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Geomorphology of Naples and the Campi Flegrei: human and natural landscapes in a restless land

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ABSTRACT
Naples and its surroundings are a very young landscape, originated from 40 ka in response to strong and explosive volcanic processes, which created the Campi Flegrei, one of the largest volcanic fields of the world. Despite the repeated and continuous volcanic activity, this territory was selected for human settlements since Neolithic times and hosted some of the most important Greek and Roman towns in the Mediterranean area (e.g., Cuma, Parthenope, Neapolis, Baia and Puteoli). Geoarcheological data and historical chronicles testify to human coexistence with eruptions, bradyseismic ground motions, coastline changes, floods and landslides. With the aim of describing the geomorphological evolution of this area to a wide audience, including also non-experts, we constructed a synthetic geomorphological map of the area and sketches that synthesise the main stages of the geomorphological evolution of the historical centre of Naples and the coastal belt of the Gulf of Pozzuoli during the last millennia.

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Landscape evolution; volcanic geomorphology; urban geomorphology; bradyseism

1. Introduction

The uniqueness of the territory of Naples is its young landscape, generated in the last 40 ka as a result of intense, mainly explosive, still active, volcanism, which originated one of the largest volcanic fields, the Campi Flegrei, and one of the most famous strato-volcano, the Somma-Vesuvius, in the Mediterranean area and worldwide. The iconic landscape of Naples is linked to Vesuvius that makes remarkable the view from the town, which is however built on and inside the Campi Flegrei caldera. This peculiar landscape attracted human settlements since Neolithic times. The establishment of a commercial basis on the island of Pithecusa (Ischia) around 770 BC and the foundation of the first Greek colony Kime (Cuma) in the same century marked an increase of human presence, emphasised by the foundation of Parthenope and Neapolis between the VII and V centuries BC, (Carsana et al., 2009; D'Agostino & Giampaola, 2005). Widespread urbanisation of the Campi Flegrei occurred after the settlement of the Roman colony of Puteoli (now Pozzuoli) in 194 BC, which soon became the main commercial port of Rome. In the area of the city of Naples, Greek and Roman settlements were located at the foot of the volcanic hill of San Martino, over a wide terrace protected by invasions and natural hazards. Despite the hydrothermal phenomena and ground motions, the *amoenitas* of the Campi Flegrei natural landscape attracted wealthy people from the Roman aristocracy of the Late Republican period, leading to the urbanisation of the coast.

The Neapolitan landscape includes different geomorphological units such as hilly terrains, coastal plains and coastal cliffs, which have been increasingly urbanised over time. During the Middle Ages and Renaissance, the urban expansion of Naples interested the coastal area of Chiaia and the foothills of Capodimonte (see main map for location). The modern urban expansion has affected both the outer flanks and inner part of the Campi Flegrei caldera and the Sebeto coastal plain, giving rise to a municipality of ~1 million inhabitants, which is part of one of the most densely populated metropolitan areas in Europe.

Here we present the geomorphological map and topography features of the area that spans from the Vesuvius apron, to the east, to the western coast of the Campi Flegrei. In addition, we present sketches (frames A and B) that synthesise the main stages of the landscape evolution during the last millennia of two sectors where the environmental changes are well documented, i.e. the Naples historical centre and coastal belt of the Gulf of Pozzuoli. Overall information provides a key to unravel the landscape of the Neapolitan area, which due to its young age and long-lasting urbanisation, is a magnificent example of the mutual interactions linking the human and natural environments.

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2. Methods

The study is based on the synthesis and reinterpretation of the literature concerning the geological background, volcanological history and geomorphological evolution of the area that extends from the Somma-Vesuvius slopes to the coast of the Campi Flegrei. The analyzed literature includes several studies dealing with the stratigraphic setting both of the shallow subsurface of the Naples urban area and low-lying coastal areas that provide information crucial to the reconstruction of the changes that have affected the coastal belt during the Holocene. The geological-geomorphological information is integrated with geoarcheological data from the historical centre and the Chiaia coastal strip of Naples, as well as the coastal belt of the Gulf of Pozzuoli.

Overall collected information is used for the creation of the geomorphological map and a number of sketches that synthesise the main stages of the geomorphological evolution of the Naples historical centre and Pozzuoli area during the last millennia. In order to synthesize the large-scale topographic features of the analyzed area, an elevation map and a swath profile have been constructed by the analysis of Lidar data in Gis software (ArcGis 10.7 ©). The swath profile, 20 km long and SW-NE oriented, is constructed using the SwathProfiler Add-in of ArcGis (Pérez-Peña et al., 2017).

3. Study area

Volcanism in the Neapolitan area developed in the framework of the extensional processes that governed the opening of the Tyrrhenian back-arc basin since Late Miocene times (e.g. Cinque et al., 1993; Doglioni et al., 2004; Patacca et al., 1990). The Neapolitan volcanic area is located in the wide, ~ 3000 m deep Campanian Plain coastal graben, which experienced strong subsidence during the Quaternary (e.g. Brancaccio et al., 1991; Caiazzo et al., 2006; Santangelo et al., 2017; Figure 1). Late Pleistocene – Holocene subsidence in the southern part of the Campanian Plain graben and its offshore, namely the Gulf of Naples, was governed by NE trending structures (Milia & Torrente, 2000, 2003; Cinque 1991; Valente et al., 2019a; Figure 1) that include the offshore Magnaghi-Sebeto Line (MS; Bruno et al., 2003; Figure 1). Inland, the MS structure is expressed by a fault zone composed of NE-SW and E-W trending segments (Cinque et al., 2011; Irollo, 2005; Irollo et al., 2005) that bounds the coastal strip of Naples and the alluvial-coastal Sebeto plain (Figure 1).

Volcanism at the Somma-Vesuvius started at around 25 ka (Alessio et al., 1974) and was characterised by the alternation of very strong explosive eruptions consisting of plinian and subplinian events, with periods of less intense eruptions with lava flows and pyroclastic material emissions (e.g. ISPRA, 2014; Santacroce & Sbrana, 2003). Between single eruptions, periods of variable time of repose occurred. Among the high magnitude eruptions are those of Mercato (8 ka), Avellino (3.9 ka) and Pompeii (79 AD) (e.g. Cioni et al., 2008 and references therein). The last eruption occurred in 1944 and produced a wide, still visible lava flow (Figure 2).

The Campi Flegrei are characterised by a resurgent caldera that formed after two major collapses related to the eruptions of the Campanian Ignimbrite (CI, ~39 ka old; De Vivo et al., 2001; Giaccio et al., 2017; Valente et al., 2019b) and Neapolitan Yellow Tuff (NYT, ~15 ka old; Deino et al., 2004). The caldera consists of a quasi-circular area, ~8 km in diameter, that includes the Gulf of Pozzuoli. The age of onset of volcanism in the area is unknown, and the oldest dated volcanic rocks are ~60 ka old (Pappalardo et al., 1999). During the CI eruption, at least 300 km^3 (Fedele et al., 2003) of magma were emplaced as pyroclastic-fall and flow deposits over an area covering the entire Campania region. Volcanism between the major CI and NYT eruptions was confined within the caldera and characterised by explosive, mainly phreatomagmatic eruptions. The NYT eruption and caldera collapse represented the second cataclysmic event. This eruption extruded at least 40 km^3 of magma emplaced as pyroclastic-fall and -flow deposits and caused the formation of the main circular slopes of the caldera. After the NYT eruption, volcanic activity was mainly characterised by hydromagmatic phenomena with occasional plinian phases and minor effusive activity forming lava domes. Inside the NYT caldera, volcanism originated several tens of monogenic vents, which include tuff rings, tuff cones, cinder and spatter cones (De Vita et al., 1999; Di Renzo et al., 2011; Di Vito et al., 1999; Isaia et al., 2015; Smith et al., 2011).

Remarkable ground motions have characterised the history of the Campi Flegrei, causing repeated episodes of uplift and subsidence in the range of several metres to several tens of metres (e.g. Bellucci et al., 2006; Cinque et al., 1985; Cinque et al., 1997; Morhange et al., 2006), with bradyseismic crisis continuing nowadays (e.g. Del Gaudio et al., 2010). With the latest volcanic event, the Monte Nuovo volcano was created in 1538 AD following a ~100 yr long uplift phase (De Natale et al., 2006; Di Vito et al., 1987; 2016; Morhange et al., 1999).

4. Features of the landscape and description of the geomorphological map

Notwithstanding the growth of the Neapolitan urban area (Figure 3), the main geomorphological units are still detectable in the landscape. We synthesise the multifaceted features of the landscape of the analyzed area with reference to the following units: (i) slopes of the Campi Flegrei caldera, (ii) Campi Flegrei caldera inner area, (iii) alluvial-coastal plains, and (iv) coastal plains and coastal cliffs.

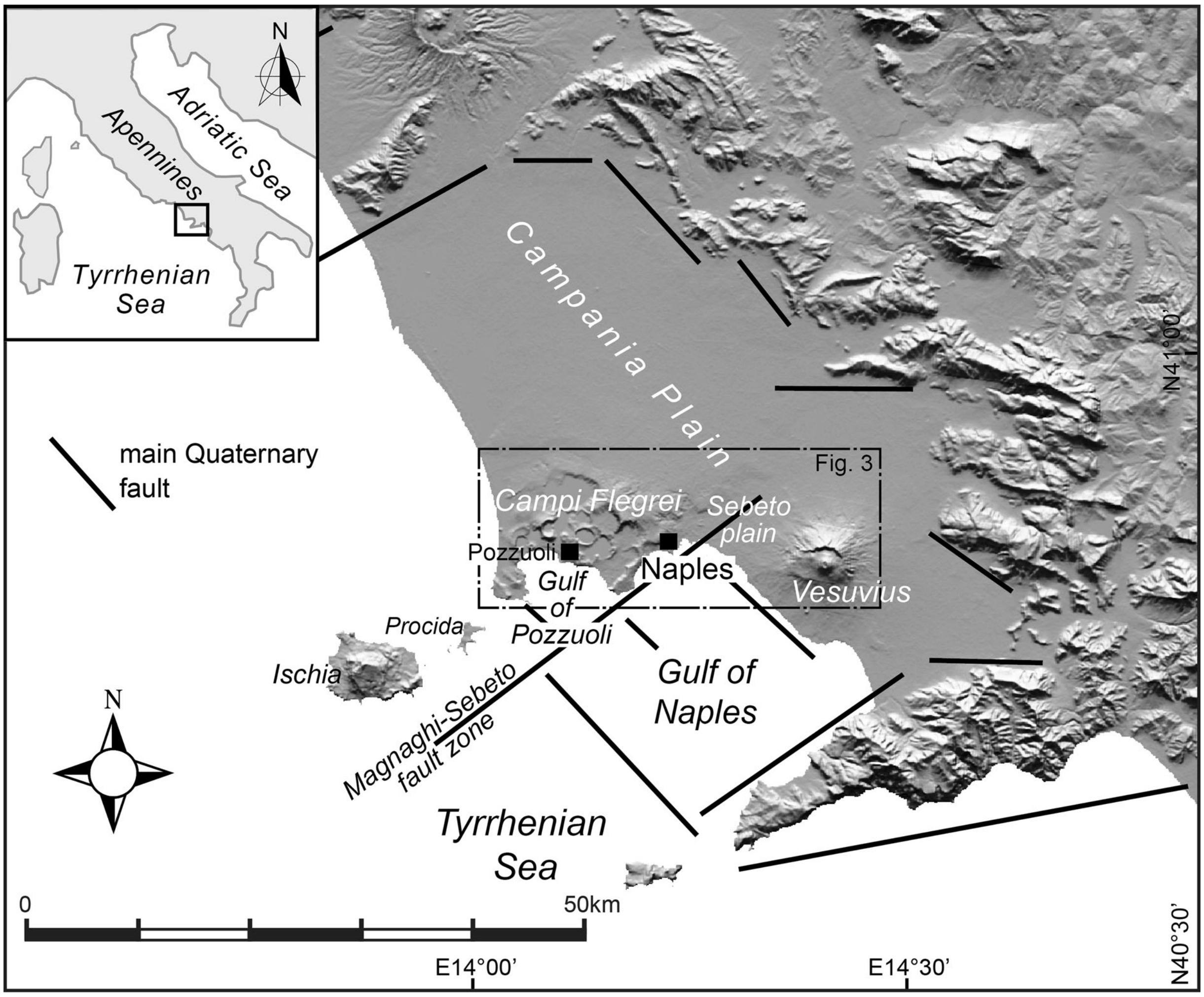

Figure 1. Sketch map of the Campana Plain coastal graben (location in the inset map) and volcanic areas of Campi Flegrei and Vesuvius, with the indication of the main Quaternary fault zones. The frame indicates the location of the satellite view of Figure 3.

4.1. The slopes of the Campi Flegrei caldera

The hills of Naples correspond to the gently inclined outer slopes of the Campi Flegrei caldera that underly the Camaldoli, Vomero-San Martino quarters, in the east, and the Monte di Procida town, in the west (Figure 2; see main map and swath profile). The backbone of these hills consists of the several tens of metre thick NYT and is generally blanketed by younger (< 15 ka) pyroclastic fall deposits (e.g. ISPRA, 2015). The caldera's outer slopes are the oldest geomorphological unit in the analyzed region and, consistently, correspond to an area where a well-developed hydrographical network, with deeply incised valleys, occurs. The drainage pattern is radial–centrifugal, even if some straight, subsequent streams controlled by N-S and E-W fractures and faults are present. In several instances (e.g. Montesanto and Vergini streams; frame B), the downstream segments of the main incisions have been incorporated in the urban area. Such a condition causes significant problems during intense rainfall events, when the man-made underground channel network is unable to collect high discharge flows.

The caldera inner slopes have typical semi-circular planar shapes and steep profiles that make them prone to landsliding (Brandolini et al., 2019; Calcaterra et al., 2007). Conversely, the southeastern flank of the caldera has an overall rectilinear, SW-NE oriented plan form. It consists of a succession of fault scarps and structure-controlled sea-cliffs that represent the expression inland of the MS fault zone. The Holocene activation of the MS fault zone is considered responsible for the uplift of a terraced landform (Pendino terrace; Cinque et al., 2011; Irollo et al., 2005) located between 25 and 60 m a.s.l. on which the ancient Neapolis was built (see 5.1). The Pendino terrace, which corresponds to a raised piedmont area, is formed by a 15 m thick sequence of reworked and *in situ* pyroclastic deposits overlying the NYT. In response to vertical fault motion plus relative sea level rise, the SE-facing fault scarp that bounds the Pendino terrace became a coastal cliff during the Holocene.

4.2. The caldera inner area

The landscape of this area, which is the effective 'volcanic field', is strongly influenced by volcanic processes. Several monogenic vents, such as tuff/ash cones and

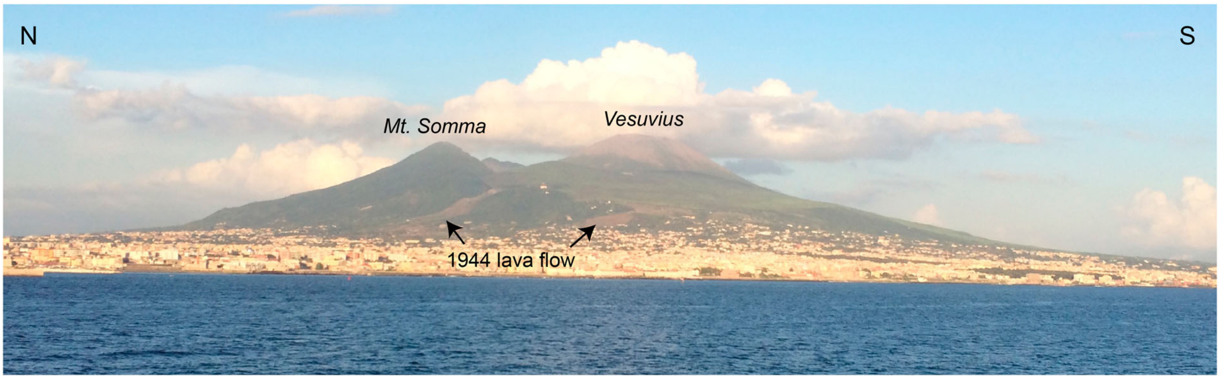

Figure 2. View, from the Posillipo coast, of the Vesuvius main cone, the rim of the Somma caldera and 1944 lava flows; the eastern part of the Naples urban area is visible on the left.

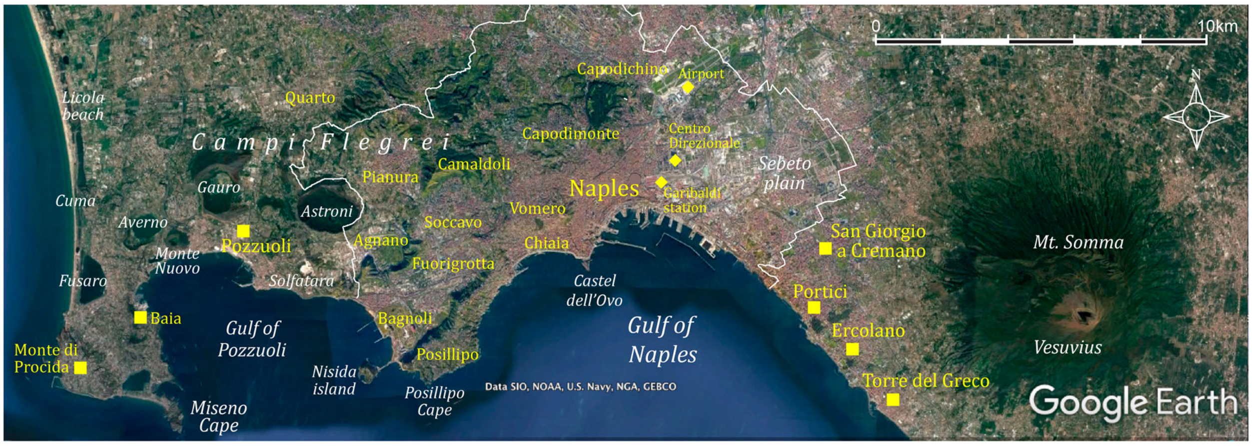

Figure 3. Satellite view (from GoogleEarthPro; location in Figure 1) of the Naples and Campi Flegrei area, with the indication of locations of the quarters of the Naples urban area and main towns of the Naples metropolitan area (yellow characters) and main toponyms (white characters). The white line delimitates Naples municipality.

tuff/ash rings occur, creating a rugged topography (see swath profile in the map). Among the best-preserved vents are the Gauro tuff cone, the tuff rings of Astroni and Averno (which hosts a crater lake), and the Monte Nuovo tuff cone, which was formed in 1538 with the latest eruption in the area (Figure 4).

After the NYT eruption, the collapsed caldera was initially (around 14–10 ka) invaded by the sea, as inferred from marine deposits recovered both in boreholes and outcrops (Cinque et al., 1985), while some of the ancient tuff cones rose within it as islets. Then, part of the caldera progressively emerged in response to both abundant pyroclastic inputs and uplift of its central portion. Volcanoclastic, slope and alluvial deposits filled the bottom of the volcano-tectonic depression that hosts the Soccavo and Pianura quarters of Naples, and the Quarto plain. The uplifted area hosts the town of Pozzuoli, which expands over a wide marine terrace called 'La Starza', located from 30 to 55 m a.s.l. and bounded seaward by a paleo-sea cliff (Figure 4). The succession exposed along the paleo-sea cliff consists of fossiliferous littoral deposits, interlayered with pyroclastic deposits and paleosoils, suggesting alternating phases of uplift and subsidence. The oldest and youngest marine deposits, 10 and 5 ka in age, respectively (Cinque et al., 1985; 1997; Di Vito et al., 1999; Isaia et al., 2009), were deposited at depths ranging from 30 to 50 m b.s.l. Accordingly, a total uplift in the range of 60–80 m since 5000 yr is estimated for La Starza terrace. Ground deformation occurred also more recently. Thanks to the submerged ruins of Portus Julius (Baia) and evidence from the Macellum Roman market (also known as Serapeo) of Pozzuoli (Figure 5), at least two major uplift and subsidence phases in the last 2200 yr, with ground motions in the range of 12 m, are reconstructed (Bellucci et al., 2006; Cinque et al., 1997; Morhange et al., 2006). Cumulative subsidence is also documented for the same period by submerged Roman ruins along the Posillipo coastal belt (i.e. Palazzo degli Spiriti at La Gaiola, Figure 5), Nisida and Castel dell'Ovo areas (green areas in the map; e.g. Aucelli et al., 2018, 2019; Pappone et al., 2019). Recent bradyseismic crises occurred in 1950–1952, 1969–1972, 1982–1984 and since 2005 that uplifted the Pozzuoli area of 0.7, 1.7, 1.8 and 0.3 m, respectively (Del Gaudio et al., 2010; Troise et al., 2007). Evidence of such motions are the raised dock of Pozzuoli harbour and the coastal strip

Figure 4. Views of the main geomorphological elements of the Campi Flegrei caldera inner area. A: View from the south (Posillipo hill) of the Campi Flegrei caldera rim and inner slopes (in the background) and the Bagnoli plain. B: View of the Gulf of Pozzuoli from the Miseno Cape, with indication of the Monte Nuovo and Gauro tuff cones and, in the background, the Monteruscello tuff ring; the dashed yellow line marks the surface of the La Starza marine terrace; in the foreground the northern rim (Pennata island) of the drowned crater, which hosted the Roman harbour of Miseno. C: Aerial view of Monte Nuovo volcano, formed in 1538 AD, Averno volcano and crater lake and Lucrino and Fusaro lagoons. D: View of the southern termination of the Gulf of Pozzuoli (right side), with the Nisida island and Miseno Cape; in the background the island of Ischia is visible. E: View from the west of the steep sea cliff eroded in the cone and crater of the 3.7 ka old Miseno volcano.

spanning from Pozzuoli to Bagnoli (white arrows in the geomorphological map).

4.3. Alluvial-coastal plains

Alluvial plains, passing laterally into coastal plains, occur in the eastern part of the investigated area (Sebeto plain) and in the Fuorigrotta-Bagnoli area. The Sebeto plain lays at the footslope of the Somma–Vesuvius and hosts the eastern part of the Naples urban area, which includes the Garibaldi railway station and the Centro Direzionale business district (Figure 2). The Sebeto plain has been subject to tectonic subsidence during the late Holocene, with rates in the range of 1.5–2 mm/y (Bellucci, 1994, 1998; Irollo, 2005). According to these Authors, with the Holocene sea-level rise a pronounced gulf formed in the Sebeto plain at around 6 ka. From 4.8 ka onwards, the coastline started prograding and, during the Roman period, a wide coastal area with swamps formed.

The Fuorigrotta-Bagnoli alluvial plain (Figure 4) occupies the southern part of the Campi Flegrei volcano-tectonic depression. An irregular, up to 2 m high erosional scarp, which separates the almost flat, raised terrace of Fuorigrotta from the Bagnoli area, is interpreted as a paleo-sea cliff based on the occurrence of shallow beach deposits laying at its toe (Calderoni & Russo, 1998). Overall morphological features and the occurrence of peaty, palustrine sediments along the coast indicate that a marshy back-barrier environment characterised a large part of the Bagnoli plain until recent times when it was occupied by Italsider industry.

4.4. Coastal plains and coastal cliffs

The Neapolitan coastal belt is composed of both low coasts with sandy beaches and rocky, indented coasts characterised by deep bays, narrow headlands (e.g. Posillipo and Miseno capes) and small islands (e.g. the Nisida and Megaride/Castel dell'Ovo) bounded by steep, mostly tufaceous cliffs. The first group includes the coastal belts of the Sebeto and Bagnoli plains, and the littoral zones of Municipio, Chiaia, and Pozzuoli, which have been progressively invaded by urban expansion and modified by man-made fills. Coastal and transitional environments such as marshes, dunes and beaches, which appear in the Sebeto plains in historical maps of the XVI and XVII centuries, have been reclaimed and urbanised. In the western part of the Campi Flegrei area, beach ridges, dunes and lagoons (e.g. Fusaro lagoon) still occur along with lagoons hosted in semi-circular bays of volcanic origin closed by littoral spits (i.e. Miseno and Lucrino lagoons). To the north of the Fusaro lagoon, an isolated promontory preserved behind the beach ridge is a relic of a volcanic dome on which the Greek town of Cuma was built.

The sea cliffs of Naples are mainly cut in the NYT, which is dissected by a dense network of mainly NE-SW trending faults and fractures (Vitale & Isaia, 2014) that act as critical zones from which rock falls originate (Figure 6). The shape of the Posillipo coastal cliff, a residential area since the antiquity and highly urbanised (Figure 7), has been modified since the Roman period by quarrying activities for the extraction of the NYT. The cliffs of the Nisida island and Miseno Cape are nice natural sections of volcanic cones eroded by the sea during the last millennia (Figure 4d-e). The young age of the Miseno Cape tuff cones (3.7 ka; Di Renzo et al., 2011) suggests a high rate of cliff retreat, which is also inferred for other sectors of the Campi Flegrei coast from the presence of Roman ruins hanging over the cliffs (Figure 7).

Figure 5. Evidence of post-Roman subsidence along the coast of Pozzuoli and Posillipo. A) Macellum columns with Lithofaga burrows up to 7 m a.s.l.; B) the Palazzo degli Spiriti Roman building with the first floor completely submerged.

Figure 6. Rocky tufaceous cliffs with rockfalls along the Naples coast. A) Capo Miseno southern cliff; B) Trenataremi cliff; C) Coroglio cliff.

5. Landscape evolution of the Naples and Pozzuoli areas in the last millennia

The landscape evolution during the last millennia of the area that includes the historical centre of Naples and the northern coastal belt of the Gulf of Pozzuoli is well documented. Available information from the two areas has allowed the construction of the multi-temporal sketches in frames A and B, which are explained in the following sections.

5.1. Pozzuoli

The following four-stage (A1, A2, A3 and A4) reconstruction is based on the re-elaboration of literature data (Camodeca, 1994; Cinque et al., 1985, 1997; Welter-Schultes & Richling, 2000; Bellucci et al., 2006; Morhange et al., 2006; Benini & Lanterni, 2010; Giangrotta, 2012; Amato & Gialanella, 2013; Aucelli et al. 2017a,b; 2018).

Figure 7. Views of the coast of Posillipo. A) La Gaiola; B) Posillipo Cape.

Stage A1. Strabo, in his opera De Geografia, describes Lucrino as a gulf whose coastline was close to the Averno crater lake 'surrounded by steep slopes, now cultivated, but formerly covered by a wild forest of large trees, impenetrable'. This description is confirmed by core data, testifying that the Averno lake was occupied by freshwater and therefore sheltered from the sea. In the Pozzuoli coastal sector, an active sea cliff bounded the large La Starza terrace and an underwater environment of low energy characterised the area, which was subsequently occupied by the Serapeo.

Stage A2. The coastal landscape of the Campi Flegrei was strongly modified by anthropogenic activities. Strabo (Geogr., V) describes it as an uninterrupted sequence of luxurious villas and gardens, with the shores between Miseno and Baia scattered by maritime villas with port annexes and fish tanks. The Lucrino Gulf turned into a lake due to the construction of via Herculeanea on a spit formed between Baia and Pozzuoli (Strabo, Geogr., V). In 37 BC, the military port was positioned into the Lucrino lake and the narrow aperture connecting Averno and Lucrino lakes was enlarged and fortified by walls, to create a sheltered landing for warships. In the Pozzuoli sector, archeo-stratigraphic data testify to an abrupt coastal progradation of anthropic origin during the I century BC and burial of the beach by a man-made fill, allowing the foundation of commercial neighbourhoods (vicus Annianus and vicus Lartidianus) and the macellum. Historical evidence points to a subsidence trend of this area. Strabo reports that during the Agrippa restorations, via Herculanea was raised to avoid the submersion during the storms, and the military Portus Julius was abandoned in 12 BC.

Stage A3. During the IV-VI century AD, subsidence accelerated and the relative sea level reached 7 m a.s.l., as demonstrated by the marble columns of the Roman market with traces of lithodome holes in their middle part (Figure 5). The coastal landscape and the Roman towns of Baia and via Herculeanea were submerged and the sea invaded the Lucrino lake, as inferred from the increase of marine species in the mollusc record.

Stage A4. The volcano-tectonic uplift and, in 1538 AD, the eruption of Monte Nuovo volcano changed abruptly the morphology of the area reshaping the southwestern portion of the La Starza terrace and separating definitively the Averno lake from the sea. The eruption lasted 8 days and was preceded by a long seismic crisis and uplift leading to the emersion of a strip of the coast. Afterwards, uplift has affected the area with some acceleration recorded for the last decades.

5.2. Naples

Three main stages (B1, B2 and B3) of landscape evolution have been reconstructed based on the re-elaboration of available literature (Cinque et al., 2011; Di Donato et al., 2018; Romano et al., 2013; Russo Ermolli et al., 2014).

Stage B1. The coastline of Naples was located inland (up to 500 metres in the Municipio area) with respect to the modern one. Promontories and inlets characterised the coast, and the slopes were incised by a dense fluvial network. To the east, a narrow beach strip was present at the base of the sea cliff bordering the Pendino terrace and a sheltered bay, protected by a small tufaceous promontory, characterised the Municipio area. The western coastline (Chiaia) consisted in a rocky sea-cliff bordering a restricted wave cut platform. Behind the cliff, there were remnants of uplifted terraces.

Stage B2. The Greeks founded the ancient Parthenope in the VII century BC on Mt. Echia hill. Then, due to its increasing importance and inhabitant growth, a new settlement (Neapolis) was founded in the VI century BC on the wide Pendino terrace. The Neapolis city walls setting was adapted to the natural features: streams at the sides and a cliff towards the sea. The main roads were built with a SW-NE direction and they led towards the western region where other towns were established, such as Puteoli and Cuma. This first Greek town system now represents the historical centre of Naples where the main streets still follow the traces of the ancient roads and where many Greek and Roman archeological remains rest under the modern ground level. In the Municipio bay, port activities started between the IV and the II century BC, as testified by traces of dredging on the sea floors. Dredging was carried out to lower the sea bottom and to make the inner part of the basin suitable for shipping. Important buried harbour structures (quay, dock, pier) and shipwrecks testify to the commercial activities during the classic and imperial age. The sandy beach in the eastern coastal sector expanded and human activities developed in this period also outside the city walls. In fact, remains of a temple and of the gymnasium were found on the ancient beach. The rich archeological content allowed the sediments of the port to be dated from the II century BC to the V century AD. Pollen analysis suggested that a deciduous oak forest was present on the surrounding slopes and that the Mediterranean maquis occupied the most sunny and rocky sectors.

Stage B3. The main episode is the closing of the harbour area, that took place in the V century AD thanks to the progradation of the shoreline due to alluvial fan accumulation and related growth of a beach. Port activities in this part of the bay ended even before, during the IV century AD, when the town walls expanded westward. Towards the end of the V century the bay was completely filled and the site was used from the beginning of the VI century AD as farmland. To the west, the coastal palaeolandscape consisted of a narrow beach alternating with prograding river mouths and lobes of massive alluvial and slope deposits.

6. Concluding remarks

The rugged, fascinating natural landscape of Naples and the Campi Flegrei results from the continuing interaction of volcanic and tectonic processes with slope, alluvial and coastal processes. It is worthy to note that significant changes of the natural landscape have occurred concurrent with the establishing and development of human settlements, making such a region a peculiar example of human adaptation to phenomena such as volcanism and relative sea level change recorded since its colonisation. Indeed, the entire area is currently exposed to multiple sources of natural hazard, e.g. geomorphic hazards such as flooding, landsliding and coastal cliff instability, bradyseismic crises such as the one that in the '80s caused the abandonment of the historical centre (Rione Terra) of Pozzuoli, and volcanic hazard, managed through the development of National Emergency Plans by the Italian Civil Protection Department. On the other hand, human activity has altered the natural landscape by means of quarrying activities, river network regulation (construction of culverts, reclamation of swamps) and re-shaping of the coastal strips. However, in the last decades increasing awareness on natural and cultural heritage has allowed the establishment of protected areas such as those of Astroni, Monte Nuovo, Camaldoli hills and the underwater archaeological park of Baia and the La Gaiola.

Software

The map presented in this work has been produced using Esri ArcGis 10.7 © for the vector and raster datasets, and Corel Draw 2019 © for the editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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