GEOMORPHOLOGICAL SENSITIVITY: THE CASE STUDY OF THE NATURAL RESERVE OF "SALSE DI NIRANO" (MODENA APENNINES)

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Abstract

This research deals with the geomorphological characteristics of the Salse di Nirano area located at the margin of the Modena Apennines and with the changes in the landscape induced by the establishment of a Natural Reserve in this area.

The "salse" (mud volcanoes) of Nirano, have been described in very numerous studies since they are the pseudo-volcanic phenomenon best developed in Italy, and since 1982 they have become a Natural Reserve.

The aims of this study were to get an in-depth knowledge of the geomorphological characteristics of the Reserve and carry out a qualitative assessment on the geomorphological sensitivity of the area related to the establishment of the protected area.

The study was carried out according to the following investigation phases: (i) bibliographic research; (ii) morphological analysis through the interpretation of aerial photographs taken in various periods; (iii) field survey; (iv) elaboration of geomorphological maps referring to the features identified in 2002 and in 1973 by means of ArcView GIS computer programme; (v) assessment of the geomorphological sensitivity.

In this area, where silt-clay soil types (Plio-Pleistocene in age) crop out, landforms and deposits resulting from the "endogenetic" activity of the mud volcanoes, due to running water, gravity, anthropogenetic activities and polygenetic landforms. Landforms were recognised and deposits have been distinguished in active and dormant/inactive. In the geomorphological maps also the hydrographic pattern has been indicated.

A qualitative assessment of the geomorphological sensitivity induced by the establishment of a Natural Reserve in the Salse di Nirano area was carried out by the comparing the features represented in the geomorphological maps of 2002 and 1973, respectively. The comparison has pinpointed that the environmental protection measures introduced in this area has favoured the growth of spontaneous vegetation, consequent to the reduction of sheep farming. As a result, many landforms and deposits due to running waters and gravity-induced processes have been stabilised. The neglect of artificial ponds has led to the formation of small swamps or to the filling of water basins. As regards anthropogenetic landforms, the areas affected by creep due to grazing were reduced, a quarrying area was abandoned, farming area was closed and a car park for visitors was built. From literature, it results that the considerable reduction of anthropogenetic disturbance has allowed the increase of the mud-volcano cones which can now grow with no constraints.

Keywords: Geomorphological sensitivity, mud volcanoes, Modena Apennines

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Introduction

This research deals with the geomorphological characteristics of the Salse di Nirano area, located at the margin of the Modena Apennines (Fig. 1), and with the landscape changes induced by the establishment of a Natural Reserve in this area.

"Salse" (mud volcanoes) are the only "endogenetic" forms found in the Emilia Apennines. These phenomena are genetically linked to the ascent to the surface of mud, gas and oil along tectonic discontinuities produced by the overthrusting along the front of the Apennine chain.

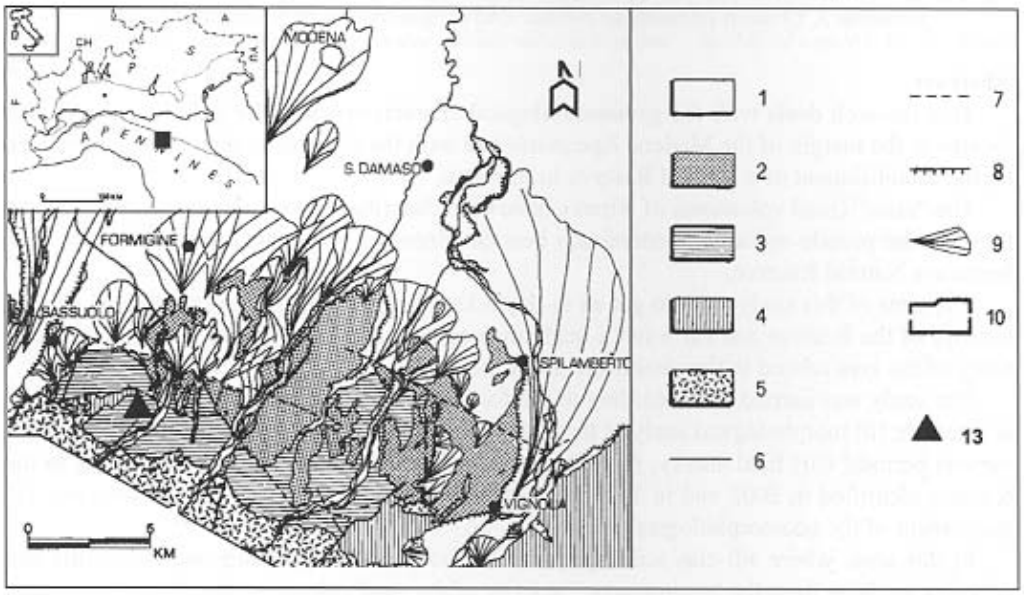

Fig. 1 - Geological map of the Modena Apennine margin and plain (Mod. from GASPERI et al., 1989) Alluvial fan and plain deposits (Holocene); 2) Alluvial fan deposits (Pleistocene); 3) Marine clays, sands and beach gravel at the top (Upper Pliocene?- Lower Pleistocene); 4) Marine clays (Pliocene); 5) Pre-Pliocene substratum; 6) Fault; 7) Buried or probable fault; 8) Scarp edge; 9) Alluvial fan; 10) Flow regulation systems; 11) Location of the Salse di Nirano Natural Reserve.

Since they are the most developed pseudo-volcanic phenomenon of the whole Italian territory, Salse di Nirano have always aroused great interest and were first described by PLINY THE ELDER, around A.D. 60, in his monumental "Naturalis Historia". Many others authors followed (e.g. Stoppani, 1876; Pantanelli & Santi, 1896; Biasutti, 1907; Mucchi, 1966; Bertolani, 1980; Bonazzi & Tosatti, 1999; Castaldini et al. 2003; Gorgoni, 2003). In 1982, in order to safeguard and preserve the natural and environmental characteristic of the site and organise this territory for fruition with scientific, cultural, educational and recreational purposes, the Nature Reserve of Salse di Nirano was established in the area by the Emilia-Romagna Region.

The aims of this study were: a) to get an in-depth knowledge of the geomorphological characteristics of the Natural Reserve; b) to carry out a qualitative assessment of the geomorphological sensitivity of the Natural Reserve.

Geographical and geological outline of the Modena Apennine Margin

The Natural Reserve of Salse di Nirano is located in the western sector of the Modena Apennine margin, which belongs to the Northern Apennines (Fig. 1). The territory of the Nature Reserve covers a total area of about 200 ha with elevations ranging from 140 and 308 m a.s.l. The area where the mud volcanoes are found is some 10 ha and is situated at the bottom of a wide sub-circular depression at an altitude of about 200 m (Fig. 2).

Fig. 2 - Panoramic view of the sub-circular depression of the Salse di Nirano. The picture shows the artificial pond, mud volcanoes alignment and badlands.

From a climatic viewpoint, the study area is comprised within the Sub-continental temperate Climate with average precipitation of about 800 mm/year and average temperatures of 12 to 13 °C (cf. Servizio Meteorologico della Regione Emilia-Romagna, 1995).

From a geological point of view, the Modena Apennine margin is characterised by prevalently compressive structures which correspond to the so called "Emilia Folds" (GASPERI et al., 1989). Sediments ranging from the Lower Pliocene to the Lower Pleistocene outcrop almost continuously in this area. To the south, these deposits are usually transgressive on the Ligurian Units (made up of deep-sea sediments followed by thick sequences of Cretaceous to Eocene calcareous or terrigenous turbidites); to the north, towards the Po Plain, they are covered by alluvial deposits of the Middle-Upper Pleistocene. In the Apennine margin many faults and folds affecting the marine Quaternary sediments, indicate a Middle Pleistocene uplift of the Apennine sector with respect to the plain and a tendency of the southern structures to overthrust the northern structures (Castaldini et al., 1988). The present day tectonic activity of the

Apennine margin is shown by earthquakes that, in this area, are mostly concentrated along the plain-hill boundary. Among the most intense seismic events, the quakes of 1438 (VIII MCS), 1501 (VIII-IX), 1547 (VIII), 1818 (VII-VIII), 1971 (VII-VIII) should be mentioned (cf. Gruppo di Lavoro CPTI, 1999). In the past, some authors noted a correspondence between episodes of violent activity of the mud volcanoes and earthquakes (e.g., Pantanelli & Santi, 1896). Recent investigations (Gorgoni et al., 1988; Gorgoni, 2003) have confirmed that the activity of the mud volcanoes is influenced by local seismicity.

Methods of study

The study was carried out according to the following investigation phases:

(i) bibliographic research.

Various papers were reviewed concerning the geomorphology, geology, hydrography, human intervention and land use in the sector of the Modena Apennines comprising the study area.

(ii) morphological analysis by means of interpretation of aerial photographs taken in various periods.

The aerial photographs examined include black and white aerial photographs at a 1:15,000 scale (approximately) taken in 1973 and at a 1:75,000 scale (approximately) taken in 1994, and colour digital ortho-photographs taken in 1998/99 (IT 2000 Programme) at a 1:10,000 scale.

(iii) field survey.

Field survey was carried out in autumn 2002 in order to verify the present-day morphological features.

(iv) Elaboration of geomorphological maps

On the basis of the above mentioned investigations, two geomorphological maps at a scale of 1:5,000 were prepared: one referring to the features found in 2002 and one referring to the features of 1973. The geomorphological maps have been elaborated by means of ArcView GIS.

(v) Assessment of the geomorphological sensitivity

The geomorphological sensitivity assessment of the study area was performed essentially on the basis of comparison between the morphological features represented in the 2002 (present-day morphology) and 1973 (morphology before the establishment of the Nature Reserve) maps.

Present-day geomorphology (year 2002)

The present day (year 2002) geomorphological map (Fig. 3), resulting from analysis of recent aerial photographs (1994 and 1998/99) and field survey.

In the reserve area only silt-clay soil types (Plio-Pleistocene age) crop out: the "Argille del T. Tiepido" (marine silty-clays) which are found nearly all over the territory and the "Argille del Rio del Petrolio" (marine marly-clays) cropping out to the north. The mud volcanoes area, where the Argille del T. Tiepido crop out, is located at the top of a mild anticline (Gasperi et al., 1989). The study area is characterised by the presence of two systems of tectonic discontinuities (faults and/or joints), NW-SE and SW-NE oriented, respectively. These discontinuities have been identified by means of aerial photo interpretation and field observations of the mud volcanoes arrangement which shows a clear alignment.

The main streams are the Rio Chianca (which marks the western and northern boundary of the park), Rio delle Salse and its tributary Rio Serra which, as previously stated, flow in the southern sector of the Reserve. Furthermore, some small ponds are also found. Their origin is

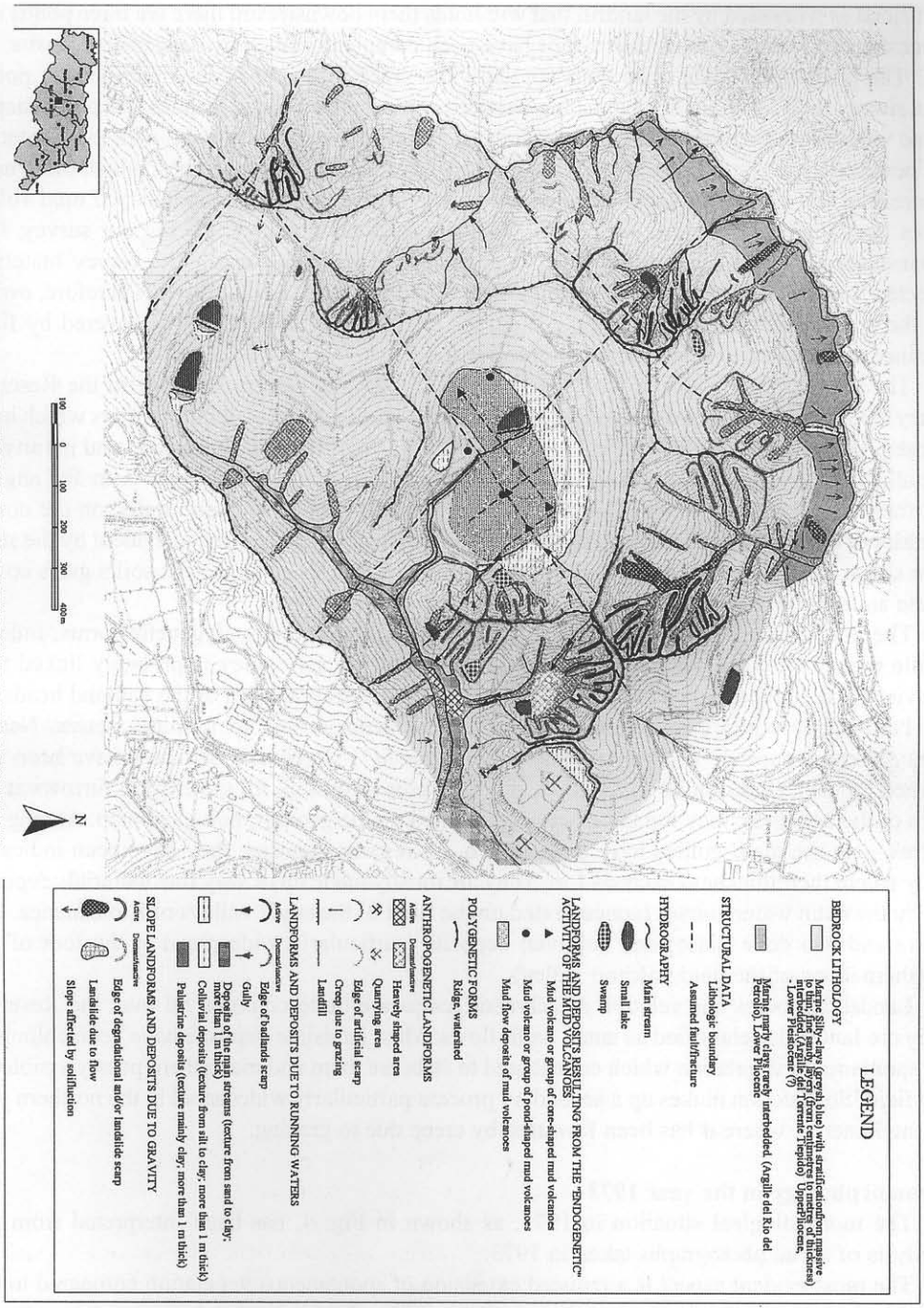

Fig. 3 - Present day geomorphological map (year 2002) of the Natural Reserve of "Salse di Nirano" (Modena Apennines)

artificial as witnessed by the landfill that withholds them downstream: there are three ponds and four marshes. Another four relict ponds have been completely filled by palustrine deposits.

The geomorphological map does not show the precise number of the mud-ejecting points but simply their location, distinguishing between cone-shaped mud volcanoes and pond-shaped mud volcanoes. The morphology of this area is, in fact, constantly evolving with the formation of new craters whilst others cease their activity. Cone-shaped mud volcanoes, which often have more than one crater, are some decimetres to some metres high. The pond-shaped mud volcanoes have diameters ranging from some decimetres to some meters. During our survey, five cone-shaped mud volcanoes and three pond-shaped ones were found. The clayey materials ejected from the craters cover the surrounding ground by means of mudflows. Therefore, owing to the constant emission of mud with time, the floor of this small valley is covered by fine-grained deposits up to a few metres in thickness.

The main anthropogenetic landforms are found near the eastern entrance to the Reserve. They are: i) an abandoned quarrying area, modelled at present by the running waters which have created the badlands, gullies and colluvial deposits; ii) a parking area for visitors and iii) an artificially flattened ground corresponding to a disused farming area a worm farm for angles. Furthermore, the areas affected by creep due to grazing, which are concentrated on the northern slopes of the Reserve are also shown. This man-induced process is made evident by the step-like shape of the slopes which result from pasturing sheep. By reducing the soil's grass cover, these animals have also favoured the onset of solifluction.

The numerous crests and watersheds have been considered as polygenetic forms. Indeed, while the sub-circular crest which surrounds the mud-volcano valley is probably linked to a gravitational collapse, other watershed were created by retrogradation of the badland heads.

Particularly widespread are the landforms and deposits due to running waters. Nearly everywhere is possible to observe badlands (*"calanchi"*) which in most cases have been stabilised by vegetation. Small earth flows, in most cases stabilised, fill the erosion furrows at the foot of the badlands; they too have been represented on the geomorphological map. Among the forms, also the main gullies have been shown. As regards deposits, they have been indicated only where their thickness exceeds 1 m. They are mostly made up of very fine materials deposited by the main watercourses (concentrated on the floor of the small valleys of Rio Chianca, Rio Serra and Rio delle Salse) and colluvial deposits (particularly widespread at the foot of the northern slope of the mud volcano valley).

Landslide bodies and relative detachment scarps are quite common all over the Reserve; they are landslides classified as small earth flows. Most landslide deposits have been colonised by spontaneous vegetation which contributed to stabilise them and make them poorly visible on the field. Solifluction makes up a secondary process particularly widespread in the northern part of the Reserve, where it has been favoured by creep due to grazing.

Geomorphology in the year 1973

The morphological situation in 1973, as shown in Fig. 4, has been interpreted from the analysis of aerial photographs taken in 1973.

The most evident aspect is a reduced extension of spontaneous vegetation compared to the present day; consequently, the morphogenetic processes due to running waters and gravity can clearly be seen.

In detail, the badlands appear in most cases active and free from vegetation, like the numer-

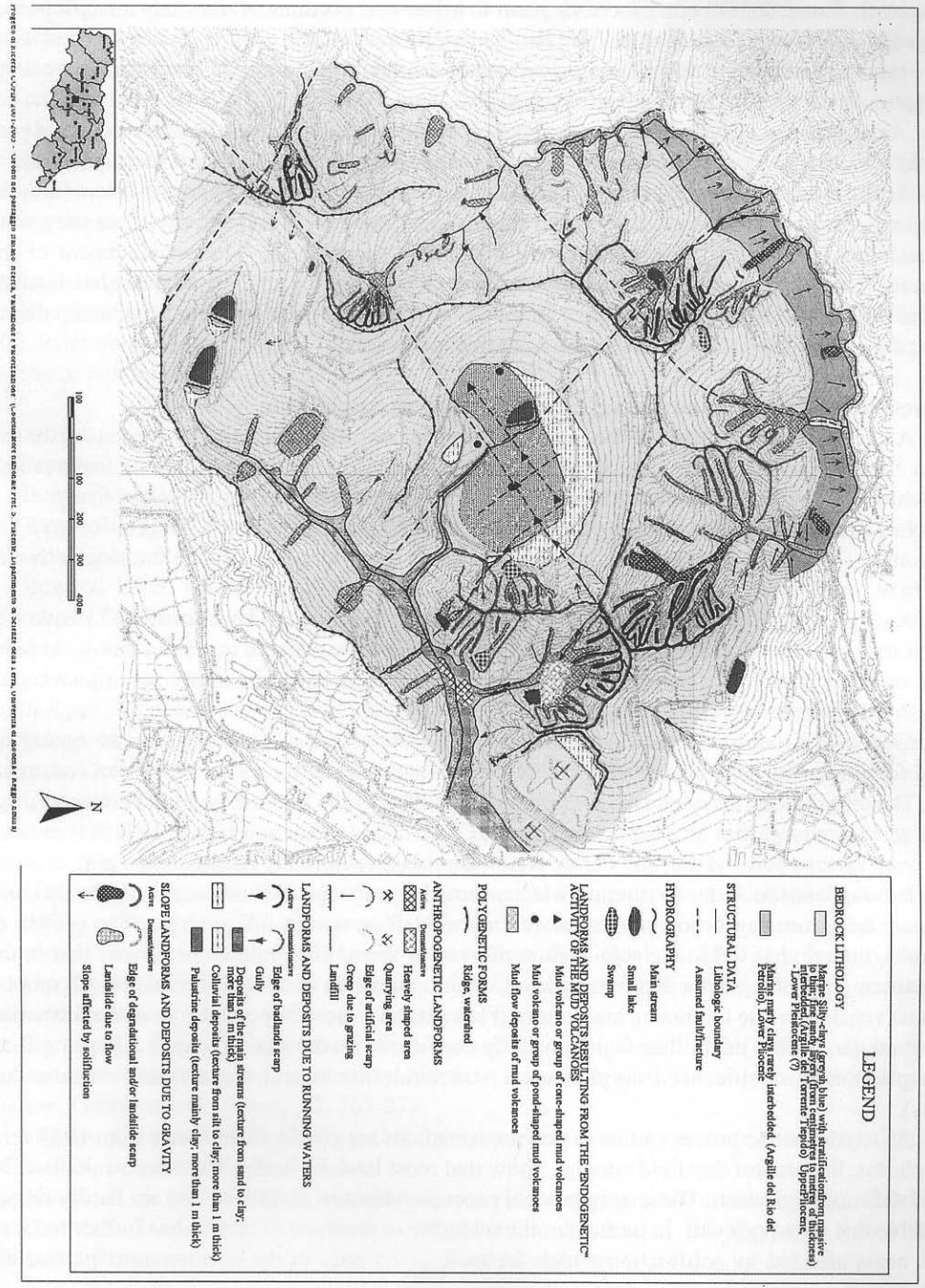

Fig. 4 - Geomorphological map of the year 1973 of the Natural Reserve of "Salse di Nirano" (Modena Apennines)

ous earth flows. Solifluction processes seem to affect vast portions of the study area, in particular the slopes of the Rio Chianca and Rio Serra valleys.

Among the hydrographic features, ten small artificial ponds can be identified (they were constructed in the 1960s for irriguous purposes).

As regards the activity of mud volcanoes, from aerial photograph observations it is not possible to distinguish particular aspects: the mud cones seem to occupy their present positions.

As for anthropogenetic landforms, the quarrying area and the farming area (a worm farm for anglers), located in the eastern sector of the Reserve, are still in full activity since they were abandoned in the mid-1970s and in the early 1980s, respectively. The establishment of the Nature Reserve has definitively stopped the project to utilise the abandoned quarry as landfill. In addition, the farming area was transferred since it was bad-smelling. Traces of creep due to grazing are widespread in various sectors of the study area.

Assessment of the geomorphological sensitivity and conclusions

A qualitative assessment of the geomorphological sensitivity induced by the establishment of a Natural Reserve in the Salse di Nirano area was carried out by comparing the features represented in the Geomorphological maps of 2002 (Fig. 3) and 1973 (Fig. 4), respectively.

In general, the comparison has pinpointed that the establishment of a Natural Reserve has favoured the growth of shrubbery since, at the same time, forest and sheep farming activities were reduced.

As regards hydrographic features, the ten small artificial lakes identified in 1973 have lost their irriguous function and, since they were abandoned, have evolved in a natural way. At present, only the three major ponds have remained; four of them have turned into swamps whereas another four have been filled by palustrine deposits.

Concerning anthropogenetic landforms, in the eastern sector of the Reserve the quarrying and farming areas have been abandoned whereas a parking site for visitors has been constructed. The abandoned quarrying area is at present modelled by the running waters which have originated badlands, gullies and colluvial deposits. Creep due to grazing, which in 1973 was extended over various parts of the study area, is now circumscribed to the northernmost part.

Among landforms due to running waters, some 30 years ago the badlands were nearly completely free from vegetation and therefore their modelling was in full progress. The growth of shrubs, though, has led to the stabilisation of most of them. This induces to assume that in the Northern Apennine sector here considered, anthropogenetic activity (elimination of spontaneous vegetation due to grazing and farming) has played a more important role in the formation of these landforms than other factors usually considered in the main theories regarding their morphogenetic significance (morphological, structural, lithological, tectonic and climatic factors).

As regards slope processes due to gravity, landslides are clearly identifiable from 1973 aerial photos; the present day field surveys, show that most landslip bodies have been colonised by spontaneous vegetation. These gravitational processes are now stabilised and are hardly recognisable due to overgrowth. In particular, the widespread presence of shrubs has further reduced the areas affected by solifluction which are now found only in the northernmost part of the Reserve.

By comparing the geomorphological features of 2002 and 1973 is not possible to make remarks on the landforms and deposits resulting from the activity of the mud-volcanoes.

According to recent literature data (Bonazzi & Tosatti, 1999; Tosatti, 2002), the considerable reduction of anthropogenetic disturbance following the establishment of the reserve has allowed the increase in size of the mud volcanoes which can now develop with no constrains. Indeed in the past the mud cones where flattened in order to increase the surface available for farming or the fluid mud was collected for therapeutic purposes.

In conclusion, this case study illustrates the geomorphological sensitivity of a low-hill area subject to environmental protection measures and describes its assessment by means of comparing the morphological situations observed in different periods.

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References

Bertolani M. (1980) - *Fiorano e il suo territorio*. Docum. e Ric. Com. di Fiorano Modenese, 1-24.

Biasutti R. (1907) – *Le salse dell'Appennino settentrionale*. Mem. Geogr. **2**, pubbl. suppl. alla Riv. Geogr. It.

Bonazzi U. & Tosatti G. (1999) - *Le Salse di Nirano*. In M. Bertacchini, C. Giusti, M. Marchetti, M. Panizza & M. Pellegrini (eds.) (1999) - *I Beni Geologici della Provincia di Modena*. Artioli Editore, Modena, 48-50.

Castaldini D., Chiriac C., Ilies D., with a contribution of Barozzini E. (2003) - *Documenti digitali per la conoscenza integrata dei Geositi: l'esempio della Riserva Naturale delle Salse di Nirano*. In S. Piacente & G. Poli (eds.) - *La memoria della Terra. La Terra della Memoria.* Regione Emilia-Romagna. Ed. L'Inchiostro Blu, Bologna, 121-127.

Castaldini D., Moretti S. & Rodolfi G. (eds.) (1988) - *Guidebook to the excursion in the Toscana, Emilia and Veneto Regions*. Proc. I.G.U. Joint Meeting on Geomorphological Hazards. May 28 - June 4, 1988, Firenze-Modena-Padova (Italy), 151 pp.

Gasperi G., Cremaschi M., Mantovani Uguzzoni M.P., Cardarelli A., Cattani M. & Labate D. (1989) – *Evoluzione Plio-Quaternaria del margine appenninico modenese e dell'antistante pianura. Note illustrative alla Carta Geologica*. Mem. Soc. Geol. It., 39, 431 pp.

Gorgoni C. (2003) - *Le salse di Nirano e le altre salse emiliane - I segreti di un fenomeno tra mito e realtà*. Comune di Fiorano Modenese, 90 pp.

Gorgoni C., Bonori O., Lombardi S., Martinelli G. & Sighinolfi G.P. (1988) – *Radon and helium anomalies in mud volcanoes from Northern Apennines (Italy)-A tool for earthquake prediction*. Geochemical Journal, **22**, 265-273.

Gruppo di Lavoro CPTI (1999) - *Catalogo parametrico di terremoti italiani*. ING-GNDT-SGA-SSN, Bologna, 88 pp.

Mucchi A.M. (1968) – *Le salse del Modenese e del Reggiano*. L'Universo, 48 (3), 421-436.

Pantanelli D. & Santi V. (1896) - *L'Appennnino Modenese*. Ed. Cappelli, Rocca San Casciano, Ristampa 1996, Ed. Iaccheri, Pavullo nel Frignano.

Pliny the Elder (A.D. 60) – *Historia Mundi Naturalis*. Libro II-85, Einaudi Ed., Torino.

Stoppani A., (1876) - *Il Bel Paese*. Milano.

Servizio Meteorologico della Regione Emilia-Romagna (1995) - *I numeri del clima*. Ed.

Promodis Italia, Brescia, 305 pp.

Tosatti G. (2002) - *The Mud Volcanoes of Salse di Nirano*. In: P. Coratza & M. Marchetti (eds.) *"Geomorphological Sites: research, assessment and improvement"*, Workshop Proceedings, Modena, 19-22 June 2002. Legoprint, Lavis (TN), 95-97.