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GEOMORPHOLOGICAL MAP OF THE TRIGNO BASIN (ITALY): EXPLANATORY NOTES

ABSTRACT: AUCELLI P.P.C., CINQUE A. & ROSSKOPF C., *Geomorphological map of the Trigno basin (Italy): explanatory notes.* (IT ISSN 0391-9838, 2001).

A new 1:50,000 Geomorphological Map of the Trigno River basin (Molise Region; Italy) is being presented and discussed in this paper. It represents the reduction of the original mapping at a scale of 1:5,000 which was obtained through both field surveys and aerial photo interpretation. Besides the main relic landforms showing the Pliocene-Quaternary evolution of the area, the Map also shows in detail the distribution of the most recent and active geomorphic phenomena. The present paper contains information about the materials and methods used as well as the geological-geomorphological setting of the mapped area. Moreover, it explains the meaning of the less standardised terms used in the Key and gives additional information about the age, magnitude and/or causal factors of some geomorphic phenomena recognised in the area.

KEY WORDS: Geomorphological mapping, Present morphodynamics, Trigno River basin, Molise (Italy).

RIASSUNTO: AUCELLI P.P.C., CINQUE A. & ROSSKOPF C., *Carta geomorfologica del bacino del fiume Trigno (Italia): note illustrative.* (IT ISSN 0391-9838, 2001).

Viene presentata una Carta Geomorfologica del bacino del fiume Trigno in scala 1:50.000. Essa rappresenta la riduzione di originali redatti in scala 1:5.000 sulla base di osservazioni dirette e della interpretazione di carte topografiche e foto aeree. La Carta riporta sia elementi relitti attribuibili a vari stadi della evoluzione Plio-Quaternaria della zona (paleosuperfici, *glacis* e terrazzi fluviali sospesi), sia, con maggior dettaglio e completezza, forme e processi legati alla evoluzione geomorfologica più recente (tardo Quaternario-Attuale). Questo articolo di accompagnamento alla Carta fornisce informazioni aggiuntive sull'assetto geologico dell'area, sulla metodologia di indagine e sul significato dei termini e delle simbologie adottate. Per alcune forme vengono inoltre forniti dati ed elementi di valutazione circa i caratteri geometrici più tipici, le dinamiche di modellamento e, ove possibile, l'età dei fenomeni.

Come emerge chiaramente dalla Carta, vaste porzioni del bacino indagato presentano, in ragione di una notevole predisposizione litologica e strutturale, una morfodinamica recente ed attiva che appare nettamente dominata da fenomeni di instabilità gravitativa, sia superficiali che profondi.

La distribuzione di tali fenomeni è molto legata allo sviluppo della dissezione fluvio-torrentizia ed allo scalzamento di pendii per migrazione laterale di canali fluviali. Nel contempo, i fenomeni franosi sembrano aver giocato un ruolo decisivo nella genesi ed evoluzione di alcuni impluvi di basso ordine gerarchico.

TERMINI CHIAVE: Cartografia geomorfologica, Morfodinamica attuale, Bacino del Trigno, Molise.

INTRODUCTION

The present paper illustrates a geomorphologic map of the Trigno River basin (Molise Region; Italy) and summarises the results of a detailed survey carried out throughout the last four years, initially as part of a PhD Thesis (Aucelli, 1999) and subsequently as a more specific and independent task.

In existing scientific literature there are very few papers dealing with the geomorphology of this study area. Among them, the papers of interest are those by Budetta & De Riso (1982), which deals with the general geomophological setting of the Trigno basin, and by Almagià (1910) which discusses the age and distribution of landslide phenomena. In terms of thematic cartography, the product we present here is the first basin-wide and middle scale geomorphological map to be pubblished.

Though the enclosed Map also shows many geomorphological elements that help to decipher the long term (Pliocene-Quaternary) evolution of the area, much more

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attention has been paid to landforms witnessing the most recent (Late Quaternary) phases of landscape evolution, as well as showing active geomorphic phenomena. This choice was governed by our desire to contribute towards the planning and management of the study area, which appears to contain a number of fragile and hazardous geomorphic situations caused by soil and slope instability as well as fluvial erosion.

The scope of this article is to explain the Map by providing the reader with information about the materials and methods used, the geology of the area and the meaning of the less standardised terms used in the Key adopted.

GEOGRAPHICAL SETTING

The Trigno river basin is cut along the Northeastern flank of the Apennines chain and terminates on the Adriatic coast of the Italian peninsula. It covers about 1200 km^2 and represents one of the three major watersheds in the Molise region. The total Trigno basin relief is about 1700 m and the highest springs feeding the water course are located at about 1400 m above sea level. The upper part of the basin, cut into relatively resistant bedrock, is dominated by mountainous landscape, while the medium and lower portions, where the terrain is prevalently soft, are characterised by a hilly, sometimes terraced, morphology and values of local relief that decrease progressively toward the coast.

The Trigno river is a 7^{th} order stream about 120 km long. With the exception of the Treste river, which is a 6^{th} order watercourse running almost parallel to the Trigno river, all other major tributaries are 4^{th} and 5^{th} order streams whose axes are commonly oriented perpendicularly to the main water course. On the whole, the drainage pattern may be defined as dendritic, though some deviations toward angular and trellis-like patterns do locally occur in relation to both the passive influence of ancient structures and the active control exerted by Quaternary faults.

The upper sector of the Trigno basin has a high average elevation and a landscape that appears to be in a mature stage of evolution, compared to other sectors of the same basin and considering the young orogenic context. Much declined denudational slopes, mature karstic landforms and slightly incised valleys characterise this sector of the basin (fig. 1). Starting from the Chiauci gorge (710 m a.s.l.), where the main knickpoint of the Trigno River longitudinal profile lies, a different (middle) sector of the basin is to be found. It is characterised by mountainous - hilly relief, high slope angles and narrow V-shaped incisions along which strong interactions of fluvial and slope dynamics take place. Commonly, along the valley side slopes, are present relics of almost planar erosion surfaces dipping towards the valley axes (fig. 2). In this sector, the occurrence of lithologic units offering different resistance to erosion, create alternations of V-shaped gorges and wider valley reaches along the Trigno River. The wider reaches are often associated with flat valley floors deriving from the combined effects of lateral planation and aggradation. The latter is fed not only by the load carried by the Trigno and its main tributaries, but also by alluvial fan and landslide deposits deriving from the degradation of valley side slopes. The lower sector of the Trigno basin

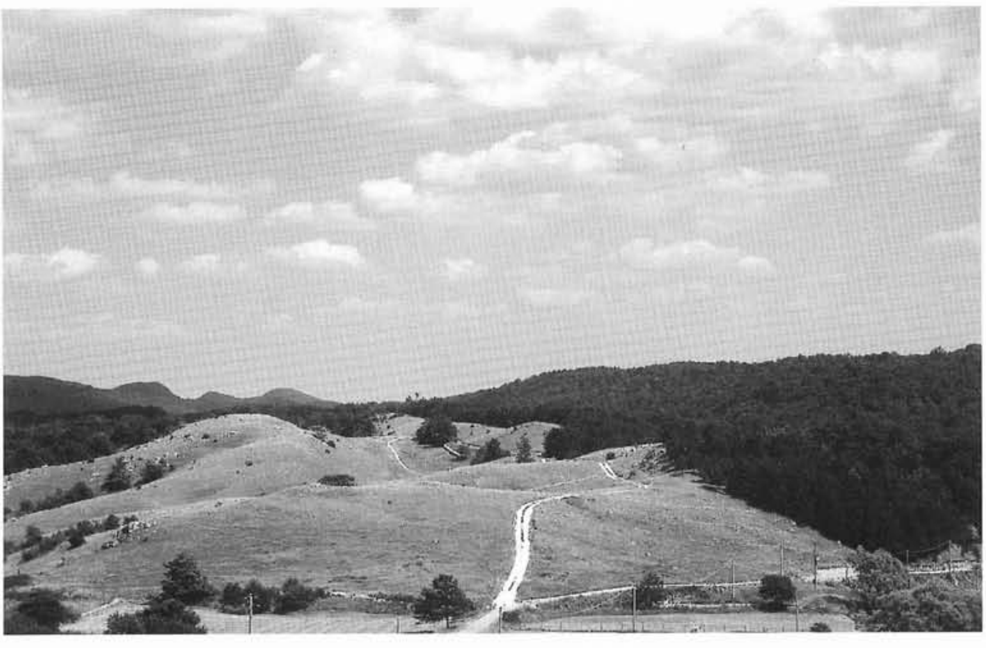

FIG. 1 - Typical hummocky karst landscape in the upper Trigno valley.

FIG. 2 - Well preserved hanging valley side glacis in the middle sector of the Trigno valley.

extends from the confluence of the Canniviere stream (60 m a.s.l.) down to the river mouth on the Adriatic coast. Due to its gentle, hilly topography and the noticeable width of its valley floors (which are often terraced), this sector has current morphodynamics that show only limited interaction between fluvial and slope dynamics (fig. 3).

Though the Trigno basin as a whole is subject to a warm temperate climate with prolonged summers and mild winters, its most elevated portion, and especially the N and NE facing mountain slopes, experience up to two months of snow cover per year. As it is typical of the Mediterranean climate, precipitation is concentrated in the cold semester with two peaks: one in October-January and the other centred around April. The rain-gauge stations situated at low and middle elevations showed mean annual rainfall values of between about 600 and 1200 mm during the period 1944-1990. On the highest portion of the basin, annual rainfall is normally between 1300 and 2000 mm. The highest value ever recorded was 3235 mm in 1963 at Castiglione M. Marino (1081 m a.s.l.). Noticeable differences of annual values may exist between different rain gauges, while the same rain gauge may measure very different values of annual rainfall from year to year.

FIG. 3 - The hilly to terraced landscape in the lower Trigno valley.

It is worthwhile noting, for its geomorphic consequences, that most of the rainfall is concentrated over a few months and that daily precipitation of several tens of mms or even above 100 mm may occur.

GEOLOGICAL SETTING

From a geological point of view the Trigno River basin is characterised by an extremely complex setting. The basin is carved on the external flank (i.e. the fore side) of the Molisano-Sannitico Apennines, which forms one of the minor arcs into which the Southern Apennine Chain can be subdivided. This chain originated during Miocene and Pliocene times from the detachment, transport and piling up of Mesozoic-Tertiary sedimentary sequences that originally formed the sedimentary cover of the western margin of the Adriatic micro-plate (Patacca & *alii*, 1992; Corrado & *alii*, 1998).

In the upper and middle parts of the basin, the Trigno River transversally cuts the compressive structures of the chain, which are represented by thrust plains, folds and fold propagation faults prevalently oriented in a NNW-SSE direction and north-east verging. Structural complications due to superimposed extensional and strike slip tectonics also occur. The lower part of the river basin is carved into younger and less deformed formations that represent the Pliocene-Lower Pleistocene sedimentary filling-in of the foredeep. The emersion and deformation of these deposits may be related to the activity of blind thrusts and to the generalized uplift which affected this sector of the Apennines during the Quaternary (Aucelli & *alii*, 1996, 1997; Rapisardi, 1978).

The main structural-stratigraphic units

On the basis of pre-existing data, the following main structural-stratigraphic units can be distinguished within the chain:

THE MOLISE SEQUENCES

In terms of pre-orogenic palaeogeography, the Molise sequences are said to have come from a pelagic domain (Molisano Basin *sensu* D'Argenio & *alii*, 1973; Ippolito & *alii*, 1975; Patacca & *alii*, 1991; Corrado & *alii*, 1998) that existed along the western margin of the Adriatic plate side by side with intraoceanic, carbonatic platforms. The Molise sequences occur in the chain as four different tectonic units which are supposed to derive from different portions of the ancient pelagic basin. Ordered from the most proximal to the most distal one, they are: the Frosolone, Agnone, Tufillo and Daunia units. These sequences are prevalently made of calcareous (more abundant in the Frosolone unit) and pelagic sediments (variegated clays of the Agnone, Tufillo and Daunia units) evolving upwards to marly and calcareous facies.

The incorporation of the Molisano basin in the foredeep system of the chain occurred in Late Tortonian-Messinian times and was marked by the deposition of siliciclastic flysch deposits (Frosolone and Agnone Flysches, Olmi and Treste Formations) which are characterized by alternations of clayey and arenaceous beds.

THE SANNITIC NAPPES

The Sannitic nappes represent the structurally most elevated thrust unit of the accretionary wedge in the study area. They are prevalently made of basinal clayey deposits (*Argille varicolori*) evolving upwards to marls and detritic limestones. These sediments date from the Early Tertiary to the Miocene while their palaeogeographic position is still uncertain. Some authors (Di Bucci & *alii*, 1999 and references therein) suggest their origin to be the same as that of the Molisano basin, while others (Patacca & *alii*, 1992 and references therein) hypothesise that the Sannitic Nappes derived from a different and more internal pelagic basin.

THE SAN BARTOLOMEO FORMATION

This formation (also known as *Flysch di San Bartolomeo*; Czostella & Vezzani, 1964) is Upper Tortonian-Lower Messinian in age and is interpreted as having been deposited in a piggy-back basin (Patacca & *alii*, 1990) lying on the Sannitic nappes. The formation includes a basal member (*Membro Vallone Castelluccio*) made mainly of clays and marls, and a section prevalently made of sandstones and conglomerates (*Membro Valli*).

THE DEPOSITS OF THE LAST APENNINIC FOREDEEP

These deposits indicate the gradual filling of the last Apenninic foredeep. Their upper portion, which is largely exposed in the terminal sector of the Trigno basin, is represented by an Upper Pliocene-Lower Pleistocene succession made mainly of clays and sands of marine to transitional environments.

The main lithological units

As many of the above described structural-stratigraphic units are lithologically varied, for the purpose of the present study it was considered more reliable to classify the outcropping terrains in terms of lithological units of substantially homogeneous geomorphological response to erosion and gravity driven processes. The geographic distribution of these units is shown by the «Sketch map of the main lithological units» (see inset on the enclosed sheet), while their characteristics are as follows:

LIMESTONES

This unit's outcrops are mainly concentrated in the head portion of the Trigno basin. It is formed mainly by limestones of a prevailing detritic nature and includes terms of both the Frosolone unit and the Sannitic nappes. Generally this terrain has a good degree of cementation, is well stratified, and often densely jointed. It is characterized by a high secondary permeability and high resistance to erosion. These limestones are involved in mass movements (rock falls and slides) only when exposed along sub-vertical to vertical cliffs.

MARLS AND MARLY LIMESTONES

This unit is particularly diffuse in the medium sector of the basin and is formed by alternations of marls, marly limestones, sandstones and clayey marls. It includes elements of the Daunia unit (Faeto flysch), the Tufillo formation and, locally, the Frosolone and Agnone units as well. Its resistance to erosion is generally medium to low, due to intense fracturing and jointing as well as to the presence of clayey interlayers. Materials belonging to this unit often appear to be involved in mass movements, some of which are of noticeable extent and depth.

LIMESTONES AND GYPSUM

This unit crops out prevalently in the final sector of the Treste basin, one of the major tributary watersheds of the Trigno river. It is composed mainly of limestone, gypsum, and other evaporitic sediments. It is characterised by an elevated heterogeneity and shows medium to low values of permeability and resistance to erosion.

VARICOLOURED SCALY CLAYS

This unit comprises the marly-clayey elements of the Sannitic nappes as well as other varicoloured clays that occur in the basal portion of some Molise sequences. Frequent but usually thin and broken intercalations of sandstone, marl and marly limestone are also present. Due also to the chaotic nature of the strata, this unit has very limited permeability and low to very low resistance to erosion. Mass instability is frequent both as deep seated and shallow phenomena, the latter being favoured by the strong alteration of the more superficial strata.

MARLS AND CLAYS

This unit corresponds largely to the Olmi and Treste formations and is made of clayey marls and clays with intercalations of limestone and sandstone. On the whole this unit presents low values of permeability and offers little resistance to erosion, being intensively affected by phenomena of mass movement and dissection.

SANDSTONES AND CLAYS

This lithological unit includes members of the Agnone and Frosolone flysches and the S. Bartolomeo formation as well. It is characterized by sandstones alternating with thick intervals of clayey to marly strata. Due to the dominance of pelitic intervals, it has a low degree of permeability. On the other hand, the intense jointing of the sandstone beds makes its resistance to erosion very low, giving rise to a high propensity to mass movements.

CLAYS AND SANDS

This unit only crops up in the lower part of the basin and corresponds to the Pliocene-Pleistocene deposits of the last foredeep. It comprises clays and sands which have low degrees of cementation, horizontal to gently inclined stratification and very little tectonization. This unit is characterised by low to medium permeability values and low resistance to erosion, so that badlands are easily generated. Mass movements are generally shallow and restricted to the weathered mantle of clayey outcrops.

FLUVIAL AND COASTAL DEPOSITS

This unit comprises Late Quaternary alluvial sediments (valley floors and alluvial coastal plains) and the Holocene dune and beach sediments of the Trigno river mouth zone. It contains mainly loose sands and gravels of high to very high permeability and low resistance to erosion.

THE GEOMORPHOLOGICAL MAP

Materials and methods

The geomorphologic map enclosed herein represents the results of an investigation that included both preliminary interpretation phases, based on the analysis of both aerial photographs and topographic maps and field control, and refinement phases that advanced through a basin wide reconnaissance survey and more careful examination of the more complex and/or important sectors of the basin. The aerial photographs used are to different scales (1:13,000 and 1:33,000) and were taken at different dates (1992 and 1954 respectively). As a topographic basis we used the 1:5,000 sheets of the Carta Tecnica Regionale (edited by the Molise Region in 1992) and the 1:25,000 sheets of the Carta Topografica d'Italia (edited by the Istituto Geografico Militare Italiano in 1954).

The recognized landforms were delineated firstly on the 1:5,000 base maps and then transferred to those at the 1:25,000 scale. From the latter, we ultimately obtained a reduction to a 1:50,000 scale which was printed on a simplified topographic base including 100 m spaced contour lines, the drainage network and the elevation of the main summits. All the cartographic operations were carried out using a Geographic Information System (software «Arc-Info Format») which allowed to associate data bases to the cartographic elements of the map.

In conceiving the map and its legend, priority was given to landforms to be reasonably related to recent and/or active phenomena on the basis of one or more of the following lines of evidence: (i) activity observed during the study, (ii) changes detected by comparing aerial photos and maps of different ages, (iii) «freshness» of geomorphic evidence and (iv) coherence with present orography and local base levels.

Most of the terms appearing in the legend adopt the terminology proposed by G.N.G.F.G. (1994). As far as landslides are concerned, we followed the classification and terminology introduced by Varnes (1978) and re-discussed by Cruden & Varnes (1996), while also taking into account the Italian version (Canuti & Esu, 1995) of the Multilingual Glossary for Landslides (WP/WPLI, 1994).

Besides active phenomena and recent landforms, we also mapped several elements that are clearly inherited from past stages of the long-term geomorphological evolution of the area. An exhaustive discussion of their genesis, significance and age goes beyond the scope of this paper. Nevertheless the following chapter also contains some indications about these aspects of the Trigno basin geomorphology.

Notes about the legend

The enclosed geomorphological map gives information about the most relevant, elementary landforms occurring in the Trigno basin, with special attention given to those representing the most recent phases of geomorphic activity. In the legend, the various erosional and depositional landforms are grouped with reference to the main process or processes which are at their origin. In the following pages we complete the information contained in the Map by illustrating the exact meaning given to some symbols and by providing the reader with additional descriptions of the phenomena observed.

LANDFORMS, PROCESSES AND DEPOSITS CAUSED BY RUNNING WATER

Due to the fact that the Trigno basin is dominated by rock outcrops and soils with low permeability and high erodability, the landforms caused by running waters, from rills to large valleys, are very widespread features across the landscape. Moreover, small scale features of linear dissection are sometimes lacking on hillslopes with favourable lithology and gradient simply because cancelled by periodical agricultural practices, or overcome by active mass movements.

Forms of gully erosion are especially concentrated along the lower portions of valley side slopes, which are frequently steeper than the upper portions having been created by more recent (Late Quaternary) valley deepening phases. Well developed gullies are frequent along fluvial scarps which have declined below the threshold angle for mass instability after the river stopped cutting their base. On the other hand, there are many cases showing that gully erosion starts developing along an hillslope after that gravity-induced processes have created topographic conditions capable of giving run-off concentration.

Badlands and similar landforms are limited to relatively steep (generally >30°) valley side slopes and fluvial scarps cut into the *Argille varicolori* and the Pliocene-Pleistocene clays of the former foredeep area. The field survey revealed that piping phenomena are common on slopes affected by either gullying or badland erosion, with evidence that they may play an important role in the formation of discontinuous gullies.

Dealing with large scale forms of dissection, it can be observed that both the longitudinal and transversal profiles of the main valleys disclose some signs of polyphased deepening of the drainage network during Quaternary times. Evidence of this long-term history are found in some Relic Planation Surfaces (which sometimes include elements of very mature, hanging palaeo-valleys), in the Hanging Valley Side Glacis and, less frequently, in terraces with associated fluvial deposits.

What we label as Hanging Valley Side Glacis are gently inclined (typically 3° to 8°) erosion surfaces, sloping towards the rivers and distributed at various heights along the main valley flanks (fig. 4). In some cases,

FIG. 4 - Deeply dissected hanging valley side glacis in the Verrino valley.

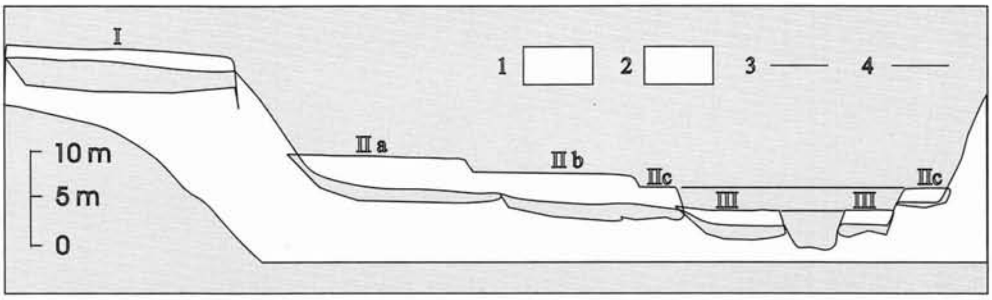

FIG. 5 - Schematic cross section of the Trigno river alluvial plain in the lower reach showing floodplain changes occurred since 1875: 1 - alluvial deposits; 2 - bedrock; 3 - floodplain level in 1875; 4 - floodplain level in 1954 (after Aucelli & Rosskopf, 2000).

sandy/gravelly alluvial deposits were found to be associated with the lower portion of such glacis. The origin of these surfaces may be related to phases of substantial stability of local base levels or, at the very least, to phases of valleyside decline processes prevailing over those of downcutting. As far as the genesis of the youngest (lowest) glacis is concerned, favourable conditions were probably created by the Last Glacial's cold climate which could have favoured slope decline and fluvial lateral planation by enhancing the phenomena of mass wasting (especially flows due to the seasonal thawing of frozen ground) and increasing the river bedload. The following dissection could be related to the post-glacial passage towards warmer and more humid climatic conditions and the return of a dense forest cover at the beginning of the Holocene period (Aucelli & *alii*, 2000).

When referring to fluvial terraces we have made a distinction between recent terraces found at moderate elevations above the present thalwegs (Valley Floor Terraces) and older terraces hanging along the valley flanks (Hanging Fluvial Terraces). The latter occur between 12 and 150 m above the present valley floors, but they are quite rare and generally badly preserved, proving that the Quaternary history of this fluvial basin has been dominated by deepening and broadening of the valleys.

Recent phases of valley floor aggradation are represented by more generations of Valley Floor Terraces. They occur with greater continuity in the portion of the Trigno valley that lies below the confluences of the Verrino and the Vella streams (about 320-330 m a.s.l.), but they can also be followed along the lower and medium reaches of some 4th , 5th and 6th order tributary valleys (i.e. the Verrino, Vella, Sente, Rivo, Monnola, Castellelce and Treste valleys).

Along the Trigno river three orders of Valley Floor Terraces were found, at 8 to 12 m (I Order), 4 to 8 m (II Order) and 2,5 to 4 m (III Order) respectively above the present low water level.

The I Order terrace may be traced to the late Roman period based on recent archaeological and stratigraphic data (Aucelli & Rosskopf, 2000 and references therein). Within the terraces of the II Order, two distinct levels (with local differences in height of about 1-2 m) can often be distinguished. In geomorphological terms, the sediments forming the II and III Order terraces appear coeval with those forming most of the Dissected Alluvial Fans shown on the Map. By analysing old topographic maps and aerial photos, we found evidence that the II and III order terraces can be traced to floodplains that were still active in 1875 and in 1955 respectively (fig. 5).

Other terraced, valley floor features of local extent and value (not easily correlated with those mentioned above) were also found in the study area. They appear related to localised aggradation phases occurred upstream of valley-narrowings due to resistant outcrops and behind obstructions due to fan and/or landslide deposition.

A variable but diffuse tendency to downcut characterizes the evolution of the Trigno river system during the last few decades. This tendency is particularly noticeable along the last 6 km of the Trigno course (Aucelli & Rosskopf, 2000), where the channel has recently dissected the entire depth of the alluvial deposits (up to 6 m) and is presently eroding the bedrock. Further upstream along the Trigno river (up to the confluence with the Rivo stream) the current tendency is shown by the appearance of high river-banks and the undermining of artificial structures such as embankments and barrages. This very recent phase of river entrenchment caused a noticeable restriction of the channel system and floodplain (about 60% on average) and was accompanied by consistent changes in the fluvial pattern (from braided to single threaded channel of low sinuosity; Aucelli & Rosskopf, 2000).

While the Trigno river and its major tributaries have been developing the above mentioned entrenchment, local aggradation, in the form of alluvial fans, has been occurring at the base of minor catchments (of the 1st to the 3rd order) converging toward the tributary valleys.

SLOPE LANDFORMS, PROCESSES AND DEPOSITS CAUSED BY GRAVITY

Landforms which originated and/or were reshaped by mass movements are very diffuse in the Trigno basin.

Slow and superficial slope deformation phenomena such as soil creep and solifluction are quite common not only where inherently weak formations crop out, but also on clay rich weathering mantles, soils and recent detrital formations such as landslide deposits. Creep and solifluction become the dominant processes in the areas that, due to their relatively low gradient, are either totally unaffected or only affected intermittently by more severe forms of instability. This case is typical of the landforms that have been mapped as Relicts of Ancient Planation Surfaces (see Complex Origin Landforms) and Hanging Valley Side Glacis.

Deeper seated mass movements concentrate largely along the most inclined slope elements of the area such as, for example, the flanks and head portions of young incisions, the recently cut or undermined basal portion of major valleys and, finally, the places where the lithostructural setting is such as to favour undermining and retreat of cliffs (e.g. hard, fragile rocks overlying soft and/or plastic ones).

Whenever supported by field evidence and permitted by the scale used, we separately distinguished and mapped, for each landslide or cluster of landslides, the upper sector (Landslide Area of Prevailing Detachment and Transport) and the Landslide Deposit occurring further downslope.

In addition to the landslides whose genesis is related to a single type of movement (falls, slides or flows), we also introduced the category of Complex or composite landslides which is more suitable when referring to many of the instability phenomena occurring in the Trigno basin. In fact, a great percentage of the landslides we recognised in the study area appear to be the result of various types of movement (for example slide and flow) which either occurred in sequence (a complex landslide) or simultaneously, in different sectors of the displaced mass (a composite landslide).

Some of the landslides which denote a long and complex history have been mapped as Landslide Catchments, as they are valley-like systems whose origin seems to have been caused by mutual interactions between gravity induced phenomena and fluvial erosion. These landslide catchments are associated with drainage networks reaching up to the 3rd or, more rarely, the 4th hierarchical order. They usually cover an area of between 2 and 3 square kilometres, but some of them reach up to 5 or 6 square kilometres.

The evolution of these landslide systems is mainly controlled by the concurrent and alternating action of (i) retrogressive landslide activity and (ii) headward extension of both gullies and larger dissection forms. Both of these phenomena usually begin at the steep basal element of a valley side slope and proceed towards higher and higher slope elements (e.g. becoming embedded in Hanging Valley Side Glacis) while branching at the same time (Aucelli & *alii*, 2000). The Landslide Catchment's head portions are generally characterised by more or less marked concave profiles and plan forms. They mainly evolve through enlargements caused by shallow landslides operating with low threshold angles. On the contrary, the morphodynamics of the lower portion of such catchments appears controlled mainly by fluvial erosion, which is responsible for the periodical removal of the landslide deposits that accumulate there during periods of increased instability of the catchment's head and flanks. The removed materials are sometimes left in alluvial fans growing at the outlet of the landslide catchment and sometimes trasported further downstream.

In the category of Slope Landforms, Processes and Deposits due to Gravity we also included the so-called Hanging Aggradation Surfaces Fed Mainly by Landslides. Surfaces of this kind were noted from about 10 to 25 m above present thalwegs, and are locally organised in more orders. Their topography is hummocky but, on the whole, subplanar and gently inclined towards the main valleys' axis. Though they represent phases of aggradation followed by phases of dissection, their correlation with the actual fluvial terraces of the main rivers appears difficult and unsafe, because they could have grown with noticeable and variable independence from fluvial base levels.

Again dealing with gravity-induced landforms, some further explanation is necessary for other terms used in the Map legend. As Water Divides Strongly Affected by Degradation we indicate water-divides whose evolution is mainly controlled by landslide phenomena. They appear like narrow crests whose undulating altimetry and sinuous plan shape clearly appear to be caused by the presence of sequences of landslide scars on both sides of the divide itself. However, some of their concavities represent normal valley heads of low hierarchical order.

What we label as Valley Head Reshaped by Shallow Landslides are landforms of fluvial origin whose evolution is primarily related to shallow landslides, solifluction and soil creep phenomena producing a progressive enlargement and rounding of the valley head.

As far as deep-seated gravitative slope deformations are concerned, at least two cases have been observed in the Trigno basin. One of them affects Mt. La Civita, on the right side of the Chiauci gorge; the other occurs in the upper Sente valley. While little is known about the latter, the former is presently under study by several professionals and researchers because of possibly hazardous repercussions for the nearby town of Civitanova del Sannio (see also Aucelli & *alii*, 2001). As revealed by geomorphological evidence, it involves a slow, multiple and composite landslide (translational rock slide plus rock topple) affecting thick-bedded limestones and marly limestones of Miocene age. These phenomena are to be interpreted as the shallow part of a deeper failure that, as a whole, can be classified as C-sagging (Hutchinson, 1988). On the basis of field evidence and geomorphological considerations, this phenomenon appears markedly controlled by the final (Late Quaternary) phase of valley deepening, which enhanced the topographic factors and reduced the contrasting forces by removing much of a clayey formation outcropping at the foot of the La Civita carbonatic relief.

LANDFORMS OF COMPLEX ORIGIN

In this category of landforms we included Valley Heads of Fluvial-Gravitative Origin. These are large concavities primarily generated by gravitative phenomena giving way to large landslide scars, which then evolve both by fluvial and gravitative processes. Their extent frequently exceeds 1 square kilometre and the great role played in their genesis by gravity is often proved by the presence of relicts of Hanging Aggradation Surfaces Fed Mainly by Landslides at their base.

Other forms of complex origin are the Relicts of Planation Surfaces. It has been possible to distinguish two generations of such remnants of low relief erosional landscapes: A first one, modelled during Pliocene-Early Pleistocene times, and a second one that dates from the Early-Middle Pleistocene age. The first generation is present from the upper to the lower part of the basin in the form of scattered summit remnants (i.e. resting along the divides or slightly below them); the second generation is limited to the coastal sector and is represented both by remnants that are in a summit position and, where higher hills occur, by remnants that hang along valley flanks.

The older planation surfaces were probably modelled by fluvio-denudational processes that preceded the development of a drainage network much entrenched into the Apenninic relief. The genesis of the younger planation surfaces is not yet clear, but it could be related to the migrating coastal erosion that accompanied the final emergence of the area from the foredeep basin, locally accompanied by fluvial deposition and lateral planation.

TECTONIC AND STRUCTURAL LANDFORMS

Though it is a pervasive character of the Trigno basin area, the influence of structure on geomorphology is rather difficult to decipher and classify because of the variable combinations of passive influences of old structures and active influences of recent tectonics. We did not study specifically this aspect, and therefore only the morphostructural elements of clearer evidence have been shown on the map. They fall into the category of Fault Scarp or Fault Line Scarp which are particularly steep and high when cut in resistant lithologic units such as limestones, sandstones and marls. These structural forms are usually associated with N, NW and E trending high angle faults that were active during Pliocene and Pleistocene times.

KARST LANDFORMS

Landforms related to karst processes are concentrated in the upper sector of the Trigno basin, where carbonatic rocks (limestones and marly limestones) of the Frosolone and Agnone units crop out. Karst landforms are represented by Dolines (which include also karst depressions originated by the union of different dolines), structurally controlled Poljes which may extend up to 0,5 square km, and remnants of Karst Planation Surfaces with associated Hums. Landforms of the last two types appear locally associated to the already mentioned Relicts of Planation Surfaces (for example in the Vastogirardi area), and the beginning of their evolution may therefore traced back to Late Pliocene-Lower Pleistocene times. Some of the polje are still active. Others are either captured by fluvial erosion or partially filled with fluvio-palustrine sediments.

ANTHROPOGENETIC LANDFORMS

In order to describe the anthropogenetic features which have had major impacts on the recent natural dynamics of the area, we mapped man made features like Artificial Levees, Check Dams, Fluvial Barrages, Artificial Channels, Dams, as well as areas of Artificial Denudation and Areal Embankment. The mapping of all the above listed artificial features had to be based largely on field controls, as most of them have been created very recently and do not appear on the topographic maps and aerial photographs we used.

FINAL REMARKS

Like other sectors of the Apennines Chain, the area of the Trigno River basin has geologic and climatic conditions that favour a noticeable degree of geomorphic dynamism. This is particularly true for those portions of the basin where weak sedimentary formations, often highly fractured and sheared during the orogeny, crop out along steep slopes of either structural or dissectional origin. The abundance of steep hillslopes elements appears as an effect of the uplift that affected the Apenninic chain during the Quaternary period and consequent dissection. But in recent times (post-Glacial to historical) firstly climatic changes and, later on, phases of human impact, have also played a role in modifying the balance between detrital production by hillslopes and transport capacity of streams, with consequent alternations of phases of aggradation and dissection. Man induced modifications concern, above all, changes in land-use (deforestation, land abandonment, overgrazing) which mostly occurred during the last 150 years as well as quarrying and engineering interventions on the fluvial system which have been very particularly intensive during the last few decades.

The Trigno basin is an area that shows an exceptional density and variety of landslide phenomena. This creates a high degree of danger and many problems for the management of natural resources such as soils and forests. But, on the other hand, it represents a natural laboratory of elevated scientific interest which may produce significant advancements in understanding the factors and mechanisms of several forms of hillslope and fluvial dynamics.

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