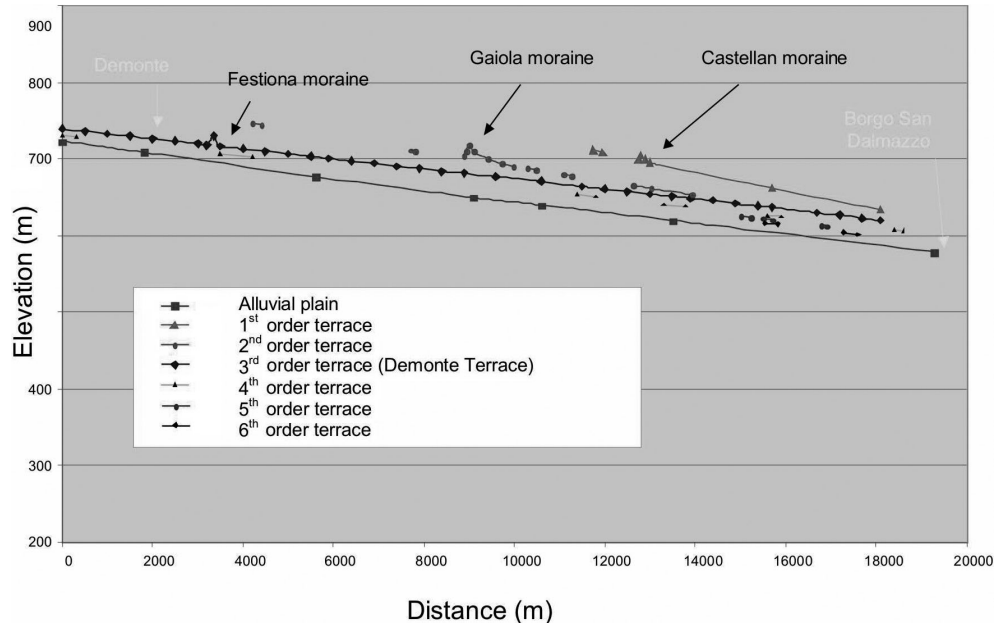


FIG. 4 - Variation in the rate of exhumation of Argentera Massive since Miocene (from Bogdanoff, 1991).

riod, its capture. The existence of recent tectonic activity, according to this author, is confirmed by the fact that all the water courses coming from the Ligurian Alps, after a S-N valley direction towards, abruptly change direction eastwards and flow directly or indirectly into the Tanaro.

Among the tectonic elements identified for the Lower Po Plain, of particular importance is both the NE-SW-directed syncline along the Savigliano-Cuneo line and also the Fossano-Trinità-Magliano anticline in a NW-SE direction (fig. 5). The beginning of these deformational structures was referred by Carraro & Petrucci (in Bottino & *alii*, 1994) and by Biancotti (1979, b) to the Middle-Upper Pleistocene. Furthermore, according to the latter author both the Savigliano-Cuneo syncline and the Fossano-Trinità-Magliano anticline are likely to be still active. These tectonic elements acting in different ways in the Po Plain have caused respectively the uplift of the north-eastern sectors and the subsidence of the areas which, located in the western sectors of this plain, coincide with those in front of the opening of the Stura Valley.

A further tectonic element, whose activity in the past could have caused subsidence of the Cuneo plain with respect to the Middle and Lower Stura Valley, is the presence (Bottino & *alii*, 1994) at the contact between the front of the Maritime Alps and the Po Plain, of a series of normal faults with a vertical trend, whose activity is difficult to date.

All these elements therefore oblige us to take into account the possibility that tectonic activity, associated both with the uplift of the Argentera Massif and with the subsidence of the Cuneo plain, has had an important role in the fluvial evolution of the Stura. This is not only due to the events characterizing the erosion of the Demonte terrace but also those regarding all the other terraces.

The repetition of phases of fluvial aggradation and incision could be interpreted, within a more general picture, also as a direct consequence of the superimposition of the effects induced by the main climatic variations and those produced by both a tectonic uplift of the study area and subsidence of the Cuneo plain.

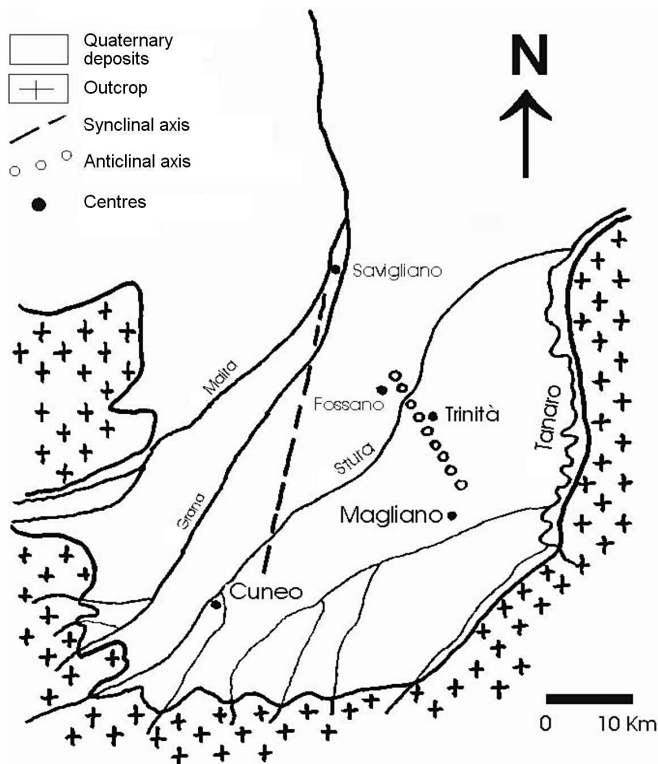


FIG. 5 - Main tectonic elements of Cuneo plain (simplified from Biancotti, 1979).

It seems less difficult to interpret the phases characterizing the Stura Valley from deposition of the Demonte terrace until the present day. The terraces of a lower order than the Demonte terrace have a diverging trend, both with respect to this third terrace and also in relation with the present longitudinal profile of the Stura. This trend can be related to a progressive lowering of the base level of the main catchment drain of the valley which occurred with greater intensity in the areas located more downvalley of the study area than those higher up. In particular, if we keep in mind the fact that the terraces of an order lower than third constitute, compared with those of first, second and third order, the expression of lesser aggradation, the evolution of the base level of the Stura, following development of the Demonte terrace, can be related to regressive fluvial erosion. This saw a progressive lowering of the main catchment drain of the valley, followed by short periods of standstill and vertical erosion, with associated limited flood events.

According to Gabert (1951) and Biancotti (1979 a, b) the capture of the Tanaro, occurring shortly after or during the last glacial period, prompted regressive erosion which affected the whole hydrographic network of this water course. This caused a general hollowing out of the relative tributaries and the development of a series of deep terraces. As the Demonte terrace is referable to a

depositional event which certainly occurred after a Late-glacial standing phase and given the way in which the base level of the Stura has evolved, from the third order terrace to the present course, typical of regressive erosion, it is plausible to correlate the vertical incision occurring after formation of the Demonte terrace with the hydrographic rearrangement associated with the capture of the Tanaro.

Given the type of terraces, diverging and not converging, we can hypothesize that, in the period between the incision of the Demonte terrace and the development of the present profile of the Stura, the uplift of the Argentera Massif had less of an impact than that of the lowering of the base level induced, downvalley of the study area, by the hydrographic evolution of the Tanaro. Evidence of this comes from the fact that the longitudinal profile of the Demonte terrace, having only a limited variation in mean gradient, between the upvalley and downvalley sectors, is not particularly indicative of an uplift of the study area following incision of the terrace. In these terms, the tectonic elements in correspondence with the Cuneo plain seem to have had a greater influence. In fact, the activity associated with the uplift of the Fossano-Trinità-Magliano syncline could have influenced the way in which the regressive downcutting caused by the capture of the Tanaro developed. According to Biancotti (1979, a) the activity of this tectonic element is likely to have created disturbances in the areas of the Stura west of the Fossano-Trinità-Magliano line, connected with the non-erosive stage and the onset of prevailing deposition. In fact, the author indicates a similar evolution for the present tendency to deposit shown by the Stura river upvalley of this anticline, where a localised resumption of uplift appears to be the cause of a new aggradation phase. From this point of view it could be plausible to associate the development of the terraces of a lower order than that of Demonte, which in themselves indicate brief periods of aggradation, with an intermittent tectonic activity. The lowering of the base level of the Stura following regressive downcutting caused by the capture of the Tanaro, in fact, could have been slowed down or undergone non-erosive moments induced by a periodic resumption of tectonic activity connected with uplift of the Fossano-Trinità-Magliano anticline. During this moment the terraces of fourth, fifth and sixth order could have been formed.

The incision of the Demonte terrace therefore occurred due to a regressive-style mechanism, and can be essentially related to the hydrographic rearrangement caused by the capture of the Tanaro.

The onset of this phase came about by means of a concurrent variation in the bed of the Stura which caused the formation of Fillstrath Terraces and Strath Terraces, located in correspondence with the middle-terminal stretch of the valley. Successively, the Stura downcut into the rocky basement in the sector between Gaiola and Ponte di Vi-

gnolo. This caused, very probably, both the conservation of the main ring moraines and the development of an asymmetry in the distribution of the various terraces throughout the study area.

CONCLUSIONS

In conclusion, the depositional sequence relative to the Demonte terrace is expression of a phase of aggradation which, occurring almost certainly at the end of the Late-glacial during the retreat of the glaciers responsible for the formation of the morainic arch of Festiona, brought about the partial infilling of the valley. This seems characteristic of a typically paraglacial period, in which sedimentation rates were likely to be very high due to the presence of a thin vegetation cover and the widespread availability of easily erodible material (glacial deposits), in addition to a general release of tension on the valley sides.

Following the depositional phase of the Demonte terrace, the Stura inverted its dynamics and cut into its own alluvial deposits. The reason for this inversion of tendency is certainly a reduction in solid load available, but it is above all due to the tectonic activity that influenced the zone at the end of the valley together with the effect produced by the capture of the Tanaro. The Stura of Demonte from the end of the aggradation phase of the terrace till the present day, has undergone negative variations in its base level which, with alternating periods of standstill and aggradation, have brought about the formation of the fourth, fifth and sixth order terraces. The incision of the Demonte terrace came about by means of a regressive mechanism, and can therefore be associated with the hydrographic rearrangement caused by the capture of the Tanaro river.

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