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Rosario Ruggieri

# Speleological and Speleogenetic Aspects of the Monti di Capo San Vito (Sicily)

Influence of Morphotectonic  
Evolution



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Rosario Ruggieri

# Speleological and Speleogenetic Aspects of the Monti di Capo San Vito (Sicily)

Influence of Morphotectonic Evolution

Doctoral Thesis accepted by  
the University of Nova Gorica, Slovenia

 Springer

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*I dedicate this work to my wife Iolanda who has been walking with me the inscrutable paths of this life, sharing the passion for the magic world of the caves, and also for encouraging me to carry out the karst story here presented.*

*I also want to dedicate it to my small always smiling grandchild Rosario hoping that one day he might like to go across the exciting underground world.*

## Supervisor's Foreword

Initially this study started with the aims of seeking the relationship between the tectonic evolution and the karst processes in the Trapani mountains, in the extreme north-west of Sicily, an exceptional karst context for the unique variety and richness of forms, both surface and underground. Then this study underwent an unexpected surge, well ahead of expected expectations, with the results of two important discoveries that have allowed it to extend the framework of knowledge on the speleogenesis of the study area and its interaction with the paleoclimatic factors.

The discovery of caves considered of marine origin, present along the relict paleo-cliffs of the study area, which originated with *flank margin cave* mechanisms, was the first element that has expanded the geographical presence of this speleogenetic phenomenology, found and studied in tropical environments, but so far detected in the Mediterranean only in some conglomeratic formations in Croatia. These morphologies, certainly interesting, for the “hypogenic connotations”, as described by the author, are more directly related to ancient marine levels, than to the epigenic caves. But this element, although important, alone would definitely not have added more insights into the evolution of the karst processes along the coastal belt, unless in this research the second and most important discovery concerning the extraordinary fossil content of marine organisms and of speleothems had not happened with evidence of different stages of ingress and regression of the sea, in the *flank margin caves* Grotta Rumena.

With this further element the scientific findings of this study have embraced a broader Mediterranean context than the study area of the Capo San Vito Mountains, for different aspects of research related to the elements encountered, and the paleoclimate implications and of change of sea level during the Pleistocene age.

Therefore, this research and its discoveries will surely activate, as indeed in some respects has already happened, a whole series of paleontological and paleoecological investigations on the communities of submerged caves, for the widespread deposits of marine fossils, and on the paleogeography linked to the paleoclimatic and sea levels changes, as well as the tectonic implications, during

the Pleistocene in the central Mediterranean. Remarkable changes etched on the walls and speleothems in the Grotta Rumena, thanks to this study, have been protected and established as a geosite of worldwide importance.

Postojna, Slovenia  
July 2015

Associate Professor Martin Knez  
univ. grad. eng. geology

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# Chapter 1

## Introduction

### 1.1 Importance of the Study Area

The area of research is in the extreme north-west of the island of Sicily (Fig. 1.1) and forms part of the mountain range of Trapani. It is bound, to the north, by the Tyrrhenian Sea, to the west, by the Gulf of Cofano, to the east, by the Gulf of Castellammare and to the south by the Guidaloca and Forgia streams.

The orography of the area, which is predominantly mountainous, consists of a system of ridges, usually ranged NW-SE, separated by structural depressions. Along the sea, the study area is characterized by narrow to medium coastal extension strips. From a geological point of view, this territory displays evidence of a complex morpho-structural context, derived from deformations and overthrusting induced during the Sicilian-Appennine-Maghrebian orogenesis. The latter began in the Upper Oligocene period, and endured through successive Plio-Pleistocene extensional transcurrent neotectonic phases linked to the evolution of the southern Tyrrhenian margin.

The prevalently carbonatic nature of the area and the structural discontinuities present due to the diverse orogenic and neotectonic phases that the area has undergone, have all favoured, guided and controlled the development of widespread and important karst phenomena. These can be observed on the surface in an extremely variegated range of morphologies ranging from micro to macro in dimension, and underground in the form of numerous caves, mostly vertical, all of which are decorated by diffuse calcite deposits.

The study area comprehends two municipalities: San Vito Lo Capo and Custonaci. The latter community is the centre of the second most important Italian marble industry (after Carrara, in Tuscany). This commercial activity, which has had deleterious effects on the general environment, has also negatively affected the karst phenomena of the area. The numerous quarries have not only already destroyed many areas but also threaten caves of particular scientific and aesthetic interest in neighbouring exploitation zones. Hence, there is an urgent need to

**Fig. 1.1** Location of the study area



protect the surface and underground karst morphologies both from physical degradation and, particularly, from the problems related to pollution of the aquifers. The latter are especially vulnerable to waste generated by these quarries together with other contaminating material.

In this context, it is imperative to stress the conservation value of these carbonate formations. Especially those morphologies that originate from erosive/corrosive processes and that evolve inside peculiar geostructural context. In view of this, the study and analysis of certain karst morphologies (e.g. vadose/phreatic, sea paleo-notch, speleothems with lihtophagic holes, paleokarst fillings), can provide information on past geological and paleogeographical contexts, such as orogenic deformative phases and neotectonic and eustatic events.

## 1.2 Goals of the Thesis

The objective of this study is to encompass the karst processes that have developed in the Monti di Capo San Vito in the context of the morpho-tectonic evolution of the area. The aim is to understand the possible relation between the Plio-Pleistocene and present tectonic phases and the karst morphogenetic and speleogenetic processes that have evolved in this particular area of the Apenninic-Maghrebian chain.

As a result, the goals of the present research have been to establish the following:

1. Characterization of the karst morphologies (surface and underground)
2. Tectonic structural control in the karstification process
3. Influence of morpho-tectonic evolution and climate change on the speleogenesis.

## 1.3 Methodology

The research that is presented in the following thesis has been structured in two main sections:

- (a) The first part describes the main physical, geomorphological, hydrographic, geological and hydrogeological characteristics of the research area.
- (b) The second part has been divided in a number of subsections, mainly:

- *Karst geomorphological features*

This chapter is subdivided in two main parts:

The main surface karst morphologies classified according to both genetic and morphological criteria are presented in the first part while in the second part the main caves that have been explored and surveyed in the study area by the author are described from a structural and morphological point of view.

- *Structural geological analysis of the karst surface*

In this chapter the structural surveys carried out in the research area are described and analyzed. The aim is to define the tectonic controls on the speleogenetic processes mentioned before. In this context, the structural data and kinematic evidence surveyed at the surface are compared with those obtained from the various caves. From this comparison, the main tectonic deformations are correlated to the caves located in the four zones in which the area of study has been sub-divided.

- *Results and discussion*

In this last chapter, based on the structural and morphological karst data analyzed, a model of the speleogenetic evolution of the main karst structures in the study area is formulated and presented. These structures are represented in the coastal zone by the karst caves Grotta del Fantasma and Grotta Rumena, and, inland, by the karst system Polje di Purgatorio-Dolina della Bufara. The model shows evidence of the influence of the morpho-tectonic evolution on the speleogenesis of the above mentioned karst system during the Plio-Pleistocene.

In conclusion, the main outcomes of this research, which have enabled a better understanding of the geological and paleoclimatic characteristics of the study area, are illustrated.

# Chapter 2

## Research Area

### 2.1 Physical Geography

The area under study is situated in the northern part of the Monti di Trapani in the extreme north-west of Sicily: it is bordered to the south by the hills enclosing the towns of Trapani and Castellammare del Golfo and, to the east and west, by the Tyrrhenian Sea (Fig. 2.1). The territory is predominantly mountainous and its orographic profile is characterized by the following system of reliefs:

- (a) the Mt. Sparagio ridge mainly oriented WNW-ESE, which, at 1,110 m asl, is the highest point in the Monti di Trapani;
- (b) the NW-SE ridges of Mt. Palatimone–Mt. San Giovanni with their respective maximum peaks of 595 and 455 m asl and Mt. Cofano, which reaches an altitude of 657 m; and
- (c) the Mt. Monaco–Mt. Speciale ridges, oriented towards the N-S and with peaks of 532 and 943 m asl respectively.

There are also some separate elevations within the Mt. Sparagio mountain system: the Prima Colma (1,007 m asl), the Colma di Mezzo (1,001 m asl), the Pizzo Bufala (861 m asl) and the Pizzo di Giacolamaro (791 m asl). Lesser elevations worth noting are the NW-SE Pizzo Corvo–Cozzo Pignatello, with peaks of 334 and 295 m asl; the complex of Rocca Rumena–Monte Bufara (323 m asl)—Mt. Zimmaria (315 m asl), which is elongated in the direction of NE-SW and the small isolated elevation of Cozzo Cataruccia (279 m asl). There are areas of plain or semi-plain land in the more extended Purgatorio plain, where heights above sea level range from 240 to 290 m. Similar topography is also to be found in: (a) the areas of Piano Zubbìa–Scaletta–Assieni–Piano dei Tribli, with elevations from 180 to 240 m asl; (b) the Cornino plain in the stretch of land from 0 to 100 m asl and bordered to the S-W by the Forgia stream, to the N-E by the slopes of Mt. Cofano, to the east by the rocky cliffs of Scurati–Cerriolo–Rocca Rumena and to the west by



**Fig. 2.1** General map of the study area Mt. di Capo San Vito (*Hillshade map from DEM Regione Siciliana 2007–2008*)

the sea; (c) the Castelluzzo plain, situated along a strip of terrain ranging from 0 to 130 m asl; and (d) the Piana di Sopra di San Vito, in the northernmost sector of the area, having altitudes ranging from 60 to 80 m asl. Plain-like zones or mildly undulating topography, less extensive than the ones described above, are also found in the Mt. Sparagio mountain system, in the Le Colme locality (920–900 m asl), Giacolamaro, Piano delle Ferle, Coccuccio and Muciara–Noce areas. From an environmental point of view the discussed territory is of extreme importance both for its natural beauty and for the biodiversity of its flora and fauna. This is further demonstrated by the fact that this area includes two of the most important Sicilian

Nature Reserves: (i) The Riserva Naturale Orientata dello Zingaro and (ii) the Riserva di Monte Cofano. However, the zone also includes the second most important marble quarrying industry in Italy, located at Custonaci which, although providing welcome local employment, has certainly brought about a general and serious degradation of the natural environment, as well as interfering with the karst features located in the quarried area.

## 2.2 Geomorphological Features

The main karst features, the focus of this research, are a constituent part of the general geomorphological context of the territory and traceable to different morphogenetic processes. In particular, six major areas of different landforms were recognized (Agnesi et al. 2002), all of which are described in the next chapters (Fig. 2.1).

### 2.2.1 Coastal Areas

These areas (Cornino, Castelluzzo and S. Vito Lo Capo plains) are characterized by a series of marine terraces, consisting of platforms at different levels, and formed by the abrasion of sea water. The terraces are, sometimes covered by continental or marine deposits and separated from each other by modestly sized banks and irregular cliffs. They have been carved by sea-notches, or more frequently, by shelters and caves, both of marine and karst in origin and reworked by hyperkarst marine processes (Antonioli et al. 1993; Antonioli and Ruggieri 2000; Ruggieri 2009; Ruggieri and Messina Panfalone 2011). Altogether seven orders of marine terraces have been observed at altitudes between about 95–105 m (I order) and 1–5 m (VII order) (Di Maggio et al. 1999).

At higher levels (200–225 m asl) the presence of other marine platforms in the Triassic-Liassic substrate has been observed. As far as the dating is concerned, the succession of the terraces has been formed after the Late Lower Pleistocene since the features are cut into deposits attributable to that period, whereas those at higher levels are, as a result, coeval or older than the Lower Pleistocene. The VI order terrace is datable to the Euthyrrhenian because of the presence of *Strombus bubonius* deposits, while the VII order terrace was cut into the previous order and is therefore younger and should presumably be considered 'Neotyrrhenian'. The presence of faunal remains relating to the *Elephas falconeri* type in the sedimentary deposits of the order II terrace, bears witness to a date older than 250 or 350 thousand years, but probably earlier than 750 or 850 thousand. The changes of levels of the inner margins belonging to the same terrace order, show differential movements in the different sectors, with a range of uplift of about 0.11–0.14 m/kyr for the Middle to Late Pleistocene and 0.01–0.1 m/kyr for the post Eutyrrhenian period (Di Maggio et al. 1999; Antonioli et al. 1999a, b, 2002).

### **2.2.2 *The Mt. Sparagio Ridge***

Monte Sparagio is a ridge formation of Mesozoic carbonate rocks that develops in a WNW-ESE direction and reaches a peak of 1,110 m asl, the highest point in the Capo San Vito mountain system. Along the northern face, a large fault slope is visible, while the southern side is characterized by an eastern sector exhibiting structural slopes and a western sector constituted by an upper slope and by numerous other fault scarps. The summit areas (situated at altitudes from 190 to 900 m asl) consist of steps of more or less flat surfaces, probably formed by erosion during the 'planation' in the continental phase. Both the flat areas and the slopes, as will be described in the sections to follow, are of particular interest for their various karst morphologies, such as karren, dry valleys and deep fluviokarst canyons.

### **2.2.3 *The Mt. Palatimone Ridge***

This ridge constitutes a *cuesta* monocline relief of Mesozoic dolomite extending NW-SE and with a southern side that links up with a structural slope. In its northernmost sector the slope was eroded by the Pleistocene sea and a cliff was created. Along its southern parts, the structural slope seems to have come apart and retreated back due to phenomena of both erosion and karst corrosion caused by the flooding phases of the Purgatorio polje described hereunder. This area shows a vast amount of surface karst morphologies, particularly along the southern structural slope together with numerous vertical caves located on both sides of the ridge.

### **2.2.4 *The Purgatorio Plain***

This area consists of a large depression, including a relict polje. This landform was formed, not only due to selective processes resulting from the presence of clay and karst soluble terrains in the area between the carbonate outcroppings of Mt. Sparagio and Mt. Palatimone but also as a result of tectonic processes pointed out by systems of faults. To the south-west of Mt. Palatimone small monocline and relict relief features are to be found, all resulting from karst processes. This depression, which is opened with a deep fluviokarst gorge along its north-west margin, is particularly karstified with surface and underground morphologies, many of which are among the most interesting in the area.

### **2.2.5 *The Mt. Acci-Pizzo di Sella Ridge***

The Pizzo di Sella-Mt. Acci ridge extends as a large anticline, of which the fold-back axis plunges first N-S at Pizzo di Sella, then progressively verges NW-SE

and finally E-W towards Mt. Acci. The eastern flank of this ridge/anticline consists of a large fault slope, while the western flank is made up of a series of recumbent folds, the partial erosion of which has brought to light an alternation of hard and soft rocks. In this area the enormous energy involved in uplifting has led to selective erosion processes with carbonate rock scarps affected by collapses, and clay denudation surfaces ruined by landslides.

### ***2.2.6 The Mt. Speziale–Mt. Scardina Ridge***

These areas are prevalently made up of Upper Triassic dolomitic rocks and are essentially characterized by two types of landscape: (a) the summit areas where ancient relict forms have been preserved and (b) the slopes where the processes of degradation and denudation predominate.

The area between Mt. Speziale and Mt. Scardina is dominated by some depressions, which extend NNW-SSE at altitudes between 600 and 900 m asl. These surfaces have been initially dislocated by tectonic movements (responsible for the formation of scarps and faults) and afterwards been karstified forming uvala landforms. This area, particularly on the eastern slope, is marked by deep canyons, which have originated during the tectonic uplift (with block-faults) and with the consequential lowering of the erosional base level.

### ***2.2.7 The Mt. Cofano Area***

The Mt. Cofano relief is surrounded by extensive fault slopes and abandoned cliffs along its southwestern side. The latter have been intensely subject to processes of physical rock disintegration with the accumulation of modern and ancient debris.

### ***2.2.8 The Scopello Area***

The overlapping of carbonate rocks (display a fragile behavior) onto pelagic deposits (have a plastic behavior) allowed for the genesis of deep-seated gravitational slope deformations (DPGV) (Agnesi et al. 1984, 1987, 1989, 1995, 2000, 2002), which are particularly evident in the Scopello area (Agnesi et al. 1987). The result of these processes is an extremely jagged landscape with extensive detached scarps subject to collapse or overturning, large unattached blocks prone to movement and deep trenches, sometimes open and sometimes filled with detritus.

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# Chapter 3

## Hydrographic Aspects

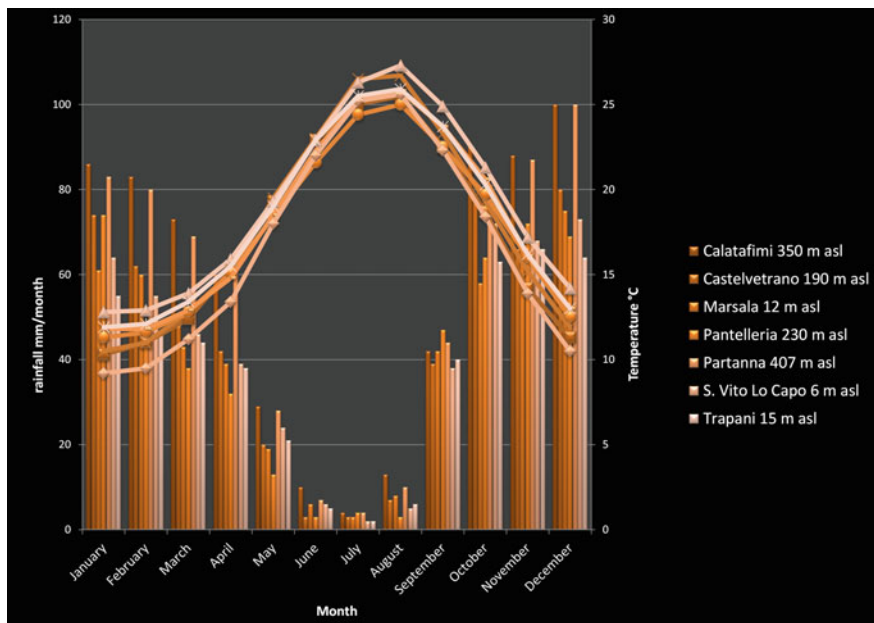
### 3.1 Climatic Aspects

The climatic conditions that characterize the area under study can be deduced from the general situation determined for the whole territory of the Province of Trapani. These have been based on the statistical elaboration of rainfall and temperature data referring to the years 1965–1994 (AA 1998) and collected at meteorological stations (Fig. 3.1). As far as temperature data is concerned the observations that were carried out made it possible to distinguish two large distinct areas: (a) a coastal area including those internal zones closest to it with an average annual temperatures of 18–19 °C; and (b) another comprising the more hilly parts with an average annual temperature of 17 °C. With regard to rainfall, the overall average annual precipitation for the Province of Trapani was 545 mm. Within the area, three macro areas can be further distinguished: (i) a coastal area with an average annual rainfall between 450 and 500 mm; (ii) an intermediate zone with values of 500–600 mm; and (iii) an internal hilly area and the coastal highlands with average annual rainfall ranging between 600 and 680 mm. If the climatic classification indices of De Martonne (1926) and Thornthwaite (1948) were to be applied, the territory under study would be classified as a temperate-hot/dry sub-humid area/region for the internal hilly areas, and semi-arid for the remaining areas (AA 1998).

### 3.2 Elements of Hydrology

#### 3.2.1 Streams

There are two streams that cut through the research area both in the central part and also its southern side (Fig. 3.2). The former is the Biro stream whose basin is limited, in its initial stages of flow, by a superficial watershed passing through Piano



**Fig. 3.1** Diagram of the average monthly rainfall—temperatures (1965–1994) of the meteorological stations sited in the Trapani province (AA 1998)

dell’Arena. This is a linking sector between the aforementioned ridges, which flows, on average, from the east-south-east to the west-north-west along the southern sector of the Castelluzzo plain until it meets the Golfo di Cofano. The Biro flows and cuts, for approximately half of its length (about 8 km), through the Mesozoic carbonate series. For its remaining course reaching the sea, it cuts into the Lower Pleistocene calcarenites of the Castelluzzo plain. The fact that it flows parallel to the fault slope of the Mt. Palatimone ridge brings into question whether a certain control has been exercised by this structure on its development. The evolution of the stream, in any case tied to the depression of the Castelluzzo plain, has been affected by regular tectonic upliftings and by eustatic phases that have interested the plain beginning from the end of the Lower Pleistocene. The second, the Forgia stream, runs from SE to NW for about 15 km reaching the Tyrrhenian sea. It borders the southern part of the study area, for most of its length, into Tortonian clay terrains. In other areas, the Forgia stream cuts into outcroppings that are initially basaltic then change to limestones (Mesozoic) in the final part along of the Cornino plain.

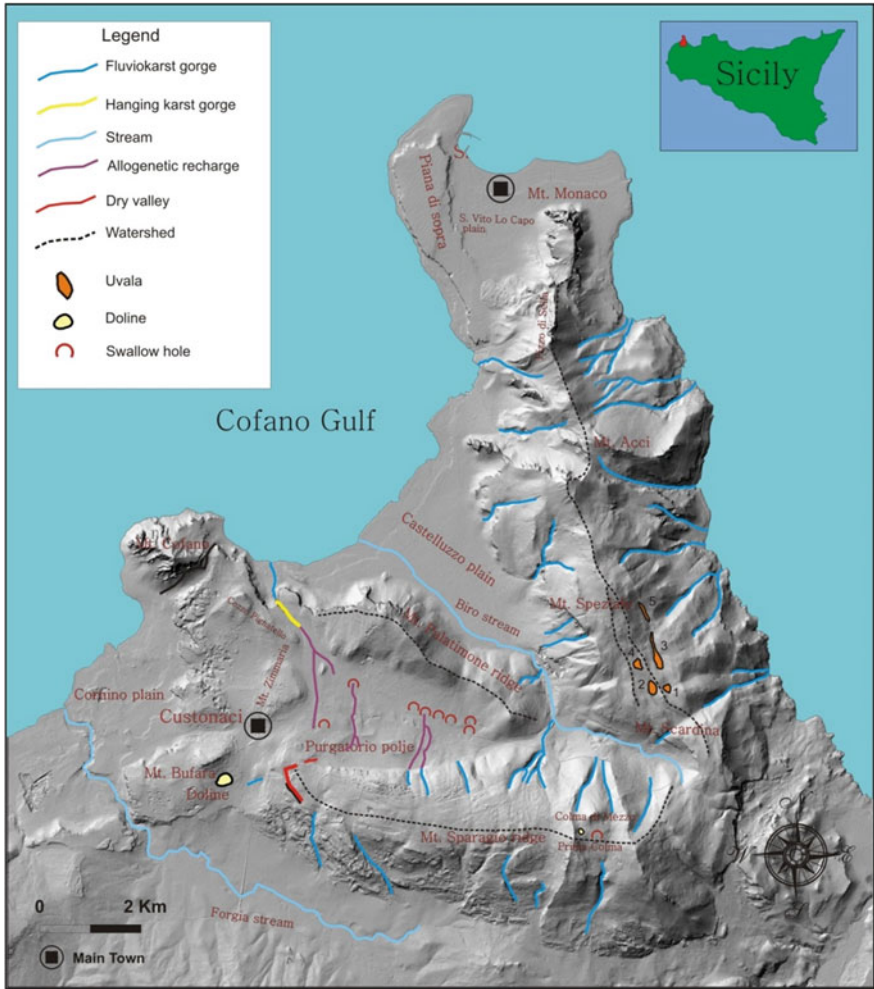


Fig. 3.2 Map of the study area with the main hydrographic features (Hillshade map from DEM Regione Siciliana 2007–2008)

### 3.2.2 Springs

The vast majority of springs located in the study area led back to sources that emerge along the coastal belt, the only exception being a small discharge spring sited in the upper part of the basin of the Biro stream. Some springs of limited discharge are present along the shoreline of the Cornino coastal belt, drained from the biocalcarenes of the Lower Pleistocene, which constitute a shallow porous aquifer whose action is tied to the state of the seasonal rains. A certain number of submerged marine springs, present along the coastal belt of the Zingaro Reserve,

are of greater importance in terms of discharge. These drain deep karst aquifers in the dolomite and dolomitic limestones of the Upper Triassic–Lower Liassic and are characterized by flow in conduits and karst caves sited at variable depth from a few meters to about 30 m below sea level (Cassinis 1967; Cassa per il Mezzogiorno 1976; Bartolomei et al. 1983).

### 3.3 Hydrographic Network

The landforms that characterize the hydrographic network in the research area can be subdivided into the following categories:

1. Fluviokarstic canyons
2. Fluviokarstic gorges
3. Dry valleys
4. Poljes
5. Uvalas
6. Dolines
7. Swallow holes

#### 3.3.1 *Fluviokarstic Canyons*

The canyons present in the study area are located on the slopes of the mountain ridges and can be clearly seen as deep cuts in the landscape. These usually trending NNW-ENE, E-W and NE-SW on the eastern slopes of the Mt. Monaco-Speziale-Scardina ridges (Figs. 3.2 and 3.3–4) with lengths extending from 800 m to 2,600 m and slopes ranging in interval of 20–40 %. The NNE-SSW, NNW-SSE and N-S orientations on the slopes of Mt. Sparagio (Figs. 3.2 and 3.3–4), have lengths varying between 300 and 1,000 m and slopes ranging in the interval of 25–35 %. The above mentioned canyons, cut into Mesozoic dolomite and dolomitic limestone terrains, are mainly aligned along fault lines. The evolution of these deep cuttings has been tied to the deformation tectonic phases and to the uplifting of the ridges, which started at the end of the Miocene and is still active up to the present day.

#### 3.3.2 *Fluviokarstic Gorges*

A deep narrow gorge cutting into the Upper Jurassic–Lower Cretaceous calcarenites along a tectonic structure oriented NNW-SSE, is located in the extreme north-western sector of the Purgatorio plain, in the Cipollazzo area. The gorge



**Figs. 3.3–4** Canyons in the Zingaro Reserve (*left photo*) and in the Sparagio north-eastern slope (*right photo*) (from Google Earth)

develops for about 550 m with an average topographic slope of about 22 %, a width ranging from 4 to 8 m and by vertical walls of about 20–30 m in height. Along its longitudinal axis several morphological steps and swallow holes are present, with giant potholes at the bottom. In particular, about half way down on the right bank, a sink cave known as the “Abisso delle Gole” opens up a few meters above the bed. According to the records, this cave has been explored to a depth of about 140 m. The gorge constitutes the only outlet of the polje, with a spectacular 2 m opening downflow hanging about 40 m above the Castelluzzo plain (Figs. 3.2, 3.5 and 3.6).



**Fig. 3.5–6** Cipollazzo gorge outlet (*left photo*) of the Purgatorio polje (from Google Earth) and its final downflow part 40 m above the Castelluzzo plain (*right photo*)