Chapter 1

The Role of Soil Mineralogy, Geochemistry and Grain Size in the Development of Mediterranean Badlands: A Review

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Additional information is available at the end of the chapter

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1. Introduction

It has long been recognized that the local Mediterranean climate, tectonics and human impact interact to determine the gross morphology and surface conditions of this landscape. However, attention has recently been given to the explanatory role of lithology, in particular sediment size and clay mineralogy, in explaining the badland formation [1-9].

For instance, on *biancane* sites, Battaglia et al. [10] found clay fractions to be significantly high. These sites have been reported to possess also high percentage of clay minerals in particular in the smectitic group.

Additionally, for these clay minerals, high exchangeable sodium on the exchange complex promotes dispersion (deflocculation) of the clays. The exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), sodium percentage (PS) and total dissolved salts (TDS) are commonly used to measure the dispersive state.

This chapter aims to contribute to the international framework of research on water erosion processes, and to identify critical emerging erosional risk factors. It focuses particularly on experimental research on material properties that could be the promoter of soil erosion processes.

Results show that many components of soil erosional response, such as soil dispersivity, badlands development or surface and subsurface processes like crusting or pipes, are strongly affected by spatially variable and temporally dynamic soil properties.

2. Soil degradation

When land is degraded, its productivity is reduced and many other eco system services are deleteriously affected. Land degradation may be primarily caused by natural processes, related to the characteristics of the given land resources and ecosystems. However, human activities often accelerate these degradation processes, leading to a rapid decline in the quality and quantity of the land resources and the ecosystem services flowing from these. Drylands are fragile and particularly susceptible to land degradation.

The United Nations Convention to Combat Desertification (UNCCD) defines land degradation in the context of drylands as: "a reduction or loss, in arid and semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns" [11].

Land degradation is caused by a variety of complex interrelated degradation processes. These can be grouped into three major land degradation types, each of which can be subdivided according to a specific sub-set of degradation processes, namely:

1. Soil degradation;
2. Vegetation degradation;
3. Water resources degradation.

Vegetation degradation involves a combination of processes that may be natural, notably climate change which may lead to a loss of certain species and habitats, reduced biomass due to reduced moisture availability, or encroachment by invasive species. However, vegetation degradation is generally induced by human activity, through the over use or mis-management of forests, grazing and croplands, uncontrolled burning or introduction of pests and diseases.

Degradation of water resources in terms of quantity, quality and flow regime will lead to reduced productivity of the aquatic system in terms of fish and other useful aquatic species and products. It also affects the availability of clean drinking water for consumption by humans, livestock and wildlife.

Soil degradation is defined as the decline in soil quality caused through its misuse by human activity [12]. Degradation or decline of soil quality may occur due to physical or chemical processes triggered off by natural phenomena, or induced by humans through misuse of land resources. Processes such as soil erosion, nutrient run-off, water logging, desertification or compaction, may give examples of physical degradation processes, while acidification, organic matter loss, salinization, nutrient depletion by leaching, or toxicants accumulation, are all processes that can be classified as being agents and indicators of chemical degradation of soil.

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2.1. Soil degradation types and processes

Soil degradation occurs when there is a decline in the productive capacity of the soil as a result of adverse changes in its biological, chemical, physical and hydrological properties and/or attributed to the removal of soil through erosion by water or wind or by mass movement. Sheet, rill and gully erosion by water, also the scouring and re-deposition of soil by wind and landslides are some of the most visible symptoms of soil degradation, but other less visible forms of degradation of soil properties are even more widespread and sometimes more serious, notably depletion of nutrients and soil organic matter decline.

The key processes that are responsible for soil degradation are listed in Table 1 [1, 11-12].

Degradation of soil biological properties	Degradation of soil chemical properties	Degradation of soil physical properties	Degradation of soil hydrological properties	Soil erosion	Soil pollution
• Increase in numbers and activity of harmful soil organisms • Reduction in numbers and activity of beneficial soil organisms	• Decline in number and availability of soil nutrients • Chemical imbalances and toxicities • Changes in soil pH (acidification or alkalinisation) • Salinization and sodicity • Chemical pollution	• Surface crusting and compaction and burning • Sub-soil compaction • Reduced soil rooting depth (erosion) • Loss of topsoil structure • Loss of soil fines (erosion of silts and clay) leaving sandier and stonier soils	• Waterlogging • Aridification • Reduced plant water uptake due to soil salinization	• Soil erosion by water (splash, sheet, rill and gully erosion) • Soil erosion by wind (removal and re-deposition of soil particles, abrasion by transported materials and formation of mobile sand dunes) • Gravitational erosion (mass movement through landslides, slumps, earth flows and debris avalanches) • Freeze/thaw erosion	• Soil chemical imbalances and nutrient toxicities • Build up of inorganic pollutants in the soil • Accumulation of pollutants/ toxicities of organic origin following the planting of certain crops • Emissions of toxic chemicals

Table 1. Soil degradation types

3. Soil erosion

Soil erosion is a major form of land degradation. It comprises various processes that are described separately below. However, any one of these processes may occur in the same locality, either in combination or at different times of year.

Soil erosion by water is often quite widespread and can occur in all parts of drylands where rainfall is sufficiently intense for surface runoff to occur. This category includes processes such as splash, sheet, rill and gully erosion. Splash erosion is commonly the first stage of water erosion and occurs when rain drops fall onto the bare soil surface. Their impact can break up surface soil aggregates and splash particles into the air. As water runs over the soil surface it has the power to pick up particles released by splash erosion and the capacity to detach particles from the soil surface. This may result in sheet erosion, where soil particles are removed from the whole soil surface on a fairly uniform basis.

Where runoff becomes concentrated into channels, rill and gully erosion may result. Rills are small rivulets of such a size that they can be ploughed over with farm machinery. Gullies are much deeper (often being several metres deep and wide) and form a physical impediment to the movement across the slope of farm machinery, even people and livestock [13].

Soil erosion by wind is also widespread throughout drylands that are exposed to strong winds. It includes both the removal and re-deposition of soil particles by wind action and the abrasive effects of moving particles as they are transported. In areas with extensive loose, sandy material, wind erosion can lead to the formation of mobile sand dunes that cause considerable economic losses through engulfing adjacent farm land, pastures, settlements, roads and other infrastructure [14].

Gravitational erosion tends to be more localised in regions with steep, rocky slopes and in mountain ranges. On sloping land when soil is saturated, its weight increases and the downward forces of gravity will induce a relatively large down-slope movement of soil and / or rocks (e.g. landslides, slumps, earth flows and debris avalanches). This mass movement of material may be very rapid and involve large volumes of soil, but is usually limited to isolated and localised events. Landslides may be natural events, however, their frequency and severity is likely to greatly increase following deterioration or loss of the natural vegetative cover by logging, overgrazing and / or clearing for cultivation [5, 15-17].

Freeze/thaw erosion is restricted to high altitude areas and areas with cold climates. It occurs when water in the topsoil initially freezes and expands, then melts, damaging topsoil structure and enabling loosened surface soil particles to be carried away in melt water runoff. It is primarily a natural process rather than one which is accelerated by particular human activities [15, 17-18].

This chapter covers only the assessment of soil erosion by water.

3.1. Soil erosion landscape: Badlands

The term badlands is currently used for areas of unconsolidated sediments or poorly consolidated bedrock, with little or no vegetation. They are useless for agriculture because of their intensely dissected landscape.

They appear to offer in a miniature spatial scale and a shortened temporal scale many of the processes and landforms exhibited by more normal fluvial landscapes, including a variety of slope forms, bedrock or alluvium-floored rills and washes, and flat alluvial expanses similar to large-scale pediments.

Although badlands evoke an arid image, they can develop in nearly any climate in soft sediments where vegetation is absent or disturbed. General reviews of badlands and badland processes are provided by Campbell [19] and Bryan and Yair [20], including discussions of the climatic, geologic, and geographic setting of badlands, sediment yields, host rock and regolith variations among badlands and field measurements of processes.

Badland landscapes are typically asymmetrical (Figure 1). The sunny aspects show impoverished or null vegetation cover because of the strong control on water availability effected by radiation, whereas the shady aspects may bear a vegetation cover close to 100% [21-23]. Steep slopes and gullies do not allow the formation of a developed soil because erosion processes are either frequent and/or intense.

Figure 1. Typical badland form at Pisticci (Basilicata Southern Italy) with southern eroded side and northern vegetated side

Calanchi and *biancane* are considered peculiar forms of badlands evolution [10].

The term *calanchi* describes the dendritic network of slope forms created on a single hillslope scarp (Figure 2). An individual *calanco* is defined by knife-edged ridges, separating small hydrographic drainage networks with horseshoe-shaped headwalls [24-25]. *Biancane* are small, conical or dome-shaped forms up to 20 m high (Figure 2), which may occur singly or in groups [9, 26-28].

Calanchi is the result of a rill erosion. Rill erosion is the removal of soil by water from very small but well defined, visible channels or streamlets where there is a concentration of overland flow [29]. In general, rill erosion is more serious than sheet erosion, and it is most accentuated when intense storms occur in watersheds or sites with high runoff-producing characteristics, loose, and grading operations.

Rill erosion is often described as the intermediate stage between sheet and gully erosion, and occurs by a concentration of runoff or low points through the soil.

Gully erosion could be considered as an advanced stage of rill erosion, where surface channel gullies (intermittent stream channels larger than rills) have been eroded to the point where they cannot be smoothed over by normal tillage operations.

Underground (groundwater) erosion is the removal of soil caused by groundwater seepage or movement towards a free face. It is also known as piping and occurs as a result of bank drainage or, in general, when seepage forces exceed intergranular stresses or cohesive forces [29]. Pipes can form in the downstream side of earth dams, gully heads, streambanks, and slopes where water exits from the ground. Once a cavity (pipe) forms, it is able to enlarge quickly since the flow follows the path of low flow resistance.

Figure 2. Typical morphological features of the landscape forms in Mediterranean area (Aliano, Basilicata – Southern Italy)

3.2. Compositional controls of badlands occurrence

The main factor controlling badland formation is the particular character of the rocks or other materials which form the base for the interaction of weathering and erosion processes [19]. However, the existence of other risk factors such as climatic condition, human activities, geomorphological exposition, structural features, encourages the intensification of erosion and development of morphological features of the landscape forms [27, 30-36].

Soils in badlands deserve special attention, because soils are the inter-phase between the lithosphere and the atmosphere, and so constitute one of the key elements either favoring or restricting the initiation of badland formation.

When soils are resilient against erosion processes, gullies do not form; however, when soils, either because of their particular ground cover, i.e. sparse vegetation, and/or intrinsic properties, cannot withstand erosive forces, the topsoil is eroded and deep gullies develop, which may give rise to badlands if the underlying material is also erosion-sensitive.

Consequently, the characteristics of the materials underlying soils are crucial for the development of true badlands.

Lithology is a major factor for badland production, and is probably of greater importance than tectonics, climate, topography or land use [4, 6, 19, 37-38].

The general characteristics of a soil, regolith or geological formation that favours badland relief are the unconsolidated or very poorly cemented material of clay and silt, sometimes with soluble minerals such as gypsum or halite [39]. Specific characteristics, like structure, mineralogy, physical and chemical properties, may play either a primary or secondary role in material disintegration and badland development.

In the Mediterranean area most parent materials are essentially silt-dominant, with clay as the second particle size, while sand is generally very poorly represented.

Texture depends on four factors: particle-size distribution, grain shape, degree of crystallinity and relationship among grains [40]. Of these, particle-size distribution plays the key role in susceptibility for material disintegration and erosion: the larger the range of particle sizes, the higher the degree of packing, and hence the greater resistance to breakdown processes.

Conversely, the narrower the particle-size distribution, the higher the susceptibility for material disintegration, piping and, consequently, for badland development [40-41].

Besides textural properties, porosity is the second most important physical property [42-43]. If suitable macropores are available within the material for enlargement, dispersion can encourage the rapid enlargement of subsurface pipes [44-45], a process sometimes referred to as piping or tunneling.

Infiltration is defined as the process by which water enters the soil. Its rate depends on soil type, soil structure and soil water content [46]. Infiltration is important for reducing run-off and consequent erosion. Increased soil compaction and loss of surface structure (reduced aggregation) are the main factors in reducing water infiltration rates in soils. Such rates are normally dependent upon the occurrence of large pores occupying the upper surfaces of the soil; therefore they depend on soil texture in the first place [47].

Soil bulk density is defined as the mass of soil per unit volume in its natural field state, including air space and mineral matter, plus organic substance. High values of bulk density may restrict the movement of surface waters through the soil, leading to a loss of nutrients by leaching. It may also increase erosion rates. Bulk density measurements are very important for assessing soil quality, since root growth and penetration of soil, together with the ease of soil aeration, are largely controlled by this factor [48].

Geotechnical properties provide another important control for erosion: Atterberg limits (for consistency), swelling, and slaking behavior are considered in many badland studies [10, 49-50].

Certain minerals play an essential role in the breakdown of some rocks at near surface conditions.

Some minerals are important because they may become soluble, like all soluble salts (halite), but also moderately soluble like sulphates (gypsum) or carbonates (calcite and dolomite), especially when they can be dissolved because of the small size of their constitutive particles and/or solvent characteristics [51].

Some other minerals; like clay minerals (smectite in particular), can absorb water in amounts several times their dry weight, with consequent volume increases. Wetting-drying alternations in materials with expandable clays cause the formation of nets of deep cracks and may also lead to the formation of a shallow layer of loose expanded regolith fragments, usually called popcorn [5].

It was found that the percentage presence of the swelling clays in the overall material mass is very important. Where clay percentages are high, the material mass is rendered impermeable on swelling, encouraging surface wash erosion and reducing infiltration. Where clay percentages are low, the deflocculation of the clay fraction merely destructures a material already lacking in other sources of cohesion, encouraging subsurface erosion. Given the presence of a suitable hydraulic gradient through a site, this distinction will separate materials that are dispersive but which do not develop large pipes from those that do.

Clay dispersion is a physico-chemical process relevant to erosion processes, particularly to the development of pipes. Materials (soils, regoliths or rocks) with a potential to disperse are those which contain a high exchangeable sodium percentage (ESP), saturating part of the exchangeable cations of their clays. This percentage is considered to be critical when higher than 13.

To predict the tendency of materials to pipe, Faulkner et al. [52-55] explored the effectiveness of the relationship between electrical conductivity (EC) and SAR (sodium adsorption ratio), originally used by Rengasamy et al. [54]. Whilst this improves diagnosis over the use of ESP or SAR values alone, it seems that this analysis is also insufficient in itself to distinguish between badland surfaces in terms of their morphology.

The relationship between pH and SAR can be used to indicate the extent of material buffering as dispersivity changes.

3.3. Erosion prediction

In the analysis of the processes connected to the land degradation, many models were developed in the past with the objective to give a qualitative and quantitative solution to the problem of the soil loss and erosion. This estimation of those phenomena is particularly difficult due to the number of variables to consider and their typologies including both natural, i.e. soil nature, vegetation and rainfall, and anthropic ones, as the many options for management practices and land use. Models about this evaluation are often based on empirical or process-based analysis and the synthetic equations used to describe the phenomenon are necessarily complex because they have to include the interactions of all the parameters. Besides, the complexity of the erosion processes, and the need for huge data banks to compile the many algorithms which are included in the models, are also technical problems to consider in the analysis plan. Anyway many erosion prediction models are available: event-based or long-term models, empirical or physically based models, on a basin or plot scale, which have been improved in the last few decades. One of the best examples in the estimation of long-term average annual soil loss from arable lands, is the Universal Soil Loss Equation (USLE) model.

The Universal Soil Loss Equation (USLE), developed by Wischmeier, Smith, and others in the 1960, predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices.

In the applications related to the analysis of erosion processes, the USLE equation was replaced by the Revised Universal Soil Loss Equation (RUSLE), which has a similar structure (that is a black-box factor empirical model), but with more sophisticated inputs and it is designed for operation on personal computers

Because there is a wide discrepancy between predicted and observed erosion rates, models are better as research tools than as public policy and regulatory instruments or for prescriptive design measures for constructed landforms. But some models may provide useful guidance for the design engineer if adequately calibrated and verified for local conditions and if the design accounts for the uncertainty.

4. Influence of soil features on developing *calanchi* erosional landforms in Southern Italy (Basilicata)

The soil erosion risk is widespread in the Mediterranean. Some areas of Italy are an excellent example of soil erosion risk. Soil erosion vulnerability in the Basilicata region (Southern Apennines - Italy) is mostly represented by water erosion forms. *Calanchi* and *biancane* are two typical erosion landforms present in the Basilicata region and this area is a key reference for the international studies of water erosion processes [3, 8, 30, 56-58].

4.1. Geological and climatic settings

The studied sites are part of a well-known area of present desertification [1, 7, 20, 27, 30, 56-65], and is located in the far south of the Apennines (Figure 3).

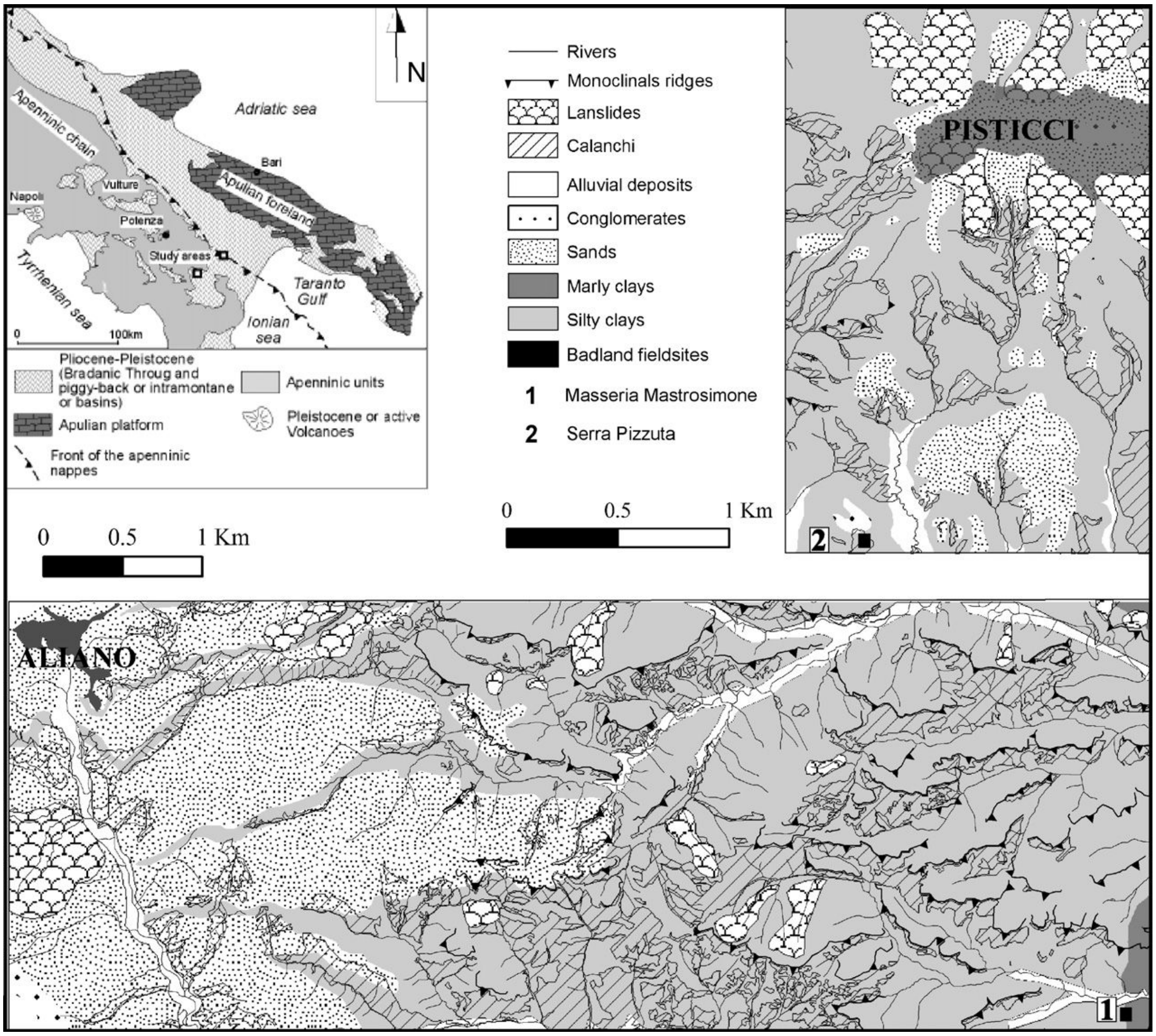

Figure 3. Geologic map showing the location of the study areas [adapted from Piccarreta et al., 2006]

The Pisticci site is a hilly area between the river Basento and the seasonal stream Salandrella, both deeply carved in the late Pliocene-Calabrian Sub-Apennine clays of the Bradanic Foredeep [61].

The Sub-Apennine clays are clays and silty clays, sometimes sandy clays, typically blue in colour. The lithological uniformity of the pelitic facies is attenuated by thin sand-silt and tuff layers (centimetric scale).

The Aliano site is situated in the heart of the Basilicata Appenines and is part of the north-eastern area of the Plio-Pleistocene Sant' Arcangelo basin.

The formations were affected by the uplift of the eastern margin of the Apennine chain during the upper Pliocene and Post-Calabrian ages [66]. The whole area shows tectonic aspects due to movements which have prevailing vertical components. This is clearly caused by the features of the sedimentary layers, from sub-horizontal to gently dipping. Generally speaking the stratification is still not well-distinguished. The stratigraphic sequence and the basin structure have been studied in depth [67-74].

In the study areas the Plio-Pleistocene clays are the most diffused lithology to be found. These are 500 to 900 m thick [27, 75] and consist of marly and silty clays with a middle–high plasticity [27, 71].

Pieri et al. [76] redefined the Plio-Pleistocene successions by subdividing them into four depositional sequences, such as the Late Pliocene – Middle Pleistocene on the basis of the stratigraphic, sedimentologic and structural features of the deposits outcropping in the northern basin. Each cycle, several hundred metres thick, represents one or more depositional systems (alluvial, marine-deltaic and lacustrine).

Patacca and Scandone [73] suggest a new structural architecture for the Southern Appenines, especially for the Plio-Pleistocene Foredeep/thrust-sheet-top deposits. According to these authors, the Plio-Pleistocene thrust-sheet-top and Foredeep deposits were subdivided into two depositional sequences both of which are governed by tectonic processes active in the mountain chain (P1-2 - lower-upper Pliocene - and Q1-2 – lower-middle Pleistocene - thrust-related depositional sequences).

Details about the thrust-related depositional sequence in the Southern Appenines and the relative systems tracts, including the characteristic stratigraphic signatures, are supplied in Patacca and Scandone [72].

The area studied is characterized by extremely widespread erosion mainly affected by the lithological features of their soils. The overall geomorphological development of this area resulted from periodic intensive erosion, which began in the Late Pleistocene and continued during the Holocene due to tectonic movements, climatic changes and related sea-level fluctuations [77].

These two sites have been chosen because they are represent by two different badlands areas.

In the Pisticci area there are "typical" badlands, a representation of the usual morphology of the semi-arid Mediterranean area – characterized both by an eroded slope facing south and a non-eroded (covered) slope facing north [56, 58, 61, 65]. Erosion was studied on sediments of Sub-Apennine clays, unvegetated slopes (SE-facing scarp slopes up to 35°-40°) with high rates of erosion, labelled "Pisticci, eroded", and opposite vegetated slopes (NW-facing scarp slopes up to 20°) labelled "Pisticci, non-eroded" (Figure 4).

Also in the Aliano area there are slopes with features of erosion common to clayey-silty rocks exposed to the south-east as well as adjacent slopes having the same exposure (south-east), but showing a different erosional action. A partially-vegetated covering can be found (Figure 5).

The annual average rainfall for the Pisticci area 1923–2000, is about 645 mm [78-79]. The most abundant precipitation is in Autumn and Winter; Summer is the driest season [80].

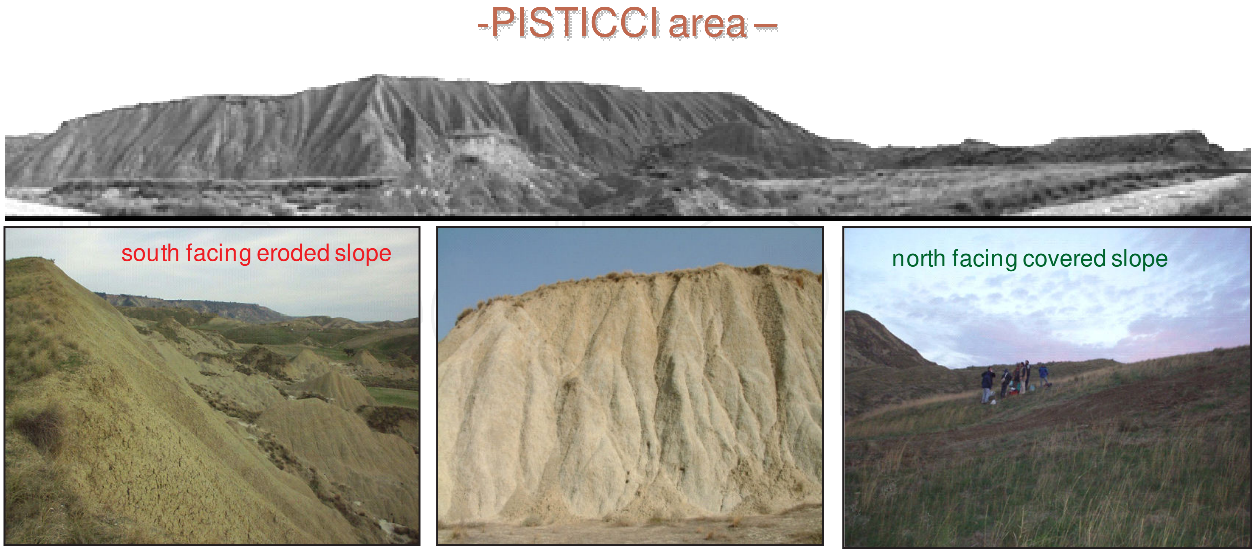

Figure 4. Photos from Pisticci studied area: "typical" badlands on sediments of Sub-Apennine clays, characterized both by an eroded slope facing south (scarp slopes up to 35°-40°) and a non-eroded (covered) slope facing north (scarp slopes up to 20°).

Figure 5. Photos from Aliano studied area: slopes with clayey-silty rocks exposed to the south-east as well as adjacent slopes having the same exposure (south-east), but showing a different erosional action.

In the Aliano area, from 1955 to 2000, the annual mean precipitation was 738 mm (st.dev. 174mm), mainly concentrated from the months of October to January. In the same area the minimum and maximum values recorded over a period of 46 years are, respectively, 367mm and 1090 mm [34].

In both areas, the climate is typically Mediterranean, characterized by warm and dry Summers with temperatures averaging 26-27°C with a maximum as high as 39°C, and cold and rainy Winters with temperatures averaging 8-10°C in January.

4.2. Materials and methods

For each slope, eroded and non eroded (in all case studies), samples were collected in order to represent the several litho-pedological levels. Since vegetated soils resist breakdown and crusting [58], within the eroded slope, the crust was only differentiated with respect to the substrate and was defined as existing at 0-2 cm depth. Below the crust, samples were labelled "substrate". For each eroded and non-eroded slope, three different profiles were sampled: top, middle, and bottom (Figure 6).

Detailed grain size analyses were carried out by laser diffraction, a Malvern MasterSizerE laser particle-sizer with a 100-mm lens, which identifies grain-size intervals from 0.5 to 100 μm. For mineralogical analysis the clay fraction (<2 μm) was separated by means of fractioned sedimentation in accordance with Stokes' law.

Mineralogical analyses were carried out by X-ray diffraction (XRD) on a Rigaku D/Max-2200/ Pc powder diffractometer (theta-theta configuration, Cu Kα radiation). Quantitative mineralogical data were obtained according to Barahona [81], and the results were checked by means of a comparison with chemical data.

Chemical bulk-rock elements were measured by X-ray fluorescence (XRF) on a Philips PW 1480/10 spectrometer with Cr radiation. Recommendations made by Franzini et al. [82] were applied in order to correct matrix effects by using international geological standards.

pH measurements were made according to the procedure indicated in Italian law no.79 [83]. Dried samples were mixed with distilled water (ratio 1:2.5) and the mixture was then stirred and pH measured.

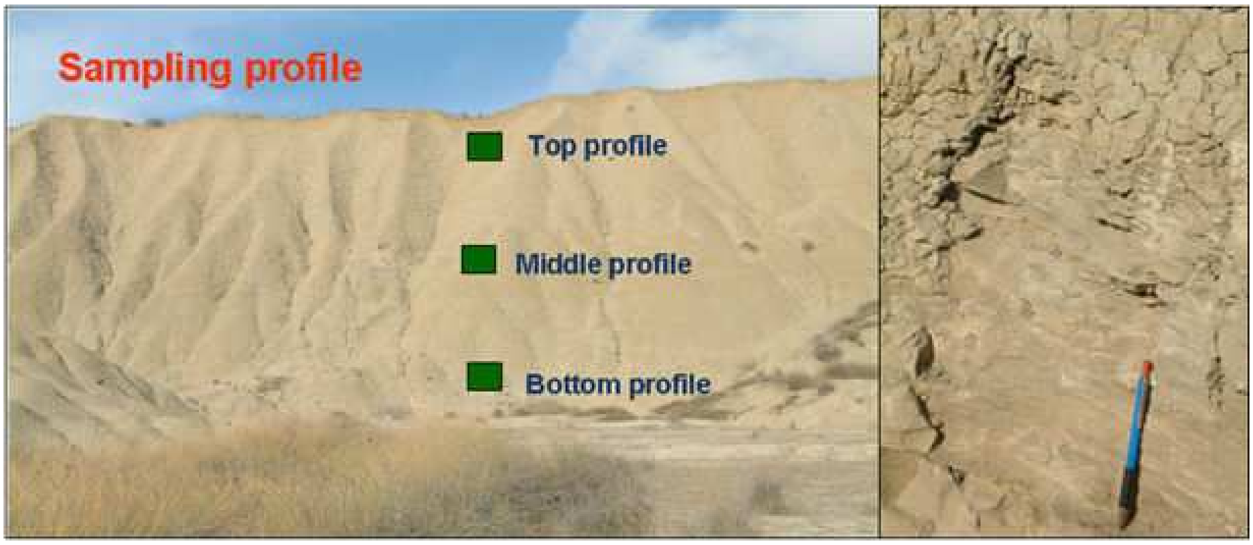

Figure 6. Sampling profile

Selected soluble salt concentrations (Na^+, K^+, Mg^{2+}, and Ca^{2+}) were measured by ion chromatography [52], and sodium adsorption ratio (SAR) and Exchangeable Sodium Percentage (ESP) calculated according to the formula:

$$SAR = \frac{Na}{\sqrt{\frac{Mg + Ca}{2}}}$$

$$ESP = \frac{Na}{CEC} 100$$

Pearson's correlation coefficients and Student's T-test were calculate to quantify the relationship between variables.

4.3. Results and discussion

The mineralogical, geochemical and grain-size composition features of these slopes has been determined to find common risk factors for the different areas.

Only a few grain-size parameters, mineralogical and geochemical features discriminate the eroded and non eroded substrates [8]. The water erosion phenomena is present where the fine fraction is abundant (more evident in Aliano than in Pisticci). This can be explained by a reduction of permeability in eroded soils while the non eroded ones are more stable with respect to the weathering phenomena, as they are more permeable.

Crusts represent the more weathered and modified part of eroded sides, but their grain size and chemical features resemble non eroded materials better than their own substrate. Such a similarity can be depicted as an auto-stabilization process of superficial portion of eroded slopes [e.g. 53, 84]. Chemical data enable discrimination between eroded and non-eroded slopes in all case studies.

pH, SAR (sodium adsorption ratio), TDS (total dissolved salts) and PS (percentage of sodium) are distinctive parameters for both eroded and non-eroded slopes. On average, eroded substrates are higher in pH, SAR and PS than non-eroded ones. The ESP (exchangeable sodium percentage) of the eroded slope has a higher value than the non-eroded one [8].

The results of this study show that, even if geological and geomorphological differences exist between the two areas, common erosion risk factors can be characterized.

4.3.1. Geomorphological and structural observations

In both study areas, the topography has a gentle dip and morphology is expressed as a typical monoclinal landscape. However, the causes for the monoclinal topography differ in the two regions (Figure 7).

The Aliano site has been interpreted as a simple monoclinal system, whereas at the Pisticci site, landslides are particularly widespread on the South-East facing hillslopes [33-34, 85].

Although the monoclinal morphology has differing origins in the two areas, in both settings, the existing primary and secondary network of fractures and joints appears to influence the genesis and development of surface drainage [33-34, 61].

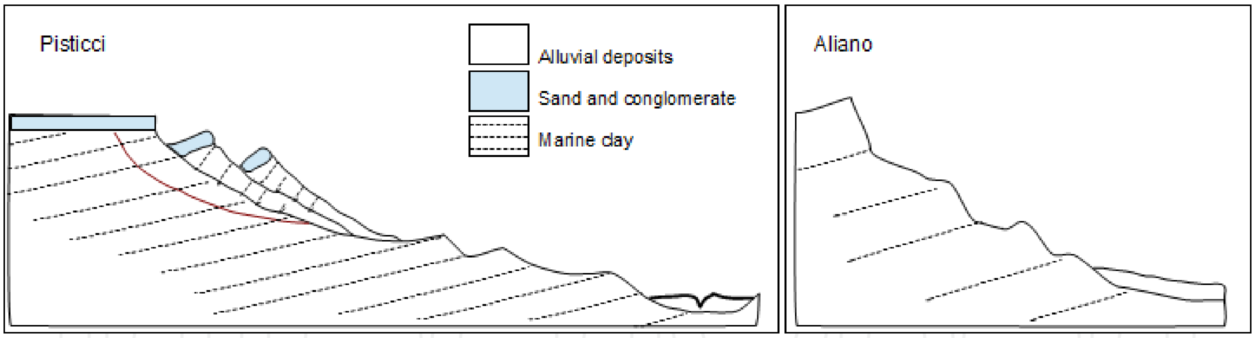

Figure 7. Schematic diagrams of the studied sites [33, modified]

In Aliano, down-valley structural features have been focussed around the weaker parts of the structural sequence of marine clays, although in the case of Pisticci, since these are failure planes not lithological features, these lineaments are more discontinuous in their down-valley pattern as might have been imagined.

In both settings, the rapidity of the geomorphic processes on the relatively steeper scarp slopes generally prohibits vegetation from securing a stable function.

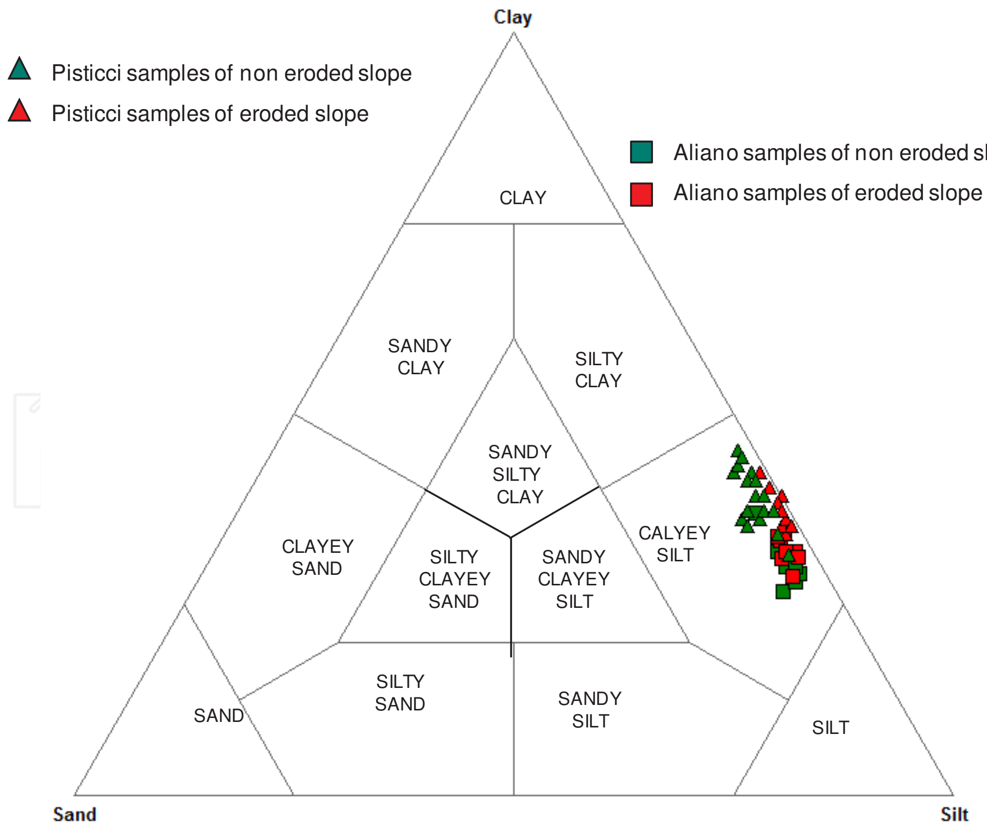

Figure 8. Granulometrical classification diagram

4.3.2. Granulometrical and mineralogical properties

After grain size analyses, all the substrate samples studied were found to be of the clayey-silt type, which is a typical substrate facilitating the formation of *calanchi*, as suggested by Battaglia et al. [10]. The grain size diagram [86] does not distinguish the eroded from the non-eroded slopes (Figure 8) neither does the soil erodibility nor the soil-quality diagram, from the CORINE Land cover [87]. However, more detailed grain-size distribution is shown in Figures 4 and 5, and gives further information, as it deals with the lower coarse fraction (>63 μm) of eroded substrates in all profiles ($r=0.783$, $p<0.000$). Comparing the profiles of the two slopes, further grain size discrimination is achieved due to the fact that the non-eroded profile of Aliano has larger course fraction (>16 μm, Figure 9) instead the non eroded profile of Pisticci are enriched in 4–63 μm fraction (Figure 10).

In both cases, the granulometric characteristics of the crust of the eroded slope are comparable with those of the substrate not eroded, as demonstrated by a linear correlation coefficient R close to 1 ($p<0.000$). This means that after erosion the most delicate part of the slope (the crust) becomes less dispersive as a sort of auto-stabilization process.

The micromorphological information on some samples of the eroded side show three distinct domains (Figure 11).

Below 20 cm the fine-grained dense sub-zone displays a massive structure and is relatively impermeable. Immediately above this dense sub-zone, a zone of isorientate structure with low porosity is present (2–20 cm).

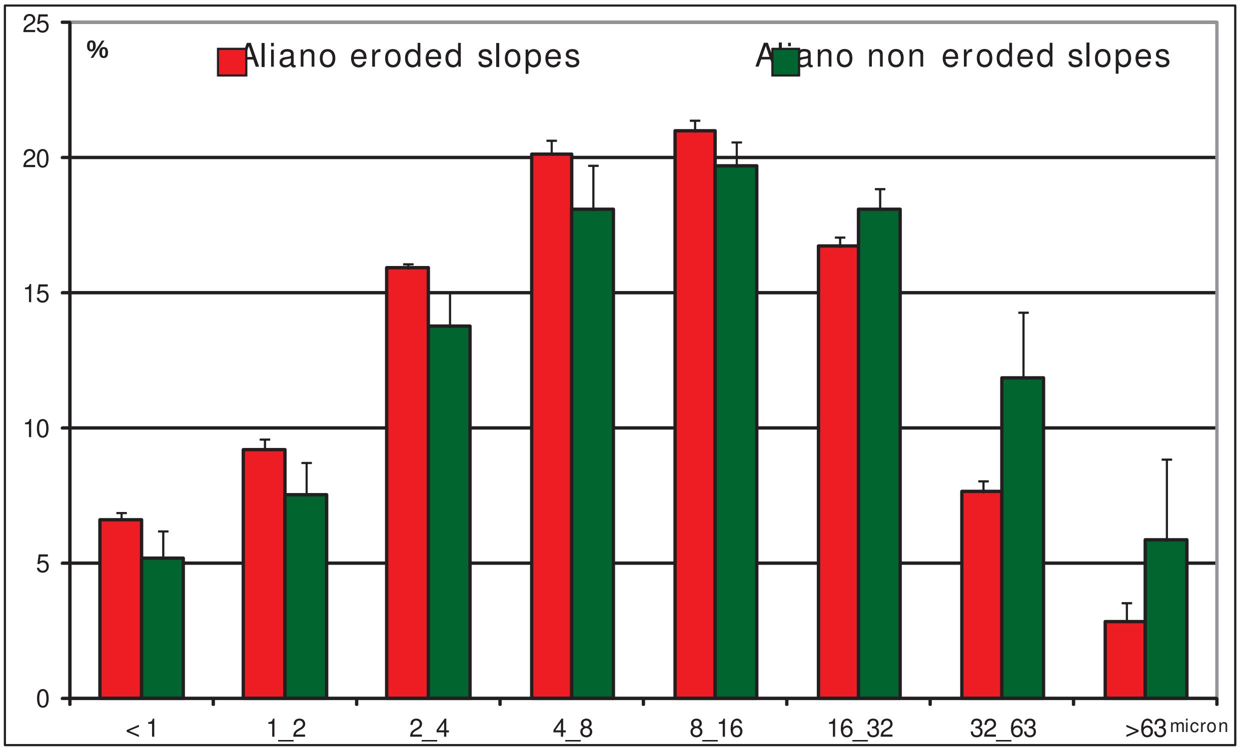

Figure 9. Average granulometrical composition of eroded and non eroded samples of Aliano

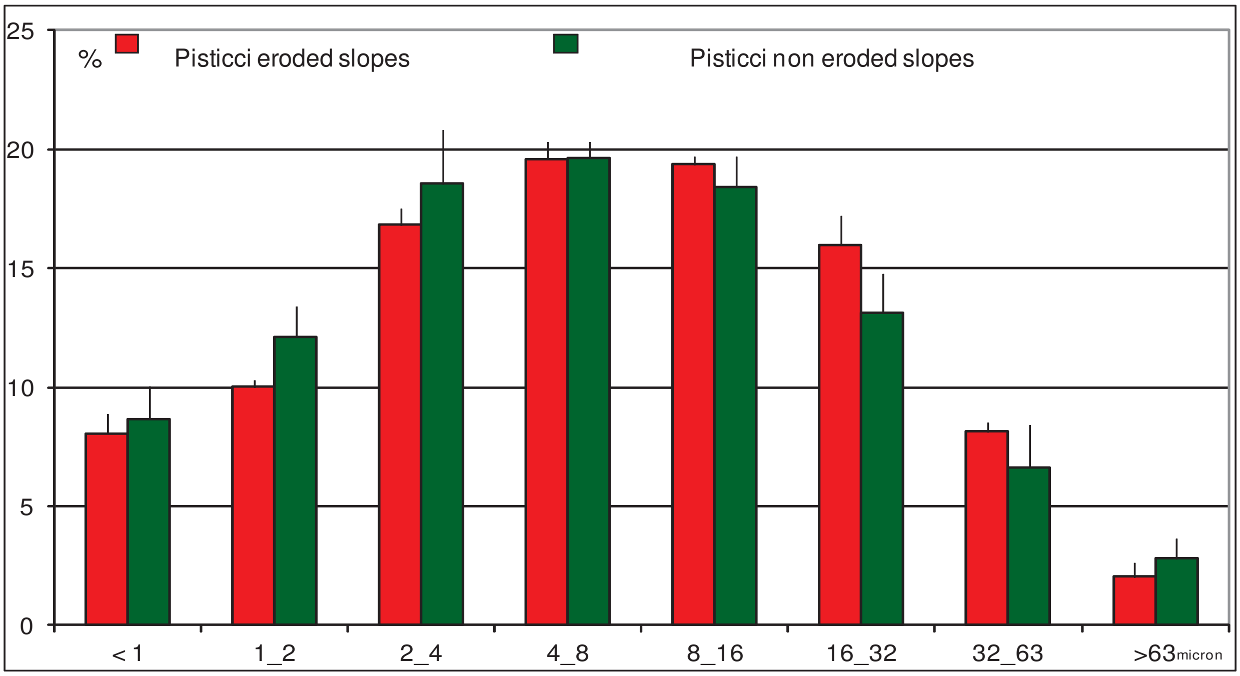

Figure 10. Average granulometrical composition of eroded and non eroded samples of Pisticci

The top 2 cm of the profile appears dispersive with high porosity. Infiltration process dominates, due to high permeability. The high porosity of the top 2 cm of the soil suggests that the most important hydraulic activity is restricted under this depth, at the intermediate level.

Both the eroded and non-eroded slopes in Aliano and Pisticci show a fairly comparable mineralogical composition of the samples on account of their mineralogical phases and quantity. So, it was not possible to define a systematic trend distinguishing bulk rock mineralogy with erosive features.

The mineralogical assemblage of the samples consists of quartz, calcite and feldspars (Table 2), with some difference in quantity for the two sites. Dolomite is always present but in lower concentrations; traces of gypsum and hematite occasionally occur at low levels. Among the clay minerals, illite is the most abundant (on average 50% of the clay fraction), while chlorite, kaolinite and mixed-layer illite–smectite generally having lower concentrations (Tab. 2). The amount of kaolinite is higher in the eroded slopes ($r=0.829$) than in the non-eroded ones ($r=-0.703$). The quantity of illite in the eroded slope is lower than that in the non-eroded one.

4.3.3. Chemical properties

Some parameters are found to be higher in the eroded substrates than in the non-eroded ones (Figure 12) ($p<0.000$). Also the crusts of eroded slopes differ from the substrates and the values of these three parameters increase with depth.

The total dissolved salts (TDS) can turn out to be quite distinctive in a comparison between the eroded and non-eroded sides. The sodium adsorption ratio (SAR) is a slightly different

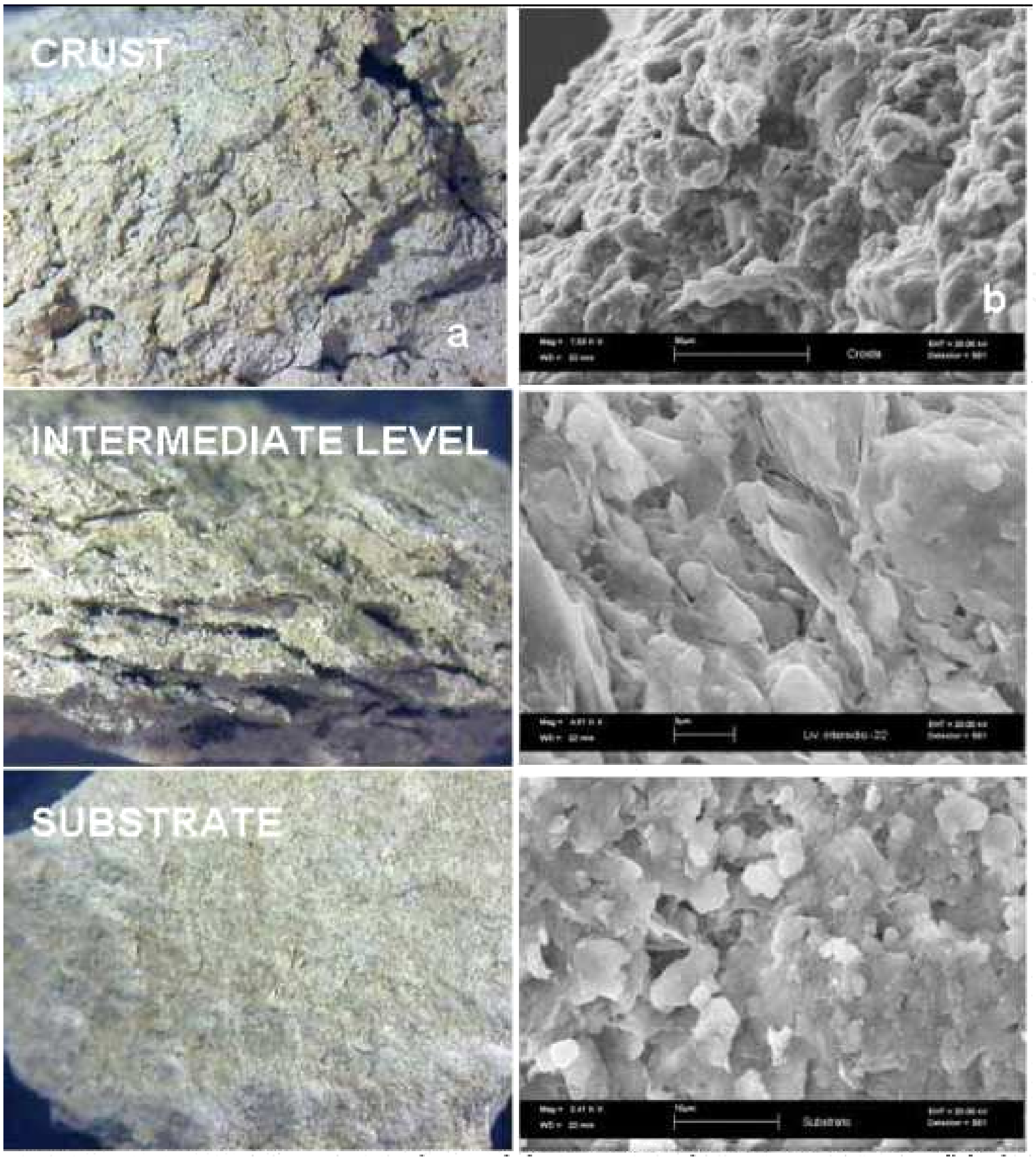

Figure 11. Sample of the eroded side at optical (a) and scanning electron microscopy (b)

expression of the importance of Na in the soluble cation composition with respect to PS. pH values are alkaline (from 8.0 to 9.1).

The sodium effect of clay stability is often expressed as ESP (exchangeable sodium percentage, [3, 8, 55]), and is closely related to the Na available for cation-exchange from the clays. ESP–depth diagrams between the eroded and non-eroded slopes turned out to be extremely differentiating (Figure 13).

The various relations between these chemical parameters, which define soil susceptibility to dispersion, can also predict the performance of the surface layers and subsoil [10, 53-55, 88-89]. According to this approach the substrate of the eroded and non eroded slopes can be

Locality	Aliano				Pisticci			
Type	non eroded		eroded		non eroded		eroded	
	Average	std. dev.	average	std. dev.	average	std. dev.	average	std. dev.
Mineralogical composition of the bulk rock								
Sheet silicates %	36,0	4,7	32,6	4,3	43,4	3,5	39,5	7,5
Quartz	28,4	2,7	27,8	2,6	21,8	2,1	21,7	2,1
Calcite	17,1	1,8	20,9	2,3	23,2	2,9	21,6	1,9
Dolomite	3,4	0,8	3,7	1,1	2,3	0,5	3,8	1,2
Feldspars	14,8	3,0	14,8	3,1	9,2	1,2	12,7	3,1
Gypsum	0,1	0,3	0,0	0,0	0,0	0,0	0,0	0,0
Hematite	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,4
Mineralogical composition of the clay fraction (< 2 µm)								
Kaolinite %	12,0	2,6	15,4	3,3	22,7	3,9	26,8	1,9
Chlorite	20,1	2,6	20,7	5,1	17,3	3,1	22,7	2,1
Illite-smectite	9,8	4,9	6,6	4,0	17,4	14,5	18,0	7,9
Illite	58,0	6,6	57,4	9,7	42,7	10,0	32,5	8,0

Table 2. Mineralogical composition of sample of Aliano and Pisticci area

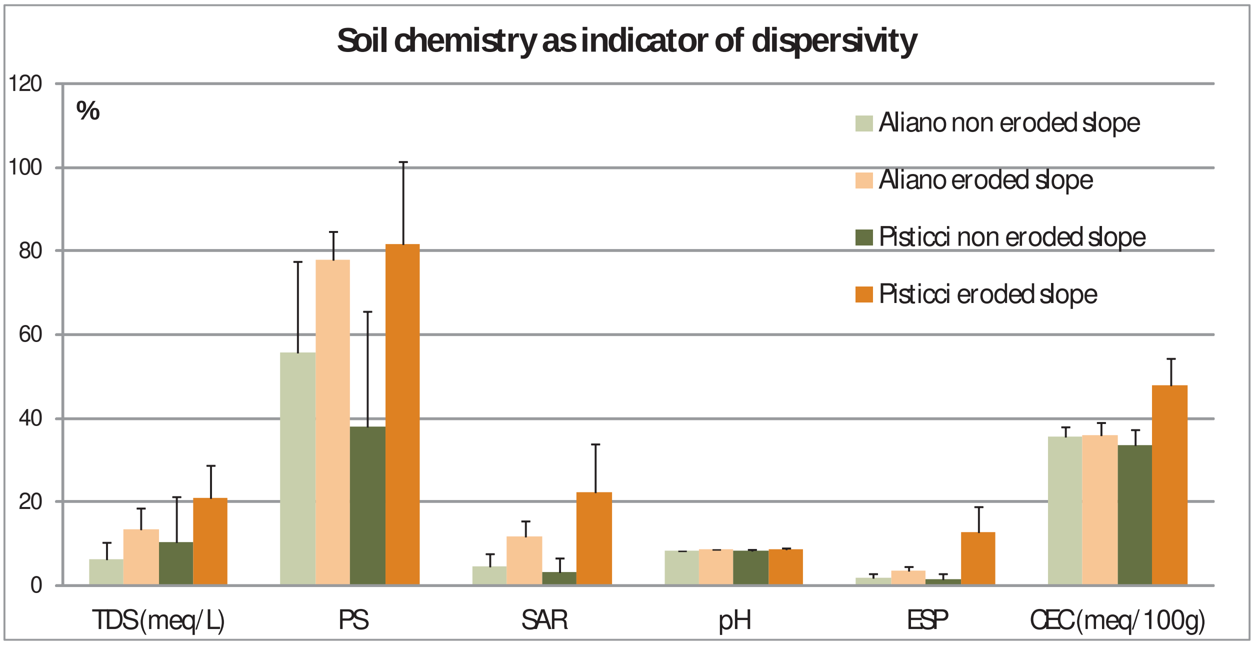

Figure 12. Comparison among some indicators of dispersivity (TDS= Total dissolved salts; PS= Sodium percentage; SAR= Sodium Adsorption ratio; ESP= Exchangeable sodium percentage; CEC= Cation exchange capability)

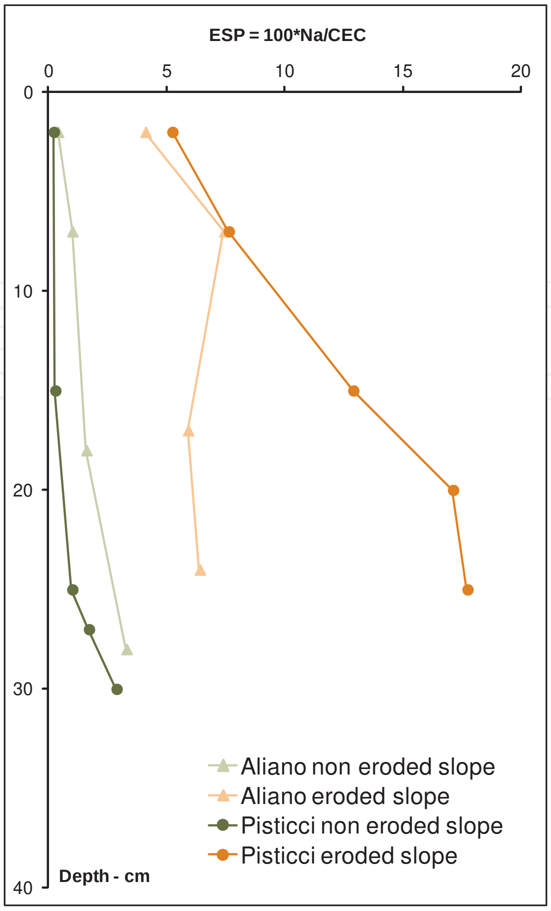

Figure 13. Exchangeable sodium percentage (ESP) versus soil depth

tentatively distinguished by using the general subdivision reported in the PS–TDS–SAR diagram of Figure 14 [8, 10, 89-90].

As shown in the diagram (Figure 14), all the samples of the non-eroded slopes have a high degree of variability as they are to be found in all the three classification zones.

The eroded slopes are mainly included in a dispersive zone, except for some samples included in the overlap zone. The dispersive properties of the latter samples are not so clear. In some cases, this shows a tendency of some portions of eroded slopes, which generally correspond to the topmost part of the slope, towards geochemical stabilization.

Other diagrams such as ESP-pH (Figure 15) can also be effective for distinguishing the eroded from non-eroded slopes [3, 8, 90]. The reason why ESP is a better discriminator may be due to the fact that the composition of the exchange complex is an intrinsic soil property.

An interesting feature that arises from many reported diagrams (Figures 14–15) is the anomalous plotting of crust samples in the eroded slope compared with other eroded profiles (white symbol in the non dispersive zone). Comparing the crusts with eroded substrates, crusts are clearly characterized by lower dispersivity parameters. The uppermost substrate samples of the non-eroded slope also follow the same trend as shown by crusts, suggesting

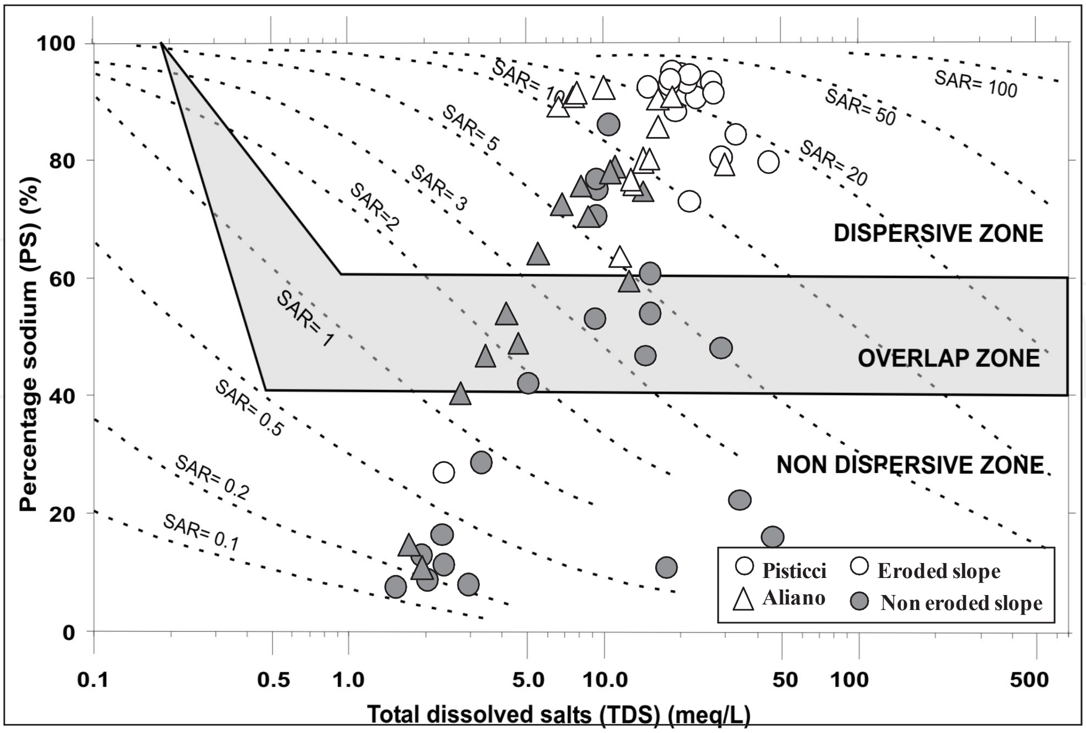

Figure 14. Relationships between sediment dispersivity and pore water composition (expressed through the PS, TDS and SAR parameters), as established by Sherard et al.[87]

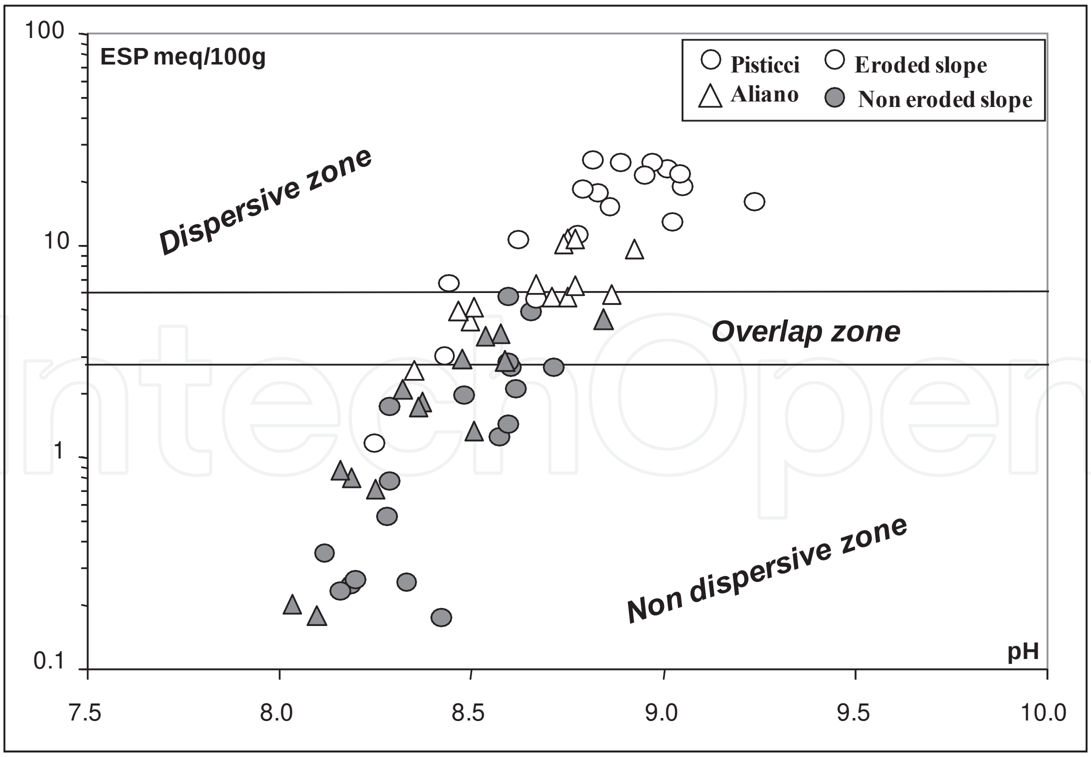

Figure 15. Correlation between ESP and pH for the prediction of dispersive behaviour of soil

that severely weathered portions of slope tend to reach a stable condition due to strong decreases in SAR, PS and ESP.

This effect, as mentioned by Faulkner et al. [53], is severe for the upper profile of the eroded slope, so that crust samples often plot in the non-dispersive field. This sort of 'auto-stabilization' process has been mentioned by several authors [e.g. 53, 84, 91] dealing with Na leaching.

As can be observed the eroded slope of Pisticci and that of Aliano have similar compositional characters with chemical characteristics associated with highly dispersive soils, regardless of exposure, or other geomorphological or climate factors.

4.4. Conclusion

This research has demonstrated that certain physico-chemical properties of the local sodic Plio-Pleistocene clays influence the different erosional processes in the two study slopes in Basilicata in fundamental ways.

Clay materials in the middle and base of the slopes retain a dispersive character. Only a few grain-size parameters discriminate eroded from non-eroded substrates. The water erosion phenomena is present where the fine fraction is abundant. This can be explained with a reduction of permeability in eroded soils while the non-eroded ones are more stable.

Erosional risk factors can be found in granulometrical features, in particular an higher fine fraction (< 16 μm for Aliano slopes and more abundant 8-16 μm for Pisticci slopes) promote erosional phenomena.

From a chemical perspective, a higher value of pH, SAR, PS parameters and above all ESP are an indication of intensive erosional processes.

The substrate of eroded and non eroded slopes can be discriminated by classification diagrams using some chemical parameters (SAR, PS and TDS) as dispersivity descriptors.

A better separation of substrates is obtained using other diagrams such as the ESP-pH.

If for the Pisticci site the exposure has always been considered one of the main erosion factors, by comparison with the slopes of Aliano we can understand how the intrinsic characteristics of the soil are crucial for the development of the erosion process.

The granulometric, mineralogical and chemical characters of the non-eroded slopes of Aliano (facing South) are comparable with those of the slopes of Pisticci (facing North).

The two study sites also have another common feature that it is possible to extend to all badlands domains: the auto-stabilization process.

This process has been identified thanks to the physico-chemical properties of the two monitored badland sites and the pH / SAR relationship that shows the tendency of the crust to auto-stabilise, confirming they are really effective signature sites.

Also the granulometrical similar composition of crusts and non-eroded substrates can be interpreted as an auto-stabilization process of superficial portion of eroded slopes.

5. Concluding remarks

Badlands are a typical landform of greatly dissected fine-grained materials. *Calanchi* and *biancane* are considered peculiar forms of badlands evolution. Their formation is closely related to the physico-chemical properties of the soil, climatic and geomorphologic conditions, and human activities.

Studies reviewed have shown that badlands have been investigated for their peculiar features and processes in the frame of landscape evolution, spatial and temporal distributions, denudation rates, effects of man's activity, and erosion risk assessment or mitigation, but several aspects of their genesis and evolution are still unclear.

Various factors and geomorphic processes seem to interplay in *calanchi* genesis and evolution, in relation to local microclimatic conditions, geological features and land use changes.

Some parameters, however, are not yet sufficiently considered: grain size, physical and mineralogical characteristics of clay sediments, soil chemistry, and chemical features of surface and underground water.

The results of the presented study show that the erosional mechanism involves morphological and geographic exposure and climatic elements as well as grain size, mineralogy, chemistry and exchangeable processes of soils. They are important characteristics of eroded soil to give a further contribution to the issue of *calanchi* genesis, in an attempt to integrate pre-existing studies with new risk factors.

It's possible to define erosional risk factors as granulometrical, mineralogical from a chemical perspective. These indicators of soil erodibility risk can be applied in different erosional development and can be used to update the current model for erosion prediction in term of soil-erodibility factor K in the RUSLE equation.

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