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EROSION AND RECENT MORPHOLOGICAL CHANGE IN A SAMPLE AREA OF THE UPPER ORCIA RIVER BASIN (SOUTHERN TUSCANY, ITALY)

ABSTRACT: CICCACCI S., DEL MONTE M. & MARINI R., *Erosion and recent morphological change in a sample area of the upper Orcia River Basin (Southern Tuscany, Italy)*. (IT ISSN 1724-4757, 2003).

Qualitative and quantitative geomorphological investigation has been carried out in a restricted area of the upper Orcia River basin (about 10 km^2) called «Landola sample area», near Siena, NE of the Monte Amiata volcano (Tuscany). The Pliocene marine claystones outcropping in this area have been uplifted during the Quaternary up to several hundreds of meters above sea-level and are now rapidly eroding, resulting in one of the highest values of suspended sediment loads in Italy.

Since 1988 detailed geomorphological field surveys hare been performed in the Orcia River basin; and beginning in 1993 monitoring of specific denudational processes on slopes characterised by rapid erosion has been completed. These slopes represent a natural laboratory, where short-term evolution and seasonal change of landforms generated by fluvial and hillslope processes could be accurately studied, and where the erosion rate could be directly measured, showing in the most extreme cases a lowering of topographic surface of a few cm/year.

The values of some morphometric parameters have also been determined, in order to estimate erosion rate indirectly. Spatial variations of this modelled rates of erosion have been compared with field measurement to confirm the extreme values.

To extend the results of this research over a longer period of time, aerial pictures taken over several decades have been analysed. The comparison between the 1954 map, drawn by air-photo interpretation, and the 2002 map show many macroscopic morphological differences. Biancane badlands have been reduced by bulldozers working (especially in the 60s and in the 70s). These areas now occupy only 30% of their previous 1954 surface.

Calanchi badlands have been greatly modified by natural causes. In the last 50 years, hillslope processes have become dominant compared to sheet wash and channalized flow in the calanchi badlands evolution.

Direct measuring of the denudation rate, mainly related to superficial running waters, have determined 2-3 cm/year mean values for calanchi badlands and 1,5-2 cm/year for biancana areas. Indirect data confirm these results, showing that mean erosion rates for small drainage basins are close to 1 cm/year, and often exceed this value.

KEY WORDS: Erosion, Badlands, Morphodynamics, Tuscany, Italy.

RIASSUNTO: CICCACCI S., DEL MONTE M. & MARINI R., *Processi di denudazione e variazioni morfologiche recenti in un'area campione dell'alto bacino del Fiume Orcia (Toscana meridionale, Italia)*. (IT ISSN 1724-4757, 2003).

Sono state condotte indagini geomorfologiche qualitative e quantitative in una limitata porzione dell'alto bacino idrografico del Fiume Orcia, denominata «area campione Landola». Essa è estesa circa 10 km^2 ed è ubicata nella provincia di Siena, a NE dell'apparato vulcanico del Monte Amiata. L'area studiata è interessata da estesi affioramenti di litotipi argillosi pliocenici, che nel Quaternario sono stati sollevati a diverse centinaia di metri s.l.m. e sono attualmente sede di processi morfogenetici particolarmente intensi, che si traducono, tra l'altro, in valori del trasporto fluviale in sospensione tra i più elevati d'Italia.

A partire dal 1988 il bacino dell'Orcia è stato oggetto di un rilevamento geomorfologico di dettaglio; inoltre, dal 1993 è stato approntato il monitoraggio dei processi di denudazione che interessano alcuni versanti soggetti a rapida morfogenesi. Questi ultimi hanno costituito una sorta di «laboratorio naturale» nel quale sono state eseguite accurate indagini sull'evoluzione a breve termine e sulle modifiche stagionali delle forme prodotte dalle acque correnti superficiali e dalla gravità, comprendenti anche misure dirette dell'entità della denudazione che, nelle situazioni più critiche, hanno rivelato abbassamenti della superficie topografica di alcuni cm/anno.

Sono stati determinati, inoltre, i valori di diversi parametri morfometrici, che hanno consentito di valutare indirettamente l'entità dell'erosione. Le variazioni areali dell'indice di denudazione, così ottenuto, sono state poi confrontate con i dati puntuali scaturiti dalle misure dirette e hanno confermato l'esistenza di processi erosivi estremamente intensi.

Il rilevamento geomorfologico di dettaglio ha mostrato una generale tendenza all'arretramento parallelo dei versanti calanchiformi e ha messo in luce l'importanza dell'azione della gravità nell'evoluzione di queste morfosculture. Le biancane sembrano derivare in alcuni casi dall'evoluzione di precedenti forme calanchive, ma in altri casi esse si trovano in aree sommitali, interessate da erosione a solchi ancora allo stadio embrionale.

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A integrazione della ricerca, è stata condotta un'analisi di fotografie aeree di anni diversi, che ha evidenziato, nell'area campione, notevoli differenze morfologiche a distanza di pochi decenni, confermando le tendenze morfoevolutive osservate durante i quattordici anni di rilevamento sul terreno. Nell'ultimo cinquantennio vaste zone a calanchi e a biancane sono state rimodellate dall'azione dell'uomo, ma altrettanto importanti sono risultate le modifiche morfologiche imputabili a cause naturali. In particolare, le aree a biancane sono state ridotte del 70% con l'utilizzo di bulldozer, mentre le aree a calanchi hanno registrato vistose modifiche naturali. Si è anche notato che nell'evoluzione delle forme calanchive sono divenuti più frequenti ed efficaci i processi gravitativi rispetto a quelli legati al dilavamento e all'azione delle acque concentrate.

Le misure dirette dell'entità dei processi di denudazione hanno consentito di valutare tassi di erosione di 2-3 cm/anno per le aree a calanchi e di 1,5-2 cm/anno per quelle a biancane. Questi valori sono compatibili con quelli derivati dalle valutazioni indirette mediante l'analisi geomorfica quantitativa: per i piccoli bacini che drenano l'area campione sono stati calcolati, infatti, valori di denudazione di circa 1 cm/anno, con massimi anche superiori.

TERMINI CHIAVE: Processi di denudazione, Calanchi, Morfodinamica, Toscana, Italia.

INTRODUCTION

The present work is part of a wider research project conducted over the past two decades by the Dipartimento di Scienze della Terra of the University of Rome «La Sapienza», whose aim is to study recent geomorphological evolution and morphodynamic aspects of some areas in central and southern Apennines. The goal of the research is to analyse in detail (1) what are the main erosion processes acting on hillslopes, and (2) to estimate their relative rates. This paper presents the results of geomorphological investigation related to an area in the upper Orcia River basin, chosen as a sample for the intense morphogenetic processes and morphological change recorded in the last 50 years. The area more or less corresponds to the Torrente Landola partial basin and extends for 10 km^2 NW of the town of Radicofani (southern Tuscany). The Pliocene marine claystones outcropping in this area have been uplifted during the Quaternary to several hundreds of meters up sea-level, and they are now suffering particularly intense erosion, lending to considerable badland formation. Since 1988, continuous detailed field surveys of the Orcia River basin have been used to describe the results of this erosion, and air-photo interpretation of pictures taken in the 1950s allow us to define of the morphological evolution of the basin in the last 50 years.

Regional quantitative information about the drainage basin and morphometric parameters have been extracted from a topographic data set in order to model the spatial variations in process and rate, which have been documented in the field surveys. Since 1993, several measurement stations have been established in order to control slope evolution under particular conditions of rapid morphological change. These slopes are a «natural laboratory» where short-term landscape evolution processes (including fluvial and colluvial processes) can be studied at the seasonal level of change, and where denudation rates can be directly measured.

STUDY AREA

The examined area is situated on the left side of the upper Orcia Valley, that is the eastern part of the Ombrone River basin (fig. 1). The area is situated in the Tuscan Preapennine, near Siena, northwards of Radicofani. The altitude varies from 650 to 350 m above sea-level.

Drainage patterns and basin shape are structurally controlled. The «Radicofani Graben», whose major axis is roughly N-S oriented, controls trunk streams' orientations (Orcia River and Torrente Formone). The position of the Orcia basin's southern watershed, which corresponds to the boundary among the basins drained by Tevere River and those drained by Ombrone River, is related to Monte Cetona and to Monte Amiata and Radicofani Quaternary volcanoes.

Vegetative cover is rather poor, and strongly affected by agricultural tilling and grazing ground. Forest trees still grow on hill tops or on the higher part of steep slopes, attributed mostly to conifer reforestation in the past 4 decades in an attempt to reduce erosion. Mean temperature is about 13 °C and mean annual precipitation is about 800 mm, especially due to autumn-winter rainfall.

The geologic setting is well known (Lazzarotto, 1993; Liotta, 1996) and summarised in the map of fig. 1. This map portray rock units in groups, each having a specific way of weathering. The main groups include Tuscan Series platform carbonates, flysch of Ligurian Nappe, marine claystones, volcanic deposits, and alluvial deposits.

FIG. 1 - Lithological schetch of Orcia River upper basin. 1) Alluvial deposits (Quaternary); 2) Tracybasaltic-andesitic lava (Pleistocene; 3) Conglomerate (Pliocene); 4) Sand, clayey sand and sandstone (Pliocene); 5) Claystone and sandy clay (Pliocene); 6) Clayey and marly flysch (Lower Cretaceous-Paleocene); 7) Carbonate rock (Triassic-Eocene). Landola sample area is framed.

Tuscan Series Platform Carbonates

Calcareous and dolomitic rocks, outcrop on Monte Cetona in very thick deposits. The older formations are characterised by stratified Rhaetic limestone with marly beds, dolomite and dolomitic limestone (Calcari a *Rhaetavicula contorta*); overlain by Liassic massive grey limestone, cherty limestone and red ammonitic limestone (Lias), *Posidonia* marl (Dogger), and chert (Malm). The youngest formation of the Tuscan Series outcropping in the area is the so-called «Scaglia Toscana», characterised by Cretaceous-Oligocenic varicoloured marls and manganese-shales.

Flysch of Ligurian Nappe

Two allochthonous formations overlay the Tuscan Serie's lithologies. The first one is a thick sequence of claystones, marly claystones, marls, and white-greyish cherty limestones thinly-bedded, known as Palombini Formation. Ophiolites commonly occur in this Lower Cretaceous sequence.

The Pietraforte Formation, late Cretaceous-Paleocene in age, overlies the Palombini Formation and has a less clay-rich. The sequence is formed alternatively of calcarenite, calcilutite, and carbonatic sandstone with silty and clayey interbeds.

Claystones

This group is made of marine claystone deposited during the Pliocene marine ingression. These deposits cover most of the sample area and represent the initial marine filling of the Radicofani Graben. The claystones and sandy claystones (early Pliocene) are several hundreds meters thick, and it is easy to find interbeds of graded sands and poorly cemented conglomeratic lenses.

The claystones outcrop in the central part of the graben, whereas the coarser deposits more commonly outcrop along the eastern and western boundaries of the watershed.

Volcanic deposits

These deposits are related to the Quaternary volcanic activity of the Radicofani volcano, situated in the southern-most sector of the Orcia River basin. The age of the volcanic activity is dated to 1,3 ± 0,003 Ma (D'Orazio & *alii*, 1991; Liotta, 1996) by $^{40}Ar/^{39}Ar$ method. Today, the only preserved part of the Radicofani volcano is a neck made of trachybasalts and olivine-latites, with olivine-trachytic scorias (Pappalardo & *alii*, 2001).

Alluvial deposits

In the Orcia River and its main tributaries, the alluvial deposits are very widespread if one considers the basin's extent. Streams show an important bed and suspended load; the solid load on the river-bed of streams draining the upper basin, is made of cobbles generated by the dismantling of flysch and Pliocene sands and Conglomerate, frequently rounded by older erosional cycles.

The tectonic history for this area (Lazzarotto, 1993) is representative of the general history of orogenesis in the northern Apennines. Cretaceous to early Oligocene deposition occurred in a compressive foreland as the Tuscan and Ligurian Thrust sheets verged eastward in a large, subaqueous accretionary wedge. Emergence of the wedge in the Miocene was accompanied by extensional faults and formation of local graben. These graben filled with marine and terrestrial deposits. More recently, in the Quaternary, there has be regional arching of the Apennines, perhaps locally influenced by volcanism, to raise Pliocene marine deposits far above sea level.

In the «Landola sample area» only the Pliocene clayey lithotypes and a small part of the sandy and conglomeratic sediments outcrop. These lithologies have been uplifted in very recent geological times, and they now outcrop at 700 meters above sea-level (Castiglioni, 1935). These outcrops show, in some cases, a clear stratification with strike about N-S and dip direction about E-ENE, a few degrees steep; in the western part of the area, the stratification is nearly horizontal or it has a western dip direction. Jointing follows a few preferential directions that seem to condition the main valley downcutting and the intense denudational processes.

METHODS

The analysis of landforms, surficial deposits and morphogenetic processes of the study area was carried out through a detailed field survey, and compiled on a Geomorphological Map at a scale of 1:10.000. The survey was systematically carried out for fourteen years (1988-2002). It allowed us to gather detailed information about active morphological dynamics and evidence that the area is characterised by intense short-term morphological change.

The legend of the Geomorphological Map follow many Italian examples known in the literature (Panizza, 1972, 1973, 1987; Pellegrini, 1976, 2000; Dramis & *alii*, 1979; Gruppo Nazionale C.N.R. «Geografia Fisica e Geomorfologia», 1987, 1995; Ciccacci & *alii*, 1988; Dramis & Bisci, 1998) and considering the specific characteristics of the surveyed area. Landforms and deposits have been assembled following genetical principles and indicated with symbols and colours. Each colour is related to a main morphogenetic process, whereas different tones of the same colour show the activity condition of each landform. Some morphochronological information appears in the map with a red colour, indicating the age of a single morphotype or a morphogenetic event (Gruppo Nazionale C.N.R. «Geografia Fisica e Geomorfologia», 1994; Pellegrini, 2000).

To cast these data in a long-term context, an aerial-photograph interpretation analysis was made using the aerial photos of the GAI flight of 1954. Thus, a Geomorphological Map at a scale of 1:10.000 was completed for that year. The comparison of this map with the one illustrating the present landscape quantifies the morphological evolution of the area in the last 50 years (see the enclosed maps).

Key morphometric parameters were extracted from a topographic data base and used to relate form to process over geologic time scale. Using these morphometric parameters, an indirect estimation of the erosion rate in the area was possible, by a method that has already been demonstrated for other Italian drainage basins. This method allow to indirectly evaluate the erosion rate applying statistically significant mathematical equation. These are obtained correlating measured suspended sediment yield (*Tu* in t/km^2/year) of a great number of basins with some significant morphometric parameters calculated for the same basins (Ciccacci & *alii*, 1981, 1986, 1988, 1992; Lupia Palmieri & *alii*, 1995, 1998, 2001). These parameters are: *drainage density* (*D*), *density of hierarchical anomaly*, (*ga*), *index of hierarchical anomaly*, (Δa). The values of these parameters are then computed starting from the drainage network map of the study area (fig. 2).

Literature data on the different morphometric parameters used, are briefly mentioned here (Avena & *alii*, 1967; Avena & Lupia Palmieri, 1969; Ciccacci & *alii*, 1981, 1986, 1988; Del Monte & *alii*, 1999, 2002; Dramis & Gentili, 1977; Horton, 1945; Lupia Palmieri & *alii*, 1995; Marini, 1995; Strahler, 1952, 1957; Tokunaga, 1984).

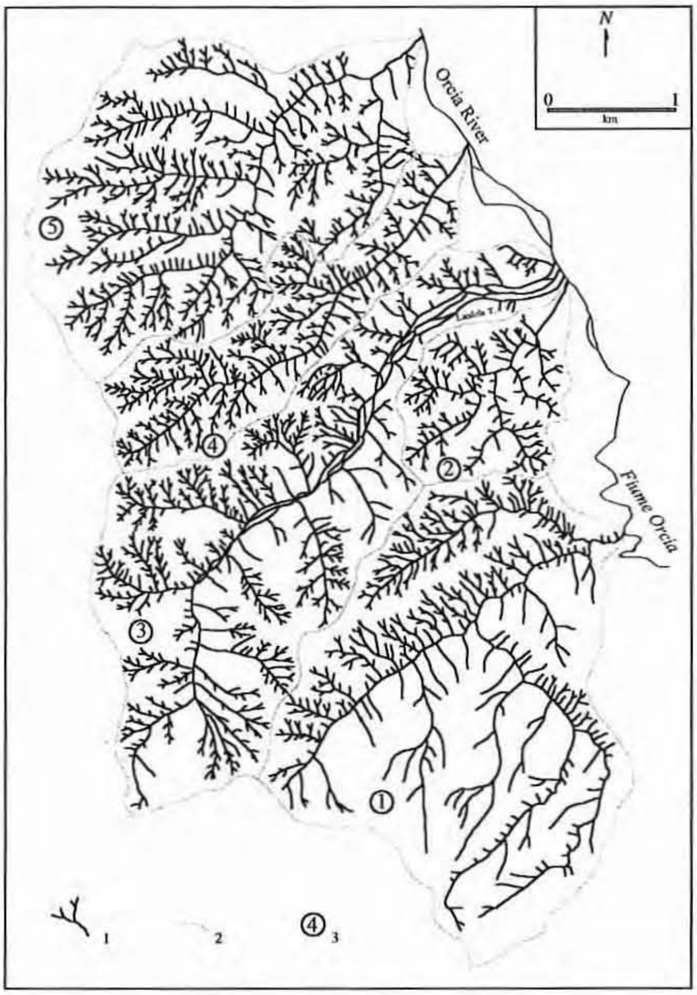

FIG. 2 - Drainage network map. 1) Drainage network; 2) Sub-basin divide; 3) Sub-basin number.

The suspended sediment yield values, considered as erosion index, have been determined for the sample area using the equation (by Ciccacci & *alii*, 1986):

$$\log Tu = 1{,}53034 + 1{,}82818 \log D + 0{,}01769\, \Delta a$$

The study of the morphographic, morphometric and morphodynamic characteristics has been completed placing several stations in the study area, in order to have a direct measure and a control of changes occurring on the topographic surface. Thus, the field monitoring stations have allowed a determination *in situ* of the intensity of present morphogenetic phenomena, and the analysis of changes in space and, where possible, in time, of the processes' velocities.

To carry out direct measurements of the erosion have been used simple metallic instruments, placed in five chosen stations (stakes and disks). These instruments have been placed in significant and poorly accessible zones, in order to avoid tampering. They have been used as datum points for accurate and continuous measuring, to collect a large series of data.

Square-sectioned (1cm^2) and at least 80 cm long metallic stakes were placed at different depths, in order to cross the horizon in which mudcracks occur, and were situated where piping is absent, as to avoid short-term damaging of the datum points (Marini, 1995).

Many microforms were noticed during field survey, such as earth pyramids in miniature, with cobbles, wood fragments or gastropods' shells on top (fig. 3a); sometimes leaves were found on top, witnessing the rapidity that characterises the shaping and dismantling of these morphologies. Considering these observations, metallic disks (some with 2 cm diameter and 1 cm thick, some others with 2,5 cm diameter and 0,1 cm thick) were placed on small horizontal portions of the slope involved in quick morphogenesis (fig. 3b), in order to favour the formation of earth micropyramids (fig. 3c). Since the slope evolution is rather quick, the disks have been often removed downdale; in other cases small earth pyramids (some cm in height) have really been observed after a certain time, and they have been used to estimate the denudation rate (Marini, 1995; fig. 3d). The 0,1 cm thick disks appear to generate more stable micropyramids than the thicker ones; this is probably due to the major weight of the latter.

The measuring stations situated in the sample area are part of a wider station net in Central Italy; they have been placed in 1993 and have since then allowed to collect a great number of data, which correspond to the stake's height measured from the topographic surface both up-hill (h) and down-dale (d) from the stake itself. The stakes are measured considering an initial value of zero, corresponding to the height determined when the stake was first placed. The stations indicated with the letters C, D, E, F and G are placed near the ridge that limits the area westwards, where many landslide crowns in progressive extension up-hill occur.

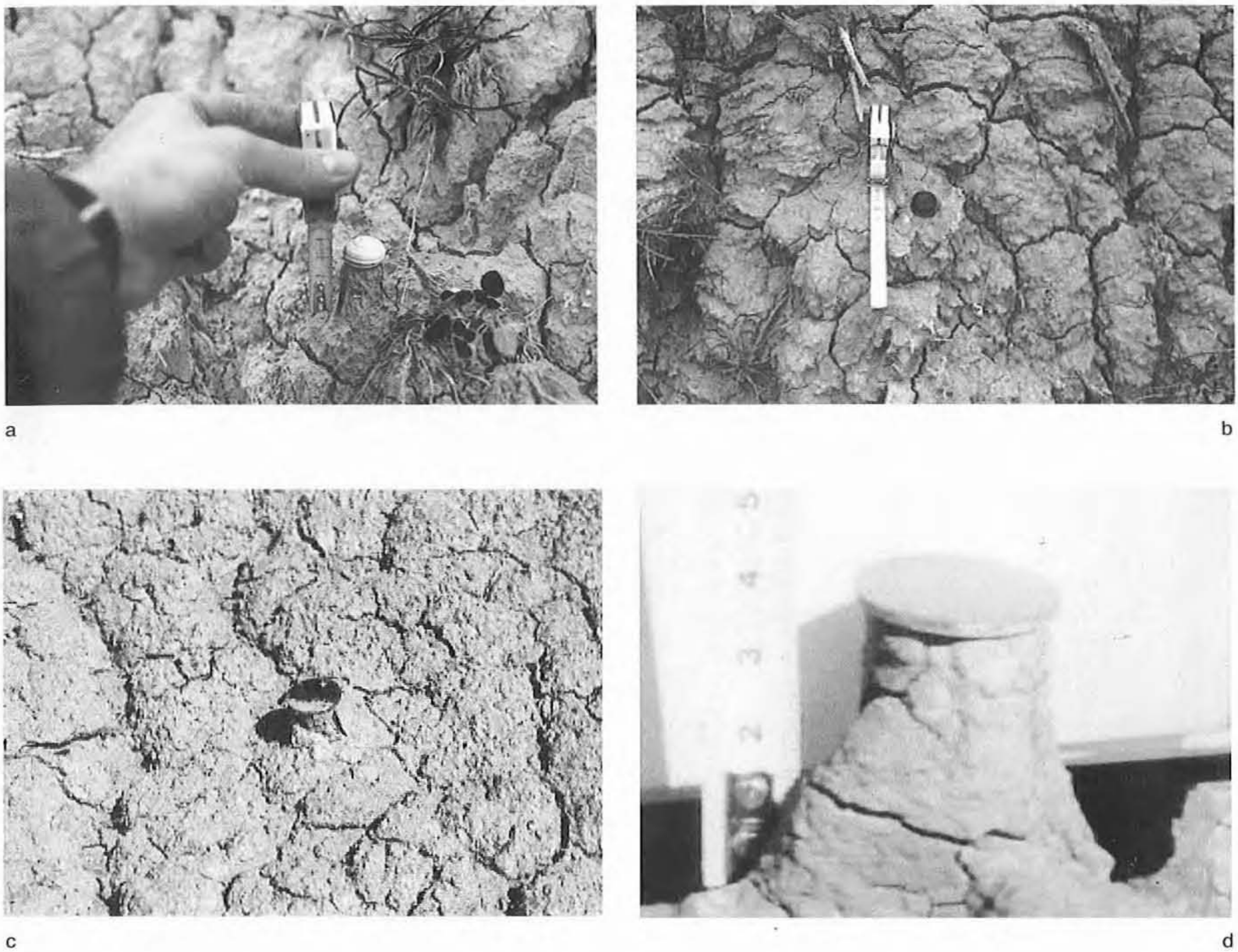

FIG. 3 - a) Mycropyramid with gastropods' shell on top; b) metallic disk placed on the slope; c) earth micropyramid formation; d) estimating the denudation rate.

DATA

GENERAL FIELD OBSERVATION

Important denudation processes are active in most of the studied area. Particularly intense seem to be the erosive processes due to channelized flow (which are responsible for the several deep valley downcutting), to sheetwash (responsible for the frequent badland and biancana morphologies), and to gravity (responsible for the continuous and frequent mass movements, both superficial and deep, active also on gentle slopes).

Fluvial valleys

Stream flow have generated deep valleys. The main valleys have rather steep slopes, with 25-35% average gradient, and are still subject to downcutting. Their cross section shows a typical large V aspect, since the linear processes are balanced by the intense denudation phenomena acting on the slopes. The longitudinal profile of valleys shows average gradient ranging from 3% for the main valley to 10-15% for the major secondary valleys and up to 50% along the thalweg of the headwater streams.

Wide and thin alluvial deposits can be observed in the Landola river-bed, due to the ample sediment supply from the slopes. On the edges of all river-beds, scarps and erosional triangular facets are commonly observed.

«Calanchi» badlands

Some of these knife-edged features are shaped as a system of narrow but deep cuts separated by thin and articulated ridges, as to reproduce a drainage network in miniature; many other badlands are made of larger incisions, with a trough-floored aspect, separated by smaller convex ridges, sometimes overgrown and characterised by less intense surface runoff phenomena.

The important role of wash denudation, acting in the area, is mainly due to local structural conditions. Calanchi badland morphology is due to the clayey outcrops, but also to anti-dip-slope strata and to sandy and conglomeratic levels that allow the development of steeper slopes. This slope evolution is related to the presence of a caprock, made of more or less cemented sands and conglomerates. If a caprock is absent, the slope steepness decreases quickly and the parallel-retreating evolution stops, as described in Scheidegger's evolutive model (1961, 1991).

The exposure seems not to influence greatly the distribution of badlands. These morphologies do not show a preferential distribution on differently exposed slopes. Therefore, important morphological and vegetational differences can be observed considering the landform itself. The washing processes shape the south-exposed slopes in very thin and sharp ridges, «blade» crests (fig. 4); at the bottom of these slopes, in parallel-retreating evolution, small pediments can be observed, as already described by Schumm (1956, 1962) and Guasparri (1978, 1993). The north-facing slopes are much more overgrown and characterised by frequent mass movements, that give a trough-floored aspect to the incisions, especially during winter.

At the slopes' foot, sheetwash deposits a large amount of alluvium that generates characteristic mud cracks up to 30 cm deep, just a few days following a rainfall.

The systematic field survey has shown that in badland areas, the erosional processes due to sheetwash and channelized flow perform together to those due to landslides and solifluction especially on the deeper slope.

Biancane badlands

«Biancane» are typical dome-shaped features a few meters in height and usually found in groups (Guasparri, 1993; Pinna & Vittorini, 1989; Torri & *alii*, 1994). These rounded landforms can reach 10 meters in height without a vegetation cover on the steeper south-facing slope, which is characterised by intense slope washing. The Biancane badlands are frequently found along the higher ridge limiting the main valleys (fig. 5), and on the top of the steep slopes supporting calanchi badlands, but they are also found in areas near the valley bottoms (fig. 6).

The biancane badlands are closely related to areas with low relief. They are found either on the flat top of a antiformal ridge that bounds the area to the west, or in the valley floors near the lower part of convex slopes. Along the valley bottoms, biancane may be residual «inselberg» re-

FIG. 5 - Biancane badlands along the highest ridge limiting the main valleys.

FIG. 4 - Calanchi badlands in a south-exposed slope.

FIG. 6 - Biancane badlands next to the main valley bottom.

lated to slope retract, as suggested by Del Prete & *alii* (1997) for the biancane badlands near Matera. Those present on the summit low relief surfaces cannot be interpreted in the same way; they are due to washing waters in interfluve areas, were steepness is low and gully erosion is still in the embryo stage.

Mass movements

Gravity driven processes include deep seated and shallow landslide, solifluction and creep.

Clues of deep seated landslides can be usually found on the main valleys' steep slopes, where undulations, counterslopes, humps, and depressions are very marked. These processes on clayey slopes have been favoured by the progressive downcutting of fluvial valleys. Our surveys indicate active movement of deep-seated landslides. Agricultural activity has recently and frequently levelled the surface of these landforms, erasing partially but only temporarily the traces of the deep movements. These clues are often hidden because of the denudational processes due to runoff or to superficial mass movements.

Shallow landslides consist of a few rock falls, frequent rotational slumps on the slopes of the western sector, sometimes of important extent, (fig. 7), and many mudflows (fig. 8) that can be reactivated several times in a year. Although anthropogenic action has tried to mitigate the effects of landslides, these processes are so intense that only 24 or 48 hours after a rainstorm, modifications of topographic surface have been noticed, as falls due to slope undermining, or as slumps and flows that have often involved roads. The landslide body get quickly modified by fluvial processes, which removes the fine fraction and changes the shape of the landslide deposit.

Solifluction and creep often affects the superficial clayey deposits, especially on sowable land where typical tongues can be observed; zones where these processes are active are involved in small superficial landslides (earthflow; «lame» Auct.) when exceptional rainstorms occur.

FIG. 8 - Mudflow.

Anthropogenic action

Large areas of the Orcia basin are modified because of anthropogenic activity (Regione Toscana, 1985; Marini, 1995; Del Monte & *alii*, 1999). During the fourteen year survey in the sample area, human impact has been documented (fig. 9) including modifications aimed widening tilling and grazing ground, and attempting to control the effects of intense denudational processes. Today, sowable land and grazing ground cover most of the territory, while forest trees are restricted to small portions of the southeastern section. Untilled land dominates the badland

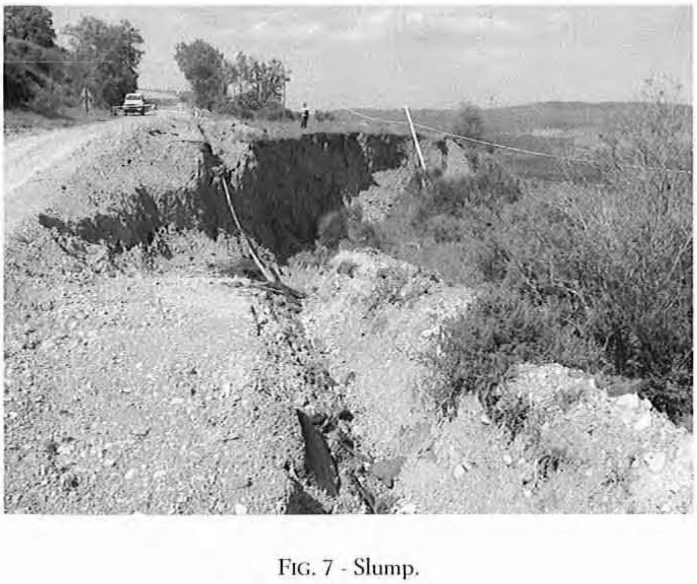

FIG. 7 - Slump.

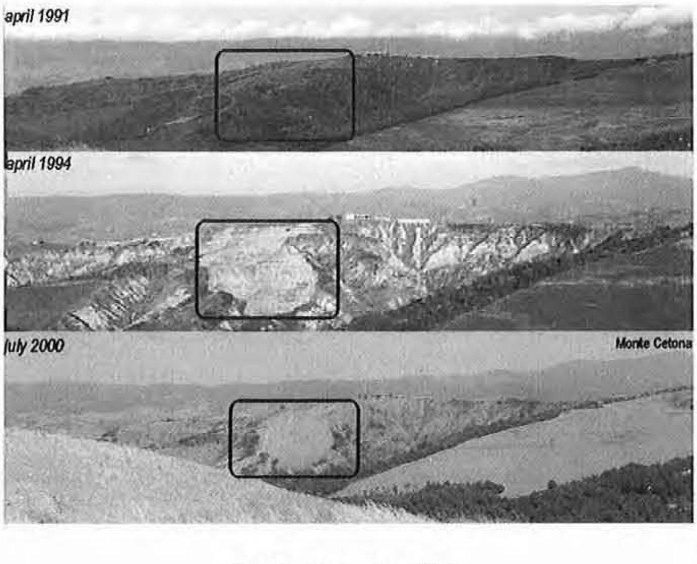

FIG. 9 - Human levelling.

slopes, and the inhabited area is limited to a few hamlets and farm-houses. Modifications, due to settlement areas and especially to the widening of sowable land, have involved much part of territory, where the slope steepness was not prohibitive. Many biancana badland and some calanchi badland were smoothed (fig. 9). Several surfaces show traces of grazing, such as sheep tracks.

Since 1988, many attempts have been made to control erosion in the areas where runoff and mass movements were particularly intense, building check dams along the gullies draining badland slopes, using mattresses or gabions, and practising reforestation. The reforestation in the area has been led by Corpo Forestale dello Stato (Forest Government Body) until about 1972, then by Comunità Montana Amiata (Amiata Mountain Community). Most of these works appear to be severely damaged. Only reforestation has given satisfying results, even if it has been obviously practised only on gentle slopes.

The Contignano road, which traverses the watershed of Landola Torrent basin, is involved in annual maintenance works. In 1995, a reinforced concrete wall, with foundation piles that crosses as deep the clays for 9 meters to a resistant layer, was built along the road where landsliding is pervasive. A few iron girders were also included where the slow gravitational movements dominate. A progressive extension of landslide crowns causes road interruption many times. The landslide of April 2001 has damaged the road, as shown in fig. 7, that was involved in the same movement in 1997 in a contiguous area, demaging some gabions and one of the measurement station that the authors placed in 1993.

Geomorphological Maps and Changes in 1954-2002

The 1988-2002 field survey has proven that processes and landforms in the sample area are involved in continuous and rapid short-term modifications. The comparison between the 1954 map, though obviously incomplete, and the recent 2002 map, has shown many macroscopic morphological differences.

It is possible to see that the «biancana» areas have been reduced, by bulldozers working, over the last 50 years (especially in the 60s and in the 70s). These areas now occupy only 30% of their previous 1954 surface. Today, they are involved in continuous human shaping frequently masking the runoff landforms due to heavy rainfalls. Nevertheless, the effects of gravity are clear in the area, due to either superficial movements (solifluction tongues, for example), or deep deformations, as witnessed by undrained depressions, humps and tension cracks.

Calanchi badlands have been less affected because of their greater steepness that is not favourable to bulldozers' passage. These areas have been modified by human impact, during the 80s and 90s, only where slopes were less steep (fig. 9).

Badlands have been greatly modified by natural causes: even the areas that appeared to be intensely shaped by runoff waters in 1954, with a characteristic network of deep incisions, steep slopes and sharp ridge-lines, seem to have a less severe badland morphology today. As shown in the enclosed maps, the interfluves in the badland areas south and east of Podere Paiccia farm-house, often don't have a knife-edged aspect like in 1954. The ridges that separate erosional gullies or incision channels are blunted and rounded. The bottom of gullies frequently gets filled with colluvium or flow deposits, producing in some cases a typical trough-floored valley.

Also in the central sector of the study area, near Podere Scarsella and Olmino farm-houses, badland reduction is important. These landforms have been replaced by gravity landforms, and in some cases by human filling or levelling. In 1994, along the right slope of Landola Valley, important mass movements have partially filled a badland area originating a slightly steep surface, useful for tilling. Many landslide crowns are compromising the road that joins the two mentioned farms with the major inhabited areas.

Already in 1954, important gravitative phenomena involved the southern sector of the area. Today some landslide body are partially or totally shaped by human impact, but meanwhile the gravitative morphogenesis has performed new denudational and accumulation landforms, or widened those observable fifty years ago.

Human activity has shaped entire slopes in order to construct buildings and cattle fences, to gain more tilling land and grazing ground; but these appear to be affected by solifluction or landslide which progressively move up-hill. Fluvial processes are very important in these areas, although their short-term morphological effects, like rill or gullies formation, are more easily erased than the result of gravitative processes; nevertheless fluvial processes perform a generalised erosion that can move a great quantity of material.

Human activity is not limited to the widening of sown land and grazing ground. There are also many works done in an attempt to mitigate the damages produced by erosional processes. These structures are meant to reduce denudation vivacity (dams, mattress, gabions) have been ruined after a few years, and in the worst cases, after a few months.

In the last few years many rudimental dams, made of rock masses or metallic material and placed along the incision bottoms, have been quickly damaged. The mattresses and gabions placed on the slopes have also been removed by washing waters and mass movements; these are responsible for the progressive reduction of reforestation zones situated in the western part of the sample area. The only attempts that seem to give satisfying results are those west of Podere Olmino farm-house: they consist of a terraced slope along a gully, with several dams and some metallic drainage channels in the steepest parts.

Quantitative Geomorphic Analysis

The results of quantitative geomorphic analysis (tab. 1) show that drainage networks of all small basins (fig. 2) are highly disorganised, with high values of the Δa and *ga* pa-

TABLE 1 - Morphometric parameters and erosional index of the drainage sub-basins of the study area (see fig. 2)

	Basin n° 1	Basin n° 2	Basin n° 3	Basin n° 4	Basin n° 5
Area (km2)	7.16	1.48	6.24	2.41	5.44
Relief/area (m/km2)	64.7	42.9	50.1	125.0	55.8
Drainage density (km/km2)	7.73	10.49	10.11	13.20	10.54
Number of hierarchical anomaly (Ga)	356	66	875	404	465
Density of hierarchical anomaly (ga)	49.72	44.59	140.22	167.63	85.48
Index of hierarchical anomaly (Δa)	0.96	0.46	1.55	1.22	0.92
Hypsometric integral (fv)	0.381	0.277	0.362	0.388	0.404
Tu (t/km2/year)	4763	9525	12203	23134	11193

rameters (ranging respectively from 0,46 to 1,55 and from 44,59 to 167,63). The high *ga* values are typical of badland areas (*ga*>30) and those higher than 100 (basin n°3 and 4) are involved with developed calanchi badlands (see the enclosed Geomorphological Map). The drainage density values (D) are also quite high, more than 7 km/km^2 in all cases; the relief/area parameter is also very high (ranging from 42 to 125 m/km^2).

The suspended sediment yield values (Tu) are quite high for all the small partial basins (Tu > 4500 t/km^2/year), with a maximum of 23134 t/km^2/year in basin n° 4. Considering a mean density of 1,95 for the clayey-prevailing sediments, the Tu values can be translated into an erosion rate terms in mm/year, obtaining a nearly quantitative indirect indication on erosion rates in the basins. These velocities range from 2,44 mm/year (basin n° 1) to 11,86 mm/year (basin n° 4); the mean erosion rate for the entire area is 5,44 mm/year, that is a Tu value of 10602 t/km^2/year. These values are extremely high and obviously reflect the rapid morphogenesis already noticed during field survey.

DIRECT MEASURING OF DENUDATION RATE

The direct measure of erosion rate led in the five selected measurement station (C, D, E, F and G station) have allowed us to collect a great number of data that will now be described. (tab. 2 and fig. 10)

C-station

The C-station is situated in a «biancana» area, in interfluve position between the badland slopes draining westwards in the Formone Torrent and those draining eastwards in the Orcia River. The investigated surface is dipping 40° to the east. On this slope-side an initial 7-8 mm deposit trend has been noticed during the first 3 months, but the following progressive denudation has performed a 2,5-3 cm erosion after 23 months, which corresponds to a mean erosion rate of 1,5 cm/year. At this station, one of the metallic disks has favoured the shaping of a 0,8 cm micropyramid in a 3 months period, from 16.01.95 to 11.04.95. In 1997, a small landslide occurred near the datum point, and a few weeks later another landslide have damaged it. It was replaced in the year 2001, measuring an erosion rate of about 1,1 cm during the following 9 months. From May 2001 to October 2002 a 4 cm high earth pyramid was shaped near the datum point.

D-station

The D-station is situated at the bottom of a slope, just a few meters above a road surface, having a 30° steepness, an eastward exposure, and characterised by sandy clays and a conglomeratic level. This slope has been in parallel-retreating evolution during the last 14 years. The measurements have shown a progressive sediment deposit up to 11,9 cm during the November 1993 - October 1995 period (tab. 2), as to prove the intense erosive activity in the upper part of the slope. The road nearby has favoured material deposition; in fact, a metallic disks, placed at the station, were found buried by abundant alluvium and colluvium.

E-station

The E-station is placed in a very interesting morphodynamic area. This east-exposed and 22° steep area can be considered as a «natural laboratory» for morphosculpture evolution. One can study drainage networks in miniature, evidence of structural conditioning on landforms, «biancane», badlands, and a great number of microforms in rapid evolution. The stake was placed on a rill bottom draining a 1 m^2 surface. The rill has changed its pattern several times and has finally avoided the obstacle (i.e. the stake). The measurements have shown a standstill and a little deposit trend (less than 1 cm) for the first 3 months, and then a great progressive erosion that has removed up to 6 cm of clay from the datum point level and up to 6,9 cm if one considers the maximum deposit (tab. 2). The respectively corresponding mean values of erosion rate are 3,69 cm/year and 4,48 cm/year. A 0,6 cm earth micropyramid was shaped under a metallic disk here placed from 16.01.95 to 11.04.95 (fig. 3c). In 1996, the datum point was probably tampered with and disappeared.

F-station

The F-station is situated about 1,5 km to the north of the previous one, near the top of a quite steep (>40°) and east-exposed calanchi badland slope (fig. 11). Sandy and conglomeratic levels can be observed, a few centimeters up to about 10 cm thick, which allow to measure a WNW dip direction. This station has shown a progressive and intense erosion that has lowered the ground surface by 16 cm in 102 months down-dale from the stake, which corresponds to a 2 cm/year mean erosion rate (tab. 2; fig. 10). Under a metallic disk a micropyramid of 0,5 cm in height was shaped from 16.01.95 to 11.04.95. On the 09.10.95 a 1,4 cm height was measured. Considering this period, these values correspond to a mean erosion rate of about 2 cm/year; this result agrees with the one referred to the whole period (8,5 years) of observation.

TABLE 2 - Changes of topographic surface measured in 1993-2002 period at C-D-E-F-G stations. Up-hill measure and down-dale measure from measurement station and their differences (Δh) are expressed in cm.

C STATION (32TQN23295861)

data	cm (*up-hill*)	Δh (cm)	cm (*down-dale*)	Δh (cm)
21-nov-93	43.6	0	43.6	0
26-feb-94	42.9	0.7	42.8	0.8
30-mar-94	43.0	0.6	43.0	0.6
16-jan-95	43.8	-0.2	45.3	-1.7
11-apr-95	45.1	-1.5	45.5	-1.9
09-oct-95	45.8	-2.2	46.5	-2.9
19-jan-97	47.0	-3.4	48.4	-4.8
13-may-99	demaged	by mass	movements	
11-may-01	48.1	0	51.5	0
22-sep-01	47.9	0.2	53.0	-1.5
01-dec-01	47.7	0.4	53.2	-1.7
08-feb-02	48.6	-0.5	53.2	-1.7
apr-02	demaged	by men		

D STATION (32TQN22716071)

data	cm (*up-hill*)	Δh (cm)	cm (*down-dale*)	Δh (cm)
21-nov-93	34.6	0	35.0	0
26-feb-94	29.7	4.9	30.4	4.6
30-mar-94	29.2	5.4	30.6	4.4
16-jan-95	28.7	5.9	29.9	5.1
11-apr-95	26.3	8.3	29.9	5.1
09-oct-95	22.7	11.9	28.0	7
19-jan-97	25.0	9.6	30.8	4.2
14-may-99	23.5	11.1	30.0	5
25-jul-00	25.4	9.2	31.2	3.8
nov-00	demaged	by men		

E STATION (32TQN23335857)

data	cm (*up-hill*)	Δh (cm)	cm (*down-dale*)	Δh (cm)
26-feb-94	56.4	0	56.4	0
30-mar-94	56.5	-0.1	55.5	0.9
16-jan-95	60.8	-4.4	58.8	-2.4
11-apr-95	60.7	-4.3	59.1	-2.7
09-oct-95	62.0	-5.6	62.4	-6
apr-1996	demaged	by men		

F STATION (32TQN22616004)

data	cm (*up-hill*)	Δh (cm)	cm (*down-dale*)	Δh (cm)
26-feb-94	58.1	0	58.5	0
30-mar-94	57.9	0.2	59.0	- 0.5
16-jan-95	59.7	- 1.6	63.8	- 5.3
11-apr-95	57.6	0.5	64.3	- 5.8
09-oct-95	61.0	- 2.9	65.1	- 6.6
19-jan-97	67.6 (52.6) *	- 9.4	69.0 (54.0) *	- 9.5
14-may-99	56.7	-13.5	54.3	- 9.8
25-jul-00	54.9	-11.7	57.2	-12.7
30-nov-00	55.0	-11.8	57.1	-12.6
11-may-01	54.7	-11.5	58.2	-13.7
22-set-01	55.0	-11.8	58.5	-14.0
08-feb-02	54.7	-11.5	58.2	-13.7
10-jul-02	56.6	-13.4	58.4	-13.9
13-oct-02	58.4	-15.2	60.2	-15.7

* starting from 20 january 1997. The stake has been put 15 cm deeper.

G STATION (32TQN22866064)

data	cm (*up-hill*)	Δh (cm)	cm (*down-dale*)	Δh (cm)
26-feb-94	44.4	0	44.9	0
30-mar-94	44.4	0	45.4	-0.5
16-jan-95	45.9	-1.5	46.4	-1.5
11-apr-95	46.3	-1.9	46.9	-2.0
09-oct-95	46.9	-2.5	47.3	-2.4
19-jan-97	50.0	-5.6	49.3	-4.4
14-may-99	52.0	-7.6	51.2	-6.3
nov-99	demaged	by mass	movements	
apr-01	destroyed	by mass	movements	

G-station

The G-station is placed on top of an East-exposed slope near the Contignano settlement. The stake lays on a 30° steep surface, made of a coarser layer (silty-sandy) at the top of a clayey slope. The results of tab. 2 show a progressive erosional trend with regular temporal tendency (fig. 10). Mean erosion rate is about 1,5 cm/year. In 1999, a slump has involved the datum point, and its crown skimmed a road. In April 2001 a new roto-translative landslide has induced another crown more up-hill and has involved and lowered the road and some buildings a few meters down (fig. 7).

DISCUSSION

GEOMORPHOLOGIC MAP

The field survey carried out for many years evidence that the study area is characterised by intense short term morphological changes. The main valleys are deep and

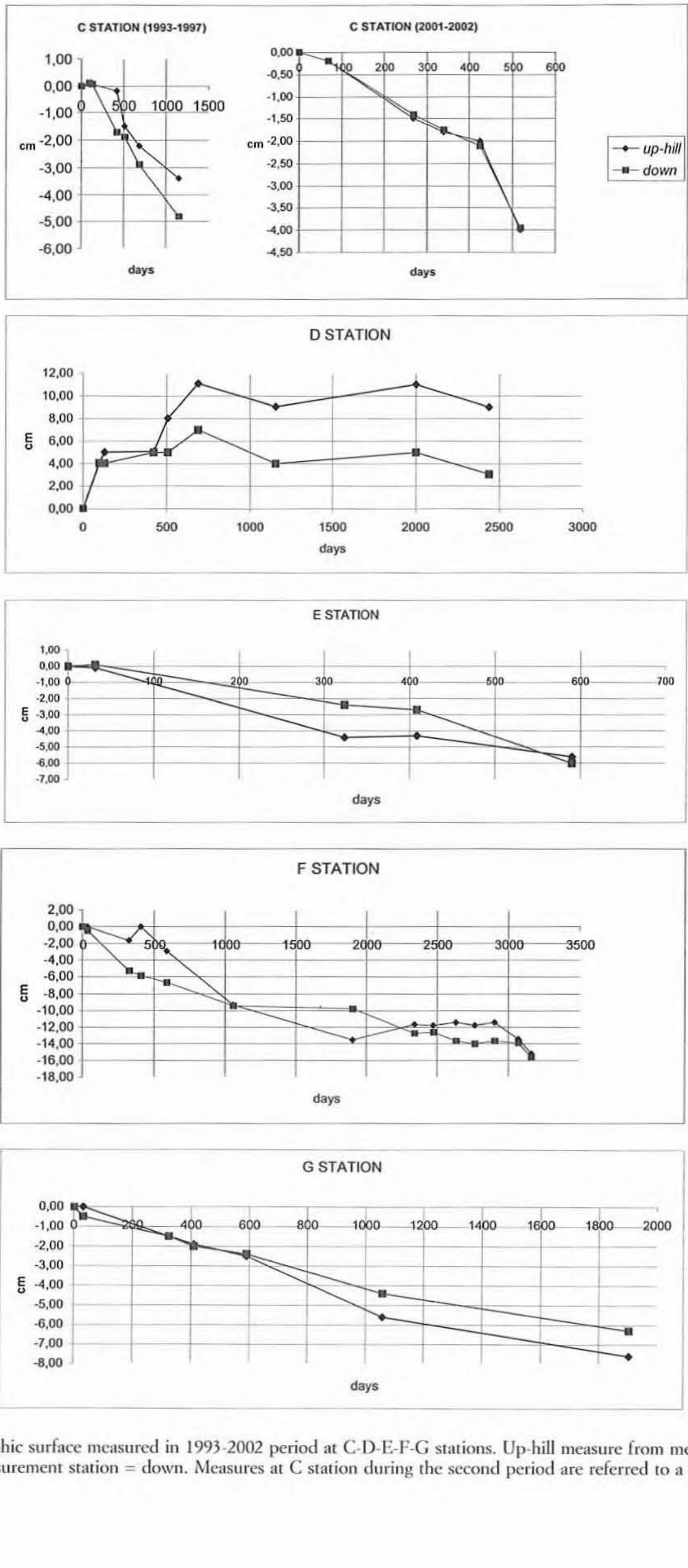

FIG. 10 - Changes of topographic surface measured in 1993-2002 period at C-D-E-F-G stations. Up-hill measure from measurement station = up-hill; down-dale measure from measurement station = down. Measures at C station during the second period are referred to a mycropiramid development.

FIG. 11 - F measurement station: a stake is placed.

still subject to downcutting and many morphological and geological evidence, like summit structural surfaces on marine Upper-Pliocenic claystone at 600-700 m above sea level, indicate that this dowcutting is related to a base level fall mainly due to a recent tectonic uplift. On the steep slopes of these valleys intense fluvial and hillslope processes are acting, originating a sharp calanchi badlands landscape, characterised also by numerous shallow and deep landslides. The field analysis suggests that the calanchi morphology evolution is controlled by sheetwash and channelled flow but also by creep, solifluction, flows and shallow landslides. The comparison between the recent 2002 geomorphological map and the map of 1954, drawn from air-photo interpretation of the GAI flight, evidences that in the last fifty years, hillslope processes have become dominant compared to sheetwash and channelized flow in the calanchi badland evolution. Moreover the reduced occurrence of badland features is caused by a fifty year shaping due to slumps and flows, some of which have been active since the beginning of the survey period. Some of these landslides are quite large, but in the same period a lot of small landslides have occurred.

EROSION RATES

The data obtained from direct field measurements of denudational processes evidence that the mean values of erosion rate range in the examined area from 2-3 cm/year on calanchi badland slopes to 1,5-2 cm/year on «biancana» badland areas, although critical periods have been observed, in which erosional rate was much greater (as far as 5-6 cm/year). These measured values of erosion rate are consistent with those calculated by morphometric analisis that, for small drainage basins, are close to 1 cm/year, and often higher.

Obtained results demonstrate that in the study area erosion rate remarkably exceeds the mean erosion rate measured in many Italian drainage basins. This usually varies between 0.05 and 1.0 mm/year and in large drainage basins, characterised by widespread clayey outcrops, can attain 1.5-2.0 mm/year (Lupia Palmieri, 1983). Still in some restricted Italian basins with calanchi and biancana badland morphologies Authors have extimated erosion rates of about 1,5-3 cm/year (Alexander, 1982; Rendell, 1982; Del Prete & *alii*, 1997; Raglione & *alii*, 1997) that are consistent with the results here showed. In badlands areas in the world, Authors have extimated values of erosion rate up to 50 cm/year (Scheidegger, 1991).

It is noteworthy that erosion rates measured in the study area are essentially referred to runoff erosion. They therefore represent only a partial result of erosion acting on slopes. Frequently, datum points have been removed or partially damaged by mass movements, which have involved a great volume of material. This volume cannot be estimated here, but the field observations show that the effects of mass movements on slopes must be considered for a correct erosion analysis; that's why it is desirable to continue investigation of this area and to collect punctual data using suitable quantitative methods.

CONCLUSIONS

The study area is characterised by recent and present substantial morphogenetic processes, mainly due to gravity and superficial running waters.

A detailed geomorphological survey, led over a period of fourteen years, has shown a parallel-retreating tendency of the calanchi badland slopes and an increasing impact of gravitative movements on the morphosculptural evolution. If a resistant caprock is present, parallel-retreating slopes keep quite steep; where caprock is absent, erosional processes dismantle the clayey formations even quicker, until the steepness decreases and erosive phenomena subdue.

Today, the biancana badlands present in Orcia River Valley are related to clayey outcrops on modestly steep slopes. Some of these seem to result from badlands evolution, whereas others, situated in summit areas, will quickly be characterised by regressive gully erosion, then cannot be considered as residual inselberg related to slope retract.

Direct measuring of the denudation rate, mainly related to superficial running waters, have determined 2-3 cm/year mean values for badlands and 1,5-2 cm/year for biancana areas. Indirect data confirm these results, showing that mean erosion rates for small drainage basins are close to 1 cm/year, and often exceed this value.

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