

Recent morphoevolution of the Fabro calanchi badlands (Umbria, Italy)

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ABSTRACT - The purpose of this paper is to analyze the recent morphoevolution of Fabro calanchi badlands (Umbria, Italy). This geomorphologic study aims 1) at reconstructing the recent morphodynamics of the badlands over a 55-year period (1955-2010), 2) at estimating the erosion rate and 3) and at analyzing the possible correlation between calanchi badland morphoevolution and properties of their parent materials. Field surveys and photogeological analysis demonstrate that Fabro calanchi badlands are mainly composed of a characteristic network of deep incisions, steep slopes and sharp knife-edged ridge-lines. In these, rilling processes predominate over landsliding and piping erosion. Direct point measurements were taken to quantify the erosion rate on two representative slopes. Selected monitoring stations have recorded a soil erosion rates ranging from 2 to 3 cm a⁻¹. Finally, analyses of grain size, mineralogy and the major element content of soil samples allowed the identification of possible correlations between these factors and both geomorphic processes and development and evolution of calanchi badlands. A major role seems to be played by clay dispersivity in calanchi badland development.

KEY WORDS: badlands, erosion rates, slope evolution, grain size, mineralogy, soluble salts

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INTRODUCTION

Calanchi badlands are peculiar erosion landforms, generated on Plio-Pleistocene marine clay outcrops; they are produced by the combined effects of runoff and rainsplash, together with mass wasting processes such as sliding and flowage (Alexander, 1982; Howard, 1994; Guasparri, 1993). "Calanchi" are defined by knife-edged ridges, separating small hydrographic drainage networks with horseshoe-shaped headwalls (Alexander, 1980; Farabegoli and Agostini, 2000; Clarke and Rendell, 2006; Buccolini and Coco, 2010). These spectacular and complex landforms are present in arid and semi-arid regions where precipitations are less than potential evapotranspiration (Bryan and Yair, 1982; Torri et al., 1994; Clarke and Rendell, 2010) and they are likely to be associated with "extreme" or "accelerated" erosion (Alexander, 1982; Clarke and Rendell, 2006). In badland areas (Campbell, 1989; Calvo-Cases et al., 1991; Faulkner et al., 2008; Alexander et al., 2008; Ciccacci et al., 2009) processes – such as rill erosion, piping and sliding – they operate with remarkable speed and change over time in relative importance in response to both intrinsic and extrinsic factors (as lithology, climate, mineralogy, chemical composition, etc.). Calanchi badlands affect fine grained sediments such as clay, silty clay, clay interbedded with sand and mudstone. Often, calanchi persistence is favored by sandy, gravel, conglomeratic or volcanic cap-rocks that help to preserve their original steepness (Guasparri, 1978). Mineralogical composition – such as the amount of swelling clay (Parker and Jenne, 1967; Sdao et al., 1984; Pinna and Vittorini, 1989) – can influence badland development, encouraging overland flow. Also the pore water composition seems to influence the clay physical properties, in particular, their tendency to spontaneous colloidal dispersion (Sherard et al., 1976; Faulkner et al., 2001). Dispersive materials seem, in fact, to

favor intense piping and tunnelling (Alexander, 1982; Vittorini, 1977; Faulkner et al., 2001), encouraging the rapid enlargement of subsurface pipes (Benito et al., 1993; Gutierrez et al., 1997).

Italian calanchi badlands are concentrated in areas characterized by mediterranean (humid to semiarid) climate, with annual precipitation ranging from 400 to 1200 mm a⁻¹ and with alternating wet and dry periods, leading to shrink-swell activity. These landforms are affected by severe and rapid erosive events with denudation rates of 1.5–3 cm a⁻¹ (Alexander, 1982; Rendell, 1982; Gutierrez et al., 1997; Del Prete et al., 1997; Raglione et al., 1997; Ciccacci et al., 2003; Del Monte, 2003; Clarke and Rendell, 2006; Della Seta et al., 2009; Buccolini et al., 2010), even though recent studies in southern Tuscany (Ciccacci et al., 2008, 2009) have shown that the erosion rate can reach values up to 5–7.5 cm a⁻¹.

The aim of this study is to define the recent morphoevolution of the Fabro calanchi badlands (Umbria, Italy) over a 55-year period (1955-2010), estimating the erosion rate and analyzing the possible correlation between the calanchi badland morphoevolution and the properties of their parent materials (such as grain size, mineralogy and pore water composition). This work is part of a wider research project that was carried out during the same time-span in a larger geographical area by the Earth Science Department of Sapienza - University of Rome.

STUDY AREA

The study area is located in a badland region of central Italy in the south-western part of Umbria - province of Terni – between 42°50' and 42°52' north and 11°58' and 12°02' east. It lies between 210 and 420 m above sea level and covers an area of about 20 km² in the lower Chiani river basin (Fig. 1).

The climate is typically Mediterranean, characterized by warm and dry summers and cold and rainy winters. Tab. 1

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shows the main characteristics of the climate in the area, with a temporal series of 80 years.

Fabro area is a part of Paglia-Tevere basin, a graben originated during Pliocene extensional tectonic activity (Fig. 1a). The tectonic history of this area is representative of the general orogenic history of the central Apennines and the Umbria region. The building phase of the Apennine orogenic wedge (Oligocene to Tortonian) led to the formation of the horst-and-graben morphostructures. These are mainly NW–SE oriented and composed of sedimentary sequences (Umbria-Marche sequence, Tuscan Nappe, Ligurian and Subligurian Nappe) overthrust towards the NE. The orogenic wedge began collapsing in the Late Miocene. Extensional tectonics, affecting the Tyrrhenian margin of the Italian peninsula, activated several NW–SE striking normal faults, which define the system of horst and graben cut by SW–NE transfer faults. A marine transgression led to the deposition of a Plio-Pleistocene sequence of clay, sands and conglomerates within the major depressions (Radicofani Graben, Val di Chiana Graben and Tevere Graben; Funicello et al., 1981; Cattuto et al., 1992; Barberi et al., 1994). Moving inland, the extensional basins are filled with lacustrine to fluvio-lacustrine continental deposits. During the Quaternary, the Plio-Pleistocene marine deposits were uplifted to several hundred meters above present sea level. This strong uplift is related to widespread volcanic activity along the Tyrrhenian margin, evidenced by the distribution of several volcanic complexes.

The Fabro area is dominated by Pliocene marine-sourced deposits (Fig. 1b). This sequence, known as “Fabro cycle” (Ambrosetti et al., 1977, 1978, 1987), is made of basal fluvial-delta conglomerate (“Basal conglomerates”) at the bottom, by mud (“Fabro clays”), sand (“*Flabellipecten* sands”) and conglomerate (“Città della Pieve conglomerates”) at the top. Sedimentological analyses (Ambrosetti et al., 1987) of each lithological unit ascertain that this sequence is prograding from the shelf (mud), to the shore face and the foreshore (sand) and, at the top, to the backshore (conglomerate). The definitive marine regression left a depressed area where the Fabro swamp was formed; southwards the sea regression was followed by the setting up of the present hydrographic net, which drained the Fabro swamps (Chiani River). Finally, during the Quaternary, the regional uplift raised the Pliocene marine deposits far above sea level. Today these deposits outcrop at about 400 m a.s.l.

METHODS

To achieve the research objectives, a combination of methods was used, including: field surveys, multitemporal photo interpretations, direct measurements of erosion rates and analysis of grain size, mineralogy and exchangeable cations content of soil samples.

Field surveys were carried out from 2006 to 2010 and were properly integrated with the stereo-interpretation of aerial photographs acquired in 2003 (I.G.M. flight at nominal scale

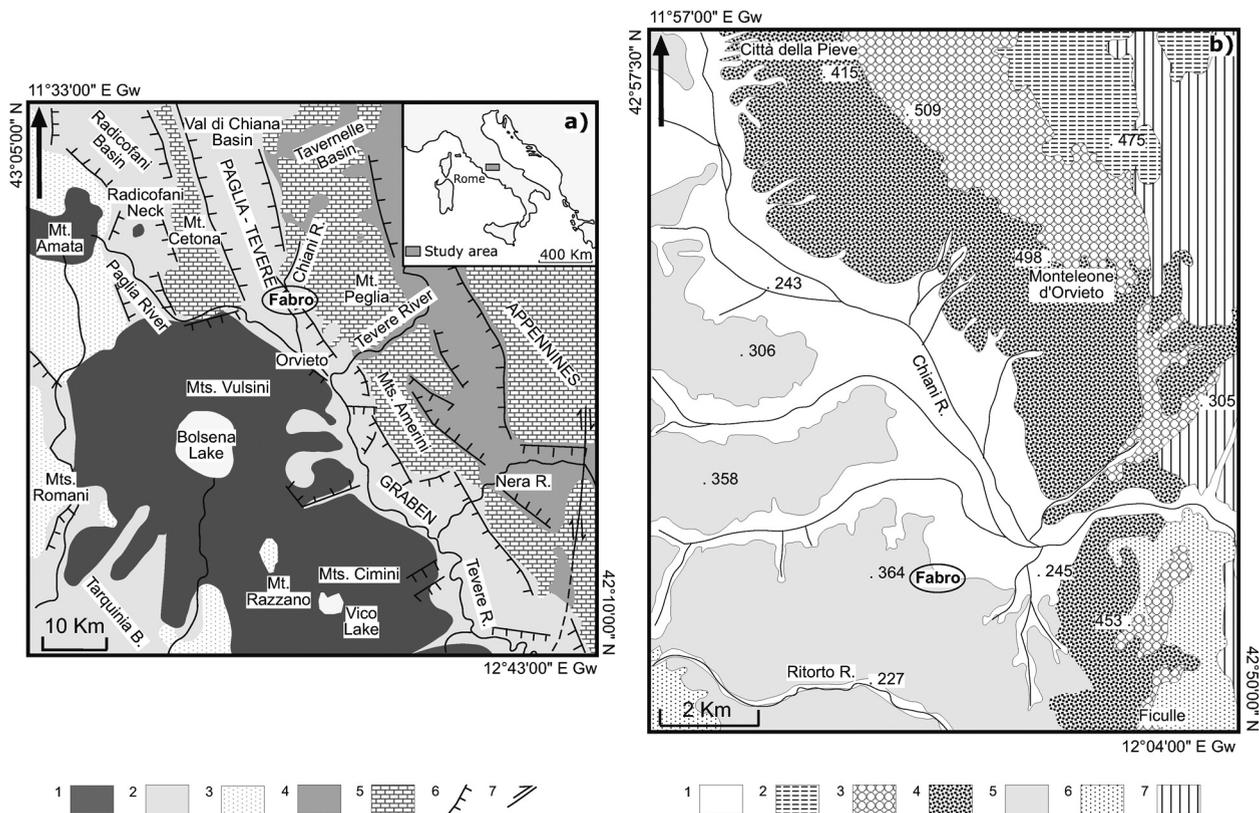


Fig. 1 - a) Geostructural sketch of central Italy: 1) Quaternary silica undersaturated to intermediate volcanic rocks; 2) “Neoautochthonous” sedimentary successions, of the marine, transitional and non-marine environments (Early Pliocene-Quaternary); 3) Siliciclastic and carbonate successions of the Tuscan and Ligurid domains (Trias-Miocene); 4) Sedimentary successions of the intermontane basins (Middle Pliocene-Quaternary); 5) Carbonate and siliclastic successions (Trias-Miocene); 6) Normal fault; 7) Transcurrent fault (modified after Mancini et al., 2004). b) Geological sketch of Fabro study area: 1) Alluvial deposits (Holocene-Present); 2) Lacustrine deposits (Pleistocene); 3) “Città della Pieve Conglomerates” (Middle and Late Pliocene.); 4) “*Flabellipecten* Sands” (Early and Middle Pliocene); 5) Fabro clays (Early Pliocene); 6) Basal Conglomerates (Late Miocene-Early Pliocene); 7) Sandstones (Miocene).

	Fabro area (1921 - 2004)
Mean annual temperature (°C)	14.3
Minimum monthly temperature (°C)	1.3 (January)
Maximum monthly temperature (°C)	31.3 (August)
Mean annual rainfall (mm)	848.1
Minimum annual rainfall (mm)	408.0
Maximum annual rainfall (mm)	1363.3
Absolute minimum monthly rainfall (mm)	24.9 (July)
Absolute maximum monthly rainfall (mm)	122.0 (November)

Tab. 1 - Climatic data of the study area.

of 1:31,000). Fieldwork and photo interpretation aimed at reconstructing geomorphic features of the study area and obtaining a detailed (1:10,000) geomorphological map updated to 2010. For publishing purposes, this map was simplified here at a scale of 1:20,000 and its goal is to serve as a geomorphological sketch.

The characterization of calanchi badlands was completed through terrain analysis, with the aim to determine slope

steepness and aspect on which badlands develop. These topographic attributes were computed from digital elevation model, extracted from 1:10,000 topographic maps, from which frequency distribution of slope and aspect classes in calanchi badland areas have resulted.

To recognize the geomorphic evolution of the study area, occurred over the last 55 years, a multitemporal analysis, based on the comparison of aerial photographs taken in 1955 ("GAI" flight at nominal scale 1:33,000) and in 1989 ("Volo Italia 1988-1989" flight at nominal scale 1:70,000) was carried out. Therefore, two other detailed geomorphological maps (scale of 1:10,000) were obtained: the first one corresponding to 1955 and the second one to 1989. The sample area of "Podere Marmarullo" was chosen as a significant sketch of the detailed geomorphological maps and was included in this work.

To determine the erosion rate, at which badland landforms are developing, direct measurements were carried out. These measurements highlight the topographic surface variations, which represent the present-day in situ erosion processes. Monitoring stations were placed in two calanchi badland areas: respectively "Podere Marmarullo" and "Pgio Fiumana" (Fig. 2). The stations were equipped with square-sectioned (1 cm²) and at least 80-cm-long iron pins (Fig. 3) and monitored during the period going from May 2006 to February 2010. Pins were placed in poorly accessible key areas to prevent tampering and short term damage. They were placed inside the calanchi badlands at different depths depending on the local thickness of the weathered layer. We measured the height of pins, measured uphill and downdale from the pins (Δy = ground level changes, referring to the

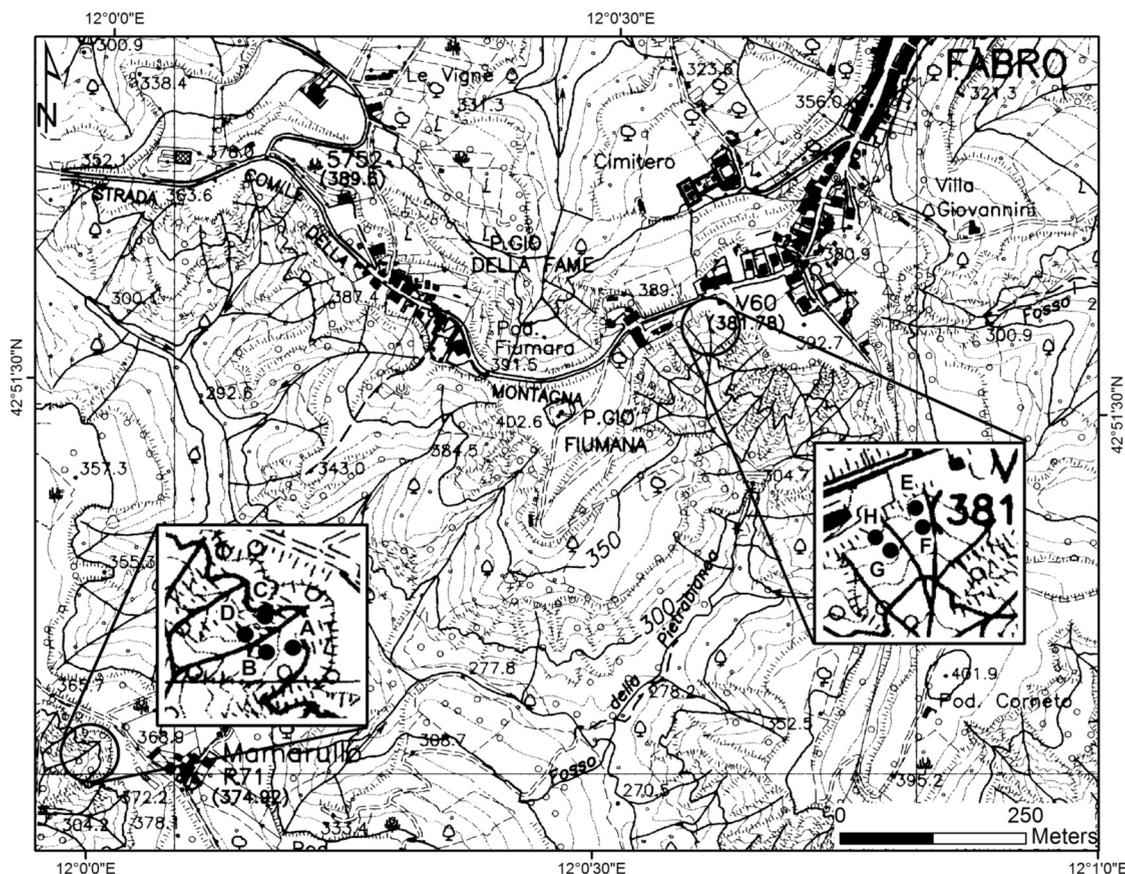


Fig. 2 - Location of Podere Marmarullo and Pgio Fiumana sample areas and monitoring points.



Fig. 3 - Metal pin used as datum point (monitoring station).

first measured pin length corresponding to zero). These observations were integrated by terrestrial photographic monitoring of slopes in the surroundings of the pins and were completed through morphometric analysis and topographic surveys in the area around the pins. Thus, seasonally repeated measurements of all (micro- and macro) landforms (tension cracks, trenches, landslide crowns, landslide scarps, landslide bodies and mass movement deposits) that developed on the slopes were executed from fixed measurement stations (such as trees, walls, fencing pins, etc.) using theodolite, laser precision diastimeters and tape measures. Local volumetric estimation of the material removed from the calanco slope portions around the pins was conducted through these morphometric measurements.

Analysis of grain size, mineralogy and major element content of soil samples were carried out in order to define the possible correlation between soil characteristics and geomorphic processes resulting in the development of the badland landform. Sampling was made at the top and bottom of two selected calanchi slopes in "Podere Marmarullo" and "P.gio Fiumana" sample areas, where the direct measurements were conducted. Grain-size analyses have been carried out using the fractionated sedimentation technique; particles larger than 63 μm were fractionated, whereas those smaller than 63 μm have been analysed through a laser particle size analyzer. Mineralogical analyses have been carried out just for determination of clay fraction (< 4 μm) and were performed using X-ray diffraction (XRD). Semiquantitative analyses of crystalline components were made by taking into account the relationships between the different elongations of their own basal reflections. The determination of exchangeable cations was performed using mixtures prepared according to the procedure proposed by Faulkner et al. (2001, 2003). The cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) were extracted using a 1:10 soil:water dilution. At last, to measure the dispersive state (Mitchell, 1976; Head, 1988), the sodium adsorption ratio (SAR) was

calculated as: $\text{SAR} = (\text{Na}^+ / [(\text{Ca}^{2+} + \text{Mg}^{2+}) / 2]^{1/2})$. The chemical characterization also includes determination of the sodium percentage as: $\text{PS} = ([\text{Na}^+ / (\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+})] * 100)$ and total dissolved salt content as: $\text{TDS} = \text{Na}^+ + \text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+}$.

RESULTS AND DISCUSSION

Morphological characteristics of Fabro area

The largest part of the study area is occupied by calanchi badlands, which represent the most characteristic landforms in Fabro site (Fig. 4). These denudational landforms are the result of water erosion, particularly active in this area, and appear as a small hydrographical unit, with steep, eroded slopes, often subdivided into several secondary valleys separated by sharp ridges (Calzolari and Ungaro, 1998).

They affect most of the valley slopes and develop most frequently on slopes with a steepness ranging between 15° and 30° and with a south-eastern aspect (Fig. 5).

Three different typologies of calanchi badlands have been identified. The first type, indicated as the "KE" (knife-edged), is presently the most widespread in the study area. It is characterized by a system of narrow but deep cuts separated by thin, knife-edged crests and reproduced on the whole drainage net in miniature. This is the typical calanchi badland morphology, described also by Rodolfi and Frascati (1979) as the "type A" calanchi badlands. The second, indicated as the "RC" (rounded crest), is characterized by trough-floored small valleys separated by smaller rounded crests and affected by noticeable mass movements. It is also described by Rodolfi and Frascati (1979) as the "type B" calanchi badlands. The third type, indicated as the "SSL" (small scattered landslides), is characterized by a higher frequency of mass movements with numerous small scattered landslides, which almost completely destroy the calanchi badland crests and fill up the bottom of the small valleys with flowing materials. On the gentler slopes of this calanchi badlands type, the vegetation cover is more widespread than in the other calanchi badland types. At present, in the badlands of the study area, piping, that in some areas of central and southern Italy seems to play an important role in badland development, does not seem to be particularly widespread in the study area and is limited to the thin altered layer covering the few fractured clay bedrock.

Rotational landslides are also present and at their foot they often evolve into mudflows because of the clayey bedrock on which they develop. Landslide bodies are characterized by traction fractures, humps and counterslopes. Frequently, they are reactivated during the year by a series of small and shallow landslides and rapidly reworked by sheet-wash processes, which remove the fine fraction of clays and sometimes mask their shape. The influence of gravity is also evident on gentler slopes, where mudflows, soil creep and solifluction are widespread, especially on cultivated lands where typical tongues and grassy mantle cracks can be observed.

At last, in the study area human impact – as deforestation, grazing and farming - has been significant and contributed to accelerate the erosion processes and the trigger of gravitational movements on the slopes (Buccolini et al., 2007). In particular, in the study area, specific agricultural practices promote water infiltration into soils and facilitate the plasticization of the top soil.

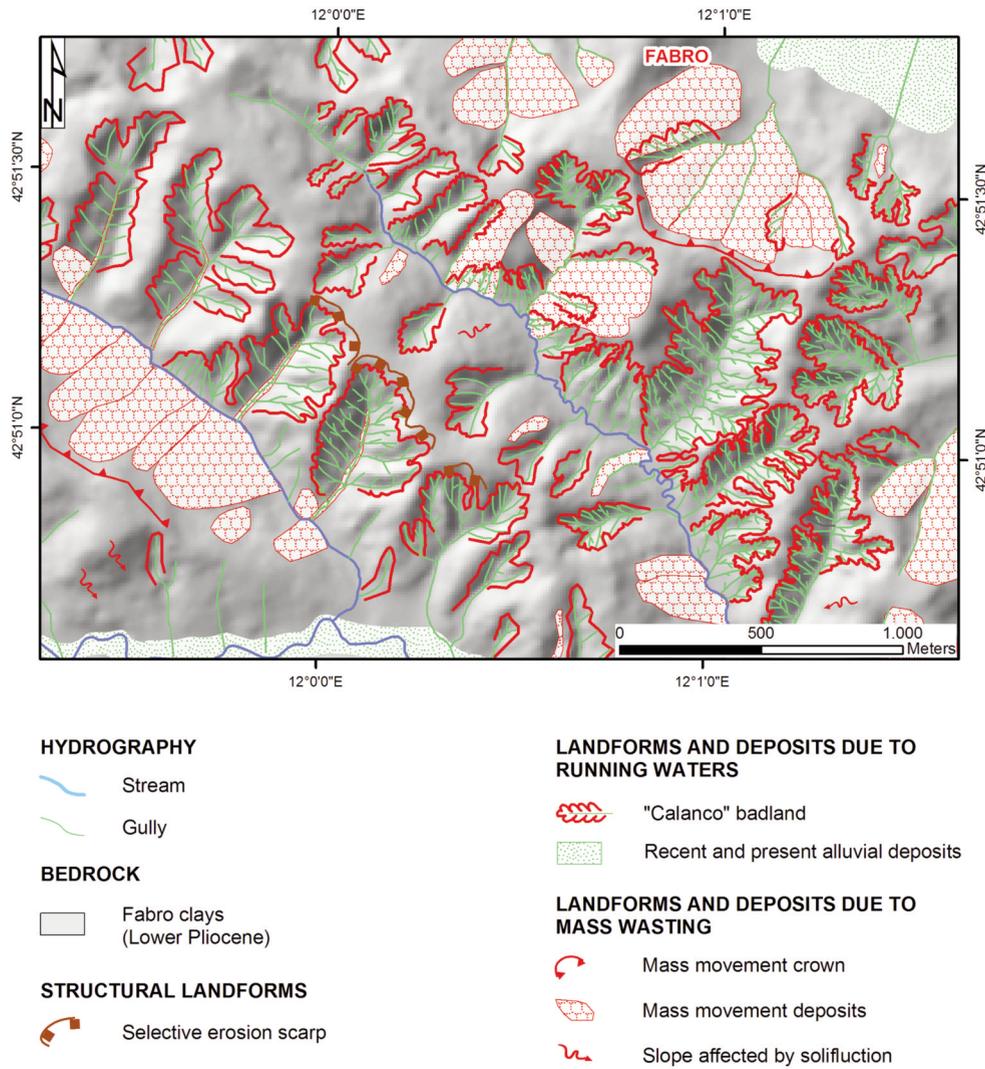


Fig. 4 - Geomorphological sketch.

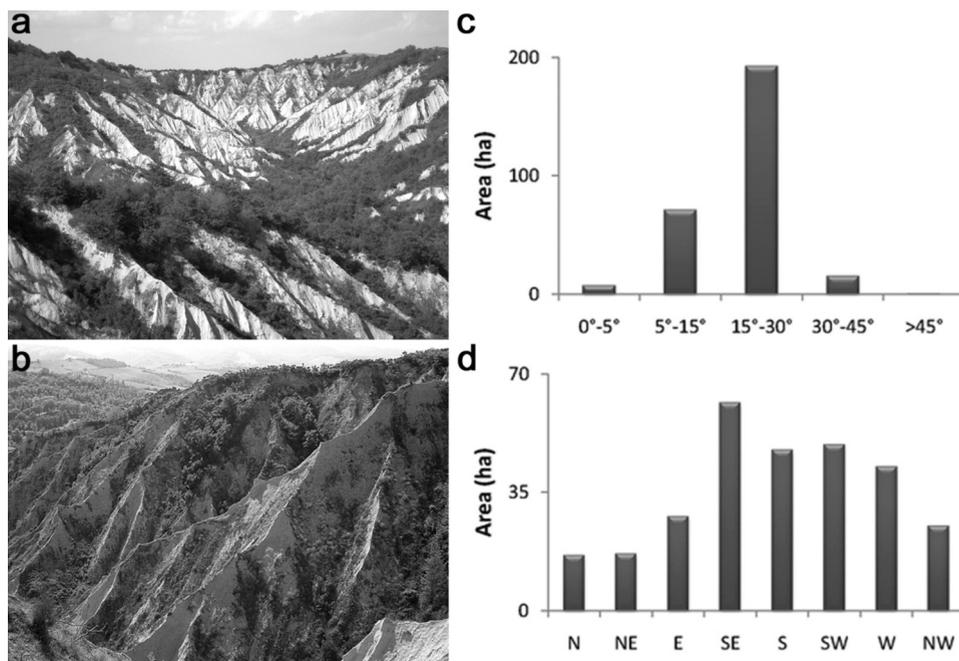


Fig. 5 - Calanchi badlands in the study area (a and b); frequency distribution of slope classes (c) and aspect classes (d) derived for calanchi areas.

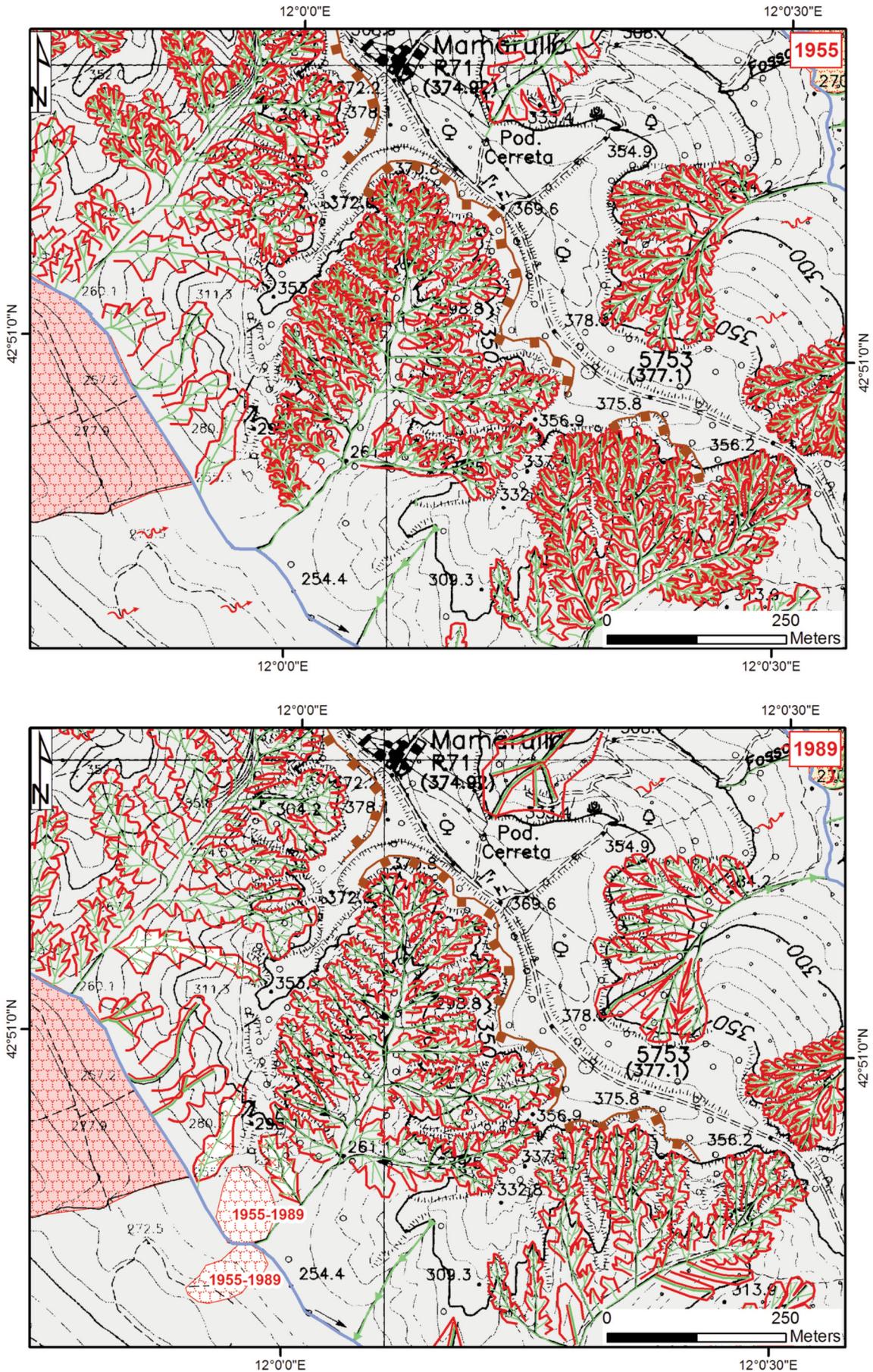


Fig. 6 - Geomorphological maps of the Podere Marmarullo sample area relative to years 1955, 1989 and 2010.

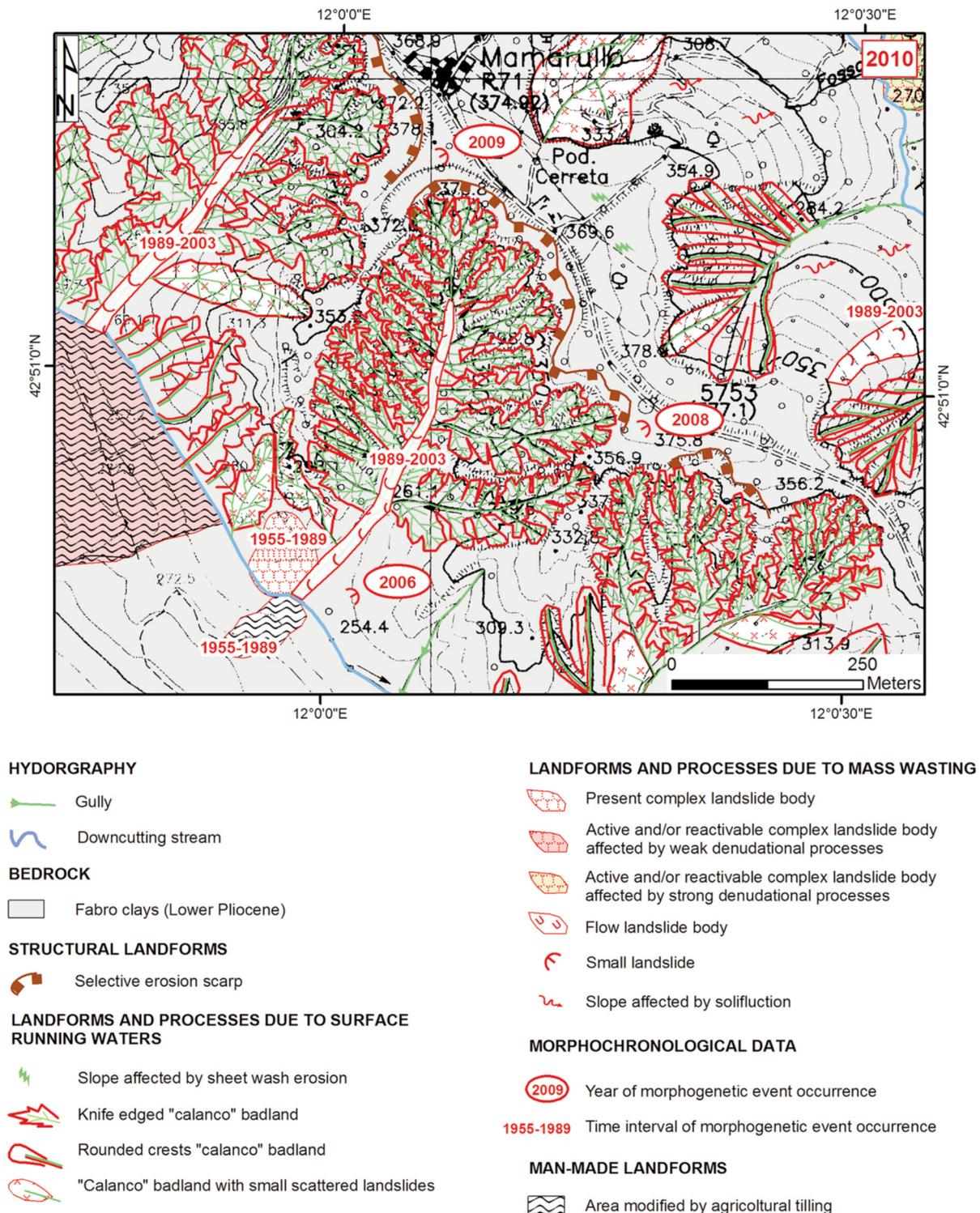


Fig. 6 - continuation

Morphodynamics of the Fabro area

Geomorphologic maps related to 1955, 1989 and 2010, and in particular the maps of the "Podere Marmarullo" sample area (Fig. 6), allowed the outlining of the evolution of Fabro area during the last 55 years. Considering the purpose of this work, particular importance was given to temporal development of badland areas. The comparison of three

geomorphologic maps and the spatial analysis, performed in the GIS environment, has shown that in the last 55 years, the total area occupied by calanchi badlands increased of 13,3 ha. In particular, in 1955 the area was 274 ha, in 1989 it increased to 278.5 ha and in 2010 it was 287.3 ha (Fig. 7a).

Although KE calanchi badland type is the most widespread in Fabro site, in the monitoring period a progressive evolution of badlands from the KE calanchi

badland type to the RC type and then to the SSL type was identified. In 1955 (Fig. 7b) almost all of calanchi badlands (96%) was mainly represented by the characteristic network of deep incisions with steep slopes and sharp crests (KE calanchi badland type). Over the last 55 years, the KE calanchi badland type percentage decreased slightly, and was reduced from 96% in 1955 to 62% in 2010. The ridges separating rills and gullies have been rounded off over time and the bottoms of gullies have been often filled with colluvium or flow deposits, which have produced, in some cases, a typical through-floored valley where vegetation cover is present. In 1955 and 1989, calanchi badlands with rounded crests (RC calanchi badland type) represent 4% and 13% of the total calanchi badland area, respectively. From 1989 until 2010, the percentage of this type of calanchi increased to 25% due to gravitational processes, which became more frequent in the area. During the last years, small scattered landslides became the features characterizing a new typology of calanchi badlands (SSL calanchi badland type), which were not present in the study area in 1955. On the contrary, in 1989 the SSL calanchi badland typology occupied 5,3 ha (2%), while in 2010 it extended over a surface of 38,8 ha (13%).

Moreover, figure 6 shows an increase of gravitational processes over the last few years, to the detriment of sheet-wash erosion. Landslide bodies can be identified in the study area since 1955 and during the last few years they have been reactivated through smaller landslides. For some of these landslides, it has been possible to establish the occurrence date both by the analysis of aerial photographs taken during different years and by repeated field surveys. Many landslide bodies have been reshaped using agricultural practices (e.g., plowing, wheat sowing and harvesting) executed through

mechanical devices. The reshaping of calanchi badlands by agricultural practices was less intense because these badlands are often inaccessible to mechanical devices.

Direct measuring of erosion rate in "Podere Marmarullo" and "P.gio Fiumana" monitoring stations.

Topographic surface changes, measured in the monitoring stations in the period May 2006-February 2010, are shown in figure 8. "Podere Marmarullo" and "P.gio Fiumana" denudation plots (Fig. 8) have a similar trend and highlight that accumulation and erosion phases have alternated on the badland slopes. These alternating phases are connected mainly to running water (sheet-wash, rill and gully erosion), but also to small landslides. In particular, pin C in winter 2007 were not found, removed by gravitational movements as testified by the accumulation of material in the same period on pin D, mainly coming from the upper part of slope. Even pin E, in "P.gio Fiumana" sample area, was affected by a similar phenomenon in the summer 2006. Obtained data have been integrated with seasonal field observations and morphometric measurements of micro- and macro-landforms that developed on the slopes (such as tension cracks, trenches, landslide crowns, landslide niches, landslide bodies and mass movement deposits). These measurements have been executed from fixed measurement stations (such as trees, walls, fencing stake etc.) using laser precision diastimeter and metric ribbon. By comparing topographic surface changes obtained with these repeated measurements, it was possible to estimate the volume of material displaced from the upper part of the slopes. All collected data allowed us to evaluate a mean annual erosion rate of 2-3 cm a⁻¹ for the time span considered. These values are in agreement with those obtained (Tab. 2) for longer periods of observation in other Italian badland areas (Alexander et al., 1982; Branca and Voltaggio, 1993; Del Prete et al., 1997; Clarke and Rendell, 2006; Della Seta et al., 2007) and smaller than those obtained in other Italian drainage basins characterized by badland morphologies affected by strong gravitational processes (flows; Ciccacci et al., 2008).

Parent material properties

Grain size analysis results, shown in Fig. 9, indicate that studied samples are clayey silts. There is a substantial homogeneity of grain size composition between these samples; in particular, there is not discrimination in grain size characters of top with respect to base of eroded slopes.

Mineralogical composition (Tab. 3) appears rather uniform. The non-clay mineral assemblage is characterized by quartz and calcite as dominant components and albite and feldspars as the subordinate ones. Illite, kaolinite and chlorite are instead the main clayey minerals. Expandable minerals, that generally favor overland flow and rill erosion, due to the considerable swelling they undergo in wet conditions, range from 0% to 32% with an average of about 20%. There is no a significant trend in clay mineralogy and no relationship was observed between the top and the bottom mineralogical composition of slopes.

Pore water composition of selected samples and related parameters controlling clay dispersivity are illustrated in Tab. 4. In the samples, the monovalent cations are less abundant than divalent cations. Sodium and potassium, in fact, are present in small concentrations in pore water, while calcium and magnesium are always dissolved in pore water

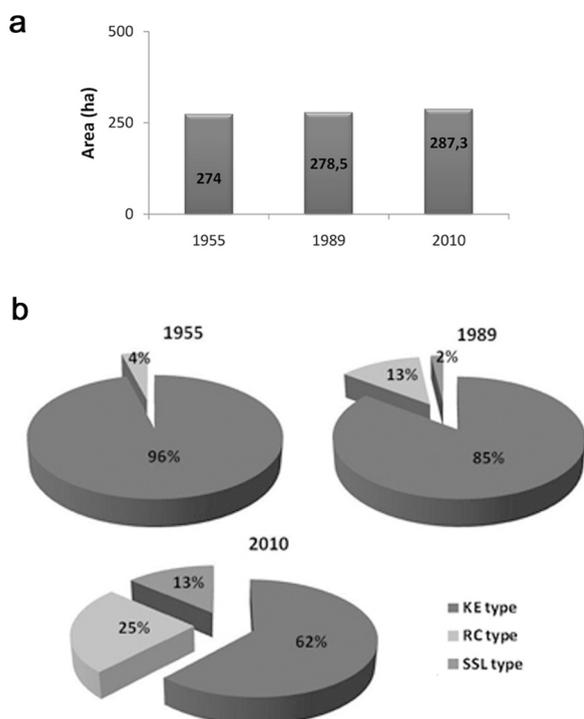


Fig. 7 - a) Areal variations (ha) of calanchi badlands during the last 55 years. b) Morphological evolution of calanchi typologies during the last 55 years. KE type: knife-edge calanchi; RC type: rounded-crest calanchi; SSL type: scattered small landslides calanchi.

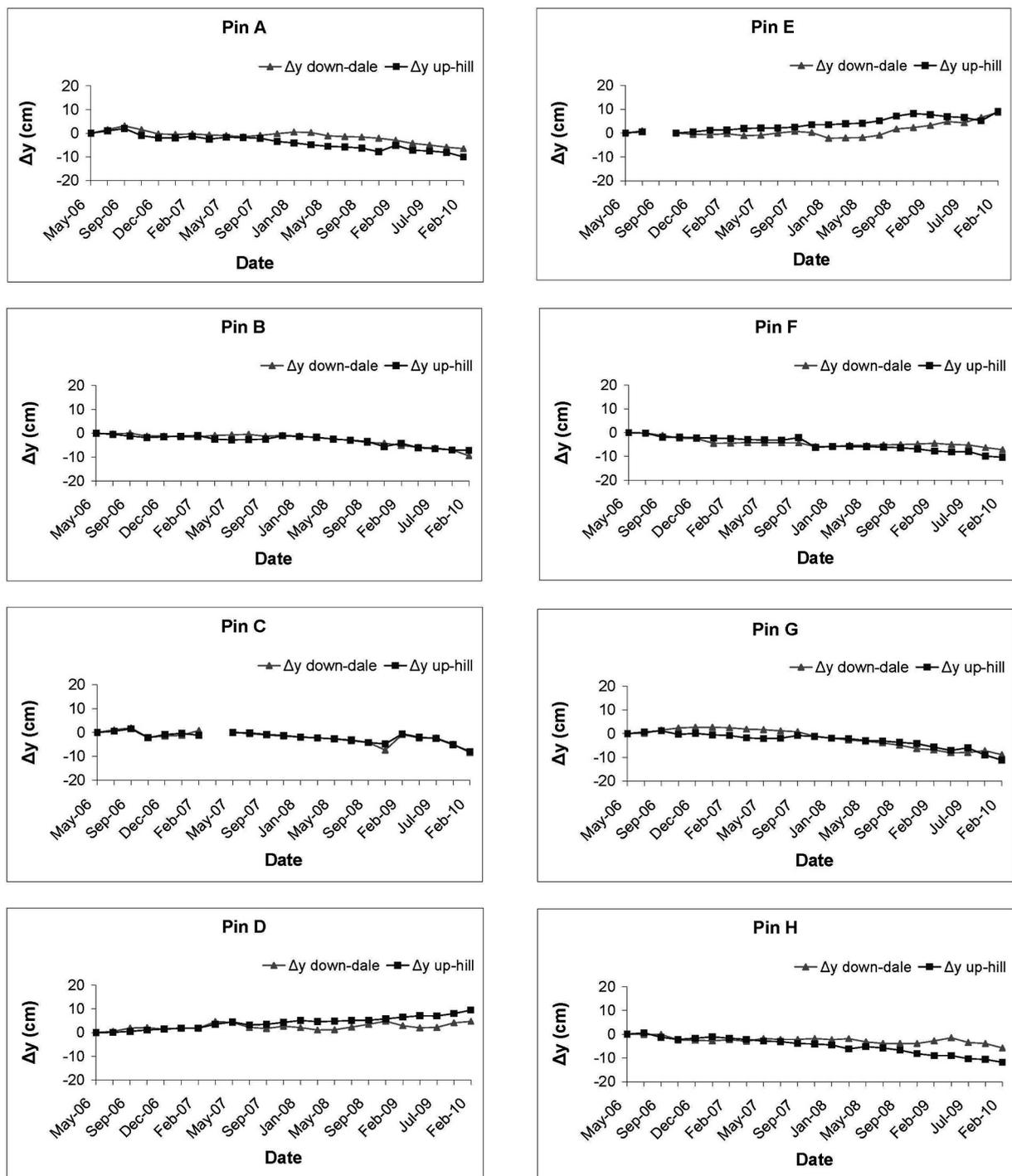


Fig. 8 - Changes in the topographic surface measured at the Podere Marmarullo and Pgio Fiumana monitoring stations.

in significant amounts. The relative amounts of monovalent and divalent cations in the pore water significantly influence the physical properties of clays, in particular their tendency to undergo spontaneous colloidal dispersion (Battaglia et al., 2002, 2011). According to Sherard et al. (1976), SAR, TDS and PS were correlated to clay dispersivity. These values are plotted in the diagram of figure 10 (modified after Sherard et al., 1976). On this diagram, clay types falling in zone A have a high tendency to undergo spontaneous dispersion, while zone B pertains to ordinary erosion-resistant clay and zone C

to potentially dispersive or non-dispersive clay. Our samples all fall in either zone B. Thus, in this area the parent materials of calanchi badlands show a non dispersive tendency and then they are not predispose to produce colloidal dispersions when saturated by rainwater.

CONCLUSIONS

Geomorphological investigation demonstrated that, in this area, KE calanchi badlands are a predominant type,

Location	Mean erosion rates (mm a ⁻¹)	Source of reference
Southern Italy (Basilicata)	20-30	Alexander, 1982
Central Italy (Paglia River Catchment)	>8.4	Branca and Voltaggio, 1993
Southern Italy (Basilicata)	9-20	Clarke and Rendell, 2006
Southern Italy (Basilicata)	30	Del Prete et al., 1997
Central Italy (Paglia and Orcia catchments)	<50	Della Seta et al., 2007
Central Italy (south Tuscany)	50-60	Ciccacci et al., 2008

Tab. 2 - Annual erosion rates measured in Italian badland areas.

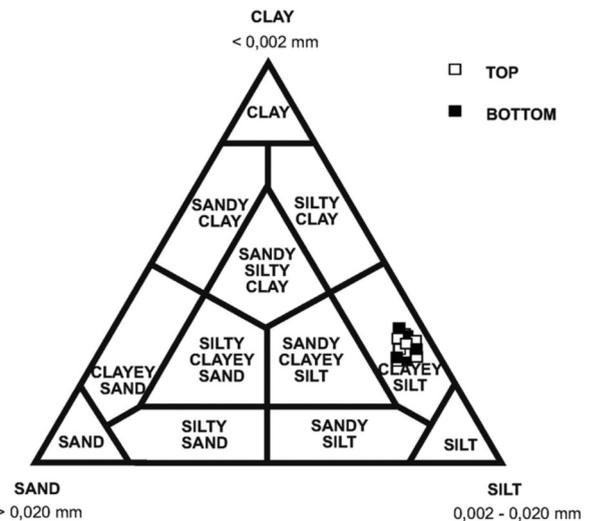


Fig. 9 - Grain size composition of the sampled sediments plotted on a ternary diagram.

Sample	Qz (%)	Cc (%)	Al (%)	Fs (%)	Ill (%)	Kln (%)	Chl (%)	Sm (%)
A1	43	39	9	9	28	16	24	32
A2	40	48	6	6	35	40	25	0
B1	50	41	9	0	29	19	23	29
B2	41	44	7	8	21	19	33	27
C1	42	44	8	6	33	24	28	15
C2	39	49	6	6	36	26	26	12
D1	47	39	9	5	28	27	24	21
D2	44	45	7	4	33	16	25	26
E1	47	45	8	0	24	12	32	32
E2	39	48	6	7	37	23	29	11
F1	48	42	8	2	35	18	30	17
F2	41	47	6	6	28	17	29	26
G1	50	44	6	0	23	27	32	18
G2	44	49	7	0	36	15	25	24
H1	43	40	9	8	25	40	22	13
H2	40	46	7	7	29	28	24	19

Tab. 3 - Mineralogical composition of the sampled sediments. Qz = quartz; Cc = calcite; Al = albite; Fs = feldspars; Kln = kaolinite; Chl = chlorite; Sm = smectite.

although in other areas of central Italy, also nearby, the SSL calanchi badlands are more widespread (Ciccacci et al., 2009). In the Fabro area, in fact, the badlands are mainly composed of a characteristic network of deep incisions, steep slopes and sharp knife-edged ridge-lines. Field surveys and multitemporal photointerpretation demonstrated also that calanchi badlands underwent changes over the last 55 years. Although KE calanchi badland type is the most widespread in Fabro site, our results provide evidence also

for a progressive evolution of badlands from the KE type to the RC type and then to the SSL type. In 1955, these landforms were mainly composed of a characteristic network of deep incisions, steep slopes and sharp knife-edged ridge-lines (KE calanchi badland type). During the last 55 years, these ridges were blunted and rounded over time (RC calanchi badland type) and the bottoms of gullies frequently became filled with colluvium or flow deposits. Some calanchi badland ridges have been almost destroyed by the increased

Sample	Na ⁺ (meq/l)	K ⁺ (meq/l)	Mg ²⁺ (meq/l)	Ca ²⁺ (meq/l)	SAR (meq/l)	TDS (meq/l)	Ps (%)
A1	1.41	0.26	7.52	9.74	0.48	18.94	7.46
A2	1.38	0.74	5.57	2.28	0.70	9.98	13.88
B1	1.82	0.46	7.25	4.63	0.74	14.15	12.83
B2	1.51	1.59	7.40	7.38	0.55	17.87	8.42
C1	0.61	0.53	0.64	0.45	0.83	2.23	27.35
C2	3.28	0.48	3.22	8.08	1.38	15.06	21.78
D1	1.53	0.46	2.62	10.37	0.60	14.98	10.21
D2	0.75	0.51	5.37	0.40	0.44	7.03	10.67
E1	0.88	1.84	4.49	7.67	0.36	14.88	5.90
E2	0.95	1.69	2.01	1.08	0.76	5.73	16.55
F1	1.87	0.67	6.47	4.52	0.80	13.53	13.82
F2	1.27	0.37	4.24	2.76	0.68	8.64	14.70
G1	0.78	1.63	8.13	12.40	0.24	22.94	3.40
G2	1.49	0.43	5.62	12.40	0.50	19.94	7.47

Tab. 4 - Pore water composition of selected samples (meq/l) and related parameters controlling clay dispersivity.

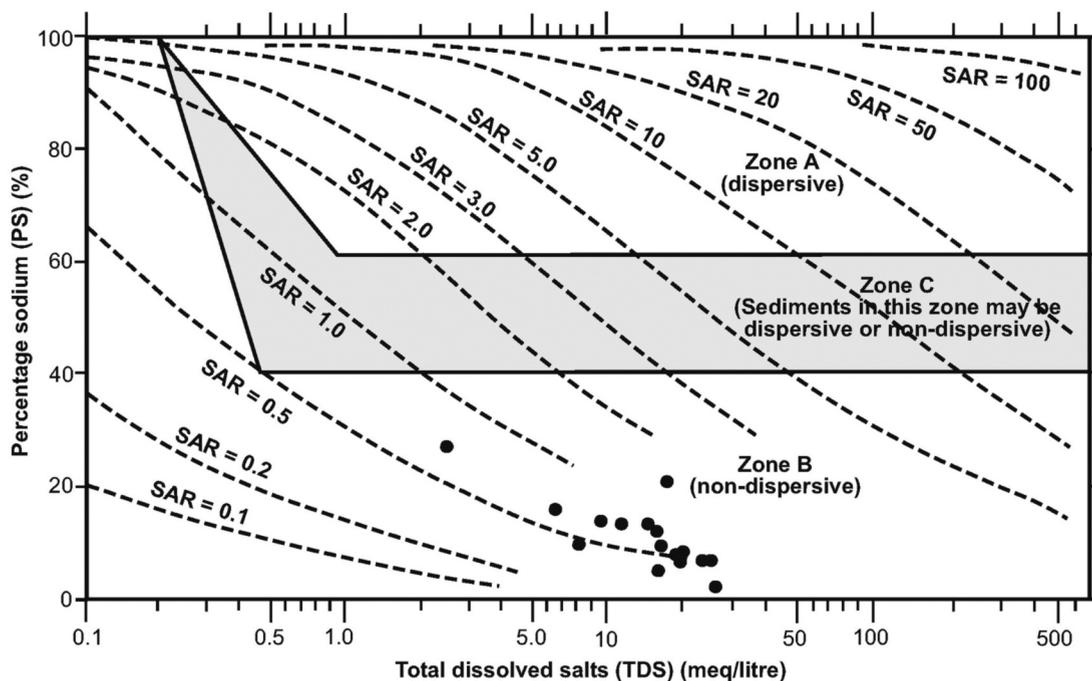


Fig. 10 - Relationships between sediment dispersivity and pore water composition expressed through the PS, TDS and SAR parameters (modified from Sherard et al., 1976). Dots indicate the analyzed sample position in the diagram.

edge shrinking and landslides on slopes. Often, small scattered flows filled the bottoms of gullies and vegetation colonized the slope foot (SSL calanchi badland type).

Direct measurements taken in the sample areas provided a mean denudation rate of 2-3 cm a⁻¹ for the time interval considered. These values are in agreement with those obtained for longer periods of observation in badland areas similar to the study area.

Analysis of parent material properties provided a

complete knowledge about the studied calanchi badlands in the Fabro area. Grain size and mineralogical composition of the sampled materials appear rather uniform and there is no a significant trend that can be correlated with calanchi badlands. Pore water composition shows a high divalent cations concentration relative to sodium concentration, which classifies the parent material as non-dispersive clay and then ordinary erosion-resistant clays. This geochemical property could explain the predominance in this area of

rilling over piping erosion and landsliding. In fact, non dispersive clays seem to favor intense processes of rill erosion (Battaglia et al., 2002, 2011; Benito et al., 1993; Sherard et al., 1976), when the content of divalent cations increases. At last, clay dispersivity seems to play an important role in the development of these landforms.

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