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LATE-QUATERNARY ALLUVIAL FANS IN THE NORTHERN MARCHE APENNINES: IMPLICATIONS OF CLIMATE CHANGES

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ABSTRACT: O. Nesci O. *et al., Late Quaternary alluvial fans in the northern Marche Apennines: implications of climate changes.* (IT ISSN 0394-3356, 2010)
Alluvial fans, fan-like deposits, and piedmont aprons are widespread at mountain-front and foothill sectors of the Umbria-Marche Apennines. They are currently regarded as significant geomophological features strictly dependent on either tectonic or climatic controls. Close relationship with tectonics, that are usually stressed by the location of such landforms along fault scarps or other active morphostructures, can be assessed only in the most internal areas of the Umbria-Marche Apennines, dissected by extensional tectonics. Conversely, in the piedmont and foothill sectors of the chain, the climatic control on fan deposition and entrenchment become dominant, whereas tectonic constrains can be only indirectly detected. Namely, within the Umbria-Marche Apennines, the late Quaternary cyclical and systematic episodes of fan deposition and entrenchment at the mouth of tributaries, usually following the main fluvial filling along the trunk valleys, are well known. Nonetheless, the main causes that have cyclically controlled the fluvial and alluvial-fan deposition and their subsequent dissection have not been thoroughly investigated yet. In this work we report a general overview on the geomorphological setting of the late Quaternary alluvial fans associated with the major fill-terraces that compose the typical staircase of river terraces in the Northern Marche territory. In particular, for the aggradational suites of the late Quaternary fill-terraces, we discuss the meaningful stratigraphic relations between the fluvial sediments of the trunk streams and the alluvial-fan deposits originating from the tributaries.
We also suggest a possible correlation between the cyclical recurrence of the principal episodes of fluvial aggradation/alluvial-fans formation and dissection and the principal late Quaternary climate fluctuations.

RIASSUNTO: Nesci O. et al., Conoidi alluvionali tardo Quaternarie nell'Appennino Marchigiano settentrionale: implicazioni paleo-climatiche. *(IT ISSN 0394-3356, 2010)*
Conoidi alluvionali tardo quaternarie (isolate e/o coalescenti) sono ampiamente diffuse lungo il fronte montuoso e l'area pedemontana dell'Appennino Umbro-Marchigiano. Le conoidi alluvionali sono correntemente considerate come significativi elementi geomorfologici in stretta connessione con la tettonica e/o con controlli di tipo climatico. Relazioni molto strette con la tettonica attiva, generalmente evidenziate dalla localizzazione delle conoidi lungo scarpate di faglia o altre morfostrutture attive, sono riconoscibili solo nelle aree interne dell'Appennino Umbro-Marchigiano, interessante da tettonica attiva di tipo estensionale. Al contrario, lungo i settori pedemontani della catena è più evidente il controllo climatico sulla deposizione e successiva dissezione degli apparati di conoide alluvionale, mentre il controllo da parte della tettonica può essere riconosciuto solo in parte e indirettamente. Lungo l'Appennino Marchigiano settentrionale, dove è incentrato il presente lavoro, da molto tempo è nota in letteratura la ciclica e sistematica ripetizione, in corrispondenza delle foci dei tributari, di alterne fasi di deposizione e re-incisione di conoidi alluvionali, le quali seguono sistematicamente fasi di aggradazione fluviale lungo i corsi d'acqua principali. Nonostante ciò, le cause principali che hanno ciclicamente controllato la deposizione di ampi apparati di conoide e la loro successiva re-incisione, ancora oggi non sono state studiate nel dettaglio. Nel presente lavoro viene descritto in alcune aree campione l'assetto geomorfologico delle conoidi alluvionali tardo quaternarie associate ai principali terrazzi deposizionali componenti la tipica successione di terrazzi fluviali all'interno delle principali valli marchigiane settentrionali. In particolare, vengono descritti in dettaglio i rapporti stratigrafici esistenti all'interno dei principali corpi alluvionali, di età compresa fra il Pleistocene medio e il Pleistocene superiore, fra le sequenze deposizionali di tipo fluviale appartenenti al corso d'acqua principale e quelle di conoide alluvionali presenti alla foce dei principali tributari.
Gli episodi che hanno portato alla formazione di ampi sistemi deposizionali di conoide alluvionale nei bacini marchigiani settentrionali sono ciclici e seguono sistematicamente le maggiori fasi di aggradazione fluviale lungo i corsi d'acqua principali. I depositi fluviali, fatta eccezione per i settori a ridosso dell'attuale fascia costiera, sono preservati nei principali terrazzi vallivi e vengono generalmente considerati come episodi deposizionali direttamente connessi con i principali cicli glaciali. Alla stessa maniera dei depositi fluviali lungo le valli principali, anche la deposizione e successiva reincisione degli apparati di conoide in corrispondenza delle confluenze dei tributari con il corso d'acqua principale sono da ritenersi strettamente connessi con le principali fluttuazioni climatiche tardo quaternarie. Inoltre, quando all'interno di un corpo alluvionale terrazzato i depositi strettamente fluviali coesistono con quelli di conoide alluvionale, fra le due tipologie di deposito esistono relazioni stratigrafiche precise e sistematiche. In particolare, i depositi di conoide seguono sistematicamente quelli fluviali; normalmente la transizione fra i depositi di conoide e quelli fluviali consiste in una rapida (fino a 2-3 m di spessore) interdigitazione di facies o, a volte, in limiti netti (anche di tipo erosivo). In ogni caso, i depositi di conoide giacciono generalmente sulla superficie non ancora rimodellata dei sottostanti depositi fluviali. Il ripetersi ciclico delle fasi deposizionali ed erosive, l'esistenza di precise e sistematiche relazioni stratigrafiche fra i due depositi e la disponibilità in letteratura, almeno per i depositi più recenti (Pleistocene superiore), di numerose età numeriche, hanno permesso di ipotizzare, tenendo anche in considerazione le analisi già effettuata per aree limitrofe e disponibili in letteratura, alcune correlazioni con le principali fluttuazioni climatiche tardo quaternarie.

Parole chiave: River terraces, Alluvial fans, Climatic controls, Northern Marche Apennines.

Keywords: Terrazzi fluviali, Conoidi alluvionali, Controllo climatico, Appennino nord Marchigiano.

1. INTRODUCTION

Alluvial fans are regarded by current literature as important geomorphological features in mountain-front and foothill settings, usually hinting at alternate phases of aggradations and entrenchment strictly dependent on tectonic and/or climatic control (e.g., BULL, 1977; HARVEY, 1984; HARVEY *et al*., 2005; SURESH *et al*., 2007 and reference therein). Tectonic controls are commonly regarded as crucial to rule both sediment load and catchment relief, promoting aggradation at the mountain-front and foothills (e.g., DAVIS, 1905; BLISSEMBACH, 1954; BULL, 1964; DE CELLES *et al*., 1991; HARTLEY, 1993; VISERAS *et al*., 2003). Equally, climate is considered to play a fundamental role in setting the rate of sediment supply, relief equilibrium, and fan geometry (e.g., LUSTING, 1965; HARVEY, 1990, 1996; RITTER *et al*., 1995; ROBERTS, 1995). Whether at fronts of high-relief areas or at tributary stream junctions, alluvial fans develop where a proper accommodation space for deposition exists, and high sediment loads encounter zones of reducing stream power (HARVEY, 2004) because of gradient lowering and, above all, of diminished flow confinement (SCHUMM, 1977). Moreover, the rate of both sediment supply and catchment erosion is rather related to stream-power which, in turn, is generally a function of precipitation intensity (SURESH *et al*., 2007). Hence, the formation and dissection of alluvial fans in a given area is ruled by a complex interlacement of climate-related and tectonic-geologic factors, whose mutual relationships and timing are often hard to unravel.

This paper reports some representative examples from the mountain-front and foothill sectors of the Adriatic side of the northern Marche Apennines (Fig. 1) in order to emphasize the close relationships in this area of systematic construction and dissection of wide alluvial fans with late Quaternary climate changes.

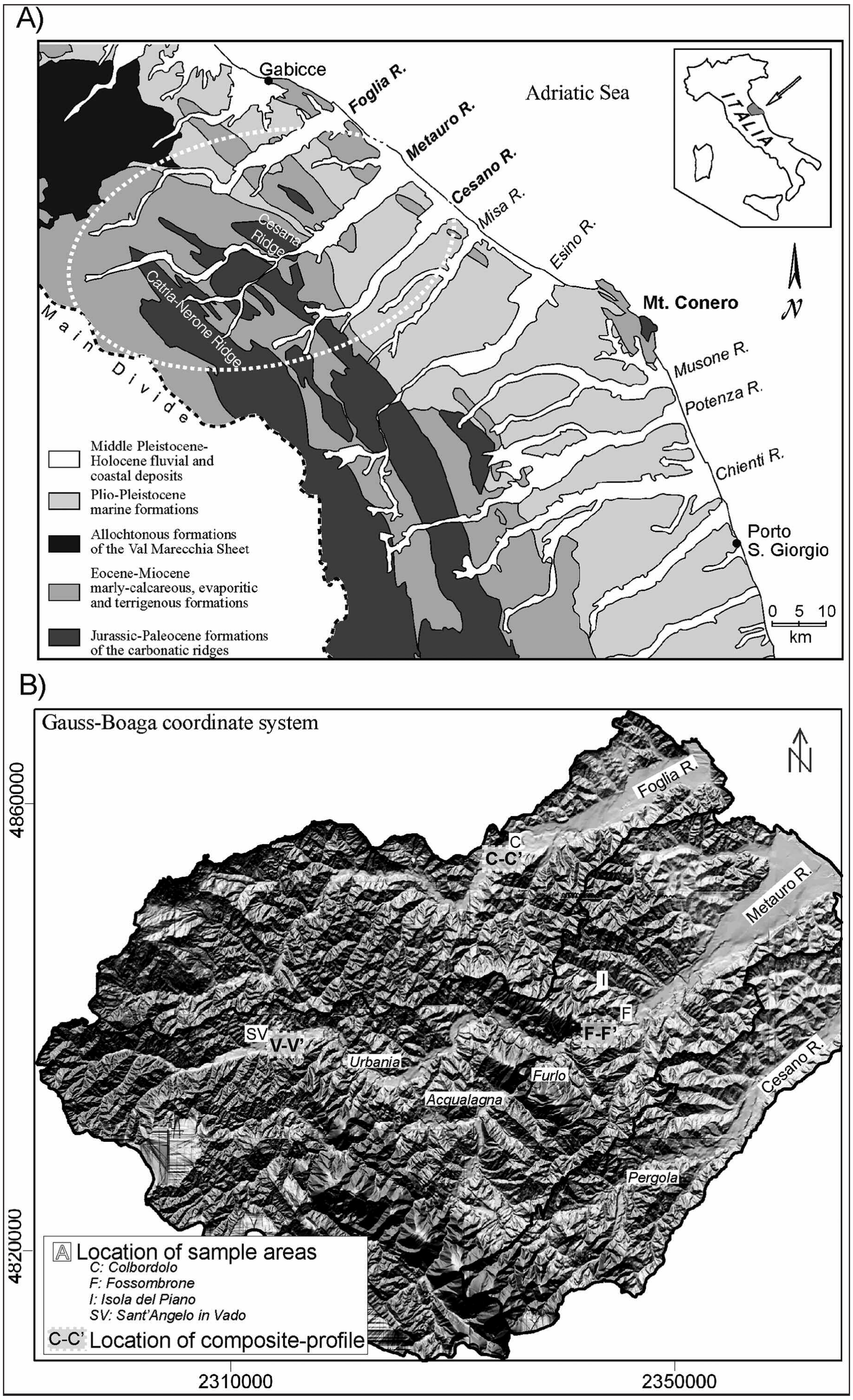

Fig. 1 - Location map. A) The study area in the morphostructural framework of the Marche Region. B) Shaded relief map of the study area with location of sample areas described in the text and outcrops shown in Figure 5.

Ubicazione dell'area e dei siti descritti nel testo . A) L'area studiata nel contesto morfostrutturale del territorio marchigiano. B) DTM dell'area analizzata con l'ubicazione delle aree campione descritte e degli affioramenti illustrati in Figura 5.

2. RIVER TERRACES IN THE MARCHE APENNINES

The Marche Apennines consist of a NE-verging thrust-and-fold belt involving a stratigraphic succession characterized by Mesozoic calcareous to marly-calcareous terrains overlain by Cenozoic dominantly terrigenous terms (DEIANA & PIALLI, 1994). A series of sub-parallel ridges and topographic depressions (Fig. 1), resulting from crustal shortening and extension driving the topographic emergence of the chain over the last three million years, generally match, respectively, the main calcareous anticlines and terrigenous synclines (CALAMITA *et al*., 1991). Since the Lower Pleistocene the area underwent a generalized tectonic uplift (BISCI & DRAMIS, 1991; DRAMIS, 1992; D'AGOSTINO *et al*., 2001) gradually achieving its definitive emersion.

The modern trunk valleys, characterized by an overall parallel pattern, perpendicular to the structural grain (MAZZANTI & TREVISAN, 1978; ALVAREZ, 1999), began to develop since the Messinian with the first stages of emersion, but achieved a configuration quite similar to the modern one in the lowermost part of the Middle Pleistocene, with the definitive emersion of the area (MAYER *et al*. 2003).

The Marche region holds an excellent preservation of late Quaternary valley terraces and a large number of terrace-alluvium exposures, supported for a long time by a great deal of scientific work (e.g., LIPPARINI, 1939; VILLA, 1942; SELLI, 1954; NESCI *et al*., 1995; COLTORTI *et al*., 1991; BISCI & DRAMIS, 1991; FANUCCI *et al*, 1996; WEGMANN & PAZZAGLIA, 2009). Particularly, in the central and northern sector of the Marche region, cyclical stages of alluvial fans and piedmont-aprons formation and dissection have been reported in close relation (Fig 2) with the valley terraces development (e.g., NESCI & SAVELLI, 1986; NESCI *et al*., 1995). The trunk valleys show at least four "orders" of alluvial terraces, ranging from Middle Pleistocene to Upper Pleistocene in age (cf. fig. 6), and designated respectively, from the older and higher one, as T_{1A}, T_{1B}, T_2, and T_3 (NESCI *et al*.,

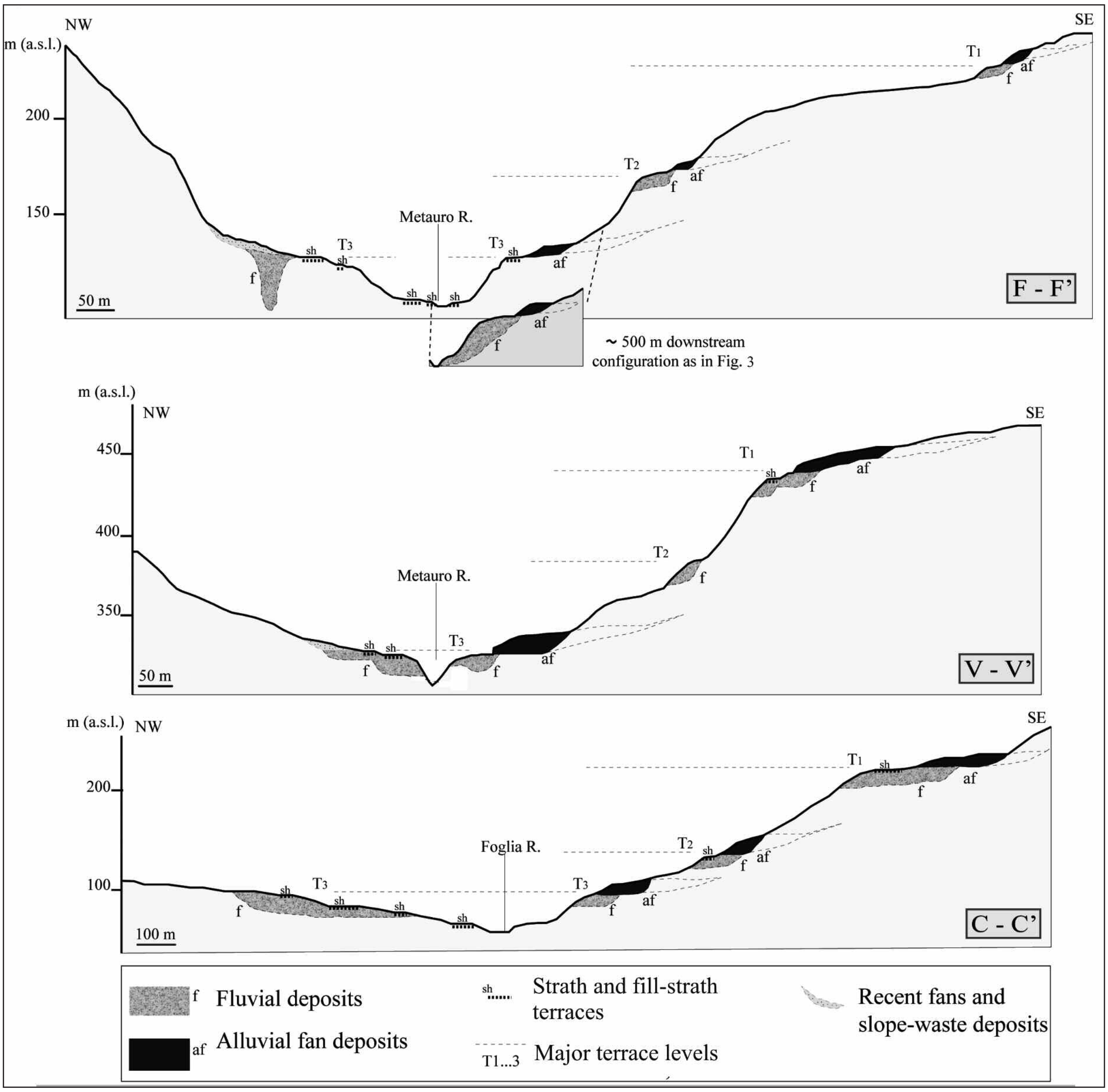

Fig. 2 - Composite topographic profiles and cross sections transversal to the trunk-valley axis displaying the arrangement of the principal alluvial-fan deposits in the frame of the major valley terraces in some selected areas of the northern Marche Apennines. The stratigraphic relationships with the fluvial fills along the trunk valleys are also shown. Location of profiles in Figure 1B.

Profili compositi trasversali agli assi vallivi che evidenziano la posizione dei principali depositi di conoide alluvionale nel contesto dei maggiori terrazzi vallivi in alcune aree campione dell'Appennino Marchigiano settentrionale. Sono evidenziati anche i rapporti stratigrafici dei depositi di conoide alluvionale con i sedimenti delle colmate fluviali degli assi vallivi principali. Ubicazione dei profili in Figura 1B.

1990, 1995; FANUCCI *et al*., 1996). They are characterized by thick alluvial covers, often exceeding 30 metres in thickness for the only sediments supplied by the trunk-valley, i.e. without the alluvial-fan additional component which, in turn, varies in thickness from a few metres (fine grained fans, NESCI & SAVELLI, 1991) up to 25-30 metres (pebbly fans). These terraces are preceded by a complex suite of strath terraces, which, according to genetic mechanisms already described by BULL (1992), have been interpreted as related to tectonic factors (FANUCCI *et al*., 1996). Conversely, as regards the T_{1A}-T_3 terraced alluvial suites with which this paper is concerned, they are usually retained to be the result of as many complex, for the most part climatically-driven, aggradation episodes, alternating with likewise complex stages of predominant stream downcutting (e.g., CALDERONI *et al*., 1991, 1992; COLTORTI *et al*., 1991; NESCI & SAVELLI, 1990; 1991; NESCI *et al*., 1995; CILLA *et al*. 1996; COLTORTI, 1997; WEGMANN & PAZZAGLIA, 2009). Being here T_{1A} and T_{1B} reported as two main distinct terraces, it is worth emphasizing that this subdivision of the traditional "first order of terraces" (cf. LIPPARINI, 1936; VILLA, 1942 and following Authors) in two distinct main stages of terrace development -i.e. with the same "hierarchic range" of the already distinguished 2^{nd} and 3^{rd} "orders of terraces" has been introduced by NESCI *et al*. (1990) just for the Metauro and Foglia river basins (the two principal catchments of the northern Marchean area), where the traditional "first order" revealed to be unsuitable to describe the altimetric distribution of the oldest terrace-alluvium which, as a matter of fact, accounts for two main, distinct stages of terrace formation.

As regards the alluvial fill stages related to the principal terrace units, the four main aggradation stages already recognized by NESCI *et al*. (1990, 1995), match in a good way with the principal stages already described by WEGMANN & PAZZAGLIA (2009) (Fig. 6). The principal episodes of aggradation took place during the major stages of late Quaternary climatic cooling and, generally, they were not continuous but often complicated by repeated minor episodes of cut-and-fill process (NESCI *et al*., 1995; ELMI *et al*., 2003). During the intervening late Quaternary warmer stages, as well as during the Holocene, because of the effect of both climate change and generalized tectonic uplift, stream downcutting and entrenchment exceeded valley aggradation leading to the formation of well-developed flights of alluvial terraces (e.g., NESCI *et al*., 1995; DI BUCCI *et al*., 2003; WEGMANN & PAZZAGLIA, 2009) which are often exposed along both trunk and tributary valleys, up to 150 meters high above the present valley-floors.

3. ALLUVIAL FANS IN THE MARCHE APENNINES: OVERVIEW

The above delineated comprehensive framework is thus inclusive of the late Quaternary alluvial fans of the northern Marche area. Specifically, in this general context, NESCI & SAVELLI (1986, 1990) stressed the systematic recurrence in the cycles of valley-terrace development of peculiar erosional-depositional steps. These steps are repeated quite unvaried in the T_{1A}-T_3 cycles of aggradation-dissection, to such an extent that NESCI & SAVELLI (1986 and following) called them "guide stages"/"guide deposits" to signify something hinting at a precise position in the cycle itself. Hence, the valley fill resulted in a first aggradational step consisting of coarse sediments of braided rivers, even though rather complicated by subordinate cut-and-fill episodes (CALDERONI *et al*, 1991) and/or by the local occurrence of different channel-patterns (CALDERONI *et al*, 1992). The second step of the trunk-valleys aggradation consists, in turn, just in a tributary-junction related construction of alluvial fans (cf. Fig. 2, 3 and 5) above the previous

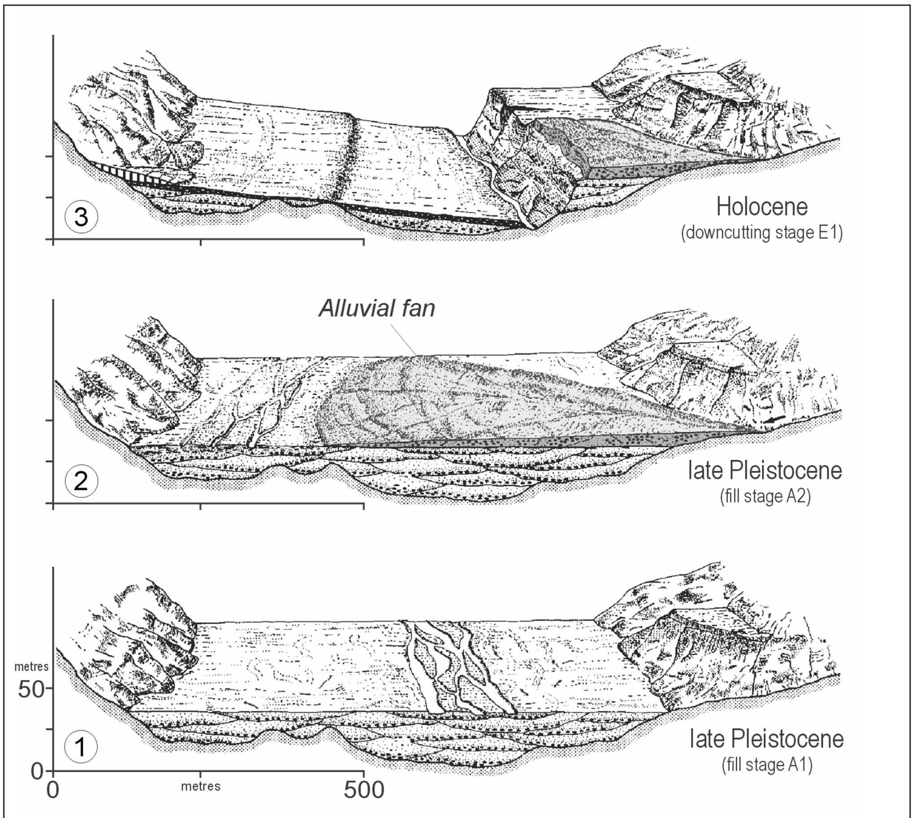

Fig. 3 - Block-diagram showing the of formation (2) and dissection (3) of a wide late Pleistocene alluvial fan on the right side of the Metauro River valley, c.ca 1 km upstream Fossombrone. Stages A1, A2, E1 as in Figure 6. Location in Figure 1B. After SAVELLI *et al.* (1984), simplified.

Block-diagramma che illustra la formazione (2) e parziale smantellamento (3) di un'ampia conoide alluvionale del Pleistocene superiore; versante destro della valle del Fiume Metauro, c.ca 1 km a monte di Fossombrone. Le fasi A1, A2. E1 si riferiscono agli eventi descritti in Figura 6. Ubicazione in Figura 1B. Da: SAVELLI et al. *(1984), semplificato.*

braided river plain or directly on the bedrock (NESCI & SAVELLI, 1991). From this perspective, alluvial fan deposits and related piedmont aprons – every so often merging erosional glacis (NESCI *et al.*, 2002) - are spread throughout the northern Marche foothills both in piedmont sectors (SAVELLI & BALLERINI, 1991; NESCI *et al.* 1993; SAVELLI *et al.*, 1994) and at the junction of tributary catchments with the main valley (NESCI & SAVELLI, 1986, 1991). They are part of the depositional suites of the principal alluvial-terraces and have been interpreted as climatically-driven landforms related to the late Quaternary glacial stages (NESCI *et al.*, 1995). Indeed, in the Umbria-Marche Apennines some close relationships between alluvial fan development and tectonics can be stressed in correspondence of either fault scarps or active morphostructures only in the most inner areas (CATTUTO *et al.*, 2004 and reference therein), dissected by extensional tectonics (LAVECCHIA, 1988 and references therein). On the contrary, in the external sectors of the area the climate control on fan development becomes dominant and the tectonic constraints can only be indirectly detected (SAVELLI *et al.*, 1994; NESCI *et al.*, 2002).

It is worth underlying that the term “alluvial fan” is used in this paper for alluvial depositional bodies which are directly connected with a specific point of water and sediment input and limited in the downstream (axial) direction. Clast lithology highlights a supply from local catchments, while morphometric characteristics of pebbles underline a relatively short travelling distance (Fig 5B). As for other places and settings, (e. g., KOCHEL, 1990; MUKERJI, 1990), the typical fan-shape can be developed or not. Most of the fans of the study area do not show the characteristic shape consisting in a downslope radiating segment of cone, because of both the occurrence of confining adjacent fans and physiographic constraints, e.g. narrow valley troughs. In the same place, a progressive confinement of fans is apparent from the older fans to the most recent ones, accounting for an enhancing rate of stream entrenchment which, in turn, can be seen as the result of an increased uplift-rate (NESCI *et al.*, 2002). The val-

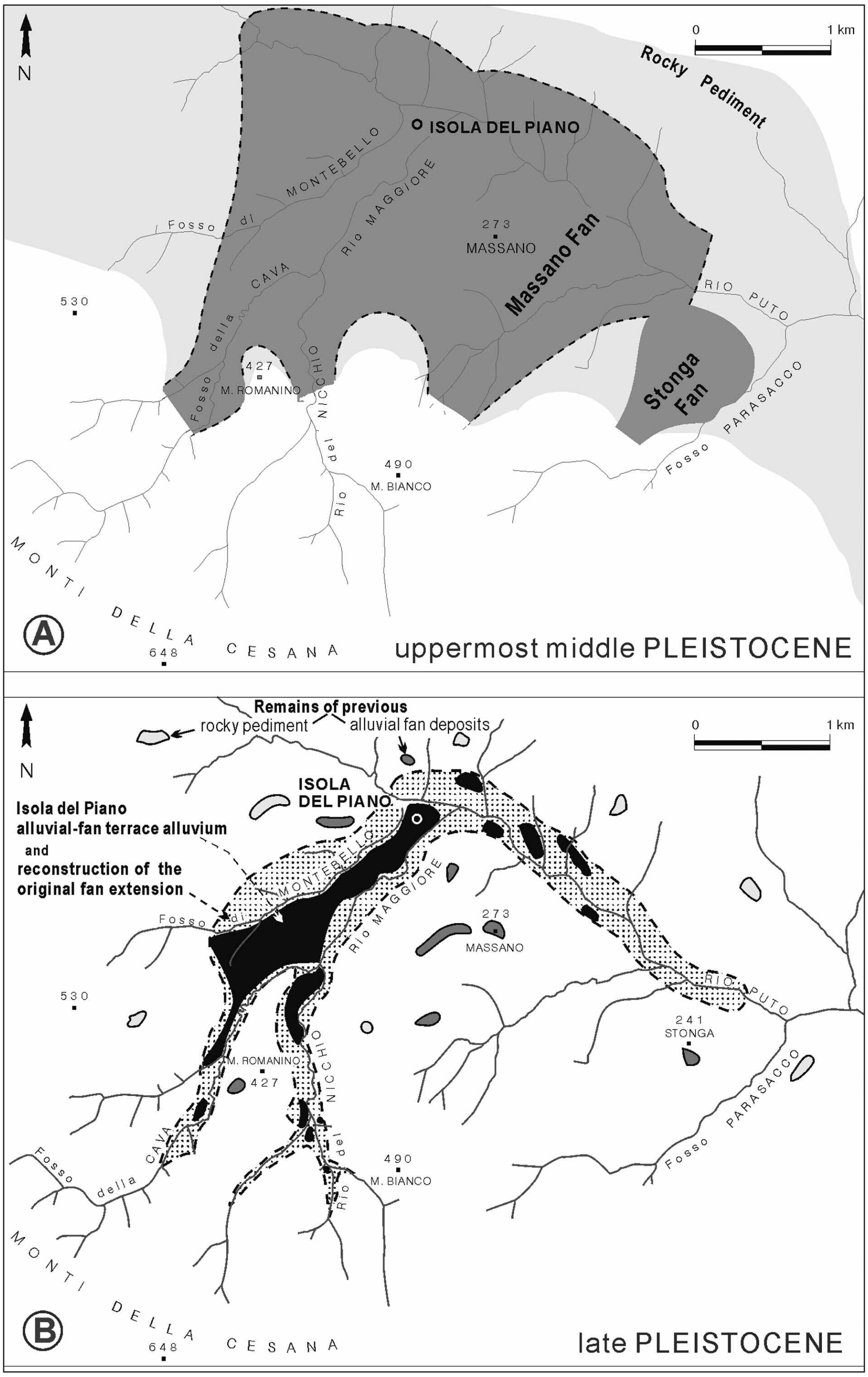

Fig. 4 - Reconstruction of the uppermost middle Pleistocene (A) and late Pleistocene (B) alluvial fans at Isola del Piano, on the north-eastern foothills of Monti della Cesana calcareous anticline ridge. A strong confinement of the most recent fans is obvious when compared to the coalescing fan-glacis development during the previous cycle. Location in Figure 1B. After NESCI *et al.* (1993), modified.

Ricostruzione delle conoidi alluvionali del Pleistocene medio finale (A) e del Pleistocene superiore (B) nei dintorni di Isola del Piano, sulle pendici nord-orientali della dorsale anticlinalica calcarea dei Monti della Cesana. Il confronto fra i due diversi eveventi di formazione di conoidi alluvionali mette in evidenza il forte confinamento che caratterizza il ciclo più recente. Ubicazione in Figura 1B. Da NESCI et al. *(1993), modificato.*

ley narrowing connected with the recent stream-net entrenchment, can be locally so strong that in areas where in earlier fan-formation cycles wide piedmont aprons have formed, in more recent cycles alluvial fans could not develop (SAVELLI *et al*., 1994).

As stated above, whatever the fan-shape, degree of confinement and location, the major northern Marche fans are cyclical and are part of the alluvial fill suites of the principal valley terraces. However, this doesn't mean that a large number of minor alluvial fans cannot form anytime and in any suitable place: widespread, scattered formation of minor fans indeed occurs almost everywhere. It is worth mentioning the large coastal-fans (uppermost Pleistocene-lowermost Holocene) which, with a sea level lower than today, developed close to the modern river mouths because of the removal of huge alluvial masses during the first dissection stages of the upper-Pleistocene alluvial plains (DI BUCCI *et al*., 2003; NESCI *et al*., 2008; CALDERONI *et al*., 2008). Other examples can be observed, which consist of a wide range of forms every so often active and frequently grading to scree cones (cf. Fig 3.3), which and are in relation with both land use and ongoing deep-seated slope gravitational deformations: an example of this latter is the San Lazzaro fan reported by FRANCAVILLA (1976) (cf. Fig. 2 F-F').

What follows is a synthetic description of some selected sites, which can be regarded as representative for the whole northern Marche sector of both piedmont pediment areas and of tributary junctions with trunk valleys. The sites have been chosen in order to highlight those cases where there are accounts in the same place of a systematic repetition of alluvial-fan deposits in the main fill sequence of each principal terrace, and where relationships with the trunk-valley terrace-alluvium can be easily assessed. The objective is to stress the cyclical recurrence of wide alluvial fan depositional systems, highlighting the stratigraphic relationships between alluvial-fan deposits and fluvial fill of the trunk valleys, and to underline the occurrence of a peculiar sequence of alluvial bodies which can be retained as the result of late Quaternary climatic-driven sedimentary and geomorphic processes.

4. ALLUVIAL FANS IN THE MARCHE APENNINES: CASE STUDIES

4.1 Metauro River valley, Fossombrone site (Figs. 2 F-F', 3 and 4)

This site extends for a few kilometres just

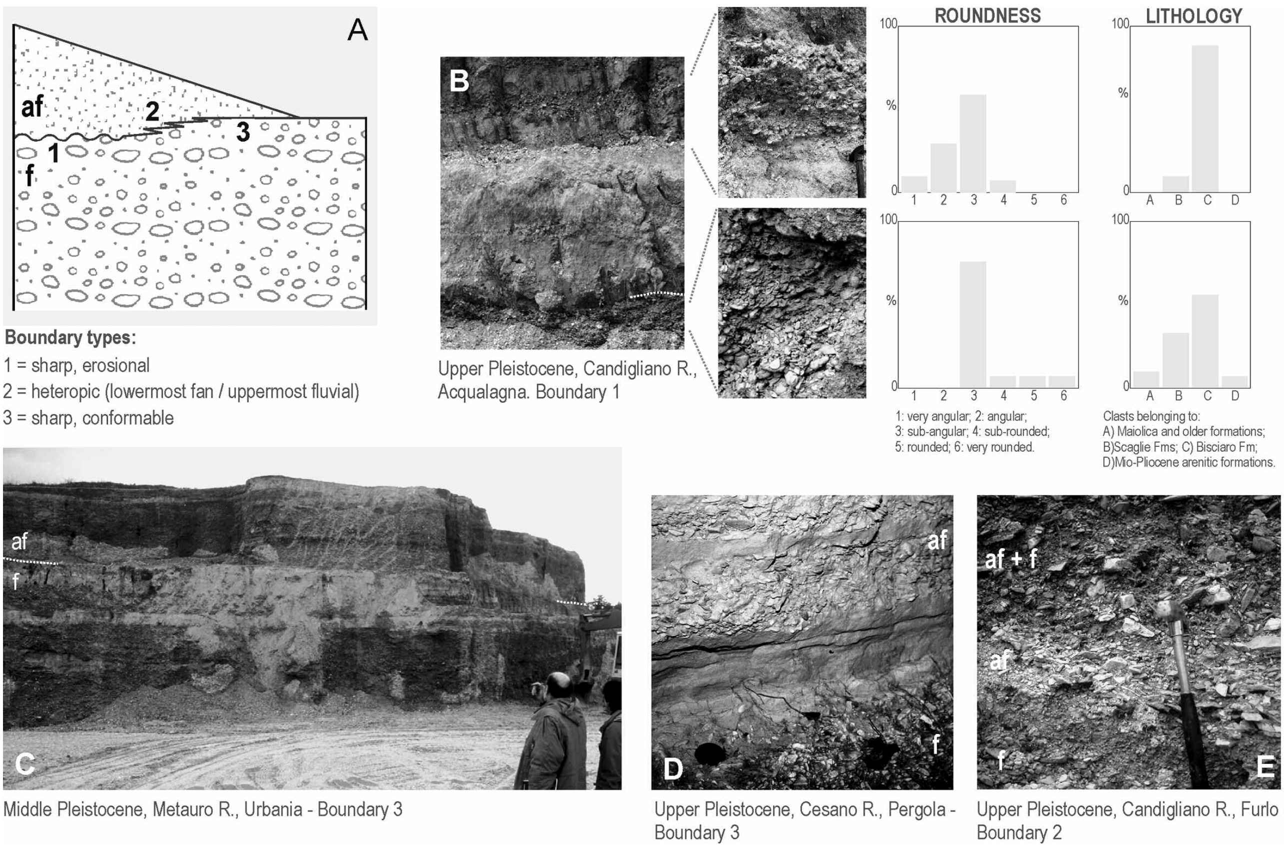

Fig. 5 - The characteristic patterns of stratigraphic superposition of alluvial-fan deposits above fluvial sediments in a typical fill-terrace of the northern Marchean area. A. Sketch displaying the stratigraphic relationships between fluvial (f) and fan (af). B-E. Some explicative outcrops and lithologic and morphometric differentiation between fluvial and alluvial fan deposits. Location of outcrop areas in Figure 1B.

Le diverse modalità nella sovrapposizione stratigrafica dei depositi di conoide alluvionale sui sedimenti fluviali nella fase aggradazionale di un tipico ciclo di terrazzamento vallivo principale dell'area marchigiana settentrionale. A. Schema dei rapporti stratigrafici fra i depositi fluviali (f) e quelli di conoide alluvionale (af). B-E. Il contatto in alcuni affioramenti significativi e alcuni elementi di differenziazione fra i depositi fluviali e quelli di conoide alluvionale. Ubicazione degli affioramenti in Figura 1B.

upstream Fossombrone, where the Metauro River crosses the Monti della Cesana anticline ridge (Fig. 1) cutting a rather narrow valley-segment in the calcareous Meso-Cenozoic units of the Umbria-Marche Succession. Three different stages of alluvial fan formation can be observed, related to as many major terrace-fill events, i.e. T_3, T_2 and T_1 (cf. Fig. 6), and each characterized by a thickness ranging from 5 to 15 metres. The late Pleistocene fans (T_3 fill stage) are preserved at the junction of the widest part of the tributaries with the trunk valley, although a severe dismantling occurred because of both a pronounced lateral erosion performed by the Metauro river during the downcutting stage (cf. Fig. 3.3), and a strong gravitational instability of a wide sector of the left valley-side. The wide and well-formed Holocenic fan already described by FRANCAVILLA (1976) can also be noticed on the left valley side, where several scree cones and an important landslide accumulation also occur, due to huge, slow deep-seated gravitational movements (PERGOLINI *et al.*, 2001). Nonetheless, it is worth underlining that close to the junction of the tributary valley from which this recent fan takes origin, residual patches of an older fan are found hanging on the flanks of the tributary valley in a position clearly correlable with the late Pleistocene fan deposits occurring in nearby sectors (e.g. the fan shown in Fig. 3). The fans of the uppermost Middle Pleistocene (i.e. T_2 fill stage, cf. Fig. 6) are preserved in some small patches on the right side of the Metauro valley, resting above fluvial gravels of the T_2 fluvial fill and/or directly on bedrock. It is worth emphasizing that, in a general way, fan deposits rest directly on bedrock both upstream along the tributary valley which fed the fan and/or in several internal sectors of the trunk valley, where fill terraces are often substituted by strath terraces. A patch of Middle Pleistocene alluvial-fan deposits can be observed in a higher position on the right valley-side (Fig. 2), resting above the fluvial gravels of the T_1 (T_{1B} according with the attribution of NESCI *et al.*, 1990). They have a scant morphological emphasis because of strong remoulding, which is at least in part related to the fine-grained nature of the deposit, supplied chiefly by marly and marly-calcareous units.

4.2 Metauro River valley, Sant'Angelo in Vado site (Fig. 2 V-V')

The site is set a few kilometres downstream of Sant'Angelo in Vado, on the right side of the valley segment that crosses the north-western termination of the Catria-Nerone anticline ridge (Fig. 1). Along the valley reach enclosing the site, terraces are preserved at different heights above the modern valley floor which account for four principal fill-stages, the oldest and highest of which has been referred to the T_{1A} (Monte Proverso terrace, 210 m above the thalweg, according to NESCI *et al.*, 1990). The composite profile in Fig. 2 crosses the valley in an area where the oldest terrace (T_{1A}) is not preserved, but some previously unreported T1B terraces occur (T_1 in Fig 2), one of which consisting of both fluvial and alluvial-fan deposits. These deposits, more than 15 meters thick, lie on the top of fluvial deposits at the most external fan-zone, whereas,

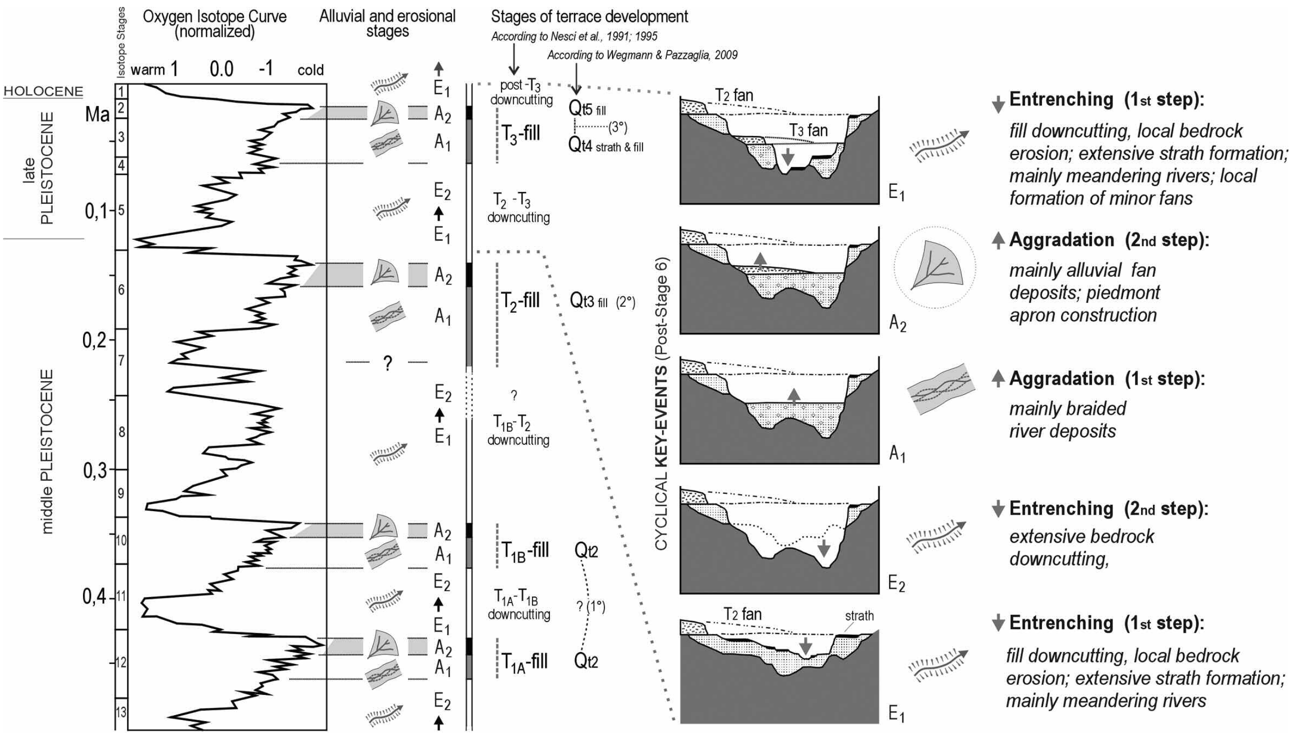

Fig. 6 - The principal stages in the development of the main valley terraces in the northern Marche Apennines: the position of principal episodes of downcutting and aggradation, including alluvial fan formation stages, are shown. Plotting against the oxygen isotope curve of LISIECKI & RAYMO (2005), after WEGMANN & PAZZAGLIA (2009), simplified.

Le principali fasi erosionali e aggradazionali, con i maggiori episodi di formazione di conoidi alluvionali, nell'evoluzione dei principali terrazzi vallivi dell'Appennino Marchigiano settentrionale. Riferimento alla curva isotopica dell'ossigeno di LISIECKI & RAYMO (2005), sulla base del lavoro DI WEGMANN & PAZZAGLIA (2009), semplificato.

toward the fan-apex zone, they generally overlay the bedrock. The alluvial fan deposits show a well-preserved top-surface, characterised by a very gentle dipping towards the trunk-valley axis, and covered by a thick decalcified, reddish-yellowish relict soil. More downslope, any patch of alluvial fan deposits related to previous T_2 terrace can be observed, likely because of erosional removal, although remains of such deposits occur both up- and down-valley. In this respect, it is worth underlying that previous T_{1B} related fan deposits could be preserved because of their topographic location, resting on a local wide divide. Conversely, deposits of alluvial fans connected with the T_3 fill stage are well preserved in several wide terraces at the junction of tributaries with the trunk valley.

4.3 Foglia River valley, Colbordolo site (Fig. 2 C-C')

This site is located on the right flank of the Foglia River valley, roughly between the villages of Colbordolo and Montefabbri, where the trunk stream crosses an anticline ridge made up mainly of Cenozoic marly-calcareous terrains (Fig. 1). Here, three main fill terraces are preserved, namely T_{1B} (T_1 in Fig 2), T_2, T_3. Not so different from the already described examples, the fill of each principal terrace consists of both fluvial and alluvial-fan sediments, with preserved thicknesses of fan deposits sometimes exceeding 20 metres.

4.4 Monti della Cesana piedmont area, Isola del Piano site (Fig. 4)

The site is located on the north-eastern foothills of the Monti della Cesana anticline ridge consisting of mainly calcareous Meso-Cenozoic terrains (Fig. 1). It is an example of alluvial fans finding – at least during some specific cycles of late Quaternary fan construction - their accomodation space not in an aggraded valley floor, but in a piedmont area wide enough to allow an erosional-depositional glacis to develop. Similar examples are diffused in several areas of the central and northern Marche region, both on authoctonous terrains (Savelli & Ballerini, 1991; Nesci *et al*., 1993, 1995, 2002) and in allochthonous ones (Guerra & Nesci, 1999; Nesci *et al*., 2002). The piedmont area around the village of Isola del Piano shows wide late Pleistocene fill terraces (Fig. 4B) characterised by mainly gravel alluvium, averaging 20-25 metres in thickness, supplied by small catchments draining the Monti della Cesana ridge to the north-east, which accounts for a narrow, SW-NE elongated, confined alluvial fan (Nesci *et al*., 1993, 2002).

At higher elevations, several patches of terraced alluvial-fans deposits are found, allowing (Nesci *et al*., 2002) to reconstruct the depositional top-surface with enough accuracy to assess the occurrence of an ancient system of partially coalescent fans. These have been correlated to several scattered remains of a wider erosional surface, hinting at a rather smooth piedmont area shaped in a wide glacis both by fan accretion and by areal erosion (Fig 4A). On the basis of morpho-stratigraphic correlation all along the piedmont area and towards the Metauro River valley, a reliable attribution to the uppermost middle Pleistocene (T2) events of terraces development can be made (Nesci *et al*., 2003). The Isola del Piano piedmont is also an area where the confinement of alluvial fans in narrow valley troughs during the late Pleistocene is particularly clear, a fact that – as mentioned above - has been related with an increasing downcutting driven, in turn, by an enhancing rate of uplift.

5. DISCUSSION AND CONCLUSIONS

During late Quaternary, a generalized crustal uplift gradually diminishing in intensity to the north-east, affected the northern Marche Apennines promoting the formation of river terrace staircases which – including the flights of erosional terraces already described by Fanucci *et al*. (1996) - along the main valley sides, reaches heights of up to 300 meters above the present valley-floors (Di Bucci *et al*., 2003 and references therein). In such a frame of progressive uplift the major late Quaternary cyclic climatic fluctuations (i.e., glacials-interglacials) can be retained to have driven temporary depositional episodes that promoted the formation of middle Pleistocene-upper Pleistocene fill-terraces, namely the terrace units referred as T_{1A}, T_{1B}, T_2, and T_3 (cf. Fig. 6) according to Fanucci *et al*. (1996). The flight of valley terraces exposed along the flanks of the main fluvial valleys, generally developed through a complex series of fill and dissection processes, stand for the most evident expression of the so called “rhythmical succession of cycles”, already underlined by Lipparini (1936). Such “rhythmical succession of cycles”, however, also include other specific morphoevolutive episodes (both erosional and depositional); in particular, among depositional events, the most outstanding and diffuse features are the alluvial-fan deposits, widespreading over the mountain-front and foothills of the Umbria-Marche Apennines (Nesci & Savelli, 1986, 1990). Namely, alluvial fans are an integral part of the alluvial valley-fillings, as they usually associate with fluvial deposits along the trunk valleys (i.e., fluvial sediments are systematically topped with alluvial-fan deposits, cf. Fig. 2). On the other hand, at the foothills of the major anticline ridges which characterize the most internal areas, the alluvial-fan sediments/landforms are the only significant alluvial contributors to terrace formation (Fig. 4), often coalescing to form typical piedmont aprons (e.g., Savelli & Ballerini, 1991; Savelli *et al*., 1994; Nesci *et al*., 2002). In the examined areas, the major alluvial fillings are currently considered as climate driven events (Coltorti *et al*., 1991; Nesci *et al*., 1995; Wegmann & Pazzaglia, 2009). At the same time, the cyclical formation of large alluvial-fan depositional systems at the junction of small tributaries with the trunk-valley and at the foothills of the major anticline ridges of the northern Marche Apennines, is to be regarded as climate-controlled (Nesci *et al*., 1995).

In this context, the geomorphologic analysis of the alluvial fans that directly connect to the major fill terraces exposed within the study area has led to some remarkable considerations, as follows.

- As shown in Figure 2, the formation of wide and thick alluvial fans is systematic and cyclical and is directly connected with the major fluvial fill stages along the trunk valleys. In particular, where both fluvial and fan depositional events occur, the fan deposits systematically follow the fluvial ones, generally overlaying the top of the fluvial fill belonging to the same depositional cycle (cf. Fig. 6). The most frequent boundaries between the two depositional sequences belonging to the same depositional events are either unconformably erosional or sharp conformable as shown in Figure 5. In several cases, however, the boundary results heteropic, with alternation of typical fluvial coarse sediments and locally-derived alluvial fan deposits. Where this typology of boundary occurs the thickness of deposits characterized by such alternation is rather low, usually less than 2-3 metres (NESCI & SAVELLI, 1991) in a cumulative thicknesses (i.e. fluvial + fan) every so often exceeding 40-50 m. Hence, notwithstanding the typology of the stratigraphic boundary, the fan deposits always lie above undissected tops of fluvial sediments (Figs. 2, 3). This pattern highlights the occurrence of specific stratigraphic relations (i.e., superposition), and a rather clear chronological succession between the two distinct depositional sequences. Namely, in a first time the trunk valley experiences a fluvial filling by aggradational behaviour of the main stream; afterwards, at the junction of the tributaries, alluvial fan systems develop.

- The T_3 terrace has to be regarded as an unavoidable key element to reconstruct the morphoevolutive events in the study area. In fact, the T_3 terrace is generally well developed along the northern Marche trunk valleys, furthermore it is usually spatially continuous and well constrained by several radiocarbon ages (CALDERONI *et al*., 1991; NESCI *et al*., 1995; ELMI *et al*., 2003; CALDERONI *et al*., 2008). These latter characteristics, in particular, allow us to define a well constrained morphoevolutive pattern and reasonably correlate the late Pleistocene depositional/erosional events with the main late Quaternary climatic fluctuations (Fig. 6). Since a cyclically recurrent suite of peculiar depositional and erosional events characterize each major fill terrace, it is plausible to extrapolate the results obtained for the late Pleistocene fill terrace to the older terrace levels (middle Pleistocene and uppermost middle Pleistocene terraces), as already indirectly demonstrated, for example, in the detailed analysis proposed by WEGMAN & PAZZAGLIA (2009). Namely, the T_3 terrace becomes an interpretative guide for the analysis of the older fill terraces and, moreover, for the analysis of fill-terrace staircases through the whole Umbria-Marche area. In this frame, the most striking expression of the late Quaternary cyclical depositional events is the cyclical formation of alluvial-fan depositional systems. Therefore, the interpretation of the alluvial fan development as climate-driven depositional events - despite some dating problems, as at the next point - actually can be reasonably projected to the middle Pleistocene (T_1) and to uppermost middle Pleistocene (T_2) terraces. On the other hand, alluvial fans are not the only feature fit for this purpose. Indeed, among the others, some features that appear to support the assertion of an effective usefulness of some repetitive facies and erosional patterns in both the reconstruction and interpretation of late Quaternary morphogenetic cycles, are, for example: i) the systematic repetitiveness of the thickness of both fluvial fills and overlying alluvial fan deposits (cf. BULL, 1992); ii) the systematic pattern of the reincision that involve the alluvial fills and, at least in part, the bedrock, promoting the formation of both strath terraces (Fig. 2) and ingrown meanders (cf. Fig. 3.3). Furthermore, in the same perspective the cyclical formation can be also interpreted - along the downstream sector of the main northern Marche trunk valleys - of typical coastal fans merging in a coeval coastal plain, as already suggested by CALDERONI *et al*. (2008).

- It is necessary to underline that for alluvial fan deposits in general, and even more so for those of the alluvial fans of the piedmont sectors of the calcareous anticline ridges - which hardly reveal peculiar, clarifying stratigraphic relationships with the alluvial fills of the trunk valleys - a very scant number of radiometric ages is available both for the whole Marche Apennines and for the studied areas. Hence, any chronological attribution and/or correlation with other deposits rests more on circumstantial evidence than on analytical data. Indeed, CALDERONI *et al*. (1991) stressed how the Cesano River deposits – but such consideration is equally reliable for the other northern Marche rivers - only the lower half of the terrace-fill hold wood fragments suitable for dating, since the upper section was lacking in any appropriate materials. On account of this, they performed an indirect computation of the expected age for the upper part of the alluvial suite, reaching an estimate that today sounds quite near to the ages reported by WEGMANN & PAZZAGLIA (2009). Furthermore, some available radiometric ages of alluvial deposits of the Marche Apennines which have been retained "other" than alluvial fans (e.g. uncorrected ^{14}C ages of 23,500±400 of CALDERONI *et al*., 1992 for the upper Esino River basin, and 23,500±1200 of MENCUCCI *et al*. 2003 for the lower Foglia River basin) could instead be reasonably referred to fan deposits. As a matter of fact, much work is to be done to achieve – every so often through expensive analytical procedures - a larger amount of numeric ages able to detail the chronological attribution and to provide a further advance in genetic explanation of these deposits. However, as targeted by this paper, a detailed field work and the reconstruction of mutual relationships between different sedimentary bodies, between them and certain peculiar erosional events, and between them and specific diagnostic landforms is essential to depict a morpho-sedimentary correlative and evolutive frame as that shown in Figure 6, which is capable of eventually being adjusted by further analytical data and/or in which such data can be suitably set.

- Based on the above considerations on the scant availability of numeric chronological constraints for both the upper part of the trunk-stream fills and alluvial fan deposits, a major question regards the fans and aprons of the piedmont areas around the major carbonate anticline ridges. In fact besides lacking in numeric ages, they hardly display obvious stratigraphic relationships with trunk-valley fills. Indeed, if their correlation with the fans occurring at the junction of the tributaries on the trunk-valleys were effective, a diachronism with respect to the same trunk-valley fill should result (cf. Figs. 2, 5, 6). Actually, in certain areas where the downstream termination of some wide piedmont aprons reaches the trunk-valley, a superposition on valley trough fill-deposits is still well recognisable. As an example, the deposits of the coalescing fans of Acquaviva, at the foothills of Catria-Nerone anticline ridge (Fig. 1), whose downstream termination reaches the trunk-valley (Burano River). Here the fan deposits overlay the fluvial valley-fill sediments (SAVELLI & BALLERINI, 1991), thus hinting at a downstream extension of the piedmont alluvial-system that expands upon the already formed alluvial-plain of the trunk valley. It is worth emphasizing that the same piedmont alluvium of Acquaviva displays a complex evolution which, starting with alluvium supplied from the south-east (i.e. from longitudinal streams), continues with the deposition of huge amounts of alluvium sourced from the south-west (i.e. from the Catria-Nerone carbonate anticline ridge) and thus distributed in an overall transverse direction (Savelli & Ballerini, 1991). This seems to account specifically for a transition from along-valley aggradation, possibly correlated with the ongoing trunk valley filling-up, to a huge deposition by overburden tributary streams, which joined trunk streams no longer capable and competent to transport the huge sedimentary load supplied from the minor catchments. It is exactly the case of the alluvial fans observed at the junction of tributary streams on the trunk valleys (Figs. 2, 3, 5 and 6). Similar behaviours, indeed, indicating significant variations in functional interaction between the trunk-stream and its tributaries, also from a conceptual standpoint could strengthen the idea of a chronologic shifting of alluvial sedimentation loci towards the piedmont zones, thus accounting for the stages of generalized development of coalescing fans observed on the foothills of the carbonate ridges.

REFERENCES

Alvarez W. (1999) - *Drainage on evolving fold-thrust belts: a study of transverse canyons in the Apennines*. Basin Research, **11**, pp. 267-284.

Bisci C. & Dramis F. (1991) - *La Geomorfologia delle Marche*. In: L'ambiente Fisico delle Marche, Regione Marche – Giunta Regionale, Assessorato Urbanistica e Ambiente, S.E.L.C.A., Firenze, pp. 81-113.

Blissembach E. (1954) - *Gelogy of alluvial fans in semiarid regions*. Geological Society of American Bulletin, **65**, pp. 175-190.

Bull W.B. (1964) - *Geomorphology of segmented alluvial fans in western Fresno County*, California. U.S. Geol. Survey Professional Paper, **352-E**, pp. 89-129.

Bull W.B. (1977) - *The alluvial fan environment*. Progress in Physical Geography, **1**, pp. 222-270.

Bull W.A. (1991) - *Geomorphic Response to Climatic Change.* J. Wiley & Sons, N.Y., 326 pp.

Calamita F., Deiana G., Invernizzi C. & Pizzi A. (1991) - *Tettonica*. In: L'ambiente Fisico delle Marche, Regione Marche – Giunta Regionale, Assessorato Urbanistica e Ambiente, S.E.L.C.A., Firenze, pp. 69-80.

Calderoni G., Nesci O. & Savelli D. (1991) - *Terrace fluvial deposits from the middle basin of Cesano River (northern Marche Apennines): reconnaissance study and radiometric constraints on their age*. Geografia Fisica e Dinamica Quaternaria, **14**, pp. 201-207.

Calderoni G., Coltorti M., Dramis F., Magnatti M. & Cilla G. (1992) - *Sedimentazione fluviale e variazioni climatiche nell'alto bacino del Fiume Esino durante il Pleistocene superiore*. Atti del Convegno "Erosione ed Alluvionamento in Aree Caratterizzate da Subsidenza o da Tettonica Attiva", Ancona, 15-15 ottobre 1991, pp. 171-190.

Calderoni G., Della Seta M., Fredi P., Lupia Palmieri E., Nesci O., Savelli D. & Troiani F. (2008) - *Late Quaternary geomorphological evolution of the Adriatic coast reach encompassing the Metauro, Cesano and Misa river mouths (northern Marche, Italy).* GeoActa, Special Pubblication **3**, pp. 49-64.

Cilla G., Coltorti M., Dramis F., Farabollini P., Gentili B., Pambianchi G. (1996) - *Fluvial sedimentation during the early Holocene in the Marchean valleys (Central Italy).* Il Quaternario, **9**, pp. 459-464.

Coltorti M. (1997) - *Human impact in the Holocene fluvial and coastal evolution of the Marche region, Central Italy*. Catena, **30**, pp. 311-335.

Coltorti M., Consoli M., Dramis F., Gentili B. & Pambianchi G. (1991) - *Evoluzione geomorfologica delle piane alluvionali delle Marche centro-meridionali*. Geografia Fisica e Dinamica Quaternaria, **14**, pp. 87-100.

D'Agostino N., Dramis F., Funiciello R. & Jackson J.A. (2001) - *Interactions between mantle upwelling, drainage evolution and active normal faulting: an example from central Apennines (Italy).* Geophysical Journal International, **147**, pp. 475-497.

Davis W.M. (1905) - *The geographical cycle in an arid climate*. Journal of Geology, **13**, pp. 381-407.

De Celles P.G., Gray M.B., Ridgway K.D., Cole R.B., Srivastava P., Pequera N. & Pivnik D.A. (1991) - *Kinematic history of a foreland uplift Paleocene synorogenic conglomerate, Beartooth Range, Wyoming and Montana*. Geological Society of American Bullettin, **103**, pp. 1458-1475.

Deiana G. & Pialli G. (1994) - *The structural provinces of the Umbro-Marchean Apennines*. Memorie della Società Geologica Italiana, **48**, pp. 473-484.

Di Bucci D., Mazzoli S., Nesci O., Savelli D., Tramontana M., De Donatis M. & Borraccini F. (2003) - *Active deformation in the frontal part of the Northern Apennines: insights from the lower Metauro River basin area (northern Marche, Italy) and adjacent Adriatic off-shore*. Journal of Geodynamics, **36**, pp. 213-238.

Dramis F. (1992) - *Il ruolo dei sollevamenti tettonici a largo raggio nella genesi del rilievo appenninico*. Studi Geologici Camerti, Special Volume **1992/1**, pp. 9-15.

Elmi C., Forti P., Nesci O. & Savelli D. (2003) - *La risposta dei processi geomorfologici alle variazioni ambientali nella pianura padana e veneto-friulana, nelle pianure minori e sulle coste nord e centro-adriatiche*. In: Biancotti A. & Motta M. (Eds.) - Risposta dei Processi Geomorfologici alle Variazioni Ambientali, Glauco Brigati, Genova, pp. 225-259.

Fanucci F., Moretti E., Nesci O., Savelli D. & Veneri F. (1996) - *Tipologia dei terrazzi vallivi ed evoluzione del rilievo nel versante adriatico dell'Appennino centro-settentrionale*. Il Quaternario, **9**, pp. 255-258.

Francavilla F. (1976) - *Alvei paralleli del Fiume Metauro a S. Lazzaro di Fossombrone (Marche settentrionali).* Studi Geologici Camerti, **2**, pp. 107-112.

Guerra C. & Nesci O. (1999) - *Glacis pleistocenici nel*

Montefeltro (Appennino Marchigiano-Romagnolo). In: Orombelli G. (Ed.) - Studi Geografici in Onore di Severino Belloni. Glauco Brigati, Genova, pp. 419-428.

Hartley A.J. (1993) - *Sedimentological response of an alluvial system to source area tectonism: The Seilao Member of the Late Cretaceous to Eocene Purilactis Formation of northern Chile*. In: Marzo M. & Puigdefabregas C. (Eds.) - *Alluvial Sedimentation*. International Association of Sedimentologists, Special Publication, **17**, pp. 489-500.

Harvey A.M. (1984) - *Aggradation and dissection sequence on Spanish alluvial fans: influence on morphological development.* Catena, **11**, pp. 289-304.

Harvey A.M (1990) - *Factors influencing Quaternary alluvial fan development in southeast Spain*. In: Rachoki A.H. & Church M. (Eds.) – Alluvial Fans, a Field Approach. J. Wiley and Sons, Chichester, pp. 247-269.

Harvey A.M. (1996) - *The role of alluvial fans in the mountain fluvial systems of southeast Spain: implications of climatic change*. Earth Surfaces Processes and Landforms, **21**, pp. 543-553.

Harvey A.M. (2004) - *Alluvial Fan*. In: GOUDIE A.S. (Ed.) - Encyclopedia of Geomorphology, vol. 1, pp. 15-19.

Harvey A.M., Mather A.E. & Stokes M. (2005) - *Alluvial fans: geomorphology, sedimentology, dynamics – introduction. A review of alluvial-fan research*. Geological Society of London, Special Publication, **251**, pp.1-7.

Kochel R.C. (1990) - *Humid Fans of the Appalachian Mountains*. In: Rachocki A. H. & Church M. (Eds.) - Alluvial Fans. A Field Approach. J. Wiley & Sons, Chichester, pp. 109-129.

Lavecchia G. (1988) - *The Tyrrhenian-Apennine system: structural setting and seismotectogenesis*. Tectonophysics, **147**, pp. 263-296.

Lipparini T. (1938) - *I terrazzi fluviali delle Marche*. Giornale di Geologia, Bologna, **13**, pp. 5-22.

Lisiecki L.E. & Raymo M.E. (2005) - *A Pliocene-Pleistocene stack of 57 globally distributed benthic d[18]O records*. Paleocenography, **20**, PA1003, doi:10.1029/2004PA001071.

Lusting L.K. (1965) - *Clastic sedimentation in deep springs valley, California*. U.S. Geol. Survey Professional Papers, **352-F**, pp. 131-192.

Mayer L., Menichetti M., Nesci O. & Savelli D. (2002) - *Morphotectonic approach to the drainage analysis in the North Marche region, central Italy*. Quaternary International, 101-102, pp. 147-157.

Mazzanti R. & Trevisan L. (1978) - *Evoluzione della rete idrografica nell'Appennino Centro-settentrionale*. Geografia Fisica e Dinamica Quaternaria, **1**, pp. 55-62.

Mencucci D., Colantoni P. & Nesci O. (2003) - *The Foglia River alluvial system (Northern Marche) and its relation to the late Quaternary evolution of the Central Adriatic shelf.* Il Quaternario., **16**, pp. 43-50.

Mukerji A. B. (1990) - *The Chandigarh Dun alluvial fans: An analysis of the process-form relationship*. In: Rachocki A. H. & Church M. (Eds.) - Alluvial Fans, A Field Approach. J. Wiley & Sons, Chichester, pp. 131-149.

Nesci O. & Savelli D. (1986) - *Cicli continentali tardo-quaternari lungo i tratti vallivi mediani delle Marche settentrionali.* Geografia Fisica e Dinamica Quaternaria, **9**, pp. 192-211.

Nesci O. & Savelli D. (1990) - *Valley terraces in the Northern Marche Apennines (Central Italy): cyclic deposition and erosion*. Giornale di Geologia, Serie 3°, **52**, pp. 189-195.

Nesci O. & Savelli D. (1991) - *Successioni alluvionali terrazzate nell'Appennino nord-marchigiano*. Geografia Fisica e Dinamica Quaternaria, **14**, pp. 149-162.

Nesci O., Savelli D., Mengarelli D. (1990) - *I terrazzi vallivi del 1° ordine nei bacini dei Fiumi Metauro e Foglia (Appennino Marchigiano).* Geografia Fisica e Dinamica Quaternaria, **13 (1)**, pp. 63-73.

Nesci O., Savelli D., Tramontana M. & Fattori D. (1993) - *Evoluzione tardo-pleistocenica delle dorsali calcaree nord-marchigiane: un esempio dai Monti della Cesana*. Il Quaternario, **7**, pp. 139-144.

Nesci O., Savelli D., Calderoni G., Elmi C. & Veneri F. (1995) - *Le antiche piane di fondovalle nell'Appennino Nord-Marchigiano*. In: Castiglioni G.B. & Federici P.R. (Eds.) - Assetto Fisico e Problemi Ambientali delle Pianure Italiane. Memorie della Società Geografica Italiana, **53**, pp. 293-312.

Nesci O., Savelli D., Tramontana M., Veneri F., De Donatis M. & Mazzoli S. (2002) - *The Evolution of Alluvial Fans in the Umbria-Marche-Romagna Apennines (Italy)*. Bollettino della Società Geologica Italiana, Special Volume, **1**, pp. 915-922.

Nesci O. Savelli D. & Troiani F. (2008) - *Evoluzione tardo quaternaria dell'area di foce del Fiume Metauro (Marche settentrionali)*. Collana dell'Autorità di Bacino della Basilicata, **9**, pp. 443-451.

Pergolini C., Savelli D. & Tramontana M. (2001) - *Itinerario 6. Dal Metauro ai Monti della Cesana*. In: Ciarapica G. & Passeri L. (Eds.) - Appennino Umbro-Marchigiano, 34 Escursioni a Piedi. Guide Geologiche Regionali a cura della Società Geologica Italiana, BE-MA Editrice, **7 (2)**, pp. 52-58.

Ritter J.B., Miller J.R., Enzel Y. & Wells S.G. (1995) - *Reconciling the roles of tectonism and climate in Quaternary alluvial fan evolution*. Geology, **23**, pp. 245-248.

Roberts N. (1995) - *Climatic forcing of alluvial fan regimes during the Late Quaternary in Konya basin, south central Turkey*. In: Lewin J., Macklin M.G. & Woodward J. (Eds.) – Mediterranean Quaternary River Environments. Balkema, Rotterdam, pp. 205-217.

Savelli D. & Ballerini L.S. (1991) - *Alluvioni pedemontane terrazzate fra Cagli e Frontone (Appennino marchigiano): un esempio di conoidi alluvionali confinate.* Geografia Fisica e Dinamica Quaternaria, **14**, pp. 179-181.

Savelli D., Bartole R. & Moretti E. (1984) - *Caratteristiche litostratigrafiche con l'ausilio del sismografo di un terrazzo alluvionale del fiume Metauro a Fossombrone (Marche settentrionali)*. Ateneo Parmense, Acta Naturalia, **20** (1), pp. 63-79.

Savelli D., Nesci O. & Mengoni S. (1994) - *From alluvial fans to intravallive floodplain: a case study from the piedmont terrace alluvium of the upper Musone River basin (Marche Apennines).* Giornale di Geologia, Serie 3, **56/2**, pp. 27-42.

SCHUMM S. A. (1977) - *The Fluvial System*. J. Wiley & Sons, New York, 388 pp.
SELLI R. (1954) - *Il Bacino del Metauro*. Giornale di Geologia, Serie 2, **24**, pp. 5-268.
SURESH N., BAGATI T.N., KUMAR R. & THAKUR V.C. (2007) - *Evolution of Quaternary alluvial fans and terraces in the intramontane Pinjaur Dun, Sub-Himalaya, NW India: interaction between tectonics and climate change*. Sedimentology, **54**, pp. 809-833.
VILLA G.M. (1942) - *Nuove ricerche sui terrazzi fluviali delle Marche*. Giornale di Geologia, Serie 2, **16**, pp. 5-75
VISERAS C., CALVACHE M.L., SORIA J.M. & FERNANDEZ J. (2003) - *Differential features of alluvial fans controlled by tectonic or eustatic accommodation space. Examples from the Betic Cordillera, Spain*. Geomorphology, **50**, pp. 181-202.
WEGMANN K.W. & PAZZAGLIA F.J. (2009) - *Late Quaternary fluvial terraces of the Romagna and Marche Apennines, Italy: Climatic, lithologic, and tectonic controls on terrace genesis in an active orogen.* Quaternary Science Reviews, **28**, pp. 137-165.

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