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ELEMENTS OF SLOPE AND FLUVIAL DYNAMICS AS EVIDENCE OF LATE HOLOCENE CLIMATIC FLUCTUATIONS IN THE CENTRAL ADRIATIC SECTOR, ITALY

ABSTRACT: MATERAZZI M., GENTILI B., ARINGOLI D., FARABOLLINI P. & PAMBIANCHI G., *Elements of slope and fluvial dynamics as evidence of Late Holocene climatic fluctuations in the central Adriatic sector, Italy*. (IT ISSN 0391-9838, 2010).

The present work aims at pointing out possible geomorphological indicators of climatic fluctuations detected within the Central Adriatic Region of Italy and whose activation and evolution is closely connected to superficial and ground circulation of large quantities of water. It shows and analyzes several indicators in three different sample areas, which are extremely representative of the same number of physiographic units of the Central Adriatic region in Italy and of the correspondent fluvial systems: mass movements and flooding processes in a wide sector of the central Apennine; fast erosion processes and landslides in the peri-Adriatic sector; historical variations along a portion of the Adriatic shoreline.

The choice of such different «environments» is not casual; in fact, the shape of a river mouth depends on the strict equilibrium among slope, river and coastal dynamics. In a given period, without significant eustatic variations, it represents the «memory» of complex environmental transformation triggered by natural or human processes within the river catchments.

The collected data have been subsequently compared with those available in literature for Mediterranean Europe. The possibility to relate climatic events and geomorphological features coming from such different areas is based on the proven congruence of their morphoclimatic settings.

KEY WORDS: Climatic fluctuations, River mouths, Mass movements, Late Holocene, Central Italy.

RIASSUNTO: MATERAZZI M., GENTILI B., ARINGOLI D., FARABOLLINI P. & PAMBIANCHI G., *Elementi di dinamica di versante e di dinamica fluviale come evidenze di fluttuazioni climatiche tardo-oloceniche in un settore dell'Italia centrale adriatica*. (IT ISSN 0391-9838, 2010).

Nel presente lavoro viene illustrato il ruolo di alcuni processi geomorfologici, la cui attivazione ed evoluzione è strettamente connessa alla circolazione superficiale e sotterranea di importanti quantitativi di acqua, come indicatori di fluttuazioni climatiche tardo-oloceniche segnalate nell'Italia centrale adriatica. Più in particolare vengono descritti diversi elementi geomorfologici presenti in tre differenti aree campione rappresentative di altrettante unità fisiografiche fondamentali e dei corrispondenti sistemi fluviali: fenomeni gravitativi e di alluvionamento in un ampio settore dell'Appennino centrale; processi di erosione accelerata e movimenti di massa nel settore peri-Adriatico; variazioni storiche delle foci fluviali in una porzione della costa adriatica.

La scelta di «ambienti» così differenti non è casuale: l'evoluzione di una foce fluviale infatti, dipende dallo stretto equilibrio esistente fra le dinamiche di versante, fluviale e costiera. In un dato periodo, a meno di significative variazioni eustatiche, essa rappresenta la «memoria» delle complesse trasformazioni (guidate da processi naturali e/o antropici) avvenute all'interno di un bacino idrografico.

I dati raccolti nel corso dello studio sono stati successivamente comparati con quelli disponibili in letteratura per l'Europa Mediterranea. La possibilità di relazionare eventi climatici ed elementi geomorfologici appartenenti ad aree geografiche così differenti è giustificata dalla comprovata congruenza dei rispettivi assetti morfoclimatici.

TERMINI CHIAVE: Fluttuazioni climatiche, Foci fluviali, Movimenti di massa, Olocene recente, Italia centrale.

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INTRODUCTION

Among the numerous environmental indicators of climatic variations, several geomorphological processes (and their related deposits and landforms) are of primary importance. Glacial landforms, stratified slope deposits and alluvial deposits, are some of these fundamental elements. Also in the Central Italian peri-Adriatic region clear evidence of such elements has been found; they represent the remnants of the main morphodynamic activity of the middle-late Pleistocene (Coltorti & *alii*, 1991; Giraudi, 2005a).

In the current morphoclimatic context, geomorphological indicators, whose activation and evolution is closely connected to superficial and ground circulation of large quantities of water, can also be considered as indicators of «minor» climatic fluctuations.

The present study shows and analyzes several indicators from three different sample areas, which are very representative of the same number of physiographic units of the Central Adriatic Region in Italy: mass movements, with particular care to debris flow phenomena, and flooding processes in a wide sector of the central Apennine; fast erosion processes (badlands and related landforms) and landslides on Mount Ascensione in the peri-Adriatic sector; historical variations of the Adriatic shoreline, close to the Chienti river mouth.

Among these, the morphometric variations of the river mouths represent one of the most significant processes; their shape in a given period, without significant eustatic variations, actually depends on the strict equilibrium between the specific dynamics of a fluvial system and the coastal dynamics and represents the «memory» of the complex environmental transformation (triggered by natural or human processes) occurred within the river catchments. In fact, an high fluvial transport and a consequent river mouth advancement (delta) are related to main fluvial-denudation processes along the slopes; on the contrary, a prevailing stability of the slopes, to which a low fluvial transport is connected, produces river mouth retreat and the creation of an estuary.

Therefore, it seems correct to suggest possible correlations among data showed in this study, even though related to different physiographic units. The great amount of data collected over more than thirty years concerning the shoreline variations close to the river mouths (particularly those occurred during the recent Holocene) in the central Adriatic sector, allowed to reconstruct a reliable evolutional scenario mainly concerning human impact during the last century.

The results of the research are in agreement, on the whole, with those contained in previous literature, both for mainland Italy (Pavese & *alii*, 1992; Bondesan & *alii*, 1995; Bellotti & *alii*, 2004; Lambeck & *alii*, 2004) and for other countries, especially those around the Mediterranean Sea (Vita Finzi, 1969; Le Roy Ladurie, 1971; Lamb, 1982; Starkel, 1991; Provansal, 1995; Dìez & *alii*, 1996; Borrego & *alii*, 1999; Grove, 2001); for that reason it seems that the present work can provide a contribution to the knowledge concerning climatic conditioning on slope and fluvial dynamics.

GEOLOGICAL AND CLIMATIC FEATURES

The Sibillini massif was made up by the merging of the southern portions of the Umbro-Marchean and Marchean ridges (fig. 1). Altitudes range between almost 350m (the lowest valley floors) and the 2,476 m a.s.l. of Mt. Vettore, with many reliefs exceeding 2,000 m a.s.l.. The landscape is characterized by deep and narrow valleys interrupted by wide watersheds with ridges and edges; relief is higher than 1,000 m and slope angles exceed 60% with frequent subvertical walls.

The bedrock is constituted by the *Successione umbro-marchigiana* (Late Trias - Aquitanian p.p.) made up of limestones at the base overlain with stratified limestones, marly limestones and marls.

The structural setting, formed during a compressive tectonic phase between the Late Messinian and the Early Pliocene, is characterized by east-verging folds whose eastern sides are truncated by thrusts. These tectonic elements caused the overlying of calcareous units on more ductile Miocene lithotypes of the piedmontane belt; normal faults, related to a Quaternary extensional phase, markedly dissected the previous structures.

Eastward of the Apennine chain, the peri-Adriatic belt is present, whose geological bedrock, in tectonic contact or transgressive on the Laga Formation (Messinian turbidites) is made up by a thick and widespread pelitic unit with sandy-conglomeratic levels (middle Pliocene-early Pleistocene) intercalated at different heights. The intense and generalized quaternary tectonic uplift, which progressively decreases to the east, generated a wide monocline (fig. 1); normal faults (with vertical displacement frequently lower than 10m) and joint systems mainly trending NW-SE, NE-SW and N-S affect more rigid and thinner levels of bedrock. The higher uplift degree (about 0.8 mm/yr) has been recognized in the Mt. Ascensione area (1,108 m a.s.l.) the highest relief of the peri-Adriatic belt; it consists of a huge conglomeratic body intercalated with clays of the Pliocene-Pleistocene sedimentary sequence.

Knowledge concerning the main geomorphological elements and the main hydrogeological characteristics, together with the geological elements described above, is fundamental for the analysis and interpretation of the mentioned processes. Calcareous and marly-calcareous lithotypes, strongly fractured, are characterized by a mean effective infiltration of about 550 mm/y, (while the mean rainfall results of 1,000-1,100 mm/y). Sometimes, where the marly levels are prevalent with respect to fracturing, permeability may become extremely low.

Marked differences are also observed in the velocity of the water circulation inside the permeable bedrock; depending on the different kind of permeability and the hydraulic gradient, this ranges from one centimeter/day, to hundreds of meters/day, up to more than one kilometer/day. Circulation by porosity characterizes the continental cover. In particular silty-clayey levels, intercalated with gravels in stratified slope deposits, generate high potentiometric levels with associated artesian aquifers located within the deposit or at the bedrock-cover contact; this fact

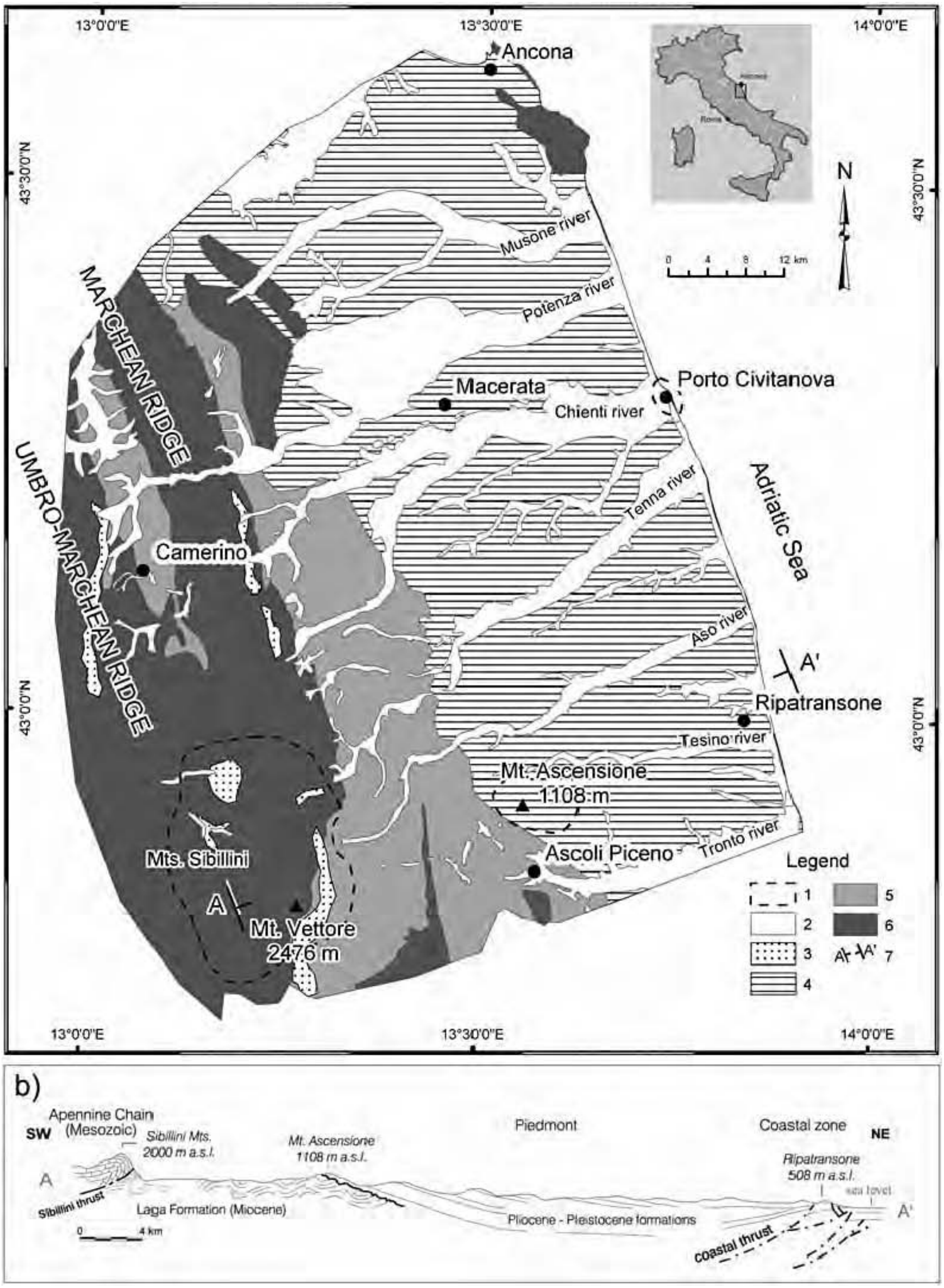

FIG. 1 - a) Geological and geomorphological sketch of central-southern Marches: 1 - study areas; 2 - main fluvial and coastal deposits; 3 - main slope deposits (Middle Pleistocene-Holocene); 4 - sands, clays and conglomerates (Pliocene-Pleistocene); 5 - sandstones and clays (Tortonian-Messinian); 6 - limestones, marly limestones and marls (Early Trias-Tortonian); 7 - trace of cross-section. b) schematic cross-section from the Apennine chain to the Adriatic coast.

may have been also responsible for the activation of rapid debris-flow phenomena (Revellino & *alii*, 2004).

Climatic data referring to the period 1921-2003 indicate that the number of rainy days ranges between 60 and 75 and the daily mean intensity ranges from 10 to 12mm. The absolute monthly maximum is registered in November (secondary maximum in spring). The summer season is rather dry, particularly near the coast, when dry periods last longer than 40 days. The mean annual temperatures vary between 12.5°C and 15.5°C; the annual temperature excursion ranges between 17°C and 19°C; the daily excursion varies from 7°C along the coast to 10°C in the inner areas.

The aridity index values range from 19.9 to 38, defining an area which presents an average slight summer aridity in the littoral portion and the low hill area. The Fournier erosion index ranges from 8.2 to 9.6; therefore, the rainfall erosion potential is generally low, except in particular conditions. The frequency of these has notably increased in the last twenty years, where rainfall values of ca. 100 mm/day and of more than 30 mm/hour were recorded, with return times limited to a few years for the period following 1970.

GEOMORPHOLOGICAL EVIDENCES FROM THE STUDY AREAS

Debris-flows, landslides and alluvial fans in the Sibillini Mountains

The main landforms connected with materials coming from isolated alluvial fans, or debris flows, were examined. The former are located at the bottom of gullies, while the latter occur along the hydrographic network of a higher order, where the relief is high and where the original fluvial-streamflow or fluvial-glacial incisions have re-shaped flat or smoothly U-shaped small valleys (fig. 2). In both cases the emplacement of such deposits, with a texture ranging from clays to pebbles with rare scattered blocks, is related to a consistent presence of superficial and groundwater (Takahashi, 1991).

The geomorphological analysis of more recent and well recognized debris flows in the Sibillini area (area of Castelsantangelo sul Nera in 1906 and 1946; Visso in 1959), oral testimony and archive data, as well as detailed geomorphological surveys and in-depth historical investigations allowed us to recognize many events (fig. 2) and to establish the existence of two main kinematic phases. The first stage eroded the detritic cover along the medium-low sectors of the slopes, causing planar slides over surfaces parallel to

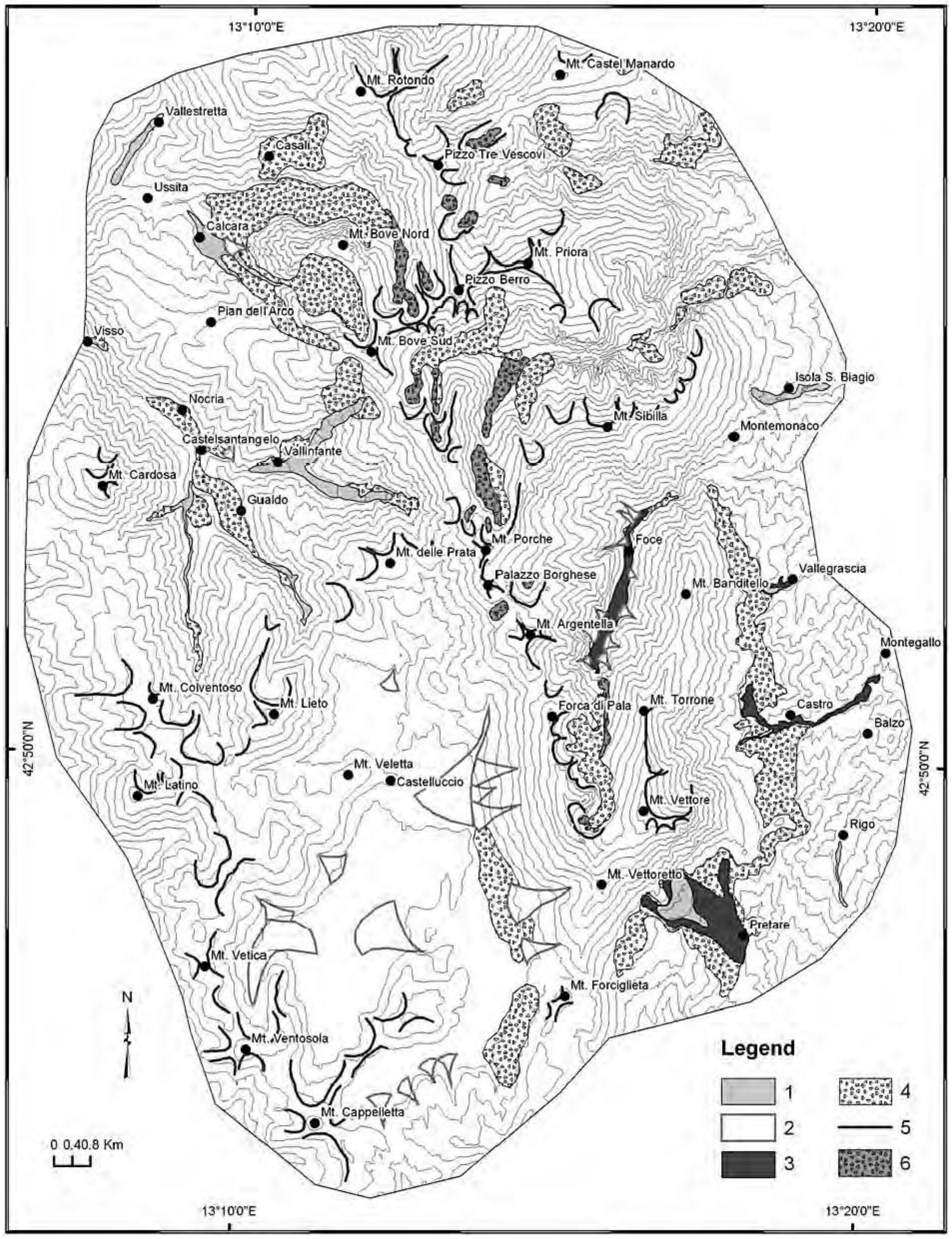

FIG. 2 - Map of main geomorphological features of Sibillini Mountains: 1) recent or active debris flow; 2) main alluvial fans of Late Pleistocene-Holocene; 3) old debris flow of Late Pleistocene-Early Holocene; 4) main slope deposits and landslide screws of Middle Pleistocene-Holocene; 5) glacial cirques of Late Pleistocene; 6) main moraines of Middle Pleistocene-Late Pleistocene.

the slope and/or piping phenomena; both processes are related to high hydrostatic pressure connected to the above-mentioned hydrogeological setting. During the second stage, which mainly occurred along the valley floors, a convergent effect in the mobilization of materials exercised by debris flows on previous mechanisms was observed. Analogous, though less intense, action seems to have been carried out also by alluvial fans (Baumann & Kaiser, 1999; Crosta & Frattini, 2004).

The resulting landforms, modelled by such processes, are systematically characterized by a regular longitudinal profile and by a transversal one, with sharp breaks linking the surface of the (U-shaped) deposit to the steep slopes. Moreover, the total absence of any hydrographic network and sporadic vegetation are evident on the deposit.

Many phenomena have been attributed, on the basis of historical investigations, to the medieval and post-medieval periods. Historical sources, directly or indirectly, witness the recurrence of such processes starting from the XIIth century, even though the most intense and destructive events occurred between the XVth and the XIXth centuries (1494, beginning of the XVIIth century, 1667, 1670, 1807, and 1858). The same sources repeatedly prove the execution of hydraulic remedial works starting from the second half of the XVth century (Fabbi, 1965). The debris flow chronology is also supported by their location, placed on top of medieval handmade items; their shape is also congruent with the morphological setting connected with the landforms of the XXth century. Unlike the latter, they are characterized by slightly smooth borders, deposition of thin colluvial deposits, local and weak incision of the deposit and well-developed vegetation covers.

The possible chronological setting of pre-medieval deposits, attributed to late the Pleistocene-early Holocene, was established on the basis of a correlation with fluvial landforms (alluvial terraces and/or erosive benches) or slope deposits. The most significant examples can be observed at Foce and at Castro, where debris flows have been supplied with materials belonging to upper Pleistocene moraines (fig. 2).

Stratified slope-waste deposits and landslides at Mount Ascensione

The fundamental geomorphological element in the Mt. Ascensione area is represented by a stratified slope-waste deposit which was later affected by fast erosion processes (mainly badlands) and mass movements. This deposit is almost unique along the peri-Adriatic belt of central Italy; it originally extended over an area of 10 km^2 or more, and the maximum thickness of the corresponding deposit possibly exceeded 30 meters.

Fragments of charcoal found at different heights inside the deposits and dated with C-14 (AMS-technique, Beta-108532 and Beta-108530, Beta Analytic Inc., Miami, Florida, U.S.A.) allowed us to estimate for this deposit an age comprised between 41.640 ± 1260 B.P. and 22.680 y ± 170 B.P. (Gentili & *alii*, 1998). This detritic cover, mostly overlying the pelitic bedrock and currently reduced to small remnants along the watersheds, is made up of polygenic and heterometric pebbly-sandy deposits, produced by the erosion of a conglomeratic-sandy-pelitic bedrock. The degree of cementation is not very high even though in some places deposits are well cemented.

The morphostructure of Mount Ascensione (1,108 m a.s.l.), which is the highest relief of the peri-Adriatic belt, is constituted by a tough conglomeratic body alternated with clayey sediments; the upper portions of the slopes were totally regularized by slope deposits at the end of the Pleistocene. This morphostructure was partially remodelled by the Holocene dynamics, which were particularly intense along the southern and eastern sectors; this was due to the overlaying processes of the detritic cover on the pelitic bedrock that favored the genesis of huge aquifers in correspondence with the thickest detritic bodies.

During the Holocene climatic improvement, such a stratigraphic setting favored an intense deepening of the hydrographic network with the spectacular associated «calanchi» morphologies, as well as widespread mass movements; these phenomena led to the current setting of the landscape (fig. 3). Said processes, in which three main erosive phases have been identified, produced a particularly high average denudation rate (about 15 mm/yr, Buccolini & *alii*, 2010).

Geomorphological surveys, supported by historical investigation, (Carlini De Carolis, 1792; Galiè & Vecchioni, 1999) provided some interesting data about the main landslides of the last millennium. The southern slope of Castignano, for instance, which is an ancient village founded at the beginning of the Middle Ages, was affected several times between the XIIIth and XXth centuries by landslide phenomena, which led people to move to the northern sectors. The highest frequency of events clearly occurred between the XVIth and the XVIIIth century. During the same period, significant landslide phenomena affected many others villages in the Mount Ascensione district (fig. 3).

Historical evolution of the Chienti river mouth

As far as the Marche region is concerned, several studies, directly or indirectly, testify a coastal morphology characterized by active cliffs and pocket beaches (in line with the river mouths) from the Early Holocene (Gori, 1988) up to pre-Roman times (Speranza, 1934; De Luca, 1939; Coltorti, 1997). More in particular, the rapid advance of the sea occurred during the Flandrian transgression (up to 2000 yrs B.C.E) created an Atlantic-type coast (ria) which characterized the whole Marchean coastline (Coltorti & *alii*, 1991; Coltorti, 1997). Geomorphological analyses and evaluations carried out in the study area, have also confirmed such a setting. After this period, a rapid advance of the coastline occurred, as a consequence of the high amount of sediment carried by the Marchean rivers which were evolving inland to a meandering pattern (Coltorti & *alii*, 1991). Nevertheless, up to the third century B.C.E. in most of the mouths and to 500 yrs C.E. in the Chienti river one, the increased fluvial deposition caused the formation of barrier beaches bordering inner swamps and lagoons

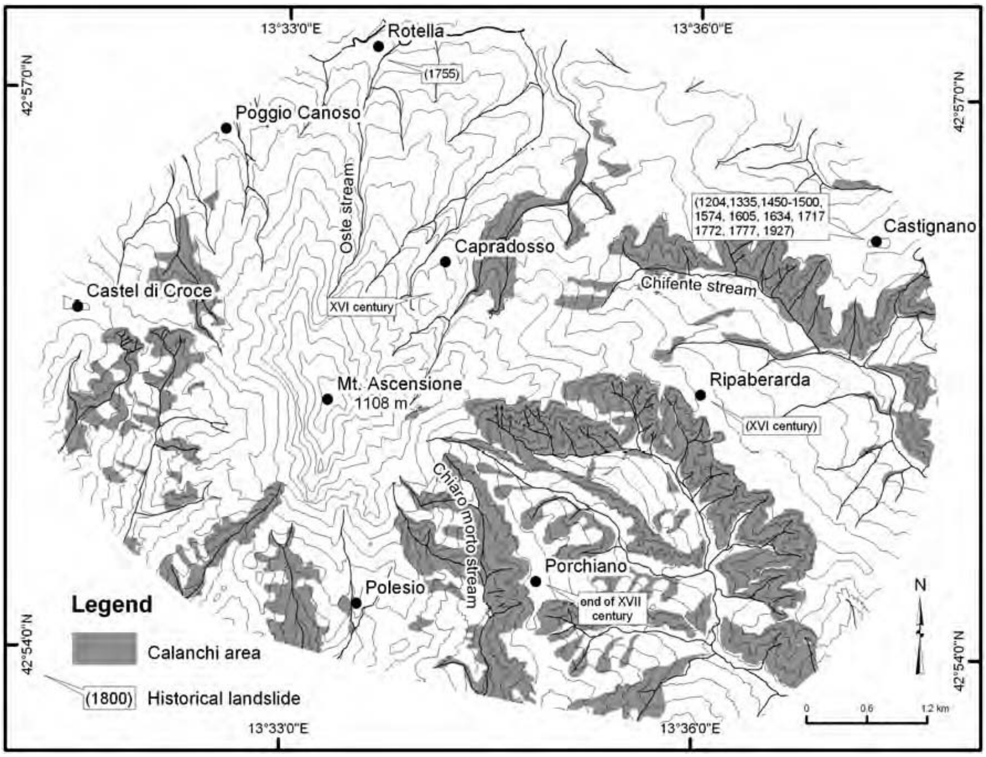

FIG. 3 - Mount Ascensione area: 1) location of main «calanchi»; 2) dated landslides.

(Coltorti & *alii*, 1991) even though other authors ascribed the formation of the above mentioned barriers to a direct marine influence (Goethals & *alii*, 2009). Unfortunately no data are available for the time interval ranging from the beginning of the Holocene up to the pre-Roman Age.

For the following periods, throughout the post-medieval period and up to the first half of the XXth century, data collected from many river mouths of the Marche region, show coastal dynamics that are characterized by evident sedimentation processes; moreover these are responsible for the genesis of the delta and low pebbly-sandy beaches with widths ranging from a few tenths of a meter to over 1,000 m (Albani, 1933; Buli, 1944; Gori, 1988; Coltorti, 1997).

Nevertheless, since their first appearance in 1850, remarkable shoreline withdrawals have been recorded in several parts of Italy. The same phenomenon has been observed in the Marche region, even though the clearest evidence dates back to the first decades of the XXth century (Albani, 1933; Buli, 1944). Because of the applied implications of shoreline variations, the topic has been analyzed in detail for more recent periods and particularly for the last 100 years (fig. 4); several studies have confirmed a general shoreline withdrawal even near river mouths with an average rate of 1.86 m/y (2.58 m/yr for the Chienti river) and a maximum of 5 m/yr for the Tronto river (Gentili & Pambianchi, 1987; Coltorti & *alii*, 1995).

Among the several river mouths analysed in the Marche, that of the Chienti and the corresponding northward shoreline portion, where the city of Porto Civitanova is located, was investigated. This choice was conditioned by the amount of available data (maps from different periods dating back to the XVIth century) and reliable historical sources from the Roman age, which do not, however, always tally (Almagià, 1960; Galiè, 1988). The mentioned evolution process can be considered as fully representative of the evolutional processes of the other river mouths in the study area.

The mouth of the Chienti river in the Adriatic Sea, with its typical delta shape, is mainly made up of polygenic gravels and a limited sandy matrix; in particular, calcare-

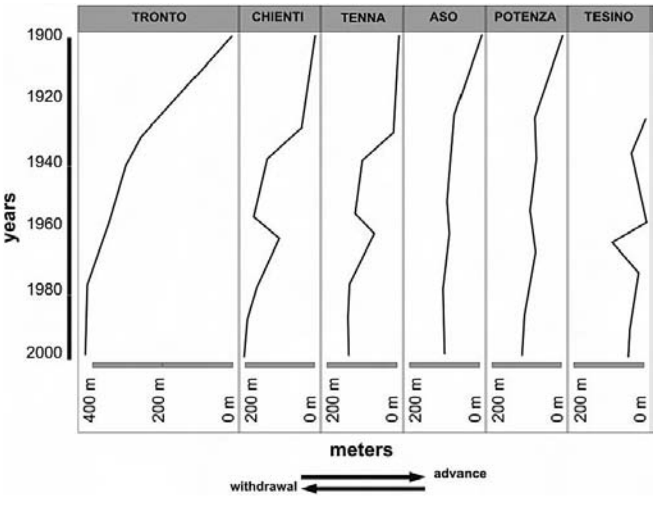

FIG. 4 - Shoreline variation (between 1900 and the present) near the main river mouths of the peri-Adriatic belt (modified from Gentili and Pambianchi, 1987).

ous and marly calcareous pebbles, coming from the Apennine Chain where the source area is located, are abundant. The circa 90-km-long river course progressively cuts (approximately from W to E), the arenaceous and clayey lithotypes of the corresponding hilly-pedemount belt. The mentioned geomorphological setting characterizes the main rivers of central-Adriatic Italy (see fig. 1).

On the basis of the data collected from the above mentioned historical chronicle, figure 5a have been inductively edited. They underline a substantial stability between the IIIrd century B.C.E. (Before Common Era) and the Vth century C.E. (Common Era); a certain period of advancement for the following millennium (about 450m, with a resulting average rate of 0.45 m/yr); little advancement increase between 1500 and 1810; a strong advancement increase between 1810 and 1902 (about 340 m equal to an average rate of 3.7 m/yr); substantial stability from 1902 up to 1935 and successively a strong withdrawal (about 200 m, average rate of 2.6 m/yr) that led to the present configuration of the river mouth.

Figure 5b represents the shoreline variations recorded during the last three centuries in the built-up area of Porto Civitanova. They were defined on the basis of the above-mentioned historical sources as well as on reliable data (starting from 1705), which derive from the planning, execution and management of structural and infrastructural works connected with the modern development of the urban area during this period. A progressive shoreline advancement characterized the period between 1705 and 1935 with an average progression rate of about 1 m/yr, with minimum of 0.3 m/yr (1810-1862) and maximum of 5 m/yr (1873-1885). The advancement that occurred after 1935 (3.5 m/yr) exceeds the average rates, still this morphodynamic evolution is not very significant because it was clearly influenced by the construction of the harbor, which began in 1932 and was completed in 1938.

DISCUSSION

The collected data have been compared with those analogous available in literature, and in particular with those related to Alpine glacial advances, extreme climatic events and fluvial mouths variations of the main rivers in Mediterranean Europe.

Figure 6 shows the results of this comparison. The first column registers the age expressed as years B.C.E. or C.E.; the other columns contain different events recorded respectively around the Mediterranean Sea (columns 1, 2, 3) and in the study areas (columns 4, 5, 6). Said events are pointed out by means of a continuous line or certain dates coming from the analyzed chronological references; dashed lines indicate the events hypothesized through geomorphological evidences. The grey bands, which summarize the correspondence between specific climatic phases and the described geomorphological dynamics, indicate the periods (starting from 2000 yrs B.C.E.) that were particularly favourable to the activation of slope denudation processes or transportation of sediments within a fluvial system.

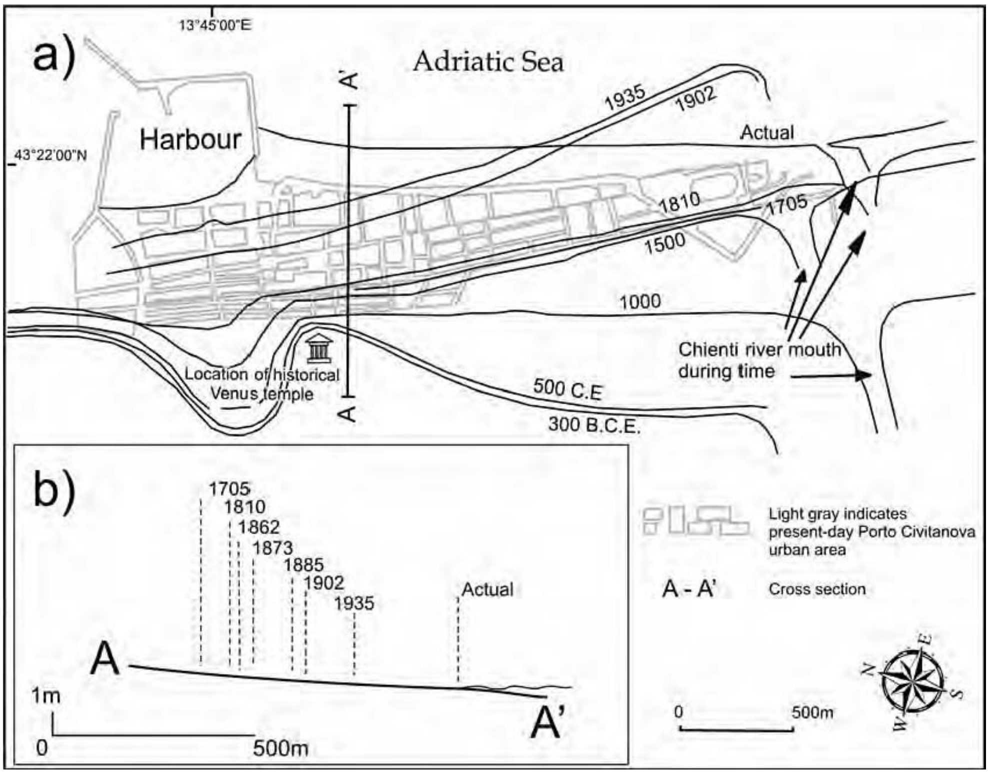

FIG. 5 - Shoreline variation: a) near Chienti river mouth, from Roman times up to presentday; b) at Porto Civitanova, from 1705 up to 1935.

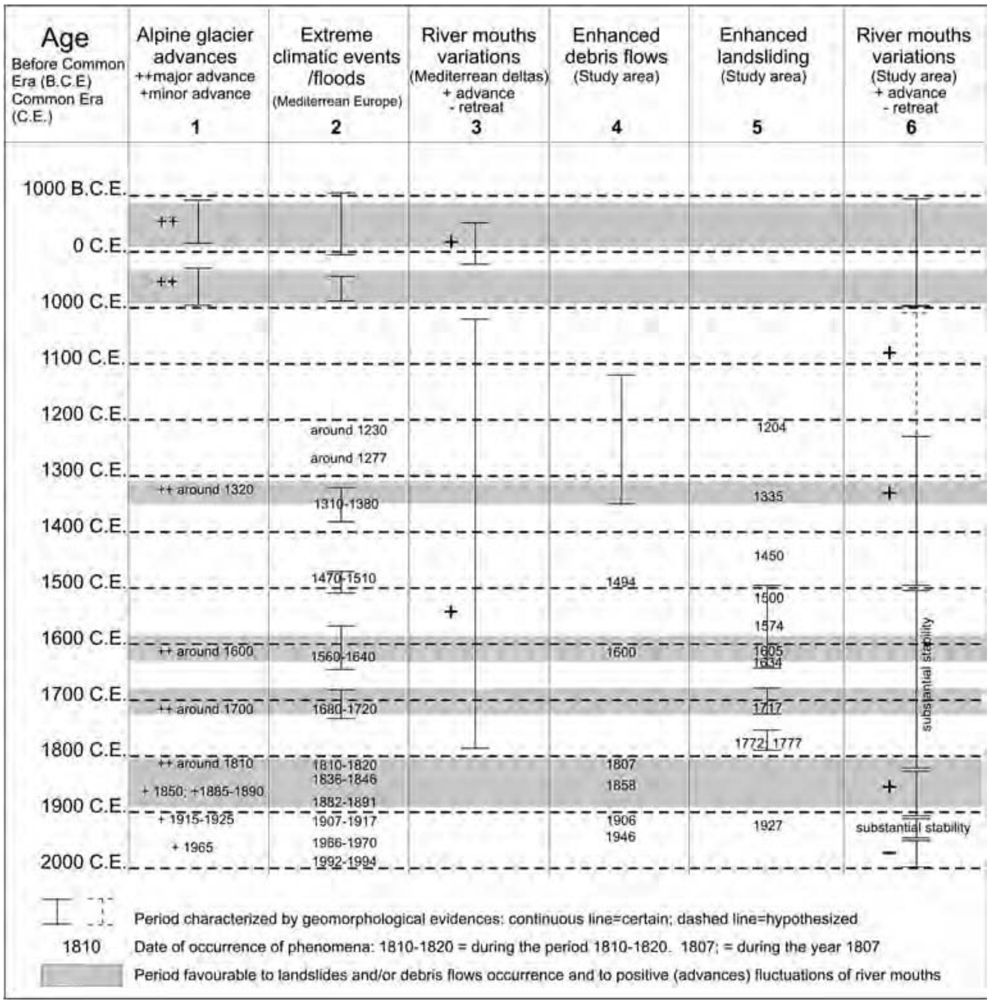

FIG. 6 - Synoptic sketch of geomorphological evidences from the study areas compared with those of the Mediterrean Europe (for references see the text).

The relation between climatic events and geomorphological features in such a large area is based on the proven congruence of the morphoclimatic settings of the compared sectors. This congruence had already been ascertained by Grove (2001), who clearly summarized, with numerous examples and in great detail, the geomorphological effects resulting from the particular historical and climatic period known as the «Little Ice Age».

Analogous baric conditions, generating very intense rainfalls without a clear seasonal distribution, do in fact characterize several mountainous regions in Mediterranean Europe (south-eastern Spain, the eastern Pyrenees-France, the south-east corner of the Massif Central-France, the Liguria and Corsica regions-Italy, the Gulf of Genoa-Italy, Montenegro, the Pindos Mountain-Greece and the highland of Crete); rainfalls from 500mm up to 1,000 mm in 48 hours, reoccurring after few years, are common (Flocas, 1988; Wigley, 1992; Llasat & Rodriguez, 1997). Such conditions are caused by the genesis of cold fronts and cold air masses from the north (or from the east) and warm-temperate ones present in the Mediterranean Sea; the atmospheric instability is enhanced by the orographic setting which presents mountain ridges and massifs that frequently exceed 2,000 m as sea level.

To said morphological setting, generally associated to the intense Quaternary tectonic uplift of these sectors of the Mediterranean basin, is obviously connected to the high relief, strong deepening of the hydrographic network and steep slopes lacking of significant detritic covers; these conditions are favourable to the production of huge quantities of unconsolidated deposits which are likely to be instable.

The strict correlation between «cold» phases (underlined by the presence of Alpine and, subordinately, Apennine glacial advances) and periods characterized by floods and extreme climatic events is well documented (Lamb, 1982; Starkel, 1991; Pavese & *alii*, 1992; Provansal, 1995; Dìez & *alii*, 1996; Grove, 2001; Issar, 2003; Soldati & *alii*, 2006; Giraudi, 2005a and b), even though most numerous and congruent data are available only for the last 500-1000 years.

Giraudi (2005b) for example evidenced that expansion phases of the Calderone glacier (central Apennine, Italy) were followed by as many flood events as the Tiber river in Rome. Analogous correlation can be demonstrated between said events and the historical level variations of two important lakes of central Italy (the Trasimeno and Fucino lakes), both located within the Tiber river catchment; in fact, the collected data showed a strict connection between floods and periods characterized by positive hydrogeologic balance.

At the beginning of the 90s, Starkel (1991) pointed out that the landforms and deposits observed along the Holocene alluvial plains of the main rivers in Mediterranean Europe (with direct supplies from mountainous areas) are connected to the reiteration of flood events that are comparable with those recorded during the «Little Ice Age». Such rivers, as a consequence, responded to what the Author called the «second order climatic fluctuation» which also occurred during the early Holocene.

Analogous correlation can be evidenced between long-lasting cold and rainy periods and river mouths advances (Vita-Finzi, 1969; Le Roy Ladurie, 1971; Bondesan & *alii*, 1995; Long, 2001). In fact, it has been clearly demonstrated (Calvet, 1993; Jacob, 1997) that such intense meteoric events can mobilize enormous quantities of sediments in a very short time (even a few days), whereas several hundreds of years are generally necessary in «normal» denudation processes. The sedimentation process at the mouth is, therefore, not connected to the contemporary «dismantling» of the slopes, but to the fluvial transportation of material previously produced (by means of landslides, debris flows, fluvial-denudational processes etc.) and later deposited within gullies and alluvial fans and, later still, along the fluvial axes.

These mechanisms have characterised at least the last 5,000 years, when the Mediterranean sea level has risen to its present level (Borrego & *alii*, 1999; Lambeck & *alii*, 2004) although the materials carried to the mouth could not contrast marine ingression, which was connected to the warming of the period evidenced both in northern and in Mediterranean Europe; in fact, the mouths were still showing an overall estuarine shape (Albani, 1933; Lamb, 1982; Coltorti, 1997). Said correlations, evident for the period comprised between 2000 yrs B.C.E. and the end of XVIIIth century, are summarized, as stated before, in the first three columns of figure 6.

Historical data and geomorphological evidence in the study areas show a good general correlation with the information indicated by the above cited Authors and, in particular, a close correspondence with events and climatic changes recorded for the late Holocene (figure 6, columns 4, 5, 6). Analogous correspondence can be hypothesized also for the most ancient mass movements (particularly the debris flows) recognized in the mountainous portions of the study areas (the Sibillini mountains) and dated with geomorphological methodologies; they probably occurred during three phases of the early Holocene, between 6500 and 5800 yr B.C.E., 5000 and 4000 yr B.C.E and 3500 and 2500 yr B.C.E. Said periods, as stated before and characterized by certain Alpine glacial advances, favoured huge mass movements and floods also in several areas of the Mediterranean (Provansal, 1995; Dìez & *alii*, 1996; Giraudi, 2005a and b).

Concerning the hilly sectors of the study areas (of which the Mount Ascensione area is the most representative example), the fundamental control factor of mass movements, which was particularly frequent and widespread between the XVth and XIXth centuries, is represented by the presence of great quantities of water that are certainly congruent with the climatic fluctuations of the period (figure 6, columns 2 and 5). In fact the crucial geomorphological settings favourable to the activation of such processes can be recognized in the overlaying of lithoid units (aquifers) on clayey terrains (aquicludes), to which significant piezometric levels can be associated; in the intense softening processes of clays, consequent to the considerable and continuous presence of water, and in the intense and rapid deepening of the fluvial network at the foot of the slopes affected by landslides, as witnessed by the historical chronicles of the period preceding the events (Buccolini & *alii*, 2007 and 2010).

The illustrated data concerning the mouth evolution of the river Chienti, dating back to 2,000 yr B.C.E., show a generalized advance up to the end of the XIXth century, even though characterized by different velocity and periods of quiescence (fig. 5 and fig. 6 column 6); this evolution is in agreement with that recorded along the shorelines and the main Mediterranean deltas (Bondesan & *alii*, 1995; Borrego & *alii*, 1999; Grove, 2001; Bellotti & *alii*, 2004). More in detail, the advance phase occurred over a long period of time (about 500 years) with respect to the cold climatic fluctuation of the interval 5,000 yrs B.C.E. and 1,000 yrs C.E. (Lamb, 1982; Provansal, 1995); this phenomenon probably took place between 1,250 and 1,500 C.E. as a consequence of the XIIIth-century floods (Pavese & *alii*, 1992; Grove, 2001) and, mainly, of those associated to the cooling process of the mid-XVth century.

The following mouth evolution (imperceptible advance rate between 1500 and 1800 and evident until 1900 C.E.), common also to other rivers of central Adriatic Italy, can be connected to analogous climatic conditions, represented by at least three phases during the «Little Ice Age» (in particular, between 1560 and 1640 C.E., around 1700 and great part of the XIXth century) (Vita-Finzi, 1969; Le Roy Ladurie, 1971; Grove, 2001; Lamb, 1982; Pavese & *alii*, 1992; Provansal, 1995; Dìez & *alii*, 1996; Giraudi, 2005a and b).

A moderate delayed response to the mentioned climatic conditions of the «Little Ice Age» can be identified in the Chienti river mouth, that is mainly made up of gravels; this phenomenon differs, although not so markedly, from other sample areas observed by several Authors along the main Mediterranean river mouths, which are composed of finer sediments and characterized by an almost contemporary response to the climatic fluctuations of the period.

This phenomenon can be explained by the significant differences recognized in the lithological composition of bedrock and in slope and fluvial dynamics. In fact the

Mediterranean rivers are generally characterized by source areas of sediments mainly composed of terrigenous lithotypes; moreover they have regular regimes and show elevated solid and liquid discharges. For this reason, they managed to rapidly and constantly transport (with suspended transport mechanisms) finer sediments towards the river mouth, thus activating the formation of the delta, which was completed by the successive deposit of gravelly materials. In the mid-upper sectors of the hydrographic basins in the study area, however, a production of manly coarse sediments, connected to the calcareous lithotypes of the chain, occurred; the natural consequence was the filling of the initial portions of the river valleys, which evolved into a «braided» system. The subsequent transportation of gravels towards the sea can be connected, according to Starkel (1991), to flood events in a thalweg, which progressively deepened within the alluvial plain.

Despite the scarsity of data concerning this topic, such a dynamics can be corroborated by direct measures carried out by several authors both along some rivers of central Italy (Cencetti & *alii*, 1994) and in other region characterized by analogous climatic conditions and fluvial regime (Haschenburger & Church, 1998). In the former case the authors evidenced that during a flood event (roughly twice in one year in the climatic context of central Italy) a set of coarse pebbles can travel for a distance ranging from 300 to 600 m; in the other cases, the data collected show analogous virtual velocity of pebbles ranging from 0.5 and 0.6 m/hr. Applying these result to the case of the Chienti river, a delay of about some tenth of years in the coarse sediments transport to the mouth can be most likely hypothesized.

This evolutional model has been confirmed by the analysis of the river mouth variations summarized in columns 3 and 6 of fig. 6, which show that advance phases which also occurred during prolonged periods of climatic stability (about 1000-1300 C.E.). This phenomenon was due to the erosion and transportation of materials produced and partly deposited (the coarsest ones), and to the overload of materials along the fluvial axes of a different order during the previous cold phases.

Data from the last century, when climatic events interacted with human activities, are a little more complicated. As a matter of fact, the role of anthropization in recent geomorphological dynamics, is far from being defined. Many Authors, in fact, consider the past deforestation practises (during the Bronze Age, the Roman Age up to Middle Age) as the main cause of the above mentioned erosive processes (Delano-Smith, 1979; Innocenti & Pranzini, 1993; Guillén & Palanques, 1997). However, it is not possible to apply this theory to a wider context, such as Mediterranean Europe, because of the different demographic situation existing in Italy during the Roman Age, with about 6 million inhabitants versus a whole European population of 17 million (Beloch, 1994). The same concept applies to previous periods (Iron Age and Bronze Age), when the density of inhabitants was much lower and confined to well-defined areas.

In the study area, the influence of human impact in relation to erosive and/or sedimentation processes within the hydrographic basins, seems to have played a significant role during the medieval and post-medieval ages, although in restricted and discontinuous territories (areas bordering the former villages); on the contrary, it assumes a morphogenetic value starting from the end of the XIXth century. In fact, deforestation and farming activities generated a morpho-cultural setting favourable to the activation of significant processes of sediment erosion and transportation towards the fluvial-coastal system; such processes were active for about half a century, until slope hydraulic systems and forestry remedial measures were carried out (Sereni, 1979; Gentili & Pambianchi, 1987; Coltorti & *alii*, 1995; Garcia Ruiz & Valero Garcés, 1998; Gentili & Pambianchi, 2002; Beguéria, 2006; Buccolini & *alii*, 2007).

The actual influence of human impact alone, in erosive-depositional processes during the last century, is still uncertain. In fact, the mouths of the study area respond to the limited glacial advances, occurred at the beginning of the XXth century and during the 60's (Grove, 2001; Giraudi, 2005a and b) and to which floods along the main Italian and European rivers and debris flows in mountain areas are related, with alternated erosive and depositional phases (figure 6, column 6).

FINAL REMARKS

The results show, for the Chienti river mouth, a general advance phenomenon starting from 7000 yrs B.C.E. up to the beginning of the XXth century; this datum is in agreement with that observed by the cited Authors, concerning the effects induced on fluvial dynamics by the Holocene climatic fluctuations recorded around the Mediterranean. In particular the numerous «cold» and rainy phases that periodically occurred during early Holocene, the Late Middle Age and, mostly, during the Little Ice Age, played a fundamental role in the production and storage of huge volumes of detritic material (mainly coarse) at the foot of the slopes and along the river valleys of different order in the mountainous and hilly sectors. The movement of materials towards the sea, which followed the climatic fluctuation that generated it, happened through prevalent bedload transport mechanisms connected to flood phenomena; this differs from other contexts where the penecontemporaneity response of river mouths is connected to a prevalent suspended transport.

The role played by slope anthropization seems to be local and, mostly limited to specific historical periods. It generated overall «anthropic rexistasy» conditions increasing sediment transport phenomena from slopes towards the main hydrographic network; its contribution to the additional production of detritic material can nevertheless be considered negligible. During the last century, the morphogenetic value of human impact in controlling the complex erosive-depositional dynamics of the mouths has become significant; its effects, however, may have been partly enhanced or reduced by the climatic fluctuations occurred in very short period.

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