SCIENCE

Geomorphology of Pisticci area (Basilicata, Southern Italy)

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ABSTRACT

This paper presents the results of geomorphological investigations carried out in Basilicata region (Southern Italy) in the sector of the youngest foredeep (Bradano trough) relative to most of the communal territory of Pisticci. The importance of the chosen area mostly lies in the presence of diffuse running-water landforms and landslides affecting urban areas. The geomorphological processes are linked with Quaternary tectonic uplift affecting the Apennine front-Bradanic foredeep sectors. A series of field surveys, supported by aerial photo interpretation, have led to the production of a geomorphological map at 1:35,000 scale which outlines the main processes and related landforms recognised in the study area. The latter are the result of the complex interplay of structural, gravitational and fluvial processes. Particular attention has been devoted to the recognition, identification and mapping of landslides which affect the slope, locally giving rise to hazardous conditions.

1. Introduction

The territory of Pisticci, Basilicata, southern Italy is emblematic of the geomorphological evolution of the Bradano trough, a NW-trending tectonic depression located between the Apennine chain and the Apulian Foreland. The whole area is dramatically characterised by hydrogeological instability due to the combination of the recent tectonic uplift, the tectono-structural arrangement of the outcropping successions and the peculiar climatic conditions. In particular, landslides and badlands, strongly affect the hilly area creating hazardous conditions (Clarke & Rendell, 2006; Guerricchio & Melidoro, 1979a). In the last 50 years, the town of Pisticci has been using a series of protective measures to mitigate risks to the community. Moreover, due to the clayey nature of the outcropping lithologies, the territory is prone to severe soil erosion, expressed in such typical extreme forms as gullies, badlands (*calanchi* and *biancane*) and rills. Periodically, during heavy rainfall events, mudflows have occurred causing damage to infrastructure (secondary roads, bridges, etc.) and to agriculture, especially in the coastal area (Piccarreta, Capolongo, Miccoli, & Bentivenga, 2012).

The morphological features in the study area are strictly controlled by structural factors and shaped by gravitational and fluvial processes. In particular, the area is largely characterised by the occurrence of landslides which are favoured by structural conditions and triggered by rainfall erosion (Floris & Bozzano, 2008; Lazzari, Piccarreta, & Capolongo, 2013).

Previous studies carried out in the area mainly deal with slope instability processes (Bentivenga, Coltorti, Prosser, & Tavarnelli, 2004; Floris & Bozzano, 2008; Guerricchio & Melidoro, 1979a, 1979b), soil erosion features (Alexander, 1982; Clarke & Rendell, 2000, 2006; Del Prete, Bentivenga, Coppola, & Rendell, 1994; Del Prete et al., 1997; Piccarreta, Capolongo, Boenzi, & Bentivenga, 2006) and processes (Capolongo, Diodato, Mannerts, Piccarreta, & Strobl, 2008; Piccarreta, Faulkner, Bentivenga, & Capolongo, 2006; Piccarreta, Bentivenga, & Capolongo, 2010; Piccarreta, Capolongo, Miccoli, & Bentivenga, 2012). Recently Bentivenga, Capolongo, Palladino, and Piccarreta (2015) produced a detailed geomorphological map of the south-western sector of Pisticci but neglected more than half of the communal territory. The present paper provides a broad picture of the main geomorphic processes occurring in the whole territory of Pisticci. As a result, a detailed geomorphological map at 1:35,000 scale has been drawn.

2. Study area

The study area lies in the Bradano trough, a NW-trending tectonic depression located between the Apennine chain and the Apulian Foreland. The southern Apennines result from the passive margin inversion of the Apulian plate, with a northeastward vergence, during the Neogene (Patacca & Scandone, 2007; Tropeano, Sabato, & Pieri, 2002 and references therein). Structurally, the sector of the chain studied in this paper represents a thick pile of tectonic units derived from different paleogeographic domains overthrusting the carbonates of the Apulia platform. The lower portion of this pile consists of Meso-Cenozoic sedimentary
rocks and, more specifically, of deep-sea sedimentary rocks of the Lagonegro-Molise basin, tectonically overlain by the neritic limestone of the Apennine platform. The highest thrust sheets of the tectonic edifice of the Southern Apennines are represented by the Liguride and Sicilide Complex. At the front of the chain outcropping the Bradano trough, the investigated sector represents the youngest foredeep basin of the southern Apennine (Patacca & Scandone, 2001). The sector of the Basilicata region falls from the southern Apennines chain and the Bradano trough. A clayey succession belonging to the meso-cenozoic deep marine sediment of the Sicilide and Sannio successions (Cavalcante, Fiore, Lettino, Piccarreta, & Tateo, 2007; Cavalcante, Belviso, Bentivenga, Fiore, & Prosser, 2011; Lentini, Carbone, Di Stefano, & Guarnieri, 2002 and references therein) crops out in the western sector of this area.

Plio – Pleistocene marine paralic and continental deposits filling the Bradano trough are present in the eastern sector of the Basilicata region (Patacca & Scandone, 2001). From the bottom the succession consists of: (i) Upper Pliocene sequence of the fan-delta-front to shallow marine conglomerates and sandstones, lagoon-to open-shelf mudstones including subordinate diatomitic clays, fan-delta-front conglomerates and sandstones laterally grading into eastward bioclastic sandstones and siliciclastic calcarenites; (ii) Lower Pleistocene – middle Pleistocene p.p. sequence made up of shallow marine sandstones and shelf mudstones (Argille di Craco), fan-delta to shelf deposits represented by Sabbie di Tursi. Upwards are present subordinately nearshore sandstones and open-shelf muddy deposits named in the literature as Argille di Appenniniche. The upper part of this sedimentary sequence (middle Pleistocene p.p.) crops out in the western area of the Bradano trough consisting of Montalbano sands while Gravina clays are present in the eastern area. The sedimentary sequence is closed by alluvial and fluvo-deltaic deposits represented by Monte Marano and Staturo Sands as well as by Irsina Conglomerates.

The uplift of the entire region during the Middle-late Pleistocene caused valley incision and exposure of the Subappennine Clays, which assumed a generalised monoclinic arrangement, gently dipping north – eastwards, due to the push of the southern Apennine thrust-belt (Amato, 2000).

The average slope angle allows the Pisticci hill to be classified into two main areas as suggested by Del Prete et al. (1994): a high-energy relief (LER) and a low-energy relief (LER) which are characterised by different morphological and evolutionary behaviours (Figure 1).

The HER consists of a compound scarp (sensu Schumm & Chorley, 1966), with a 40 m thick sandy-conglomeratic caprock, which covers the plio-pleistocenic clays (about 500 m thick). The caprock determines a moderate to strong hillslope gradient (from 25° to 45°).

The LER consists of simple scarps (sensu Schumm & Chorley, 1966), with an average slope ranging between 5° and 25°, characterised by plio-pleistocenic clays which are locally capped by a sandy lens.

The two relief settings are clearly separated by a slope pediment, which joins the upper part of the hill-slope and a Pleistocene fluvial terrace. The main distinguishable morphological element that differentiates one relief from the other is the sandy-conglomeratic caprock, which determines a different relief ratio, expressed as the ratio between the total relief of the hill-slope (elevation difference between the lowest and the highest points of a basin) and its surface length.

Moving towards the Ionian Sea, there are a series of gently sloping marine terraces. They are separated by distinct scarps, which represent the sculpting of the Plio-Pleistocene marine clays and the deposition of littoral sediments along a sequence of successively lower paleocoastlines through the Middle to Late Pleistocene (Amato, 2000; Bentivenga et al., 2004; Brückner, 1980; Cotechia & Magri, 1967; Dai Pra & Heathry, 1988; Heathry & Dai Pra, 1992; Westaway & Bridgland, 2007). The number of the terraces has been a much debated subject and different authors have claimed the existence of 7–11 terraces (Abbott, 2011).

The littoral zone extends along the modern coast, which is the locus of extensive deposition under the action of coastal, fluvial and aeolian processes.

The climate is Mediterranean, with a mean annual precipitation of about 600 mm concentrated from November to January (Piccarreta, Pasini, Capolongo, & Lazzari, 2013) and a yearly average temperature ranging from 16° to 17.5°, with an average maximum between 24° and 25.5° during the summer and an average minimum between 8° and 9.5° during the winter (Piccarreta, Capolongo, Bentivenga, & Pennetta, 2005; Piccarreta, Lazzari, & Pasini, 2015).

3. Methods

A series of field surveys supported by aerial photo interpretation have been carried out in the Pisticci area, Basilicata, southern Italy. The final map has been printed at 1:35,000 scale. Aerial photos from 1954, 1972 and 2003 were analysed to reconstruct the recent geomorphological evolution. The lithological and structural features have been derived from the geological map of Bentivenga et al. (2004), validated and implemented by means of field observations.

Geomorphological mapping was performed mainly following the guidelines proposed by the Italian Geological Survey (Gruppo di Lavoro per la Cartografia Geomorfologica, 1994). The guidelines provide symbols for a genetic representation of landforms and of the type of processes through different colours and
indicate their level of activity by means of colour intensity (more intense for more active processes).

Five main sets of landforms and deposits have been identified and mapped: (i) structural landforms, (ii) gravity induced slope landforms, (iii) fluvial and slope landforms due to running water, (iv) marine landforms and (v) aeolian landforms.

Topographic elements have been drawn in grey and have been represented as point elements (spot heights) and line elements (isohypses and roads).

4. The geomorphological map

4.1. Structural landforms

The Pisticci hill can be subdivided into HER and LER areas. In the area the two relief settings are clearly separated by a slope pediment dipping 15° towards the valley bottom, which joins the upper part of the hillslope with a Pleistocene fluvial terrace (Figure 1). The pediment surface is made of landslide detritus and consists of heterometric arenaceous and conglomeratic blocks from the upslope caprock and its surface has been reworked and smoothed by subaerial erosion processes. It has been covered by sandy colluvial material and is correlated with the alluvial deposits at the top of a Pleistocene fluvial terrace. In the HER area, the main distinguishable structural element is the sandy-conglomeratic caprock, which constitutes a marine terrace in the Pisticci area made up of heterometric pebbles in a reddish sandy matrix (Figure 2(a) and 2(b)). In the LER area, the topography has a gentle dip and morphology is expressed as a typical monoclinal landscape.

4.2. Marine and aeolian landforms

Approximately one million years ago, the deposits of the Bradanic trough began to be uplifted, causing the sea to withdraw to the southeastwards (Grove & Rackham, 2003). As the sea gradually retreated during the Middle to Late Pleistocene, a succession of shorelines were constructed and abandoned, leaving a series of marine terraces (Westaway & Bridgland, 2007). These sub-parallel terraces are cut into the Plio-Pleistocene marine clays and extend 16–20 km from Pisticci to the coast.

The terraces, which range in elevation from approximately 350–25 m above sea level, are mantled with relatively thin deposits of beach sands and gravels. The highest terraces have been deeply dissected by gully systems and tributary streams locally up to the clayey bedrock (Figure 3(a)). The gullies are perpendicular to the present shoreline in the hilly part, but subsequently they are captured southwards, probably due to a fault system which is sub-parallel to the shoreline. They are characterised by vertical sidewalls and are 10–30 m deep and 25–450 m wide, with a high
degree of lateral expansion in relation to head retreat or linear advance due to the frequent failure of gully walls and the retreat of gullies. Thus the highest terraces consist of small remnant platforms surrounded by extensive badland topography developed on the clays. The town of Pisticci occupies the entirety of one of these small inland remnant platforms. The lowest terraces are well preserved, stretching with few interruptions from valley to valley. Estimates of the number of the present marine terraces, ranging from 7 to 11, are complicated by the extreme dissection of the older, higher examples. The coastal area mainly consists of a gently inclined sand beach and Holocene aeolian dunes (Longhitano, 2015). The aeolian dunes form two distinct sets, both parallel to the shoreline, one directly in contact with the beach, the other inland. The first set is made up of free dunes while the inner one is fixed by vegetation (Figure 3(b)). The coastal plain is crosscut by a number of paleochannel traces, demonstrating that avulsion of the major streams has occurred repeatedly throughout the Late Holocene (Abbott, 2011).

4.3. Landslides
The landsliding phenomena affecting the hilly area are intimately connected with the presence of the sandy-conglomeratic caprock. Underlying the caprock, the weaker mudstones are highly unstable on steep slopes and, as a result, this part of the landscape is dominated by debris flows and shallow landslides that often initiate in low order streams (Miccoli, Capolongo, Piccarreta, & Caldara, 2014). Many landslides consist of rotational and translational earth slides and, in a few cases, earth flows and rock lateral spreading (Figure 4(a)–4(c)). The resistant caprock stands out prominently, resulting in structurally controlled slopes dominating the hilly landscape. In fact, it constitutes a structural tie which allows the maintenance of an elevated slope threshold in the underlying clays, over which the hillslopes are in continuous rejuvenation by means of channel incisions, thus resulting in the development of calanchi landforms (Figure 5(a) and 5(b)). At the same time, the erosion of the substrate leads to caprock failure (rock-falls) and collapse (Floris & Bozzano, 2008). This landscape evolution contributes to maintain a high relief ratio and to a parallel scarp retreat.

4.4. Fluvial and slope landforms due to running water
These are the most widespread morphologies of the whole area. The territory is emblematic for the presence of badlands in any forms (calanchi and biancane). Calanchi are large degraded landscapes, which can be considered as small hydrographic units, with steep, bare slopes and channels which rapidly incise and extend headwards (Alexander, 1982), whereas biancane are dome-shaped forms dominated by rills and micropipes developed in bedrock and surrounded by a basal micropediment (Calzolari & Ungaro, 1998; Torri & Bryan, 1997). Calanchi forms dominate the hilly areas, where they developed on scarps and bodies of landslides that were shaped by running water. In the LER badland erosion in any form (calanchi and biancane) affects all the steepest slopes (approximately 42°) of the NE dipping monoclinal relief, whereas the gentler slopes (approximately 12°) are affected by rill erosion and small landslides (earth flows) which are usually only related to regolith. A recurrent morphological feature in the lower valley is the coupling of low gradient badland slopes with gullies in valley fills, with the basal pediments of badland slopes which are perfectly joined with the Holocene fills (Alexander, 1982; Clarke & Rendell, 2006). Biancane are considered to have formed at an early stage of the dissection of the alluvial pediments.

The widespread presence in the area of badland gullies in valley fills is a consequence of the progressive Middle-Late Pleistocene regional uplift which brought ancestral rivers to cut deep valleys perpendicular to the coast.

The fluvial pattern is dominated by the succession of fluvial terraces of the Basento and Salandrella-Cavone rivers. In the area four orders of fluvial terraces have been recognised (Boenzi et al., 2008; Piccarreta,
Caldara, Capolongo, & Boenzi, 2011; Piccarreta, Capolongo, & Miccoli, 2012. The oldest recognised fluvial terraces belong to the Late Pleistocene age and occur at an elevation between 120 and 170 m, which is fully consistent with the fluvial terraces of the nearby Basento river. The age of these terraces is of about 39 ka BP on the base of a Campanian Ignimbrite tephra found at the top of several correspondent fluvial terraces of the Basento river (Boenzi et al., 2008). They are not well preserved in the Salandrella-Cavone river basin, where areal erosion and landsliding have reduced their extent. The terraces mainly consist of silty-loamy alluvium; the presence of conglomerates is scarce due to the nature of outcropping terrains. At an elevation of around 90–100 m, over the Middle-Late Holocene terraces, a second series of Pleistocene fluvial terraces are present (Abbott & Valastro, 1995). Their age is at present unknown and they are reduced to small poorly preserved strips of loamy colluvium with thin intercalations of sands. The Middle-Late Holocene terraces consist of a sequence of alternating silty-sand deposits with thin intercalations of conglomerate lenses occurring at elevations of 10–20 m above the present-day channel. Sedimentation started at

Figure 4. Landslide movement under marine caprock at Pisticci hill (photo a courtesy of Autorità di Bacino della Basilicata).

Figure 5. Fluvial and slope landforms due to running water affecting the study area. (a) Calanchi development in the HER area at Pisticci. (b) Calanchi and biancane development on the homoclinal ridges.
around 7200 cal yr BP and ended at around 800 cal yr BP (Boenzi et al., 2008; Piccarreta et al., 2011). The second order of Holocene terraces consists of a more than 1-m-thick basal coarse gravel layer mantled with relatively thin (2–4 m thick) sandy and silty alluvium at elevations of 3–5 m above the modern channel. On the basis of radiocarbon dating of the same terrace order in the Basento river catchment (Piccarreta et al., 2011) the sedimentation of this last terrace should have started during the Little Ice Age, at around 300 from 120 cal yr BP. The streams shift abruptly into a broad, shallow, braided channel pattern, and the high Holocene terraces that dominate the lower valleys narrow and disappear as the floodplain expands (Abbott, 2011).

5. Conclusions

The territory of Pisticci has in recent times experienced damaging landslides, causing the death of many people as well as damage to infrastructure. Moreover, due to the clayey nature of the outcropping lithologies, it is prone to be affected by severe soil erosion, expressed in such extreme forms as gullies, badlands (calanchi and biancane) and rills. Periodically, on the occasion of heavy rainfall events, mudflows have occurred causing loss of life and damage to infrastructure (secondary roads, bridges, etc.) and agriculture.

Therefore, adequate cartography is needed in order to draw a geomorphological map, representing the main active morphological processes, with a reference scale of 1:35,000.

Software

The dataset of the map, including the symbols of the geomorphological legend, has been digitised and managed using ESRI ArcGIS 9.3.

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References

Abbott, J. (2011). Geomorphology and geoarchaeology of the metapontino. In J. C. Carter & A. Prieto (Eds.), The chora of Metaponto 3 Archaeological survey Bradano to Basento (pp. 31–68). Austin: University of Texas Press.

Abbott, J., & Valastro, S. (1995). The holocene alluvial records of the chora of Metapontum, Basilicata and Croton, Calabria, Italy. In J. Lewin, M. G. Macklin, & J. C. Woodward (Eds.), Mediterranean quaternary river environments (pp. 195–205). Rotterdam: A.A. Balkema.

Alexander, D. E. (1982). Difference between ‘calanchi’ and ‘biancane’ badlands in Italy. In R. Bryan & A. Yair (Eds.), Badland geomorphology and piping (pp. 71–88). Norwich: Geo.

Amato, A. (2000). Estimating Pleistocene tectonic uplift rates in the South-eastern Appennines, Italy from erosional land surfaces and marine terraces. In O. Slaymaker (Ed.), Geomorphology, human activity and global environmental change (pp. 67–87). New York: John Wiley and Sons.

Bentivenga, M., Capolongo, D., Palladino, G., & Piccarreta, M. (2015). Geomorphological map of the area between Craco and Pisticci (Basilicata, Italy). Journal of Maps, 11 (2), 267–277. doi:10.1080/17445647.2014,935501

Bentivenga, M., Coltorti, M., Prosser, G., & Tavarnelli, E. (2004). A new interpretation of terraces in the Taranto Gulf: The role of extensional faulting. Geomorphology, 60, 383–402.

Boenzi, F., Caldana, M., Capolongo, D., Dellino, P., Piccarreta, M., & Simone, O. (2008). Late pleistocene – holocene landscape evolution in Fossa Bradanica, Basilicata (Southern Italy). Geomorphology, 102, 297–306.

Brückner, H. (1980). Marine Terrassen in Süditalien. Eine quartärmorphologische Studie über das Küstentiefland von Metapont. Düsseldorf Geographische Schriften, 14, 1–235.

Calzolari, C., & Ungaro, F. (1998). Geomorphic features of badlands (biancane) area (central Italy): Characterisation, distribution and quantitative spatial analysis. Catena, 31, 237–256.

Capolongo, D., Diodato, N., Mannaearts, C. M., Piccarreta, M., & Strobl, R. O. (2008). Analyzing temporal changes in climate erosivity using a simplified rainfall erosivity model in Basilicata, Southern Italy. Journal of Hydrology, 356, 119–130.

Cavalcante, F., Belviso, C., Bentivenga, M., Fiore, S., & Prosser, G. (2011). Occurrence of polygorskite and sepiolite in upper Paleocene – middle Eocene marine deep sediments of the lagonegro basin (southern Apennines – Italy): Paleoenvironmental and provenance inferences. Sedimentary Geology, 233, 42–52.

Cavalcante, F., Fiore, S., Lettino, A., Piccarreta, G., & Tateo, F. (2007). Illite-smectite mixed layers in Sicilide shales and piggy back deposits of the Gorgogline formation (Southern Apennines): Geological inferences. Italian Journal of Geoscience, 126, 241–257.

Clarke, M. L., & Rendell, H. M. (2000). The impact of the farming practice of remodelling hillslope topography on badland morphology and soil erosion processes. Catena, 40, 229–250.

Clarke, M. L., & Rendell, H. M. (2006). Process-form relationships in Southern Italian badlands: Erosion rates and implications for landform evolution. Earth Surface Processes and Landforms, 31, 15–29.

Cotecchia, V., & Magri, G. (1967). Gli spostamenti della linea di costa quaternaria del mar Ionico tra Capo Spulico e Taranto. Geologia Applicata e Idrogeologia, 2, 1–27.

Dai Pra, G., & Heathry, P. J. (1988). Il livelli marini pleistocenici del Golfo di Taranto. Sintesi geocronologica e tettonica. Memorie Della Societa Geologica Italiana, 41, 637–644.
Del Prete, M., Bentivenga, M., Amato, M., Basso, F., & Sacconi, P. (1997). Badland erosion processes and their interactions with vegetation: A case study from Pisticci, Basilicata, Southern Italy. *Geografia Fisica e Dinamica Quaternaria*, 20, 147–155.

Del Prete, M., Bentivenga, M., Coppola, L., & Rendell, H. (1994). Aspetti evolutivi dei reticoli calanchivi a sud di Pisticci. *Geologica Romana*, 30, 295–306.

Floris, M., & Bozzano, F. (2008). Evaluation of landslide reactivation: A modified rainfall threshold model based on historical records of rainfall and landslides. *Geomorphology*, 94, 40–57.

Grove, A. T., & Rackham, O. (2003). *The nature of Mediterranean Europe. An ecological history* (II ed.). New Haven, CT: Yale University Press.

Gruppo di Lavoro per la Cartografia Geomorfologica. (1994). Carta geomorfologica d’Italia 1:50.000 – Guida al rilevamento. *Quaderni SGN*, serie III, 4, 1–42.

Guerricchio, A., & Melidoro, G. (1979a). *Contributo alle conoscenze dell’origine dei calanchi nelle argille grigio azzurre calabriane della Lucania*. Annali Facoltà d’Ingegneria. Università di Bari, 4.

Guerricchio, A., & Melidoro, G. (1979b). Fenomeni franosi e neotettonici nelle argille grigio-azzurre calabriane di Pisticci, Lucania con saggio di cartografia. *Geologia Applicata e Idrogeologia*, 14(1), 105–138.

Hearthly, P., & Dai Pra, G. (1992). The age and stratigraphy of Middle Pleistocene and younger deposits along the Gulf of Taranto (Southeast Italy). *Journal of Coastal Research*, 8, 882–905.

Lazzari, M., Piccarreta, M., & Capolongo, D. (2013). Landslide triggering and local rainfall thresholds in Bradanic Foredeep, Basilicata Region (Southern Italy). In C. Margottini, P. Canuti, & K. Sassa (Eds.), *Landslide science and practice: Early warning, instrumentation and monitoring* (vol. 2, pp. 671–677). Berlin Heidelberg: Springer-Verlag. ISBN/ISSN: 978-3-642-31444-5. doi:10.1007/978-3-642-31445-2_88

Lentini, F., Carbone, S., Di Stefano, A., & Guarnieri, P. (2002). Stratigraphical and structural constraints in the Lucanian Apennines (Southern Italy): Tools for reconstructing the geological evolution. *Journal of Geodynamics*, 34, 141–158.

Longhitano, S. G. (2015). Short-term assessment of retreat of advancing microtidal beaches based on the backshore/foreshore length ratio: Examples from the Basilicata Coasts (Southern Italy). *Open Journal of Marine Science*, 5, 123–145.

Miccoli, M. N., Capolongo, D., Piccarreta, M., & Caldara, M. (2014). Geomorphic analyses using NEXTMap topographic data: Application for the badlands of the Basilicata region (Southern Italy). *Boletín Geológico y Minero*, 125(3), 315–328.

Patacca, E., & Scandone, P. (2001). Late thrust propagation and sedimentary response in the thrust belt-foredeep system of the Southern Apennines. In G. B. Vai & I. P. Martini (Eds.), *Anatomy of an orogen: The apennines and adjacent Mediterranean basin* (pp. 401–440). Dordrecht: Kluwer Academic.

Patacca, E., & Scandone, P. (2007). Geology of the Southern Apennines. *Italian Journal of Geoscience* (Spec. Issue), 7, 75–119.

Piccarreta, M., Bentivenga, M., & Capolongo, D. (2010). Produzione di sedimenti e tassi di erosione a medio termine nei ‘gullies’ della Fossa Bradanica, Basilicata. *Rendiconti della Società Geologica Italiana*, 12, 56–67.

Piccarreta, M., Caldara, M., Capolongo, D., & Boenzi, F. (2011). Holocene geomorphic activity related to climatic change and human impact in Basilicata, Southern Italy. *Geomorphology*, 128, 137–147.

Piccarreta, M., Capolongo, D., Bentivenga, M., & Pennetta, L. (2005). Influenza delle precipitazioni e dei cicli umidi – secco sulla morfogenesi calanchiva in un’area semi-arida della Basilicata, Italia Meridionale. *Geografia Fisica e Dinamica Quaternaria Supplementi*, VII, 281–289.

Piccarreta, M., Capolongo, D., Boenzi, F., & Bentivenga, M. (2006). Implications of decadal changes in precipitation and land use policy to soil erosion in Basilicata, Italy. *Catena*, 65, 138–151.

Piccarreta, M., Capolongo, D., & Miccoli, M. N. (2012). Deep gullies entrenchment in valley fills during the Late Holocene in the Basento basin, Basilicata (southern Italy). *Géomorphologie: Relief, Processus, Environnement*, 18, 239–248. ISSN: 1266-5304.

Piccarreta, M., Capolongo, D., Miccoli, M. N., & Bentivenga, M. (2012). Global change and long-term gully sediment production dynamics in Basilicata, Southern Italy. *Environmental Earth Science*, 67, 1619–1630. ISSN:1866-6280. doi:10.1007/s12665-012-1603-5

Piccarreta, M., Faulkner, H., Bentivenga, M., & Capolongo, D. (2006). The influence of physico-chemical material properties on erosion processes in the badlands of Basilicata, Southern Italy. *Geomorphology*, 81, 235–251.

Piccarreta, M., Lazzari, M., & Pasini, A. (2015). Trends in daily temperature extremes over the Basilicata Region (southern Italy) from 1951 to 2010 in a Mediterranean climatic context. *International Journal of Climatology*, 35(8), 1964–1975.

Piccarreta, M., Pasini, A., Capolongo, D., & Lazzari, M. (2013). Changes in daily precipitation extremes in the Mediterranean from 1951 to 2010: The Basilicata region, southern Italy. *International Journal of Climatology*, 33, 3229–3248. doi:10.1002/joc.3670

Schumm, S. A., & Chorley, R. J. (1966). *Talus weathering and scarp recession in the Colorado Plateau*. Zeitschrift für Geomorphologie, 10, 11–36.

Torri, D., & Bryan, R. (1997). Micropiping processes and biancana evolution in southeast Tuscany, Italy. *Geomorphology*, 20, 219–235.

Tropeano, M., Sabato, L., & Pieri, P. (2002). Filling and cannibalization of a foredeep: The Bradanic Trough, Southern Italy. In S. J. Jones & L. E. Frostick (Eds.), *Sediment flux to basins: Causes, controls and consequences* (pp. 55–79). London: Geological Society. Spec. Publ., 191.

Westaway, R., & Bridgland, D. (2007). Late Cenozoic uplift of southern Italy deduced from fluvial and marine sediments: Coupling between surface processes and lower-crustal flow. *Quaternary International*, 175, 86–124.