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Near-surface deposits and hillslope evolution of the Adriatic piedmont of the Central Apennines (Feltrino Stream basin and minor coastal basins, Abruzzo, Italy)

Tommaso Piacentini^a, Marco Sciarra^a, Enrico Miccadei^a & Tullio Urbano^a

^a Dipartimento di Ingegneria e Geologia (INGEO), Laboratory of Tectonic Geomorphology and GIS, Università degli Studi 'G. d'Annunzio' Chieti-Pescara, Chieti Scalo, Italy

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SCIENCE

Near-surface deposits and hillslope evolution of the Adriatic piedmont of the Central Apennines (Feltrino Stream basin and minor coastal basins, Abruzzo, Italy)

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Dipartimento di Ingegneria e Geologia (INGEO), Laboratory of Tectonic Geomorphology and GIS, Università degli Studi 'G. d'Annunzio' Chieti-Pescara, Chieti Scalo, Italy

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This work presents a geomorphological map of the Feltrino Stream basin and minor surrounding coastal basins (scale 1:20,000), located in the south-eastern Abruzzo area (Central Italy), across the Adriatic piedmont of the Maiella massif (Central Apennines). This geomorphological mapping is focused on near-surface deposits and hillslope evolution analysis and includes three sections: main geomorphological map; orography and hydrography; and geomorphological models of hillslope evolution.

In the study area, landforms and continental near-surface deposits are mainly linked to slope and fluvial processes, even though structural, marine, and anthropogenic landforms are also present. The mapping is primarily focused on near-surface deposits and landforms related to the evolution of hillslopes, resulting from the combination of tectonic (regional uplift) and surface processes. At a local scale, it can contribute to an understanding of the causes, mechanisms, and consequences of the changes of landforms and hillslopes and help solve engineering geomorphological problems. Finally, it is also a tool for the assessment of geomorphological hazards in landscapes characterized by widespread near-surface deposits and intense and rapid geomorphological processes, as well as a tool for land management.

Keywords: geomorphological map; near-surface continental deposits map; hillslope evolution; hilly landscape; Abruzzo; Central Italy

1. Introduction

Geomorphological maps are amongst the best tools for understanding the physical context of the Earth's surface, providing a full objective description of processes that shape it, and thereby to allow a better knowledge about natural hazards in order to better support land management (urban planning, land ecology, forestry, and soil science) (Dramis, Guida, & Cestari, 2011).

In this sense, near-surface deposit characterization through large-scale geomorphological mapping plays a key role in understanding the temporal and spatial distribution of geomorphological processes and so landscape evolution. Near-surface deposits are widely distributed throughout piedmont and hilly areas in mid-latitude climate regions, and particularly in areas with soft bedrock lithologies such as the entire Apennines piedmonts (Tyrrhenian and Adriatic). These

*Corresponding author. Email: tpiacentini@unich.it



deposits are influenced by the lithological and geomorphological setting, soil types, vegetation, surface and subsurface water flow, and microclimate conditions and largely control the physiography and landscape development of hillslopes, scarps, valley bottoms, etc.

This explanatory note presents a geomorphological map of the Feltrino Stream basin (Abruzzo, Italy) (Scale 1:20,000), which includes several surrounding small coastal catchments (Main Map). The mapped area is already represented at a smaller scale (1:50,000) in the morpho-tectonic map of the Aventino – Lower Sangro valley (Miccadei, Piacentini, Dal Pozzo, La Corte, & Sciarra, 2013) following an extensive drainage basin scale geomorphological analysis of the chain and Adriatic piedmont areas of the central-eastern Apennines (Italy) (see Miccadei, Piacentini, Gerbasi, & Daverio, 2012b; Miccadei et al., 2013; Santo et al., 2014).

In the case of the Feltrino Stream basin, located across the Adriatic piedmont of the Maiella massif (Central Apennines), the mapping is mostly aimed at detailing near-surface deposits and landforms associated with hillslope evolution. The Main Map is implemented within a geographical information system (GIS) by means of (i) digital elevation model (DEM) and map-based morphometric analysis of orography and hydrography (raster and vector data scale 1:25,000–1:5000, 5 m grid DEM), (ii) air-photo interpretation (scale 1:33,000–1:5000), and (iii) geological-geomorphological field mapping (scale 1:5000). It consists of three main sections:

- (1) main geomorphological map;
- (2) orography and hydrography;
- (3) geomorphology of near-surface deposits and hillslope evolution models.

The map herein presented provides a basis for the recognition of surface geology and geomorphological features of the hilly Abruzzo piedmont at a detailed scale. It allows us to define the main phases of hillslope evolution resulting from the activity of mass movement, slope, runoff, fluvial and marine processes induced by regional uplift, climate fluctuation, and sea level changes.

2. Study area

The Feltrino Stream basin and the surrounding minor coastal basins are located in the hilly area of southeastern Abruzzo, in the eastern piedmont of the Maiella massif (Central Apennines) (Figure 1(a and b)). The basins slope from SW to NE, ranging from about 400 m a.s.l. to sea level, with an overall morphology characterized by a *mesa* and *plateau* relief (Figure 2). This area is bounded to the east by a cliffed coast interrupted by alluvial valleys (most notably the Sangro River) and by the small and sharp valleys of the minor streams (e.g. the Feltrino Stream).

The Central Apennines are an asymmetric mountain range characterized by alternating >2000 m high ridges and 500–1500 m deep valleys with a NW-SE to N-S orientation, as well as by wide intermontane basins (i.e. Fucino Plain, Sulmona Basin). It is a Neogene thrust belt migrated toward the north-east (Calamita, Esestime, Paltrinieri, Scisciani, & Tavarnelli, 2009; Carminati & Doglioni, 2004; Parotto & Praturlon, 2004; Patacca & Scandone, 2007). Since the Late Pliocene the thrust belt has been affected by differential uplift and extensional tectonics inducing the displacement of the main ridges of the chain, the formation of tectonic valleys and intermontane basins, and the emergence of the western Adriatic area with the subsequent evolution of the Apennine piedmont (Ascione, Cinque, Miccadei, Villani, & Berti, 2008; Cavinato & De Celles, 1999; D'Agostino, Jackson, Dramis, & Funicello, 2001; D'Alessandro, Miccadei, & Piacentini, 2003; Piacentini & Miccadei, 2014).

The Adriatic piedmont, linked to the Apennines chain by an abrupt morphologic boundary, shows *cuestas*, *mesas* and *plateaux* landscapes, that slope from ~1000 m a.s.l. along the chain front (Maiella massif) to <100 m a.s.l. close to the coast. Here, the main rivers flow along

wide floodplains, generally in a SW-NE direction, while the minor rivers are entrenched within narrow valleys and gorges. In the piedmont area, Middle Pliocene to Early Pleistocene late-orogenic clayey-sandy marine sediments of the Adriatic basin unconformably overlie sin-orogenic foredeep arenaceous and pelitic Miocene – Early Pliocene sequences, and folded and thrust pre-orogenic clayey and carbonate pelagic sequences (see the lithological box on the map) (Calamita, Satolli, Scisciani, Esestime, & Pace, 2011; Crescenti, Milia, & Rusciadelli, 2004; Ori, Roveri, & Vannoni, 1986). A Middle Pleistocene sandy-conglomeratic sequence shows a regressive phase with a gradual transition from a marine to a subaerial environment

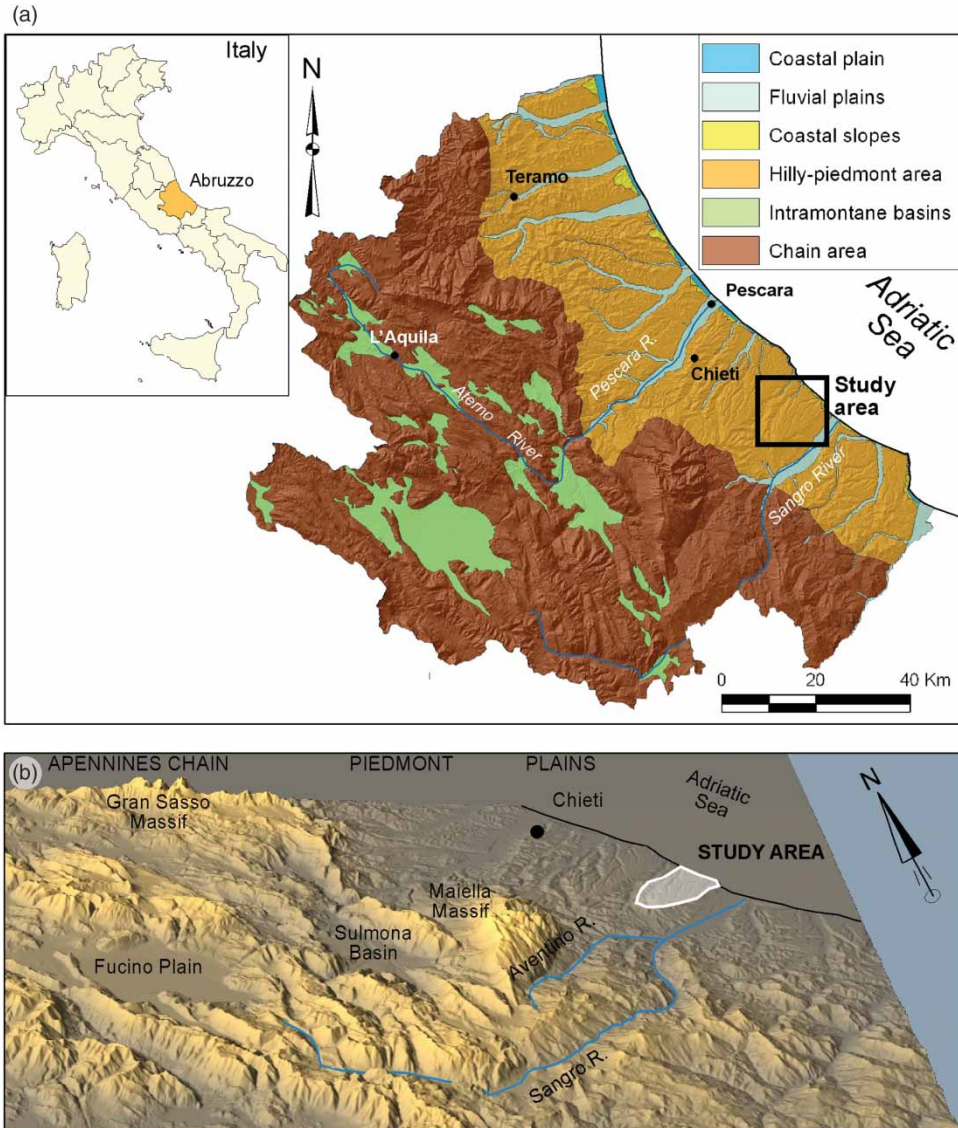


Figure 1. Location map of the Feltrino Stream basin and surrounding minor coastal basins: (a) within Italy and the Abruzzo region; and (b) within the piedmont and hilly coastal area of the Abruzzo region (3D view from south, 90 m DEM, NASA-SRTM).

(Cantalamessa & Di Celma, 2004; Coli, Modugno, Marchese, & Montaini, 2000). The present structural setting is characterized by a wide homocline dipping gently to the north-east, affected by fractures and low displacement faults, as a response to Pleistocene uplift and local tectonics, which have induced fluvial and slope processes (Buccolini et al., 2007; Buccolini, Gentili, Materazzi, & Piacentini, 2010; Chiocchini, Barbieri, Madonna, Di Stefano, & Poteti, 2006; D'Alessandro, Miccadei, & Piacentini, 2008; Della Seta et al., 2008).

A complex sequence of post-orogenic Quaternary continental deposits, mostly consisting of slope, fluvial and beach sediments, overlies the Pliocene-Pleistocene marine and transitional sequences. The fluvial deposits are arranged in a sequence of four main orders of terraces. In the most relevant literature concerning the Adriatic piedmont, the deposits are correlated with climatic fluctuations that occurred from the Middle Pleistocene to the Holocene (D'Alessandro et al., 2008; Demangeot, 1965; ISPRA, 2010a, 2010b, 2010c and references therein).

The map area includes the Feltrino Stream basin and seven minor coastal catchments (Rio Fontana, Fosso San Fino, Fosso Canali, Torrente delle Grotte, Torrente Vallegrande, Torrente San Biagio, Torrente San Giovanni). It is bordered by the Moro River basin and minor basins to the north and by the Sangro River basin to the south.

The Feltrino Stream is 19 km long and flows north-eastwards from the inner part of the Adriatic piedmont area to the Adriatic coast. The seven small coastal basins are from 480 m to 9.5 km long and have a SW-NE to S-N direction (Figure 1; Table 1; see also the hydrography scheme in the lower part of the Main Map).

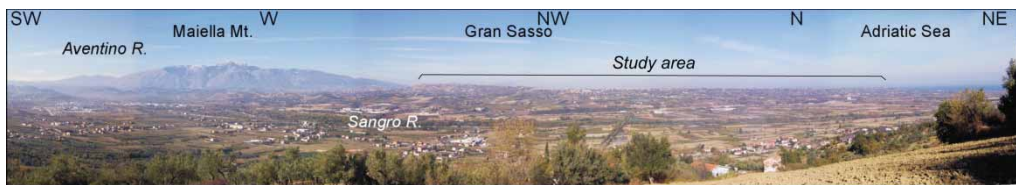


Figure 2. Panoramic view of the study area (from south) within the chain, piedmont and hilly coastal areas (southeastern Abruzzo region).

3. Methods

A detailed-scale geomorphological analysis allowed for the production of the large-scale map presented here (at 1:20,000 scale) and geomorphological block diagrams summarizing the main stages of hillslope evolution. It is primarily the result (Figure 3) of geological and geomorphological field mapping, supported by air-photo interpretation and photogeology, integrated with morphometric analysis of orography and hydrography (Dramis et al., 2011).

From the 1:5000 scale vector map (Technical Numerical Map of Abruzzo Region, from 2002 photogrammetric survey) a DEM (5 m cell) was extracted, on which the orographic (slope and hypsometry) and hydrographic (drainage patterns) analyses were based. Air-photo interpretation was performed using 1:33,000 scale aerial photos (I.G.M.I., 1956; Abruzzo Region, 1987) and 1:5000 scale color orthophotos (Abruzzo Region, 2009) to support the mapping of the main landforms. Maps and photos were provided by Struttura Speciale di Supporto Sistema Informativo Regionale of Abruzzo Region (or viewed on the webGIS <http://www.regione.abruzzo.it/xcartografia/>).

Geomorphological field mapping was carried out at 1:5000 scale, investigating the outcropping bedrock lithology and structure, near-surface deposits, and the different types of landforms (structural, slope, fluvial, marine, anthropogenic) with special consideration to the evolution of

hillslopes. Field mapping has been performed according to the guidelines of the Geological Survey of Italy (ISPRA, 2007, 2009; SGN, 1992, 1994) and the Abruzzo-Sangro Basin Authority (2005) and according to relevant geomorphological mapping literature and conventions (e.g. Capelli, Miccadei, & Raffi, 1997; Capolongo, Cecaro, Giano, Lazzari, & Schiattarella, 2005; D’Alessandro et al., 2008; Della Seta et al., 2008; Dramis et al., 2011; GNGFG, 1994; Miccadei, Orrù, Piacentini, Mascioli, & Puliga, 2012a; Miccadei, Paron, & Piacentini, 2004; Miccadei et al., 2012b, 2013; Otto, Gustavsson, & Geilhausen, 2011; Smith, Paron, & Griffiths, 2011). Landslide mapping has been performed according to Cruden and Varnes (1996) and WP/WLI (1993) defining the concept of activity with reference to the originating causes. Landslides are mapped, in terms of activity, in three main categories: active (visibly evolving under the action of their genetic agents and the related geomorphic processes), quiescent (active but characterized by a discontinuous, step-like evolution mapped in a dormant stage) and inactive (produced in a geomorphological context definitely different from the present one and evolving under the action of agents different from the genetic ones, that generally tend to destroy or bury them) (Dramis et al., 2011).

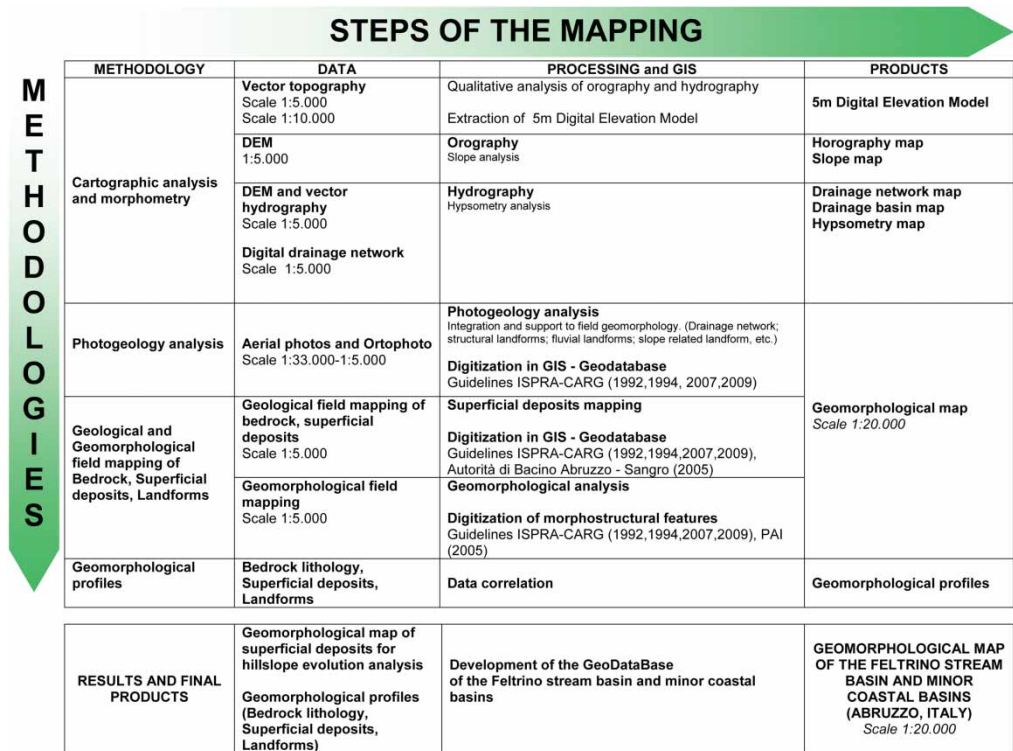


Figure 3. Methods for the creation of the geomorphological map of the Feltrino Stream basin and minor coastal basins.

4. Geomorphological map overview

4.1. Orography and hydrography

The study area is characterized by a tabular relief morphology with elevations ranging from ~400 m to ~ 100 m a.s.l. The maximum altitude is 408 m a.s.l. in the extreme SW sector.

The slopes usually reach $\leq 50\%$ with widespread steep slopes and sub-vertical scarps along the edge of the tabular relief and coastline (see center-lower part of the map).

The whole area is divided into eight catchments ranging in size from $>1 \text{ km}^2$ to $\sim 50 \text{ km}^2$ (Table 1). For each catchment, the drainage pattern and main hypsometric parameters (center-lower part on the map) were defined. The drainage pattern varies from parallel to angular in the SE catchments (with orientation from NNE-SSW to ENE-WSW), and from subparallel to trellis in the main Feltrino catchment (with orientation from N-S to NE-SW). The overall setting demonstrates strong control by bedrock structure (*mesas and plateaux*).

The catchments' hypsometric integrals show high to very high values (see the lower right part of the map). Moderately high values, associated with concave-convex hypsometric diagram, were found in the major catchments (Feltrino 0.47 and Vallegrande 0.48), which are deeply incised (up to 200 m relief) and partly enlarged. Higher values (0.68–0.89), associated with markedly convex hypsometric diagrams, characterize the minor coastal catchments, which are also deeply incised, but not enlarged.

Table 1. Main physiographic parameters of the Feltrino Stream basin and surrounding minor coastal basins.

Basin name	Length (km)	Area (km^2)	Perimeter (km)
Feltrino	19	51	40
Rio Fontana	3	2	8
San Fino	0.48	0.279	3
Canali	1	0.424	4
Valle delle Grotte	3.1	3	9
Vallegrande	9.5	32	30
San Biagio	1.3	1	5
San Giovanni	5	4	15

4.2. Lithology

The study area is characterized by a clay-sandstone-conglomerate bedrock belonging to the Upper Pliocene – Lower Pleistocene marine deposits and locally to the Middle Pleistocene marine to continental transitional deposits. The bedrock is exposed in small outcrops (2.8%) and is covered by near-surface clay-silt-sand-gravel continental deposits (97.2%) ranging in age from the Upper Pleistocene to the Holocene. Colluvial (72.78%) and landslide (15.87%) deposits are the most widespread lithological units, covering slopes, valley bottoms, and top surfaces of the *mesa* and *plateaux* relief; slope, alluvial, and beach deposits (0.05–2.61%) are scattered along valley slopes and the coastline; backfill deposits are common (3.63%) in urban areas (see pie-chart on the [Main Map](#)).

The outcropping lithologies have been classified based on their depositional environment according to the geological mapping guidelines issued by the Italian Geological Survey (ISPRA, 2009; SGN, 1992). The mapped lithology units are listed in the following sub-sections (the numbers in brackets refer to the map) and are also refer to the related units on the official Italian Geological Map of the area (ISPRA, 2010a, 2010b, 2010c).

4.2.1. Marine deposits (bedrock units from 1 to 3):

Clay deposits (1)

This unit is made up of blue-gray clays and marly-clays interbedded with thin sand and clayey-sand levels. The sand/clay ratio is $<<1$. The fossil content is represented by bivalves and small

gastropods. The maximum observed thickness is >300 m (buried thickness up to >1000 m). The unit is referred to as the ‘*Formazione di Mutignano*’ (FMTa) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Upper Pliocene p.p.-Lower Pleistocene p.p.

Sandstone deposits (2)

This unit is made up of poorly to highly cemented yellow-ocher sandstones and silty-sandstones, with interbedded grayish, thinly laminated clays and silty-clays and conglomerate lenses in the upper part. The yellowish sands and sandstones, are frequently bioturbated. Overall thickness is up to 100 m. The unit is referred to as the ‘*Formazione di Mutignano*’ (FMTc, FMTd) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Lower Pleistocene p.p.

Conglomerate deposits (3)

This unit is made up of light color calcareous conglomerates, with well sorted, moderately cemented limestone and subordinate chert clasts immersed in a sandy matrix. The clasts are mostly centimetric in size and are arranged in decimetric layers and lenses, with cross and planar bedding and imbricated pebbles; a few decimeter-thick lenses and layers of sands and silts are occasionally interbedded in the lower part of the unit. The thickness ranges from a few meters to <30 m. The unit is referred to as the ‘*Formazione di Mutignano*’ (FMTd) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Lower Pleistocene p.p.

4.2.2. *Marine to continental transitional deposits (bedrock units 4 to 5)*

Conglomerate and sand deposits (4)

This unit consists of massive or planar bedded calcareous and locally polygenic conglomerates constituted of clast-supported pebbles to cobbles in a whitish sandy matrix. Lenses of channel sands or clays are present. The thickness ranges from a few meters to 25 m. The unit is referred to as the ‘*argille e conglomerati di Ripa Teatina*’ (RPT) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Middle Pleistocene p.p.

Sand-clay deposits (5)

This unit is constituted of gray and interbedded gray-green sand, silt and clay, arranged in levels and lenses with planar or cross bedding. Thickness ranges from a few meters up to 10 m. The unit is referred to as the ‘*argille e conglomerati di Ripa Teatina*’ (RPT) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Middle Pleistocene p.p.

4.2.3. *Continental deposits (near-surface units from 6 to 11)*

Scree slope deposits (6)

Scree slopes are made up of loose to weakly cemented deposits, composed of angular, euhedral pebbles and cobbles with poor sandy matrix ([Figure 4a](#)). Conglomerate and sandstone boulders are locally present. The thickness is up to 5–10 m. The unit is referred to as the ‘slope deposits’ (olo_a) of [ISPRA \(2010a\)](#). The age is Holocene.

Landslide deposits (7)

Landslides are constituted of chaotic assemblages of polygenic clay and sand deposits, with conglomerate and sandstone boulders and, locally, very large blocks ([Figure 4b](#)). The thickness is from a few to <10 m. The unit is referred to as the ‘landslide deposits’ (olo_{a1}) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Holocene.

Colluvial deposits (8)

Colluvium is made up of loose to moderately firm heterogeneous deposits mapped in four different subunits. The unit is referred to as the ‘colluvial deposits’ (olo_{b2}) of [ISPRA \(2010a, 2010b, 2010c\)](#) and to the Holocene age. Subunits are:

- mainly silt-clay deposits (a) – grayish-brownish clayey silt, with calcareous concretions, calcrete levels and, locally, sandy levels; the thickness is variable, up to 15 m
- mainly sand-silt deposits (b) – grayish to yellowish sandy silt, silt and sand with calcareous concretions ([Figure 4c](#)); the thickness is up to 5–10 m
- mainly gravel deposits (c) – yellowish to brown gravel deposits, from clast to matrix supported, with sand and silt matrix; calcareous concretions are present; the deposits are in a chaotic assemblage or clinostratified conformably to the slopes; the thickness is up to <10 m
- mainly silt with pebble and cobble deposits (d) – brown-reddish to reddish silt with chert and calcareous pebbles and cobbles arranged in lenses with silt matrix or scattered within the main deposit ([Figure 4d](#)); calcareous concretions and calcrete levels are present; the deposits are in a chaotic assemblage or clinostratified conformably to the slopes; the thickness is up to 5–10 m.

Alluvial deposits (9)

Alluvial deposits consist of loose heterogeneous gravel, sand, silt and clay, mapped in two different subunits. The unit is referred to as the ‘alluvial deposits’ (olo_b) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Holocene. Subunits are:

- mainly silt-clay deposits (a) – fluvial clay, clayey-silt and silt, with levels(?) and lenses of sand; the thickness is <5 m
- mainly sand-gravel deposits (b) – fluvial sand and gravel, with lenses and levels of silt and clay; gravel is made up of heterometric (size 1–15 cm), polygenic (calcareous and cherty) clasts, with a sub-rounded shape, mainly matrix-supported ([Figure 4e](#)); the thickness is from a few to 5 m.

Beach deposits (10)

Beach deposits consist of loose sand and gravel, mapped in two different subunits. The unit is referred to as the ‘beach deposits’ (olo_{g2}) of [ISPRA \(2010a, 2010b, 2010c\)](#). The age is Holocene. Subunits are:

- sand deposits (a) – loose or slightly compacted yellow-ocher fine to medium sand, with cross bedding; the thickness is from a few to >5 m
- sand-gravel deposits (b) – gravel is made of heterometric (size 1–10 cm), polygenic (calcareous and cherty) subrounded to rounded clasts, with lenses and levels of sand ([Figure 4f](#)); the thickness is from a few to >5 m.

Backfill deposits (11)

Backfill deposits are made up of chaotic and heterometric material constituted by gravelly clay and sandy-clay and fragments of waste material deposited in inactive gravel quarries. The unit is referred to as the ‘backfill deposits’ (olo_h) of [ISPRA \(2010a, 2010b, 2010c\)](#) and is very recent (developed mostly after 1950, after the building of major urban areas, roads and highways).

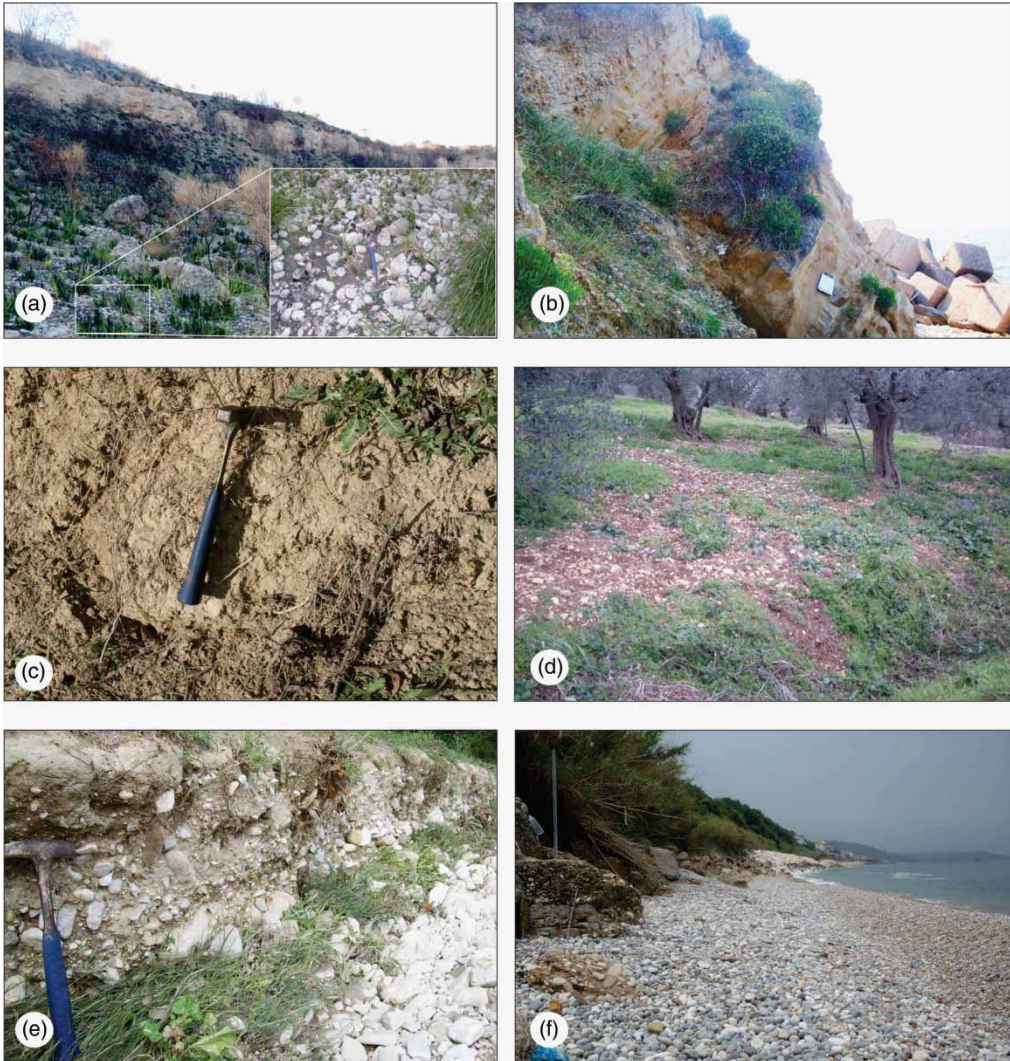


Figure 4. Continental near-surface deposits (numbers refer to the legend of the map). (a) Scree slope deposits at Punta Cavalluccio (6) and detail view of coarse debris; (b) Landslide deposits south of Punta del Guardianio; view of a highly counterslope tilted landslide block close to sea level (7); (c) Detail view of sand-silt colluvial deposits (8b) southwest of San Vito; (d) Silt with pebbles and cobbles colluvial deposits on a smooth slope (8d) north of Rocca San Giovanni; (e) Sand-gravel alluvial deposits incised along the lower Feltrino Stream (9b); and (f) Sand-gravel beach deposits (10b) at Punta Turchino.

4.3. Geomorphology

The most recurrent features in the study area are structural landforms, slope landforms due to the action of gravity (landsliding, scree production) and fluvial (bank erosion, channel incision) and soil erosion (runoff) landforms, sometimes favored because of the lithostructural characteristics of the area (Figure 5). Marine landforms (cliff edges) are only present along the Adriatic coast. Finally, anthropogenic landforms are mainly concentrated near urban areas and along the main roads and railways (Main Map).

4.3.1. Structural landforms

Mapped structural landforms, widespread in the whole study area, include *mesa* and *plateau* top surfaces, structural scarps, asymmetrical ridges, and structure-controlled saddles.

The top surfaces of *mesa* and *plateaux* are deeply weathered partly covered by colluvial deposits. Structural scarps, carved in cemented conglomerate (conglomerates of the marine and transitional deposits) border the uppermost part of the subvertical slopes of the deeply incised valleys dissecting the *mesa* and *plateaux* morphology (Figure 5a). These landforms range from steep scarps with a sharp edge, incised by fluvial and marine erosion, to smoothed scarps, progressively weathered by landslides and slope processes (due to gravity and soil erosion) (Figure 5b).

Along the drainage divide between the Feltrino Stream basin and the Sangro River and Moro Stream basins, saddles are mostly trending NNE-SSW and WNW-ESE and aligned with straight valleys and ridges and with the main direction of parallel, angular and trellis drainage. This outlines a structural control possibly related to joints and small faults affecting the bedrock (see also D'Alessandro et al., 2008).

4.3.2. Slope gravity landforms

Slope gravity landforms relate to a large number of landslides, including: reverse slopes, small landslides (shown by a point symbol), gravity trenches, rotational slides, rock falls, complex landslides and lateral spreads with related scarps (active, quiescent or inactive) (Dramis et al., 2011).

Rotational slides were mapped along the main valleys (Feltrino and Vallegrande basins) and in the coastal sector between the villages of San Vito Chietino and Fossacesia (Figure 5c and d). Affected lithologies are sandstone, sand-conglomerate, and colluvial deposits. Rock falls occur on sub-vertical scarps made of sandstone and conglomerate (Figure 5b), and are mainly located along the secondary valleys in the eastern coastal area. Complex landslides and lateral spreads, strongly influenced by the structural setting, are mapped in the southeastern sector of the study area (Figure 5e).

Large inactive complex landslides are present in the coastal sector and are occasionally partially affected by several small landslides located at the landslides' toe.

4.3.3. Fluvial and soil erosion landforms

The mapped fluvial and soil erosion landforms include: V-shaped valleys, concave valleys, flat-bottom valleys, asymmetric valleys, hanging valleys, beheaded valleys, fluvial erosion scarps, bank failures, gullies, entrenched fluvial segments, rectilinear fluvial segments, river bends, river beds with a trend to down cutting, counterflow and ninety-degree confluences, badlands, and runoff erosion areas (rill and sheet erosion).

Concave valleys were mostly recognized along the upper part of the secondary streams (generally 1st-order streams) with orientations ranging from SW-NE to WNW-ESE, and often gradually evolve downstream (usually 2nd and 3rd stream order) into V shaped valleys. Flat-bottom valleys are documented, corresponding to the main valleys where moderately wide alluvial plains are present. Hanging valleys were mapped mostly along the secondary stream divides, in the coastal sector (Figure 5f); the orientation mainly ranges from SW-NE to WNW-ESE. Beheaded valleys are present along the SW drainage divide with the neighboring Sangro River and Moro Stream basins.

Fluvial erosion scarps are present along the bottom of the main valleys (Feltrino Stream, Santo Spirito Stream, Vallegrande Stream, and San Giovanni Stream), where they affect alluvial deposits but also landslide and colluvial deposits. Along the Feltrino Stream northwards of the Treglio

village, these landforms are affected by bank failures. River bends are widespread along the streams of the study area, and are commonly connected with landslides and bedrock, related to the angular drainage pattern. Several ninety-degree confluences are mapped along the junction of the tributary valleys with the main streams (e.g. Feltrino Stream, Spirito Santo Stream, Fontanelli Stream), all related to the trellis drainage pattern.

Rill and sheet erosion mainly occurs in agricultural areas, as a consequence of ploughing; these areas are affected by soil erosion due to runoff, particularly during heavy rainfall events.

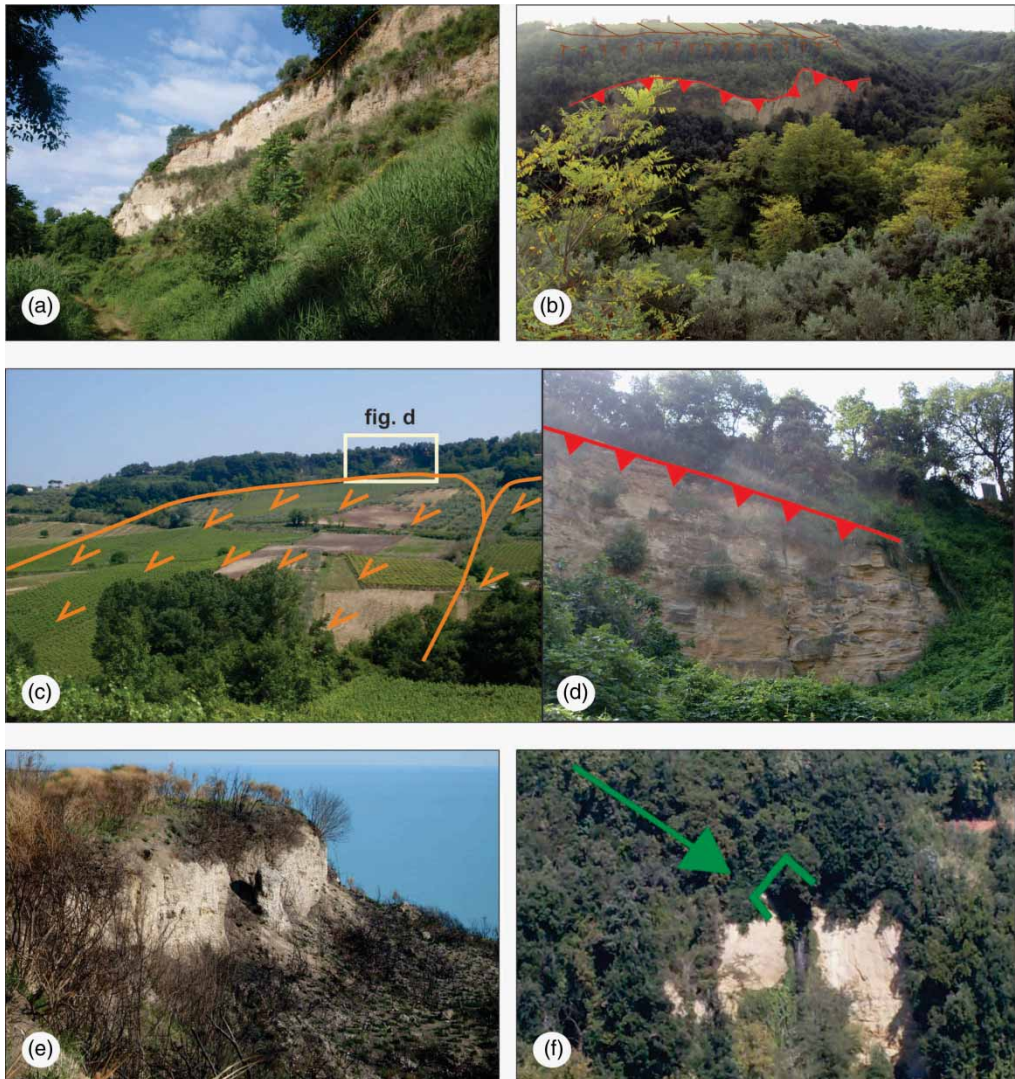


Figure 5. Geomorphological features. (a) Structural scarp near Rocca San Giovanni, (b) Weathered structural scarp, and rockfall scarp in the southern sector near San Vito Chietino, (c) Rotational landslide along the middle-lower Feltrino Stream, (d) detail view of the landslide scarp. (e) Lateral spread at Punta Cavalluccio, and (f) hanging valley along Fosso Fontanelli.

4.3.4. *Marine landforms*

Small cliffs, from a few to ~10 m high, characterize some of the main promontories of the study area (Punta Turchino, Punta del Guardiano, and Punta Cavalluccio). Frequently, these landforms affect the coastal landslides' toe, inducing several small landslides on to it.

4.3.5. *Anthropogenic landforms*

Mapped anthropogenic landforms are: scarps, gabions, river weirs, channeled rivers, river shore-line structures and quarries. Anthropogenic scarps are widespread near urban areas and along main roads and railroads. Gabions, rivers weirs, and channeled rivers are found along main streams, particularly close to their mouths. These landforms include coastal structures built up to protect roads and railways from marine erosion.

5. **Hillslope evolution**

The study area is characterized by widespread colluvial and landslide deposits covering hillslopes of the Adriatic piedmont that developed on clay-sandstone-conglomerate bedrock. The deposits (as outlined in section 4.2) are related to slope processes due to gravity and soil erosion.

Geomorphological analysis of near-surface deposits allowed: (i) an outline of the relationship between the stratigraphic setting of near-surface deposits and landforms; (ii) definition of the relationship between processes and near-surface deposits; and (iii) production of block diagrams showing geomorphological features of the hillslopes at different stages of evolution.

The geomorphological evolution of the hillslopes is summarized in four steps (see [Main Map](#)):

- (1) Hillslopes show a steep and sharp profile. Landslides (mainly rockfalls and topples) affect the sharp edges of structural scarps on hard rocks (conglomerate or sandstone with conglomerate lenses). Slope and rockfall deposits, made of sandstone and conglomerate blocks, cover the scarp base.
- (2) Progressive hillslope weathering defines multiple, step-like vertical and sub-vertical scarps, due to the control of alternating sandstone and conglomerate bedrock deposits. The scarps are bounded at the base by moderately steep and undulating slopes. Here, former slope deposits are eroded and reworked by surface runoff or sheet erosion. Slope deposits cover the base of the slopes and single scarps, while new colluvial deposition begins at the top of the slopes.
- (3) Hillslopes show an irregular profile with small discontinuous scarps; former scarps are eroded and weathered. Colluvial deposits progressively cover the upper part of the slopes and the former scarps; they also begin to affect the base of the slope due to erosion and reworking of slope deposits by surface runoff or sheet erosion; new slope deposits are locally present along the scarp remnants.
- (4) Finally, hillslopes show a smooth convex-concave profile which characterizes the deeply weathered structural scarps. Colluvial deposits progressively cover the upper part of the slopes and new deposits develop along the middle and lower parts of the slopes, blanketing the bedrock deposits and locally ancient slope and landslide deposits.

From a more general point of view, these local geomorphological processes are related to regional scale events, such as deep valley incision and marine erosion-deposition processes connected to Middle Pleistocene – Holocene uplift, climate and sea-level change ([Parlagreco et al., 2011](#) and references therein).

6. Conclusion

This study, undertaken in the coastal basins of south eastern Abruzzo (Central Italy), allowed the mapping of near-surface deposits and analysis of hillslope evolution in the Adriatic piedmont of the Central Apennines. These features are represented on the geomorphological map (1:20,000 scale) of the Feltrino Stream basin and surrounding minor coastal basins [Main Map](#).

Overall analysis highlights the widespread occurrence of near-surface deposits whose development is related to the evolution of structural landforms (i.e. structural scarps, *mesa* and *plateaux* top surfaces). This evolution is summarized in four main stages, resulting from the superimposition of major slope gravity and fluvial processes (i.e. landslides, gullies, V-shaped valleys) and of soil erosion and slope processes (i.e. surface runoff, sheet erosion, soil creep), which have progressively smoothed and blanketed the scarps with near-surface deposits.

These evolutionary stages are preserved in the different catchments of the study area. Small coastal catchments show a landscape mostly affected by linear incision (also documented by orographic features and high hypsometric values), and preserve the first stages of hillslope evolution (1, 2 lower part on the [Main Map](#)). Large catchments (i.e. Feltrino and Vallegrande) were primarily affected by linear incision and secondarily enlarged by non-linear geomorphic processes, related to large landslide and hillslope processes (also documented by orographic features and moderately high hypsometric integral values with concave-convex shaped curves), and show later hillslope evolutionary stages (3, 4 lower part on the [Main Map](#)).

Generally, local geomorphological processes were induced by Middle Pleistocene – Holocene uplift processes and climate and sea-level change, which occurred after the late Early Pleistocene emergence of the western Adriatic area and the subsequent evolution of the Adriatic piedmont into a subaerial environment. This hillslope evolution could be considered representative of hilly regions developed on uplifted soft bedrock lithologies (clay-sand-conglomerate) within mid-latitude climate conditions, such as the whole Adriatic piedmont of the Apennines chain.

In conclusion, at a local scale, the detailed mapping of near-surface deposits and landforms contributes to understanding of the causes, mechanisms, and consequences of landform change also with a view to assisting engineering geomorphological problems. More generally, the geomorphological map presented in this work may be used as a tool for land management and assessment of geomorphological hazards (i.e. soil erosion, landslides, flooding), particularly in hilly landscapes characterized by widespread and variable surface deposits and by intense and rapid geomorphological processes (slope, soil erosion, fluvial).

Software

The map presented in this work has been managed and produced using Esri ArcGIS 10.1.

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