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A geoitinerary through volcanic landforms in the restless coastal area of Campi Flegrei (southern Italy)

Abstract: Ascione A., Aucelli P., Caporizzo C., Donadio C., Mattei G., Petrosino P., Russo Ermolli E., Santangelo N., Valente E., *A geoitinerary through volcanic landforms in the restless coastal area of Campi Flegrei (southern Italy).* (IT ISSN 0391-9838, 2025). This study explores the development of a geoitinerary in the western sector of the Campi Flegrei caldera, a geologically dynamic area in southern Italy recognized for its active volcanic history and rich geoheritage. The Campi Flegrei, designated as one of the first 100 IUGS Geological Heritage Sites, exemplifies the potential of volcanic landscapes to serve as both educational platforms and tourism attractions. The proposed geoitinerary highlights seven geosites selected for their high educational and touristic value. These include prominent volcanic, archaeological, and geomorphological features such as the Cuma lava dome, La Starza marine terrace, Serapeo, Monte Nuovo, Averno Lake, Baia sommersa, and Capo Miseno. The initiative aims to promote geoeducation and sustainable tourism, emphasizing the relationship between geological processes, landscape evolution, and human settlement. The study underlines the region's long-standing appeal due to its fertile volcanic soils, strategic coastal positioning, cultural significance, and geothermal resources, despite ongoing risks related to bradyseism and seismic activity. A SWOT analysis is employed to evaluate the strengths, weaknesses, opportunities, and threats associated with the proposed geotourism initiative. Ultimately, the study advocates for geotourism as a tool for enhancing public awareness of volcanic hazards, supporting local economies, and preserving geological and cultural heritage. It calls for integrated management strategies that involve scientific, local, and policy stakeholders to address challenges like risk communication, environmental protection, and community participation. By doing so, the Campi Flegrei can serve as a model for balancing development and conservation in other volcanically active regions.

Key words: Geosite, Volcanism, Bradyseism, Marine landform, Coastline modification.

Riassunto: Ascione A., Aucelli P., Caporizzo C., Donadio C., Mattei G., Petrosino P., Russo Ermolli E., Santangelo N., Valente E., *Un geo-itinerario attraverso le forme vulcaniche nella turbolenta area costiera dei Campi Flegrei (Italia meridionale).* (IT ISSN 0391-9838, 2025). In questo lavoro viene presentato un geo-itinerario che si sviluppa nel settore occidentale dei Campi Flegrei, un'area geologicamente attiva in Italia meridionale nota per la sua storia vulcanica e il ricco patrimonio geologico. Il paesaggio vulcanico dei Campi Flegrei, riconosciuti come uno dei primi 100 siti dall'elevato interesse geologico censiti dall' IUGS in tutto il mondo, ben si presta ad attività didattiche che possono anche essere favorite dell'elevata attrattività turistica dell'area. Il geoitinerario attraversa sette geositi rappresentativi di diversi aspetti delle geoscienze quali la vulcanologia, la geoarcheologia e la geomorfologia, ovvero: il duomo lavico di Cuma, il terrazzo marino di La Starza, il Serapeo, Monte Nuovo, il lago d'Averno, Baia sommersa e Capo Miseno. Obiettivo del geo-itinerario, che si rivolge sia alla popolazione locale che ai geo-turisti, è la promozione dell'educazione ambientale e del turismo sostenibile attraverso attività mirate a sottolineare la stretta connessione tra processi geologici, evoluzione del paesaggio e loro impatto sulle dinamiche insediative. La frequentazione antropica dei Campi Flegrei, favorita dalla fertilità dei suoli, dalla posizione strategica dell'area e dalle risorse geotermiche, è stata infatti continua nel tempo nonostante i rischi legati al bradisismo e alla sismicità dell'area. I punti di forza, le debolezze, le opportunità e le difficoltà collegate allo sviluppo del geo-itinerario sono stati discussi tramite la SWOT analysis. I risultati ottenuti evidenziano l'elevato potenziale del geo-itinerario proposto che può contribuire ad aumentare la consapevolezza della popolazione locale verso il rischio vulcanico e supportare l'economia locale. A tal fine, è necessaria una gestione del territorio che veda coinvolti gli amministratori locali, la popolazione locale e la comunità scientifica attraverso attività di divulgazione finalizzate alla comunicazione dei rischi geologici che interessano l'area e alla sua protezione ambientale. In questo modo i Campi Flegrei potranno rappresentare un modello da esportare in altre regioni vulcaniche attive del mondo in cui far convivere sviluppo socio-economico del territorio e protezione ambientale.

Termini chiave: Geosito, Vulcanismo, Bradisismo, Morfologie marine, Modificazione della linea di costa.

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INTRODUCTION

Geotourism in volcanic areas centres around the observation of active geological phenomena, including eruptions and geothermal features. Iconic volcanoes such as Kilauea in Hawaii (USA), Piton de la Fournaise on La Réunion (France), Mount Etna in Sicily, Stromboli in the Aeolian Islands (Italy), and the more recent eruptive sites on Iceland's

Reykjanes Peninsula continue to draw significant numbers of visitors due to their volcanic activity (Langridge and Michaud, 2023).

Guided geotours in these regions offer more than just a visual spectacle – they serve as powerful educational tools. These tours can enhance public understanding of volcanic systems, eruption processes, and their broader environmental and societal consequences (Armiero *et al.*, 2011; Alberico *et al.*, 2023; Casadevall *et al.*, 2019; Arias *et al.*, 2025). Whether driven by scientific interest or educational outreach, geotourism fosters a deeper appreciation of the complex relationships between geological forces, natural environments, and human communities. In this sense, geotours not only enable exploration of Earth's dramatic volcanic landscapes but also raise awareness about the dynamic – and at times hazardous – nature of our planet (Petrosino *et al.*, 2019).

Active volcanic regions hold immense scientific value due to their dynamic nature and profound geological impact. The eruption of lava, the accompanying seismic activity, and the rapid creation of new landforms illustrate the intense processes at work within the Earth's lithosphere. Features such as craters, lava flows, pyroclastic deposits, and geothermal features provide direct evidence of volcanic activity, magma dynamics, and landscape evolution (Németh *et al.*, 2017; Dóniz-Páez *et al.*, 2020; Pérez-Umaña *et al.*, 2020). Volcanic events can transform entire landscapes in relatively short geological timeframes, underscoring the constantly changing nature of our planet and serving as natural archives of past eruptions, patterns of activity, and their long-term environmental and societal impacts (Zangmo *et al.*, 2017; Planagumà *et al.*, 2018).

The importance of visiting volcanic areas goes beyond their scenic and ecological value – it also plays a critical role in fostering awareness of volcanic hazards and informing risk management strategies (Petrosino *et al.*, 2019). Experiencing these landscapes firsthand can heighten public understanding of the potential dangers posed by future eruptions, even in volcanoes currently at rest.

The Campi Flegrei, located to the west of Naples in southern Italy, exemplify a volcanic region where geotourism can significantly contribute to both educational and economic growth. The Campi Flegrei is a vast volcanic caldera encompassing approximately 75 km^2. Formed through multiple eruptive events over the past 39 ka years (Sbrana *et al.*, 2021; Orsi, 2022), the area is characterized by numerous tuff rings, tuff cones, and evidence of vertical ground deformation, reflecting its dynamic volcanic activity (Ascione *et al.*, 2020, and references therein). Notably, the region experiences bradyseism, a phenomenon involving the gradual uplift and subsidence of the ground due to subterranean magma movements and hydrothermal activity (Di Vito *et al.*, 2016; Isaia *et al.*, 2019; Chiodini *et al.*, 2021; Scarpa *et al.*, 2022). This geological dynamism has profoundly influenced the area's topography and human settlement patterns (Costa *et al.*, 2022). The Campi Flegrei has been inhabited since Greek and Roman times. Volcanic deposits favoured the formation of fertile soils that allowed diffuse agricultural activities, thus resulting in continuous human frequentation through time. Hundreds of thousands of people live within the Campi Flegrei nowadays, making this area one of the most overpopulated areas of Europe (Batista e Silva *et al.*, 2013). The overpopulation exposes many inhabitants to volcanic risk, thus making necessary the development of actions to disseminate both knowledge of volcanic processes and the best practises to act in case of emergency. Dissemination can be carried out through educational activities addressed at the promotion of geosites, geomorphosites and geotourism (Pescatore *et al.*, 2019), which may significantly contribute to the increase of local economy (Farsani *et al.*, 2014).

In recognition of its unique geological features, the Campi Flegrei has been designated as one of the "First 100 IUGS Geological Heritage Sites" by the International Union of Geological Sciences (IUGS) (https://iugs-geoheritage.org/geoheritage_sites/the-quaternary-phlegrean-fields-volcanic-complex/). A IUGS Geological Heritage Site is defined as «key place with extraordinary geological elements or processes of the highest scientific relevance, used as a global reference, and/or with a substantial contribution to the development of geological sciences through history» (https://iugs-geoheritage.org/selection-process/). This acknowledgment underscores the global importance of the area's geological heritage and highlights the need for its preservation and promotion through geotourism initiatives.

Academic research has further contributed to geotourism development in the region. Esposito (2006) and Armiero *et al.* (2011) proposed several sites within the Campi Flegrei that earn the title of geosites. Most of these sites have been included in the "List of Geosites of the Campania Region" (https://sit2.regione.campania.it/documenti/mappatura-geositi#overlay-context=content/download).

More recently, Alberico *et al.* (2023) examined the effectiveness of geotrails in supporting sustainable development in the Campi Flegrei. The researchers proposed a cultural trail on the outskirts of Naples, featuring field tours of geologically and historically significant sites, as well as virtual tours of ancient underground quarries. The study highlighted the dual educational purpose of such trails: enhancing the understanding of the area's geological features and raising awareness of potential hazards, while also fostering a sense of cultural identity and belonging among local communities.

Despite the large geotourism potential of the Campi Flegrei and its potential in terms of geoeducation, the area lacks the proposal of some geoitinerary that could guide visitors in discovering this fascinating volcanic area and that could increase local people awareness about the geological dynamic territory they live in. In this paper, we try to fill this gap by proposing a geoitinerary in the western sector of the Campi Flegrei caldera. We selected seven geosites from the official catalogue of the Campania Region with the aim of describing the strong connection between volcanic processes and landscape modification, and their impact on human frequentation.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Campi Flegrei is a volcanic area located within the Campana Plain, a large tectonic depression placed along the inner, Tyrrhenian margin of the Southern Apennines. Formation of the Campana Plain is associated with the extensional tectonics that affected the Southern Apennines since the Late Miocene, thus causing the opening of the Tyrrhenian back-arc basin (Cinque *et al.*, 1993; Doglioni *et al.*, 2004). The sedimentary pile filling the Campana Plain is about 3 km thick and includes marine, transitional, continental and volcanic deposits (Brancaccio *et al.*, 1991; Santangelo *et al.*, 2017). Among volcanic deposits are those produced by the Campi Flegrei, which accumulated in the upper portion of the Campana Plain filling.

The Campi Flegrei is a ring-shaped caldera with a maximum diameter of ca. 12 km whose volcanic activity started in the Upper Pleistocene, as remnants of volcanic edifices older than 60 ka in the urban area of Naples testify (Pappalardo *et al.*, 1999; Scarpati *et al.*, 2013; fig. 1). Recently, the study of a borehole in the eastern area of Napoli (Ponti Rossi) allowed the identification of Campi Flegrei pyroclastic deposits aged ca. 110 ka (Sparice *et al.*, 2024), further expanding back in time the activity of this volcanic district. The caldera formed because of two explosive volcanic events, the Campana Ignimbrite (hereinafter CI, 39 ka; Giaccio *et al.*, 2017) and the Neapolitan Yellow Tuff (hereinafter NYT, 15 ka; Deino *et al.*, 2004). CI has been covered by younger volcanic units and outcrops only as proximal breccia (Breccia Museo) and welded ignimbrite (Piperno) deposits at Cuma, Monte di Procida and Camaldoli, whereas the NYT diffusely outcrops along the inner and outer slope of the caldera (fig. 1). Volcanic activity in the last 15 ka has been constrained within the Campi Flegrei caldera by low- to intermediate-size explosive eruptions at several monogenic vents (De Vita *et al.*, 1999; Di Renzo *et al.*, 2011; Di Vito *et al.*, 1999; Smith *et al.*, 2011; table 1). The age of this activity, overall, became younger towards the centre of the caldera (Ascione *et al.*, 2020 and references therein). The last eruption of the Campi Flegrei is the Monte Nuovo eruption that occurred in 1538 CE (Arzilli *et al.*, 2016; Liedl *et al.*, 2019).

The fascinating landscape of Campi Flegrei results from the continuous interaction of volcanic and tectonic processes with slope, alluvial and coastal ones. It mainly originated after the NYT eruption, i.e it is younger than 15 ka. According to Ascione *et al.* (2020) several geomorphological units can be detected in the area which includes(i) outer slopes of the Campi Flegrei caldera, (ii) inner slopes of the Campi Flegrei caldera, (iii) alluvial-coastal plains, and (iv) coastal plains and coastal cliffs.

The hills of Naples correspond to the gently inclined outer slopes of the Campi Flegrei caldera that underly the Camaldoli area, to the east, and the Monte di Procida town, to the west (fig. 2). The backbone of these hills consists of the several tens of meters thick NYT deposits and is generally blanketed by younger (<15 ka) pyroclastic fall deposits. 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.

The caldera inner area consists of about 30 monogenic edifices, mainly tuff rings and tuff cones (fig. 2). Generally, tuff cones have straight or gently concave sides, with a crater at the top and steeper flanks and higher height/length ratio than tuff rings. The best preserved and exemplary are the tuff rings of Astroni and Averno (which hosts a crater lake) and the Monte Nuovo tuff cone, which was formed in 1538 during the last eruption in the area. Alluvial plains, passing laterally into coastal plains, occur in the eastern part of the investigated area (Sebeto plain) and in the Fuorigrotta-Bagnoli area (fig. 2).

Besides volcanic activity, the Campi Flegrei experienced episodes of ground vertical motion in the form of bradyseism (Lima *et al.*, 2009; Cannatelli *et al.*, 2020). These episodes are testified by the uplifted Holocene marine terrace of La Starza near Pozzuoli (Cinque *et al.*, 1991) and by archaeological remains lowered below sea level (Aucelli *et al.*, 2018, 2019).

METHODS

Geosites listed in the official catalogue of the Regione Campania (https://sit2.regione.campania.it/documenti/mappatura-geositi#overlay-context=content/download) have been considered to be included in the geoitinerary. As the geoitinerary aims at disseminating concepts like landscape modification in volcanic areas and their impact on coastal areas and human settlement, we focused the analyses on the western sector of the Campi Flegrei, where landforms testifying such geomorphic processes are diffuse (Ascione *et al.*, 2020).

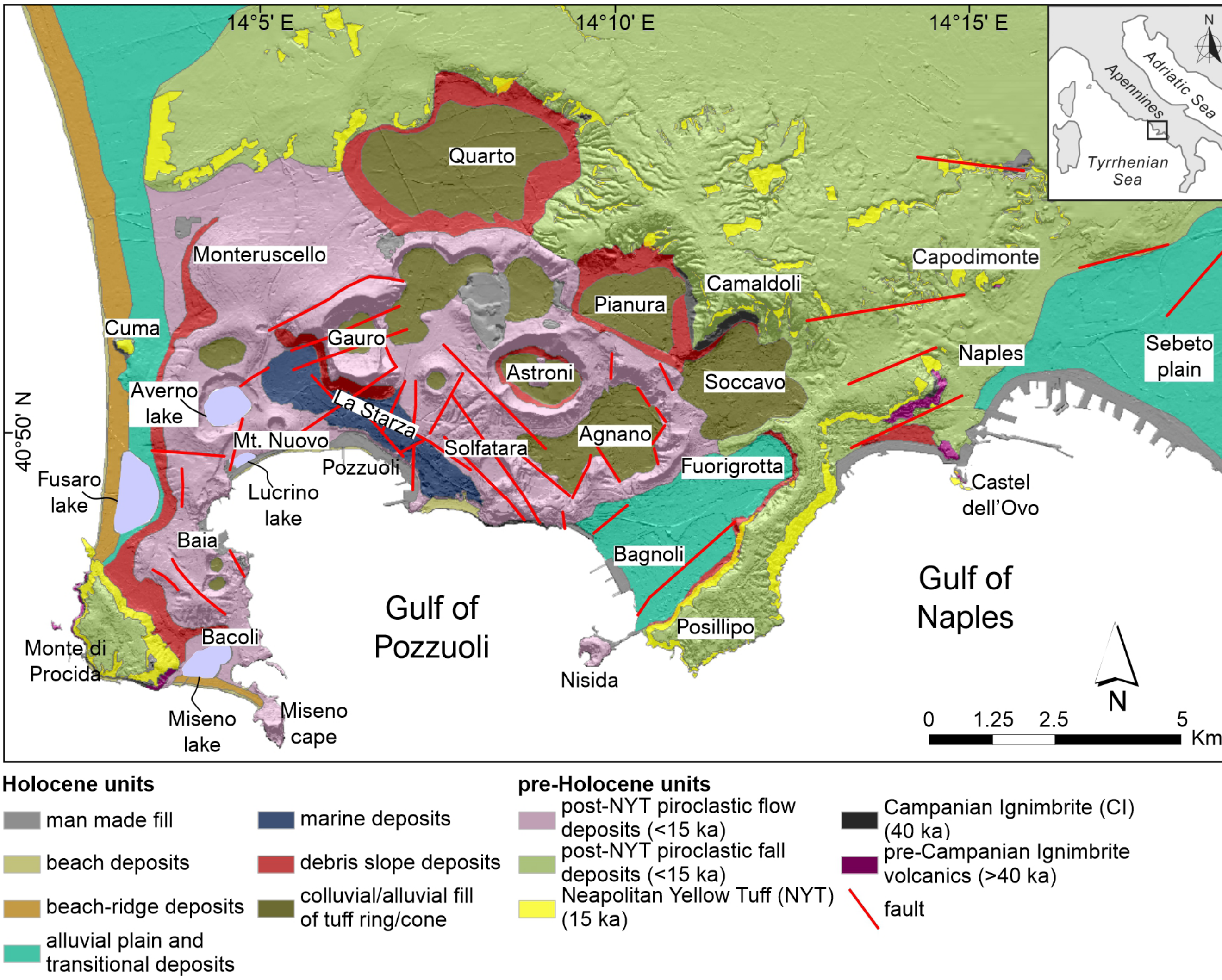

Figure 1 - Simplified geological map of the Campi Flegrei (modified from Di Crescenzo *et al.*, 2021). Coordinates are in the reference system WGS84 (EPSG 4326).

Selection of the geosites to be included in the geoitinerary followed the method proposed by Brilha (2016) by defining the Educational Value (EV) and the Potential Touristic Value (PTV) of the seventeen selected geosites. Such indicators have been chosen because of the objectiveness in defining the parameters, and related scores, for their evaluation. This allows the geoitinerary to be addressed both to local population and tourists and to serve both for educational activities (i.e., increasing awareness of local people about landscape modification due to volcanic activity) and promotional activities (i.e., diverging the tourist traffic towards some poorly known area of the Campi Flegrei). Furthermore, the EV refers to the accessibility and suitability of geosites for education purposes, whereas the PTV refers to the scenic appeal to a wide public. Both indexes are weighted according to several parameters that are: vulnerability (V), accessibility (AC), use limitations (UL), safety (SA), logistics (L), population density (DE), associations with other values (AS), scenery (SC), uniqueness (UN), and observation conditions (OC). These parameters are completed with the didactic potential (DP) and geological diversity (GD) parameters for the EV, and with the interpretative potential (IP), economic level (EL), and proximity to recreational areas parameters (PR) for the PTV (table 2). Both the EV and the PTV are ranked from 1 to 4. Geosites with values of the EV and the PTV higher than 3 have been included in the geoitinerary. This resulted in the selection of seven geosites to be included in the geoitinerary.

We also conducted a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to test the potential of the proposed geoitinerary. This method is commonly used in geotourism planning (Kubalikova, 2019, and reference therein). It requires for an accurate knowledge of the geo-

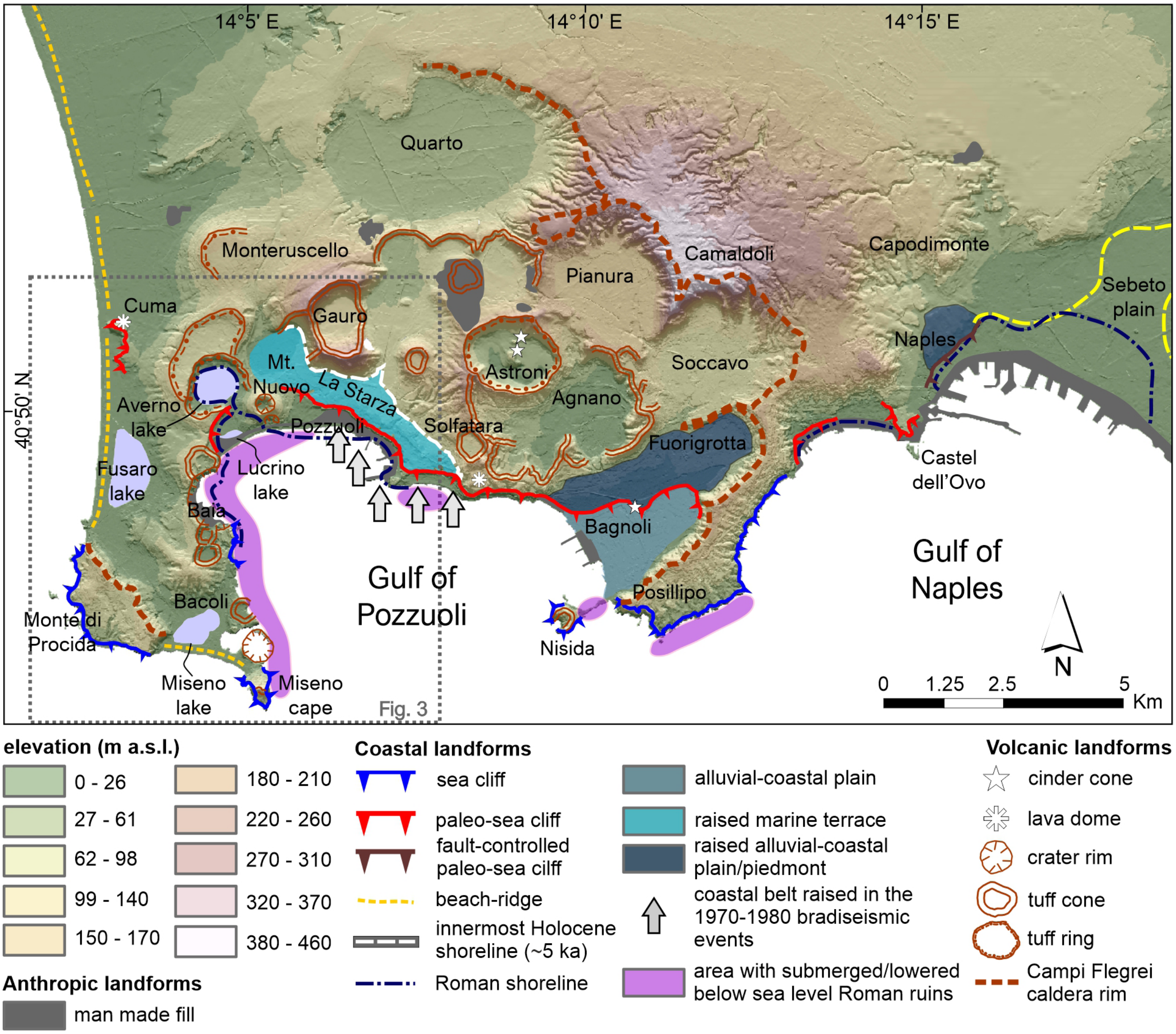

Figure 2 - Geomorphological map of the Campi Flegrei (modified from Di Crescenzo *et al.*, 2021). Dashed grey lines indicate location of the area encompassed by fig. 3. Coordinates are in the reference system WGS84 (EPSG 4326).

logical and geomorphological features of the investigates area (i.e., through literature analysis and field work) and helps defining strategies for geotourism development (Wang *et al.*, 2023). The promotion of geotourism activites requires the identification of elements favourable for geotourism (Strengths), how geotourism may contribute to local community development (Opportunities), what may negatively impact on geotourism activities (Weakeness) and what are the main difficulties to face (Threats) SWOT analysis is so crucial in geotourism planning and may help local stakeholders in their decision-making procedures. This method has been applied worldwide and provided useful information also for sustainable development of geoparks. Case studied from China (Wang *et al.*, 2025), Sri Lanka (Sumanapala *et al.*, 2021), Serbia (Antic and Tomic, 2017), Romania (Guju *et al.*, 2025), Ecuador (Carrión-Mero *et al.*, 2020) testifies for the effectiveness of the SWOT analysis in geotourism planning. SWOT analysis in Italy has been applied to both inner areas of the Apennines (Piancentini *et al.*, 2019) and geoparks (Santangelo *et al.*, 2020; Valente *et al.*, 2020, 2021) and has been proved to be a valuable tool for the geotouristic promotion of small villages that are facing the risk of human abandonment. Furthermore, Vandelli *et al.* (2024) assessed the usefulness of SWOT analysis also in geosites degradation risk analysis.

Table 1. Eruptive events at Campi Flegrei after the Neapolitan Yellow Tuff eruption, modified from Bevilacqua *et al.* (2022). * - uncertain stratigraphic order with the previous eruption. ** - coeval with the previous eruption. ? - unconstrained stratigraphic order. The Age and Magma Volume estimates are from Smith *et al.* (2011) and references therein.

ID	Eruption	Epoch	Age (cal. years BP)		Magma Volume (DRE) (km^3)		
			Percentile		Percentile		
			2.5th	97.7th	5th	50th	95th
1	Monte Nuovo	NA	1538	1538	0.03	0.03	0.03
2	Nisida	3b	3213	4188	0.01	0.02	0.03
3	Fossa Lupara	3b	3978	4192	0.01	0.02	0.03
4	Astroni 7	3b	4098	4297	0.04	0.07	0.11
5	Astroni 6	3b			0.06	0.12	0.18
6	Astroni 5	3b			0.05	0.10	0.15
7	Astroni 4	3b			0.07	0.14	0.21
8	Astroni 3	3b			0.08	0.16	0.24
9	Astroni 2	3b			0.01	0.02	0.03
10	Astroni 1	3b	4153	4345	0.03	0.06	0.09
11?	Capo Miseno	3b	3259	4286	0.01	0.02	0.03
12**	Averno 2	3b			0.04	0.07	0.11
13	Solfatara	3b	4181	4386	0.02	0.03	0.05
14*	Accademia lava dome	3b			0.00	-	0.01
15	Mt Olibano Tephra	3b			0.01	-	0.10
16	Solfatara lava dome	3b			0.00	-	0.01
17	Paleoastroni 3	3b			0.01	0.02	0.03
18*	Mt Olibano lava dome	3b			0.00	-	0.01
19	S.ta Maria delle Grazie	3b	4382	4509	0.01	-	0.10
20	Agnano - Monte Spina	3a	4482	4625	0.43	0.85	1.28
21	Paleoastroni 2	3a	4712	4757	0.10	-	0.30
22	Paleoastroni 1	3a	4745	4834	0.03	0.05	0.08
23*	Monte Sant'Angelo	3a	4832	5010	0.10	-	0.30
24	Pignatiello 2	3a			0.01	0.02	0.03
25	Cigliano	3a			0.03	0.05	0.08
26	Agnano 3	3a			0.10	0.19	0.29
27	Averno 1	3a	5064	5431	0.01	-	0.10
28	Agnano 2	3a			0.01	0.01	0.02
29	Agnano 1	3a	5266	5628	0.01	0.02	0.03
30	San Martino	2	9026	9370	0.03	0.05	0.08
31	Sartania 2	2			0.01	-	0.10
32	Pigna San Nicola	2	9201	9533	0.10	-	0.30
33	Costa San Domenico	2			0.01	-	0.10
34	Monte Spina lava dome	2			0.00	-	0.01
35	Sartania 1	2	9500	9654	0.01	-	0.10
36	Fondi di Baia	2	9525	9695	0.02	0.04	0.06
37	Baia	2			0.00	-	0.01
38?	Porto Miseno	1	10347	12860	0.01	-	0.10
39?	Bacoli	1	11511	14154	0.10	0.20	0.30
40	Casale	1			0.01	-	0.10
41	Pisani 3	1	10516	10755	0.01	-	0.10
42	Pignatiello 1	1			0.01	-	0.10
43	Montagna Spaccata	1			0.01	0.02	0.03
44	Concola	1			0.00	-	0.01
45	Fondo Riccio	1			0.00	-	0.01
46	Pisani 2	1			0.10	-	0.30
47	Pisani 1	1			0.10	-	0.30
48	Soccavo 5	1			0.01	-	0.10
49	Minopoli 2	1			0.01	-	0.10
50	Paleo San Martino	1			0.01	-	0.10
51	Soccavo 4	1			0.10	-	0.30
52	S4s3_2	1			0.01	-	0.10
53	S4s3_1	1			0.10	-	0.30
54	Soccavo 3	1			0.01	-	0.10
55	Soccavo 2	1			0.01	-	0.10
56	Paleo Pisani 2	1			0.10	-	0.30
57	Paleo Pisani 1	1			0.01	-	0.10
58	Pomici Principali	1	11915	12158	0.43	0.85	1.28
59	Gaiola	1			0.01	-	0.10
60	Soccavo 1	1			0.25	0.50	0.75
61	Paradiso	1			0.01	-	0.10
62	Minopoli 1	1			0.01	-	0.10
63	Torre Cappella	1			0.01	-	0.10
64	La Pigna 2	1			0.01	-	0.10
65	La Pigna 1	1	12749	13110	0.01	-	0.10
66	La Pietra	1			0.01	-	0.10
67	Santa Teresa	1			0.01	-	0.10
68	Gauro	1	12721	12511	0.25	0.50	0.75
69	Mofete	1			0.01	-	0.10
70	Bellavista	1			0.01	-	0.10

Table 2. List of the parameters related to both the Educational Value (EV) and the Potential Touristic Value (TV) of the geosites, and related score and relative weights. Reader may refer to Brilha (2016) for further details.

Educational Value (EV)			Potential Touristic Value (PTV)		
vulnerability (V)	1-4	10	vulnerability (V)	1-4	10
accessibility (AC)	1-4	10	accessibility (AC)	1-4	10
use limitations (UL)	1-4	5	use limitations (UL)	1-4	5
safety (SA)	1-4	10	safety (SA)	1-4	10
logistics (L)	1-4	5	logistics (L)	1-4	5
population density (DE)	1-4	5	population density (DE)	1-4	5
associations with other values (AS)	1-4	5	associations with other values (AS)	1-4	5
scenery (SC)	1-4	5	scenery (SC)	1-4	15
uniqueness (UN)	1-4	5	uniqueness (UN)	1-4	10
observation conditions (OC)	1-4	10	observation conditions (OC)	1-4	5
didactic potential (DP)	1-4	20	didactic potential (DP)	1-4	10
geological diversity (GD)	1-4	10	geological diversity (GD)	1-4	5
			proximity to recreational areas parameters (PR)	1-4	5

RESULTS - THE GEOITINERARY

The location of the seventeen geosites placed in the western portion of the Campi Flegrei and reported in the official database of the Campania region is shown in fig. 3.

These geosites include:

- sites testifying paleoshoreline location (1 – Cuma; 7 – Starza);
- anthropic cave connecting the inland with the sea (2 – Grotta di Cocceio);
- volcanic edifices formerly occupied by the sea (3 – Averno Lake);
- the youngest mountain in Europe (4 – Monte Nuovo);
- thermal area closes the coast (5 – Stufe di Nerone);
- underwater site of geological relevance (6 – Secca Fumosa; 11 – Tubipore di Torregaveta);
- archaeological sites testifying vertical ground motions (8 – Serapeo; 10 – Baia sommersa);
- sea cliffs and paleo-sea cliffs carved in volcanic units (9 – Punta Epitaffio; 12 – Torregaveta; 14 – Torrefumo);
- small island (13 – Isolotto di San Martino);
- natural coastal cave (15 – Grotta dello Zolfo);
- remnants of volcanic edifices dismembered by wave erosion (16 – Porto di Miseno; 17 – Capo Miseno).

Results of the Brilha (2016) method to assess the EV and the PTV of each geosite are listed in tables 3 and 4, respectively. Geosites with values higher than 3 of both the EV and the PTV (i.e., Cuma, Averno Lake, Monte Nuovo, La Starza, Serapeo, Baia sommersa and Capo Miseno) have been included in the geoitinerary and are listed in bold in both tables.

The proposed geoitinerary is shown in fig. 3. It is 18.5 km long and each geosites could be reached moving by car. The only geosites that include walkable paths are Cuma, Mt. Nuovo and Averno Lake. Cuma has a walkable path that led geotourists reach the interior of the lava dome through some anthropic cave. Mt. Nuovo has a 1.5-hour long trail that could bring geotourist up to the summit of the volcanic cone, whereas a 1-hour long trail borders the Averno Lake. Furthermore, geotourists may rent a boat at Baia Sommersa to reach the submerged ruins of the Roman town of Baiae, whereas the landscape of Capo Miseno could also be appreciated through boat trips.

The geoitinerary starts to the north, at Cuma, and ends to south, at Capo Miseno and will help geotourists to appreciate different themes of the geoscience (table 5). This starting point at Cuma is due to logistics as the site of Cuma is close to the main highspeed way (i.e., Tangenziale di Napoli) that could bring geotourist in this area. We do not choice the Serapeo, which is served by public transport, as a starting point because moving to the other geosites will be difficult without a car. The geosites of Cuma consists of an isolated volcanic hill that interrupts the continuity of a quasi-flat area . Geotourists could then moves towards the south-east and borders the northern flank of the Averno Lake and Mt. Nuovo volcanoes until reaching the La Starza marine terrace after 5 kilometers. This is a flat surface of marine origin testifying vertical motions in this portion of the Campi Flegrei. A tens of meters high paleo-sea cliff limits the marine terrace to the south-west where the harbor of Pozzuoli is settled. This area hosts the worldwide famous archaeological site of the Serapeo, which preserves evidence of bradyseism. Moving from the Serapeo, the geoitinerary follows a road roughly parallel to the coastline until the base of Mt. Nuovo, the youngest volcanic edifice of the Campi Flegrei. Just 1.5 km of distance separates the Mt. Nuovo area from the following geosite, the Averno Lake. The geoitinerary then proceeds along the coast and reaches Capo Miseno after 8 km.

Table 3. List of the Campi Flegrei geosites (from the official catalogue of the Campania Region; https://sit2.regione.campania.it/documenti/mappatura-geositi#overlay-context=content/download) and indicators used to assess their educational value. The number below each indicator represents its relative weight. Geosites in bold are those included in the geoitinerary.

Educational Use of the Geosites													
Indicator Geosite	V (10)	AC (10)	UL (5)	SA (10)	L (5)	DE (5)	AS (5)	SC (5)	UN (5)	OC (10)	DP (20)	GD (10)	TOT.
1 – Cuma	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3.9**
2 – Grotta di Cocceio	3	3	3	4	4	4	4	1	2	4	3	2	2.95
3 – Averno Lake	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**4**	**4**	**3.7**
4 – Monte Nuovo	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**4**	**3.85**
5 – Stufe di Nerone	3	4	4	4	4	4	4	2	1	2	1	2	2.65
6 – Secca Fumosa	4	1	3	4	4	4	4	1	2	1	1	2	2.3
7 – La Starza marine terrace	**2**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**3**	**4**	**4**	**3.65**
8 – Serapeo	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3.9**
9 – Punta Epitaffio	3	2	3	3	4	4	4	2	1	3	1	2	2.4
10 – Baia sommersa	**3**	**2**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**2**	**4**	**4**	**3.5**
11 – Tubipore di Torregaveta	3	2	3	3	4	4	4	1	1	1	1	1	2.05
12 – Torregaveta	3	3	3	4	4	4	4	1	1	3	1	3	2.65
13 – Isolotto di San Martino	3	1	3	3	4	4	4	1	1	2	1	1	2.05
14 – Torrefumo	3	2	2	3	4	4	4	1	1	3	1	3	2.4
15 – Grotta dello Zolfo	3	2	2	2	4	4	4	1	2	3	2	2	2.45
16 – Porto di Miseno	3	2	2	3	4	4	4	2	2	3	3	2	2.8
17 – Capo Miseno	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**4**	**4**	**3.85**

Table 4. List of the Campi Flegrei geosites (from the official catalogue of the Campania Region; https://sit2.regione.campania.it/documenti/mappatura-geositi#overlay-context=content/download) and indicators used to assess their potential touristic value. The number below each indicator represents its relative weight. Geosites in bold are those included in the geoitinerary.

Potential Touristic Use of the Geosites														
Indicator Geosite	V (10)	AC (10)	UL (5)	SA (10)	L (5)	DE (5)	AS (5)	SC (15)	UN (10)	OC (5)	IP (10)	EL (5)	PR (5)	TOT.
1 – Cuma	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**1**	**4**	**3.75**
2 – Grotta di Cocceio	3	3	3	4	4	4	4	1	2	4	2	1	4	2.75
3 – Averno Lake	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**4**	**1**	**4**	**3.45**
4 – Monte Nuovo	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**1**	**4**	**3.65**
5 – Stufe di Nerone	3	4	4	4	4	4	4	2	1	2	2	1	4	2.85
6 – Secca Fumosa	4	1	3	4	4	4	4	1	2	1	1	1	4	2.4
7 – La Starza marine terrace	**2**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**3**	**3**	**1**	**4**	**3.35**
8 – Serapeo	**3**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**1**	**4**	**3.75**
9 – Punta Epitaffio	3	2	3	3	4	4	4	2	1	3	2	1	4	2.55
10 – Baia sommersa	**3**	**2**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**2**	**3**	**1**	**4**	**3.35**
11 – Tubipore di Torregaveta	3	2	3	3	4	4	4	1	1	1	2	1	3	2.25
12 – Torregaveta	3	3	3	4	4	4	4	1	1	3	2	1	4	2.6
13 – Isolotto di San Martino	3	1	3	3	4	4	4	1	1	2	2	1	3	2.2
14 – Torrefumo	3	2	2	3	4	4	4	1	1	3	2	1	4	2.35
15 – Grotta dello Zolfo	3	2	2	2	4	4	4	1	2	3	2	1	4	2.35
16 – Porto di Miseno	3	2	2	3	4	4	4	2	2	3	2	1	4	2.6
17 – Capo Miseno	3	4	4	4	4	4	4	3	4	4	3	1	4	3.5

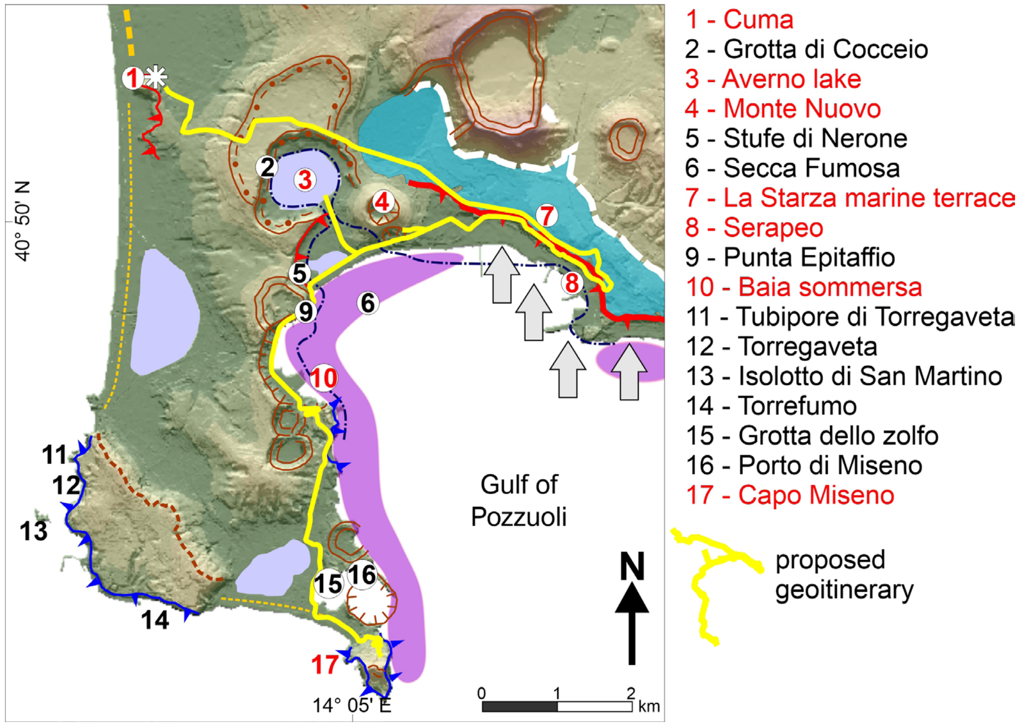

Figure 3 - Location of geosites in the western sector of the Campi Flegrei plotted on the geomorphological map of fig. 2. See fig. 2 for legend.

Table 5. Details of the main features of the geosites included in the geoitinerary.

Geosite	Main feature
Cuma	Lava dome, coastline modification, geoarchaeology, mythology
Averno Lake	Volcanism, coastline modification, mythology
Mt. Nuovo	Volcanism
La Starza marine terrace	Vertical ground motions
Serapeo	Bradeysism, geoarcheology
Baia Sommersa	Bradeysism, geoarcheology
Capo Miseno	Volcanism, cliff retreat

The geoitinerary moves in an urbanized area that provides many opportunities to rest and appreciate local food, and in which restaurants, bar, hotels, and accommodation facilities are very diffuse. The best period of the year to enjoy the geoitinerary is from October to May, summer season is not suggested due to an abrupt increase in local traffic and possibly very hot weather. Details of each stop and its geotourist significance are reported in the following sub-sections.

Stop n. 1 – Cuma

The most peculiar geological feature of the Cuma area (fig. 4a) is the presence of a lava dome (fig. 4b). The age of the lava dome was directly determined via $^{40}Ar/^{39}Ar$ dating at 42,2 ± 1,5 ka (Lirer *et al.*, 2011). The lava, with well-developed honeycomb tafoni (fig 4c), is overlain towards the SW by a pyroclastic deposit made up of whitish to grey well vesicular pumice fragments engulfed in a coarse ash matrix (fig. 4d), $^{40}Ar/^{39}Ar$ dated at 41,7 ± 0,9 ka (Lirer *et al.*, 2011). These ages are well compatible with the stratigraphic position of both the lava and the pyroclastic deposits, which lie beneath the Breccia Museo deposits (fig. 4e), the well-known proximal lithofacies of the CI eruption (Fedele *et al.*, 2008). The succession ends with the NYT lithified deposits (ca. 15 ka – Deino *et al.*, 2005).

The lava dome of the Cuma volcano is the best example of the few effusive products of Campi Flegrei activity prior to the CI eruption. This lava was used in the Augustan age to pave the Via Sacra (fig. 4f), which led from the Città Bassa (lower city) of Cumae to the main Temple on the top of the acropolis. Its features are very peculiar and could be successfully used to explain the mechanism of lava dome formation. Volcanic or lava domes form when viscous lava emerges from a volcano but does not travel far. The lava in domes builds up around the vent, creating a mound-like structure. This dome can grow as lava pushes up from within or as it slowly oozes out in lumps or spines. As more lava accumulates, the dome expands, and the mountain forms from lava spilling over the sides. Lava domes vary in shape and behaviour, influenced by factors like magma properties, the landscape, how magma rises, and how the dome grows. Dome growth can be endogenous (fig. 4g) – expanding from within as magma pushes into the dome – or exogenous (fig. 4h), where lava breaks through the surface or flows out to form new lobes. At a first glance and at the outcrop scale, the Cuma lava dome could appear constructed by the cha-

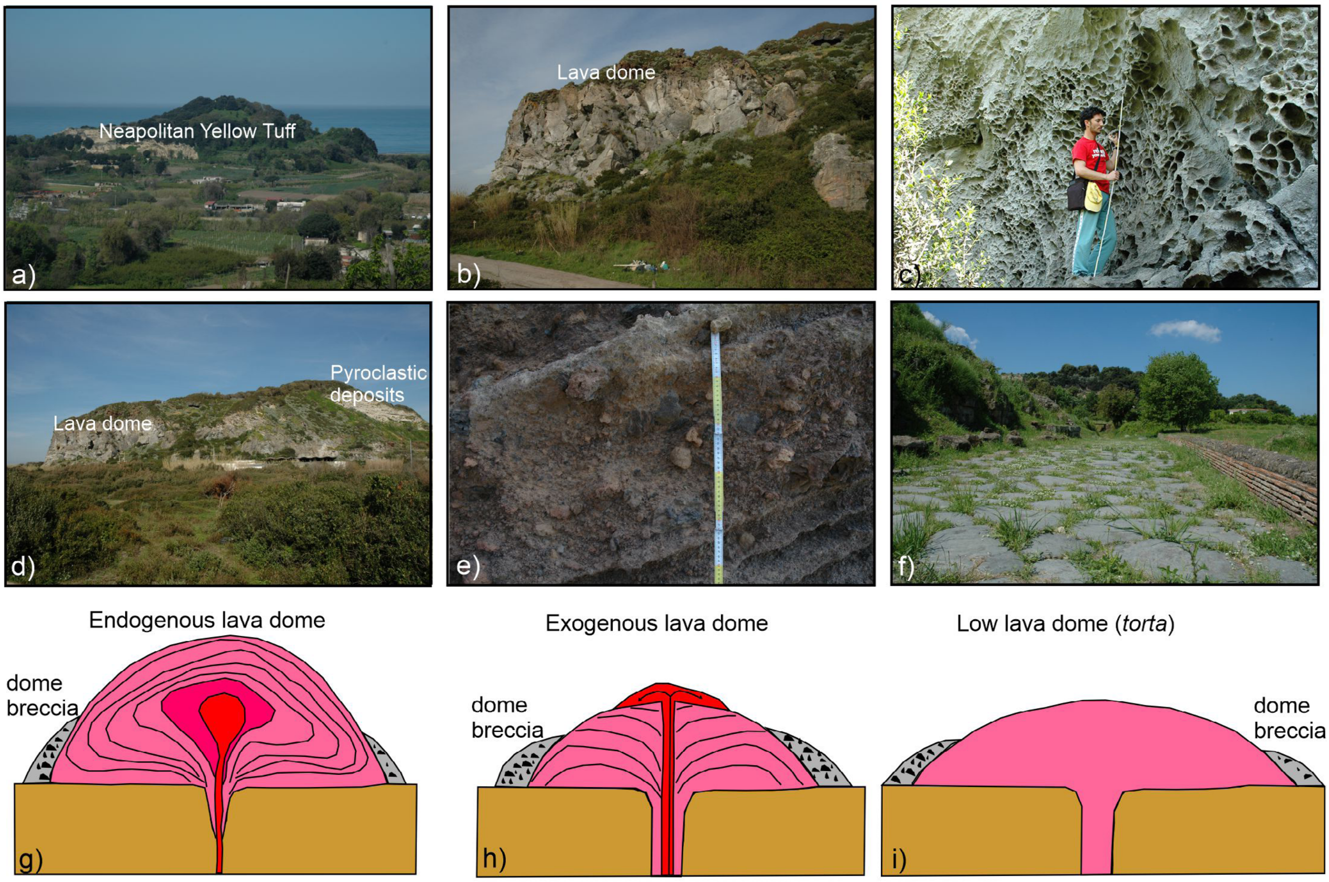

Figure 4 - Panoramic view of the Cuma Acropolis from the East (a), the Cuma lava dome (b) with a detail of the honeycomb tafoni (c), the pyroclastic deposits made up of whitish pumice fragments engulfed in a coarse ash matrix, overlying the dome towards the SW (d), the deposits of the Breccia Museo from CI eruption at Cuma (e), the Via Sacra paved with the lava of the dome (f). Sketch of an endogenous (g), exogenous (h) and low (i) lava dome. Location of the geosite is shown in fig. 3.

otic juxtaposition of lava blocks. At a more careful observation, it becomes evident that it developed an "onion-skin" foliation. Macrofractures are also common within the core of the lava dome. The dome is made up of a dark grey lava, rich in feldspar crystals, trachytic in composition (Melluso *et al.*, 2012). The very symmetrical shape of the Cuma lava dome allows its classification as a low lava dome according to the scheme of Blake (1989). These domes are also called *tortas* (the Spanish word for cake) and commonly develop on a flat surface (fig. 4i).

The lava dome served as the ideal place to settle the town of Kyme that was founded by the Greeks in 730 BCE (Boardman, 1995). It became one of the first and most important Greek colonies in the region. Thanks to its strategic location along the Tyrrhenian Sea, Kyme quickly developed into a major trading hub and cultural center (Livy, History of Rome). The city was particularly renowned for its Sibyl, a legendary prophetess who played a key role in both Greek and Roman mythology (Waszink, 1948).

In the 4^{th} century BCE, Roman influence began to expand in the region. After several conflicts, Kyme fell under Roman control in 338 BCE, along with other Greek cities in southern Italy, and was renamed Cumae. Although its political and military importance waned under Roman rule, the city remained significant for its rich history and religious heritage (Polybius, The Histories).

By the early medieval period, Cumae had been largely abandoned, but its legacy endured, especially through its association with the Cumaean Sibyl, whose influence on Roman religious thought remained strong (Virgil, Aeneid VI). Today, the archaeological remains, including the Sibyl's Cave and the ancient city walls, are part of the Cuma Archaeological Park, established in 1927.

The paleogeographic evolution of the coastal territory of Cuma has been the subject of numerous studies, whose main objective was to locate the harbour basin of the ancient city. These studies, carried out between 1994 and 2005, were characterized by a multidisciplinary approach based on geomorphological and geoarchaeological surveys, as well as sedimentological, paleontological, palynological, and chronological analyses of cores taken both north and south of the Cumaean promontory (e.g. Brun *et al.*, 2000; Vecchi *et al.*, 2000; Bravi *et al.*, 2003; Stefaniuk *et al.*, 2003; Stefaniuk and Morhange, 2005).

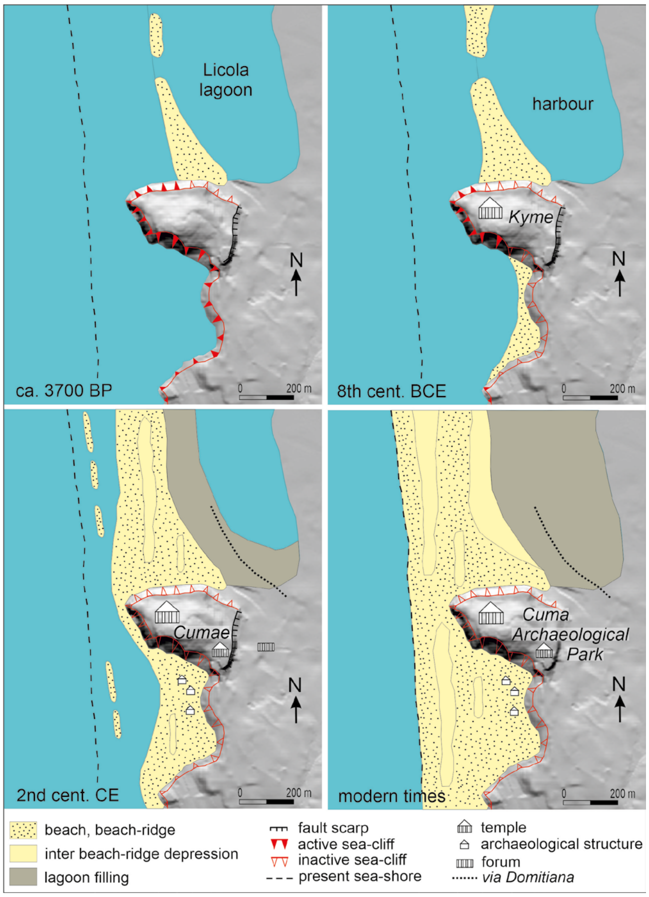

Figure 5 - Four stages in the evolution of the Cuma shoreline (redrawn and simplified after Stefaniuk and Morhange, 2008). Location of the geosite is shown in fig 3.

The initial hypothesis suggesting the possible presence of the port in the southern inlet (Paget, 1968) was refuted by core analyses, which revealed that a beach had already formed in this bay in Greek times. The beach rapidly prograded and could have offered, at most, a landing place but not a protected harbour basin. Conversely, studies on the northern sector provided convincing evidence for the use of the Licola lagoon as a potential harbour basin. Indeed, sedimentological data (grain size, morphoscopy), bio-indicators (macrobenthos, ostracods, diatoms, pollen), and geophysical methods (resistivity and magnetism) testify to a lagoon environment connected to the sea since 3700 BP, as well as a significant anthropogenic impact on the area as early as the 4th and 3rd centuries BCE (Stefaniuk and Morhange, 2005).

The four diagrams presented in fig. 5, simplified and redrawn after the work of Stefaniuk and Morhange (2008), show the evolution of the Cumaean coastline at four key moments.

The first diagram refers to 3700 BCE, shortly after the Averno 1 eruption, whose deposits contributed to the formation of the first coastal barrier to the north of the promontory, which isolated the Licola lagoon. The promontory was surrounded by the sea, and its cliffs were actively eroded by wave action.

At the time of the Greeks' arrival in the 8th century BCE (second diagram), the barrier isolating the lagoon grew while still allowing for the presence of open and navigable channels communicating with the sea, and a beach began to form in the southern inlet. Despite these deposits, the coastal setting still retained the features the Greeks considered favourable for founding a city -namely, a promontory overlooking the sea and surrounded by protected bays-.

After the Roman conquest (third diagram), the southern sector was largely filled in and exploited, as numerous remains of maritime villas dated to the 1st century CE have been uncovered in a context of an emerged and dune-like environment. In the northern sector, the silting up of the lagoon and its subsequent isolation from the sea rendered this basin (coastal lake) unusable as a port. At certain points in time, this connection was re-established, as indicated by faunal content in cores, but the tidal channels must have been very narrow and thus difficult for ships to navigate. In fact, during the Roman era, the port of Cumae was no longer active, contributing to the site's decline. The stabilization of the coastline and the fluctuations of the lagoon may explain the rapid shift of port activities from Cumae to Puteoli (Pozzuoli) and Misenum (Miseno).

The progradation of the coastline continued over the centuries, progressively distancing the city from the sea. The current coastal configuration (fourth diagram) was likely reached from the 16th to 19th centuries (Bellotti, 2000), when a significant progradation of the coastline occurred in the southern bay and the Licola lake was mostly filled in and transformed into a marsh. Major land reclamation works were undertaken in 1922 (Bertarelli, 1922).

Stop n. 2 – La Starza marine terrace

The upper part of Pozzuoli is built above a wide planar surface called "La Starza," which is clearly recognizable when looking from the harbour towards the north. This area has been identified by several authors as a marine terrace of Holocene age (Cinque *et al.*, 1985; Amore *et al.*, 1988; Orsi *et al.*, 1996; Di Vito *et al.*, 1999).

The coastal cliff bounding the terrace to the south has exposed a 30-meter sedimentary sequence younger than the NYT (15 ka), consisting mainly of fine to medium sands and silts containing several remnants of fossils, such as mollusk shells, corals (e.g., Cladocora caespitosa), and echinids (Cinque *et al.*, 1985). Posidonia oceanica rhizoliths, gastropod, and ostreid shells are also present. Marine sediments predominate in the lower part of the sequence, while higher up, they alternate with continental deposits of volcanic origin (tephra and paleosols).

The presence of marine sediments in the lower part of the sequence indicates the existence of a wide gulf in the Pozzuoli harbour area during the early Holocene (stage 1 in the fig. 6). The subsequent alternation of continental and marine sediments suggests that the area was subject to phases of subsidence and uplift due to volcano tectonic movements. The area of La Starza definitively emerged only after 5 ka (the age of the youngest marine sediments in the sequence; Isaia *et al.*, 2009), and the marine terrace formed (stages 2 and 3 in the fig. 6).

In particular, based on the paleontological record, it was possible to reconstruct the depth at which the marine sediments were deposited, which was between 30 and 50 m below sea level. Considering their present elevation at +50 m above sea level, it is possible to estimate a total uplift of about 80 meters for this part of the caldera.

Stop n. 3 – Serapeo

The Roman Macellum (so-called Serapeo) was built during the Flavian age (69-96 CE), on the model of the *Macellum Magnum* in Rome, and restored up to the 2nd century CE. This fascinating location can be considered a key site in the framework of geological studies, particularly focused on sea level changes in volcanic areas. In fact, due to the presence of the Lythophaga holes on its marble columns intended as sea-level markers, the Macellum has become one of the most famous geosites in the world since the 19th century. The 7-metre-high holes are clear evidence of the strong subsidence occurred during the Middle Age and the subsequent uplift.

This peculiarity has attracted the interest of the international scientific community to the point that the marble columns are depicted on the cover of the first Geology book written by Charles Lyell (Principles of Geology) in which the hypothesis of the vertical ground motions of volcanic origin was proposed.

Thanks to the interpretation of numerous historical pictures and photos, the Macellum is the oldest geodetic station of the Campi Flegrei geodetic network, providing a continuous record of vertical ground movements in the area since 1908.

Many scientists have adopted the Serapeo, together with other archaeological sites in the surroundings, as a study area to reconstruct ground motions in the CF during the Holocene (i.e. Babbage, 1847; Parascandola, 1947; Levi, 1969; Cinque *et al.*, 1997; Dvorak and Mastrolorenzo, 1991; Bellucci *et al.*, 2006; Morhange *et al.*, 2006; Passaro *et al.*, 2013; Todesco *et al.*, 2014; Di Vito *et al.*, 2016; Trasatti *et al.*, 2023; Mattei *et al.*, 2024a). Moreover, Morhange *et al.* (2006) correlated for the first time Lithophaga fossils into the columns with three episodes of subsidence, dated at 334-527 CE, 698-884 CE and 1336-1454 CE, which were interrupted by short-lived uplift, to which no eruption followed.

New archaeological excavation led to the detection of 3-floor levels at -3 m, -2.2 m and at the present elevation, corresponding to as many restoring phases of the Macellum. It is interesting to note that both restorations with the pavement rising occurred in periods of subsidence, instead, the two phases of Relative Sea Level (RSL; fig. 7) fall occurred between the Claudian-Augustan age (1st century CE) and Flavian-Severian age (3rd century CE), accompanied by intense phases of urbanization. So, probably the Roman took advantage of these two phases of sea level lowering to expand the port area.

During the late 15th and the early 16th century, despite an uplift interested the area with a mean rate of about 2.9-9.1 cm/yr (Di Vito *et al.*, 2016), the littoral plain and the Macellum itself were still covered by the sea (Dvorak and Mastrolorenzo, 1991). The trend continued up to the Mt. Nuovo eruption in 1538 CE when rates of 0.27 to 25.75 mm/day were reached.

The following subsidence lasted until 1970 and was interrupted by a period of prevailing uplift, from 1970 to 1985, totalling 2.6 m. Finally, after a period of prevailing subsidence alternating with minor episodes of uplift from 1985 to 2005 (total net subsidence 1.2 m; Del Gaudio *et al.*, 2010), the area has been living a new period of uplift with recorded rates in April 2025 of 15 ± 5 mm/month (Bollettino Settimanale Campi Flegrei; https://www.ov.ingv.it/index.php/monitoraggio-e-infrastrutture/bollettini-tutti/boll-sett-flegrei, accessed on 06 May 2025).

Stop n. 4 – Mt. Nuovo

The Monte Nuovo volcano is located at Pozzuoli, right in front of the former location of the *Portus Julius*, the Pozzuoli harbor in Roman age, now submerged in the bay. The Monte Nuovo eruption is the most recent event of the Campi Flegrei caldera, which built the youngest mountain in Europe. The eruption has been reconstructed through both geological, volcanological and petrological investigations, and analyses of historical documents (fig. 8a – Di Vito *et al.*, 1987 and references therein; D'Oriano *et al.*, 2005). It lasted one week and was fed by three vents: a main vent featured by the crater (Main Vent – MV) and two minor ones on the cone's slopes, at S and NE (figs 8b-c – Cioni *et al.*, 2019). It began on September 29, 1538 CE with intense phreatomagmatic explosions from the main and southern vents, depositing ash engulfing pumice and lithic fragments (figs 8d-e). Strombolian activity followed at the minor vents, forming coarse scoria deposits (fig. 8f). After a two-day pause, a second phase on October 3 featured low-energy explosions from the main vent, generating ash surges and pumice fallouts. A third brief phase began on October 6, involving dome-collapse-driven magmatic blasts. This final phase killed 24 people climbing the cone.

The juvenile products of the Monte Nuovo eruption are phenocryst-poor light-coloured pumice and dark scoria fragments phonolitic to trachy-phonolitic in composition.

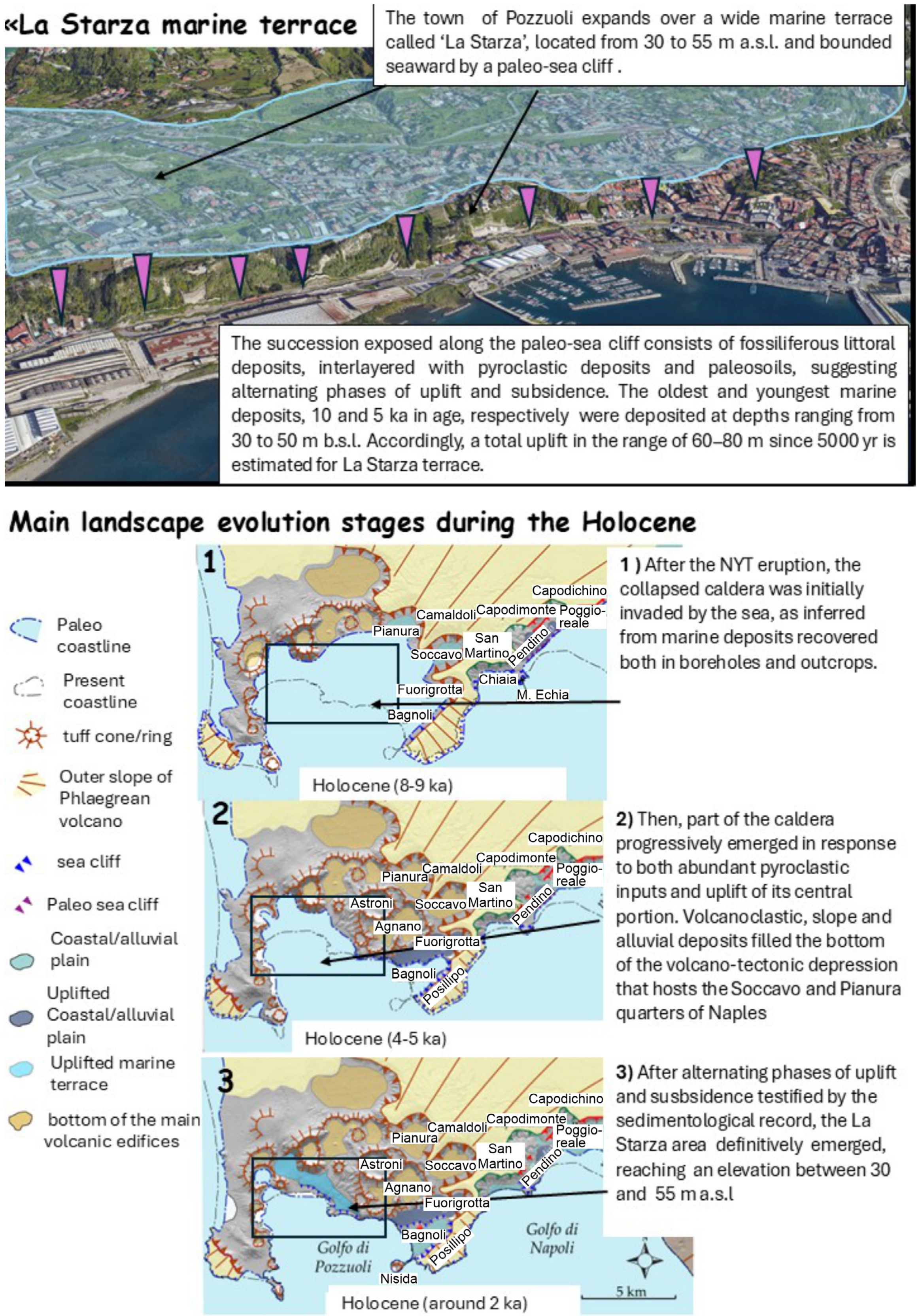

Figure 6 - Main stages in the evolution of the La Starza marine terrace (redrawn and simplified after Ascione *et al.,* 2020). The black rectangular line shows the La Starza area location. Location of the geosite is shown in fig. 3.

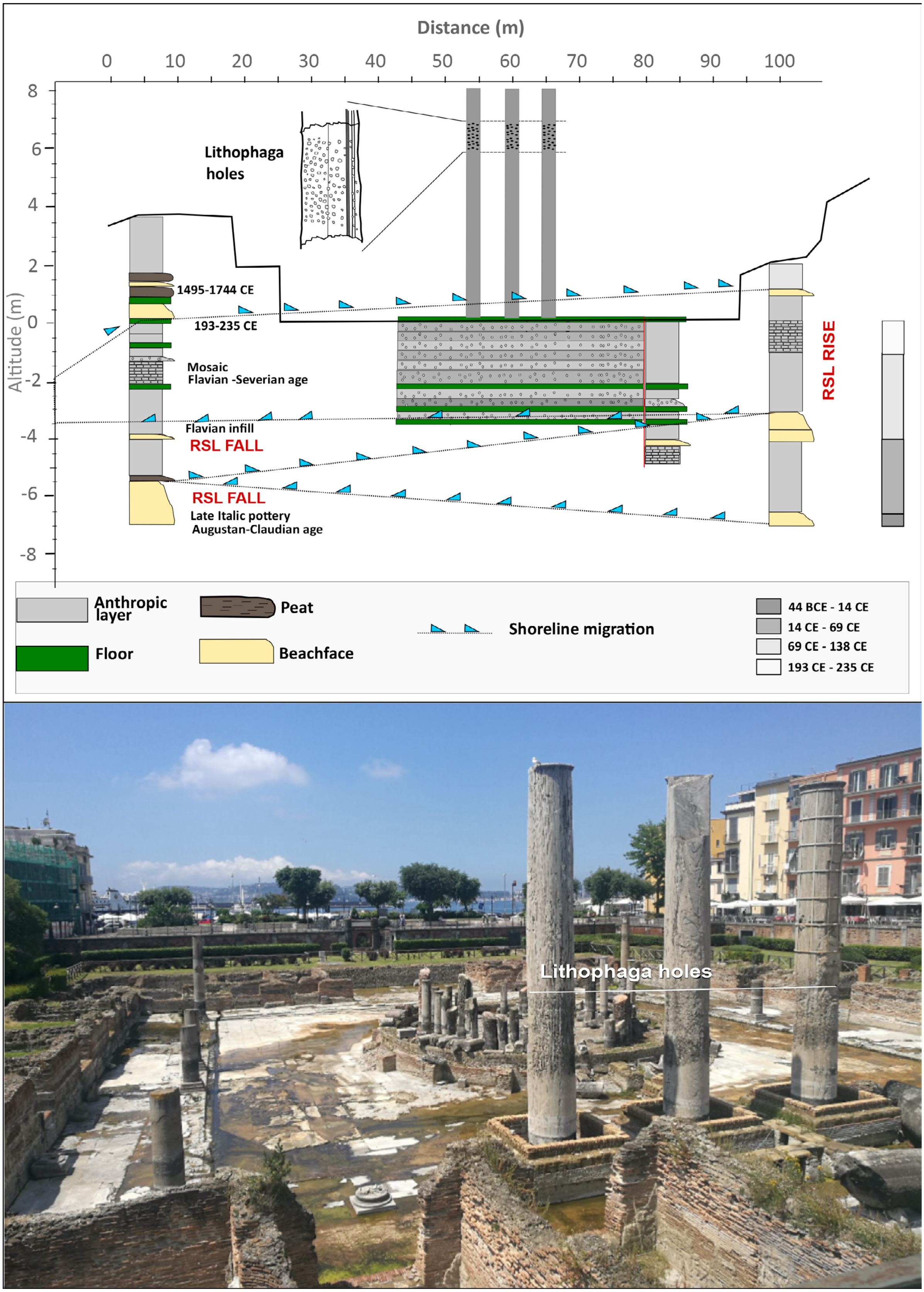

Figure 7. Stratigraphic interpretation along an NE – SW profile at Pozzuoli and related shoreline migration in the last 2400 years (modified from Mattei *et al.*, 2024b). Location of the geosite is shown in fig. 3.

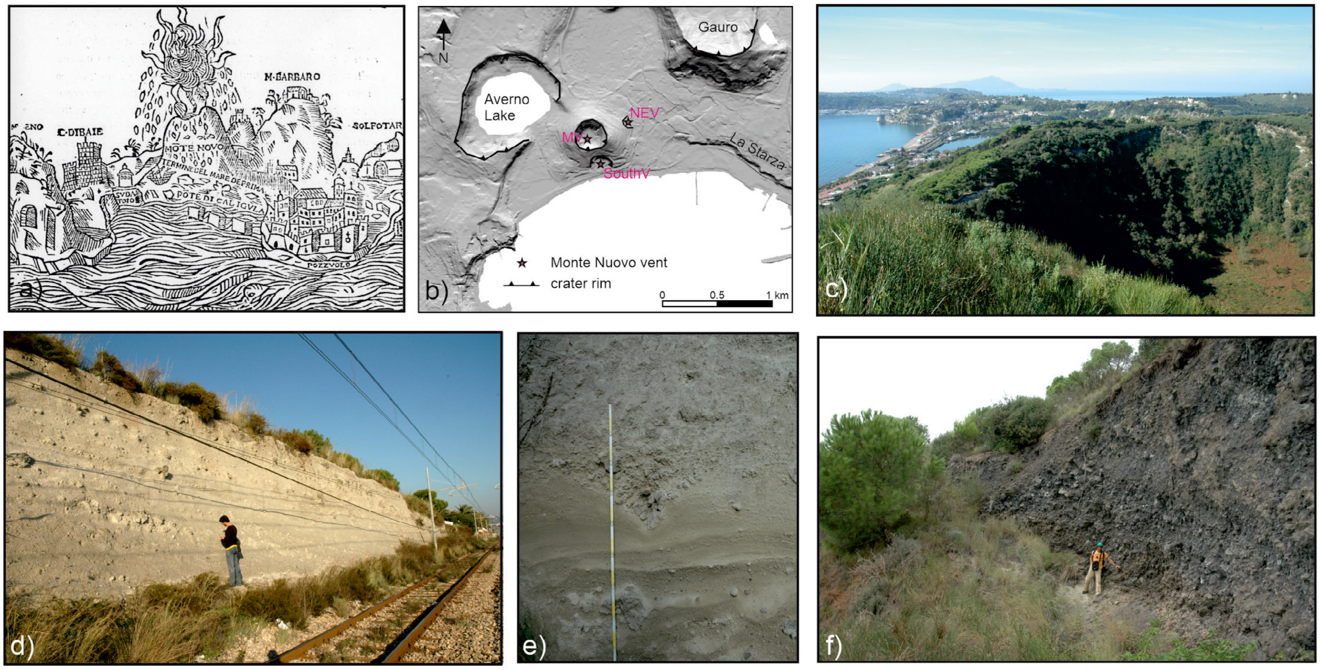

Figure 8 - The front page of the book by Marco Antonio delli Falconi (1539) on the Monte Nuovo eruption (a), location of the vents of the eruption, redrawn from Cioni *et al.* (2019) (b), view of the Monte Nuovo crater with the Lucrino Lake and Ischia Island in the background (c), phreatomagmatic deposits of the first phase of the eruption (d) with a detail (e), outcrop of scoriaceous deposits inside the Naturalistic Oasis (f). Location of the geosite is shown in fig. 3.

For the volcanic hazards assessment of the Neapolitan area, the Monte Nuovo eruption is considered as the low-magnitude type event among those expected in case of renewal of volcanism.

Currently the Monte Nuovo volcano is part of a naturalistic reserve (Monte Nuovo Naturalistic Oasis) managed by the Pozzuoli municipality and can be visited for free. Along the road of the "Monte Nuovo Oasis" we to observe the very coarse scoriae fallout emitted by the SouthV at the end of the first phase and overlying unconformably the deposits emitted by the SouthV and MV respectively. The crater rim can be reached by walking through a narrow path. It is asymmetrical in response to the syneruptive ground deformation of the vent area. The crater walls show the products of the first phases of the eruption, composed almost exclusively by a sequence of plane-parallel to undulated fine- to coarse-ash beds forming the largest part of the Monte Nuovo tuff cone, overlain by scoriae and minor ash layers erupted by the MV in the middle and last stages. Along the slopes of the volcano flourishes the Mediterranean bush, which makes the path very enjoyable mostly in late spring.

A detailed and quantitative reconstruction of the ground displacements predating the Mt. Nuovo eruption has been carried out by Di Vito *et al.* (2016). The authors integrated geomorphological, sedimentological, paleontological, archaeological and historical data of sites located along the entire coastline of the Pozzuoli Bay. Their data show that in 35 BC the coastline extended outward into what is now the Pozzuoli Bay. However, since then all the area started to be affected by a quick subsidence, which resulted in progressive submersion of the coastline until 1251. A subsequent progressive emersion of the area started during the 13^{th} century, as suggested by historical and urban planning sources, archaeological evidence and geological data. The lower time limit for the caldera uplift is given by historical documents describing the Pozzuoli promontory of Rione Terra as an island in 1251, whereas at the end of the 13^{th} and beginning of the 14^{th} century the previously submerged area around the promontory is reported as the location of three new churches, testifying to the expansion of Pozzuoli on new land formed by the coastline regression, confirming the onset of a long-term uplift. The emersion of the area from the 13^{th} to the 16^{th} century was due to the ground uplift, with maximum values recorded in the Pozzuoli area.

Since the end of the 15^{th} century this uplift was accompanied by strong seismicity. A new and stronger uplift, with a rate of 10 to 940 cm/yr, accompanied by very intense seismicity (Guidoboni and Ciuccarelli, 2011, and references therein) followed the previous one between 1536-1538, reaching a maximum value of 18.8 m in the future vent-opening area. Furthermore, all the historical sources coeval to the eruption report an evident uplift accompanied by continuous seismicity and opening of fractures in the vent area during the two days that preceded the eruption. At the time of the eruption the site where the MV opened hosted a village, Tripergole, known since ancient

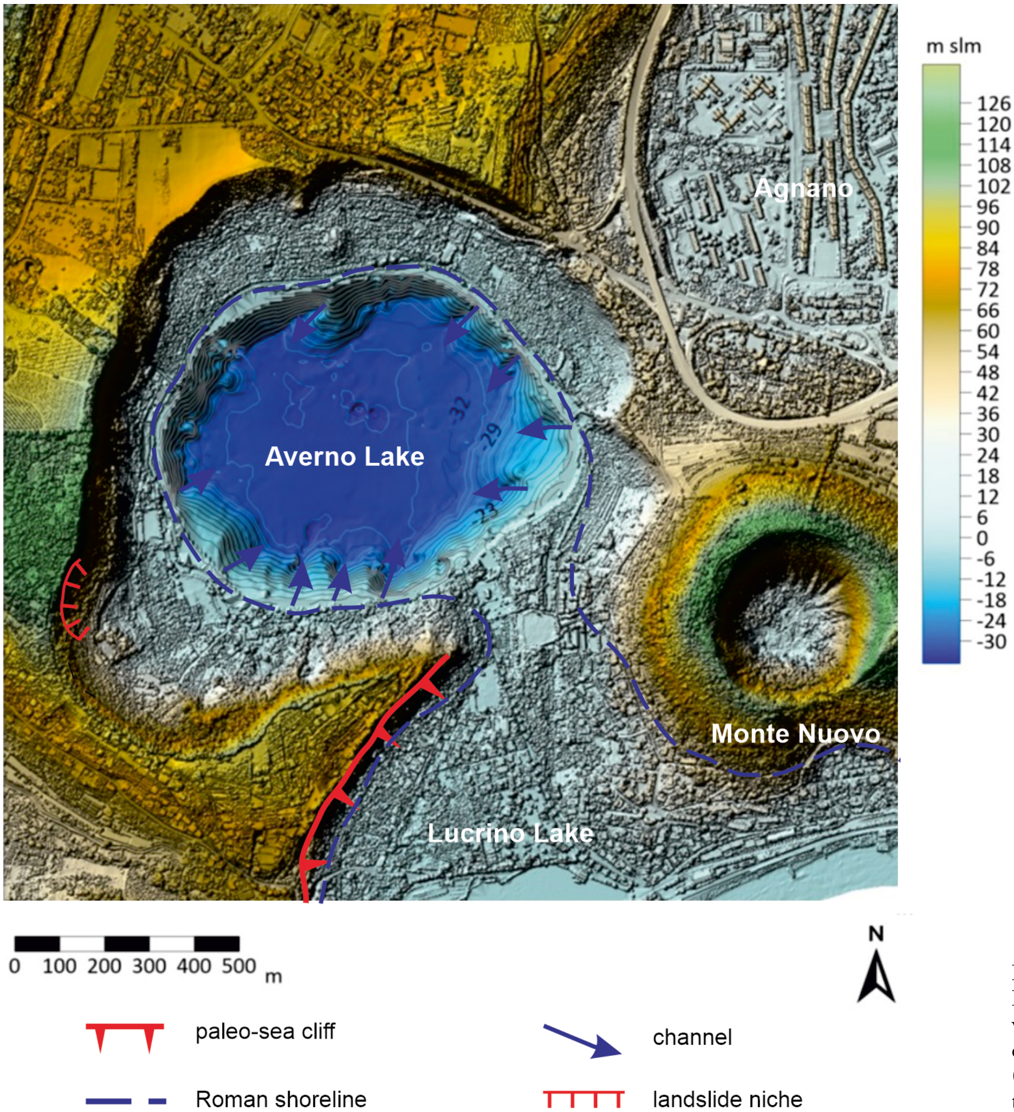

Figure 9 - Morphology of the Averno Lake with bathymetry, to the northwest, Monte Nuovo, to the southeast, and Lucrin Lake, to the south. (DTM from Bravi *et al.*, 2022). Location of the geosite is shown in fig. 3.

times for its thermal baths. The name Tripergole recalls the presence of the three different Roman rooms that made up the baths (*frigidarium, tepidarium and calidarium*). The wealth of thermal resources led Carlo II d'Angiò to found a hospital in 1298, with the function of a hospice for foreigners (xenodochio). The main aim of this hospital was to meet the needs of foreigners and the less well-off sick who came to Tripergole for the thermal treatments. The village was completely destroyed by the eruption of Monte Nuovo and the growth of the cone.

Stop n. 5 – Averno Lake

The Averno Lake is a freshwater body hosted in the homonymous volcanic structure, with eruption ages of ~5250 (Averno I) and ~4280 years (Averno II) (Di Vito *et al.*, 2011). This tuff ring volcano (Mastrolorenzo, 1994), to the northwest of Monte Nuovo, shows a typical truncated-conical morphology with a maximum height of 114 m a.s.l. to the west, while that of the banks is about 2 m a.s.l., the water surface lies at 0.5 m a.s.l., and measures 0.55 km^2. The diameter of the crater rim and the perimeter of banks are about 4.3 and 2.9 km, respectively. The shape is subelliptical, NE-SW oriented, and the maximum depth of the crater floor is -36 m (fig. 9; Bravi *et al.*, 2022). Along the sandy banks, at 8/-10 m of depth, there is a rim with steep slopes down to the almost flat depocenter, covered by fine sediments.

The toponym Averno, Avernus for the Romans, probably derives from the Greek ἄορνος, absence of birds, due to sulphureous gas emissions, or from the ancient root av–ap, meaning abyss. For this reason, mythology places the entrance to the underworld here.

The mollusc record in this freshwater lake highlights that in the period 900-500 BCE, a decrease of oxygen in the water occurred due to volcanic origin contaminations (Welther-Schultes and Richling, 2000). In comparison, episodic marine transgressions after 500 BCE with brackish conditions are related to subsidence and bradyseism. During the Roman period, this coastal lake was connected to the open sea, about 1 km away, through an artificial navigable channel built in 37 BCE (Fossa Augustea) and housed the naval arsenal. Saline conditions developed for centuries, followed by a short freshwater condition due to an uplift phase in 700 CE (Grüger and Thulin, 1998). Today, the lake is a freshwater basin from the surface down to -30 m depth, slightly drained by a narrow emissary channel built by the Spanish Viceroy of Naples, Don Pedro Álvarez de Toledo, in the 16^{th} century, which discharges into the Lucrino Lake. Below this depth and down to the bottom at -36 m, seawater was detected (Bravi *et al.*, 2022), likely due to the ongoing marine infiltration in the sediment substratum related to current sea-level rise.

Along the western bank is the entrance to the Cocceio Grotto, an underground tunnel carved through the tuff of Monte Grillo for about 1 km and a height difference of approximately 40 m, which connected Cuma with Portus Julius between the Averno and Lucrino basins. To the northeast shore stand the Roman ruins of a monumental structure of the 1^{st}-2^{nd} century CE: the Temple of Apollo.

The volcanic structure abruptly changed after the Monte Nuovo pyroclastic eruption, which displaced its base elevation up to about 3 m a.s.l., reducing the water body surface, also modifying the shape and reducing the volume of the close lagoon of Lucrino Lake, to the south. Late Holocene tectonic activities of Baia and Monte nuovo faults, NE-SW oriented, and historical bradyseismic phenomena down lifted the area by about 6 m (Vitale and Natale, 2023).

Finally, along the internal southwestern slopes of the crater, a large landslide occurred before the end of the 1700s, as represented in a painting commissioned by Sir W.D. Hamilton (1776) (fig. 10), whose debris also reached the lake bottom as shown by its hummocky morphology.

Stop n. 6 – Baia sommersa

The coastal area of ancient Baia and its surroundings, from Miseno Port to *Portus Julius*, features alternating tuffaceous cliffs and narrow plains and in Roman times underwent major changes due to human activity, glacio-isostatic adjustment, volcano-tectonic movements, and sedimentary processes. The area hosts the Baia – Fondi di Baia volcanic cones whose formation marked the beginning of the 2^{nd} epoch of volcanic activity in the Campi Flegrei (table 1; Voloschina *et al.*, 2018). Despite volcanic hazards, between the 1^{st} century BCE and the 1^{st} century CE, the coastline underwent a quick occupation with the construction of *villae maritimae* and coastal structures on every inch of available coastline.

From a geoarchaeological perspective, numerous studies have been carried out in the area over the years to assess the RSL change history and the morphological evolution of this dynamic coastal stretch since Roman Times (Morhange *et al.*, 2006; Passaro *et al.*, 2013; Ascione *et al.*, 2020; Costa *et al.*, 2022; Trasatti *et al.*, 2023; Vitale and Natale, 2023).

Specifically, the 2.5 km rocky coastline ranging from the eastern side of Miseno Cape to Punta Pennata was interrupted by a small bay hosting the ancient military harbor of *Portus Misenum* (Paget, 1971), artificially connected to the inner *Lacus Misenum* through a man-made channel. Its southern edge, marked by Punta Terone, features archaeological evidence of a fish tank (1 in fig. 11) likely associated with a maritime villa predating the harbour and built during the late 1^{st} century BCE. Direct investigations of the fish tank suggest for this period a RSL of -4.1 ± 0.3 m MSL (Aucelli *et al.*, 2021; Mattei *et al.*, 2024b).

Near Punta Terone lie the remains of the Roman Thermal Baths of *Misenum* (2 in fig. 11; Cinque *et al.*, 1991; Aucelli *et al.*, 2021), built in the 2^{nd} century CE to the west of the close military port. Excavations uncovered two well-pre-

Figure 10 - This painting of Averno Lake, N-S view, shows a landslide along the western internal slope of the crater that occurred before the end of the 1700s. To the left, Roman ruins of the Temple of Apollo on the eastern shore and Monte Nuovo; in the background, the southern coast with the Lucrino Lake, the Aragonese Castle of Baia, and Cape Miseno (Hamilton, 1776).

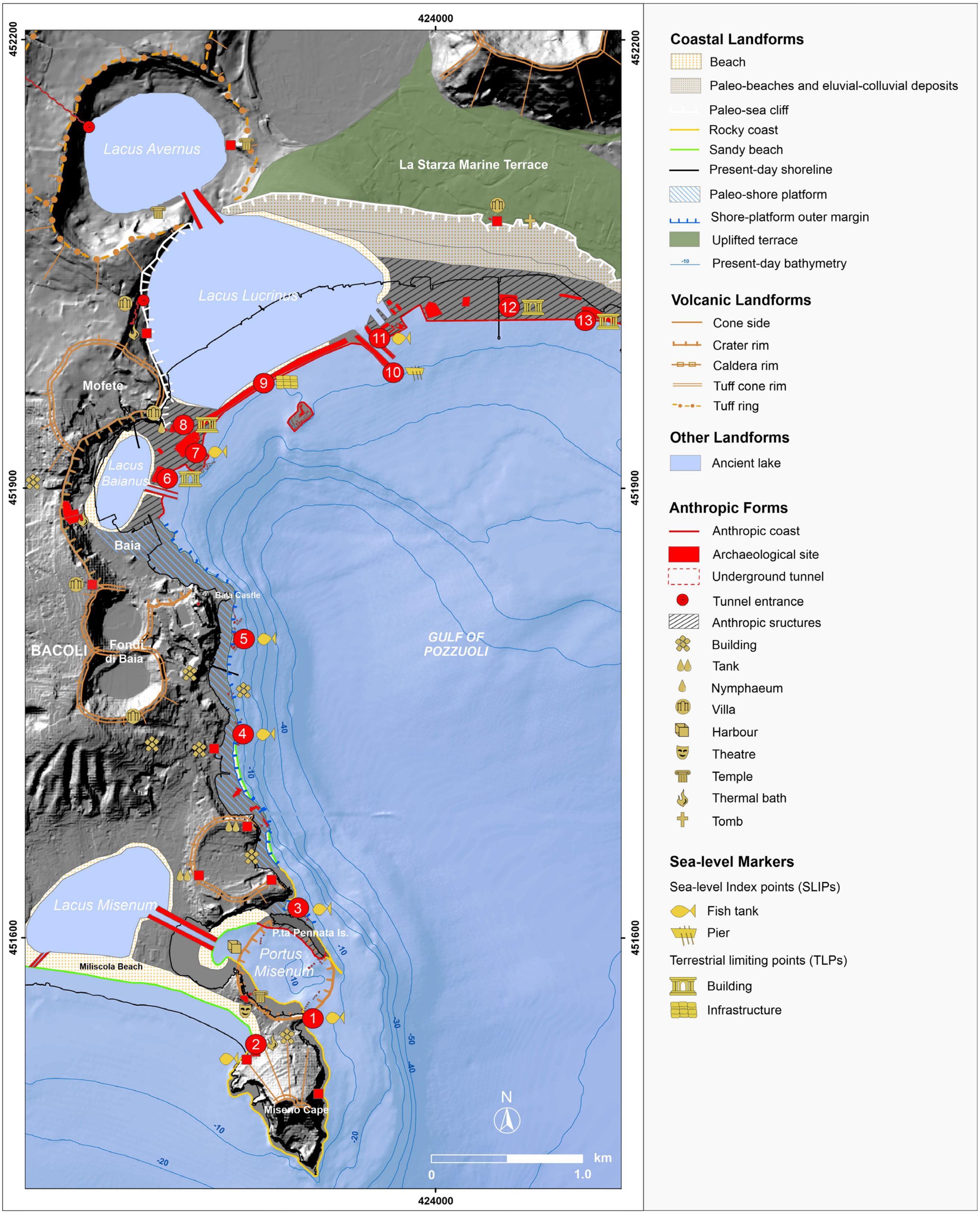

Figure 11 - Reconstruction of the coastal landscape of Baia and surroundings during Roman Times (modified from Mattei *et al.*, 2023). Location ID: 1 – Punta Terone fish tank; 2 – Thermal Baths of Misenum; 3 – Punta Pennata villa; 4 – Hortensius Hortalus Villa; 5 – Caesar Villa; 6 – Protiro Villa; 7 – Pisonis Villa; 8 – Claudius Nymphaeum; 9 – Via Herculanea; 10 – Portus Julius pilae; 11 – Portus Jiulius fish tank; 12 – Vicus Annianus; 13 – Vicus Lartidianus. Location of the geosite is shown in fig. 3.

served rooms of the thermal complex, now buried beneath stratified deposits dated to reoccupation phases of the site in the 6th-7th and 11th-12th centuries, based on ceramic evidence. The baths were likely abandoned by the late 4th century CE due to partial submersion (Cinque *et al.*, 1991). At this site, stratigraphic analyses suggest a RSL below 0.5 m MSL at the time of construction, rising to 5 ± 1 m MSL between the 8th and 11th centuries CE (Aucelli *et al.*, 2021).

On the opposite side, near Punta Pennata Island, connected to the mainland during the 1st century BCE, a raised paleoshore platform, likely formed during the third eruptive phase of Campi Flegrei (5.5-3.5 ka BP; Smith *et al.*, 2011), extended toward the modern Baia harbor. The platform, evidence of a general coastal retreat of about 0.1 km occurred in a period preceding the Roman occupation, hosted various coastal structures, including a 1st-century CE maritime villa near Punta Pennata (3 in fig. 11; Mattei *et al.*, 2024b). The submersion depth of the fish tank's sluice gate indicates a RSL of -2.3 ± 0.3 m MSL at the time of construction.

Heading north, along the coastal sector from Garibaldi dock up to Baia Castle, several coastal structures were built on top of the shore platform (Miniero, 2010; Guidone *et al.*, 2017; Iliano, 2017). Among these, the remains of the fish tank related to the *Hortensius Hortalus Villa* (4 in fig. 11) and those belonging to the fish tank located at the foot of Baia's Castle (*Caesar Villa*, 5 in fig. 11), both archaeologically dated to the 1st century BC, constrained the RSL at the time of their construction between -4.00 and -4.20 ± 0.29 m MSL, according to the data from Punta Terone (Aucelli *et al.*, 2021; Mattei *et al.*, 2023).

North of Baia Castle, the landscape in the 1st century BC was heavily modified by human activity and characterized by the presence of the ancient harbor basin of *Lacus Baianus*. This area hosted several coastal facilities, including Protiro Villa (6 in fig. 11; Di Fraia, 1993), Pisonis Villa (7 in fig. 11; Di Fraia *et al.*, 1986; Di Fraia, 1993; Passaro *et al.*, 2013), and the *Nymphaeum* of Emperor *Claudius* (8 in fig. 11; Benini, 2004; Lombardo, 2009).

These findings, all dated to the 1st century CE, constrained the RSL of the time at -6.9 ± 0.29 m MSL (Mattei *et al.*, 2023; 2024b), highlighting a stronger overall subsidence of this central sector of the caldera if compared to the coeval RSL measurements obtained at Punta Pennata.

At that time, a large breakwater, often mistakenly identified as part of the *Via Herculanea* (9 in fig. 11), was built over nearshore sediments, creating a barrier that separated the ancient *Lacus Lucrinus* from the open sea. This enclosed lagoon, used primarily for oyster cultivation, was connected to the more inland *Lacus Avernus* through a man-made channel.

The breakwater was interrupted in the central part by the entry channel of *Portus Julius*, one of the most important infrastructures of the time, in which several remains are nowadays still visible, including several *pilae* (10 in fig. 11; 1.98 ± 0.01 ka BP) and a well-preserved fish tank (11 in fig. 11; 1.96 ± 0.01 ka BP). Direct measurements of these archaeological features assessed a RSL of -3.10 ± 0.29 m MSL, highlighting a volcano-tectonic stability between the second half 1st century BCE and the beginning of the 1st century CE (Aucelli *et al.*, 2020; Mattei *et al.*, 2023; 2024a).

To the east of *Portus Julius*, the area was strongly modified through artificial infilling (Amato and Gialanella, 2013), resulting in an average coast progradation of about 200 m. This newly created land provided the foundation for the harbor districts known as *Vicus Annianus* and *Vicus Lartidianus* (12 and 13 in fig. 11).

The intense human occupation of the area lasted until the 5th century CE, when the volcano-tectonic subsidence that brought the RSL up to 7 m MSL flooded the coastal areas for centuries.

Stop n. 7 – Capo Miseno

Capo Miseno is a tuff cone placed in the southernmost sector of the Campi Flegrei. Di Renzo *et al.* (2011) indicate an age of 3.7±0.5 ka for the Capo Miseno cone that rejuvenated the age of 5.09±0.14 ka proposed by Insinga *et al.* (2006). The tuff cone has a trachytic and trachyphonolitic composition (Di Girolamo *et al.*, 1984) and derived from phreatomagmatic activity, with the zeolitization of ash deposits, as shown by the vertical transition from a yellowish lithified tuff to greyish unlithified pyroclastics (Insinga *et al.*, 2006). Because of its strategic position to control maritime routes, a harbour was settled in Roman time (1st-4th century CE; Dvorak and Mastrolorenzo, 1991) along the northern flank of the Capo Miseno cone, in the nearby remnants of the Porto di Miseno tuff cone. The Roman harbour is nowadays submerged, being one of the archaeological evidence of bradeysism in the Campi Flegrei.

Despite it is one of the youngest cones of the Campi Flegrei, just a small portion of the original volcanic edifice is still preserved. Disruption of the Capo Miseno tuff cone is due to wave erosion that causes diffuse rock-falls and toppling. The occurrence of both a dense net of NE-SW trending faults and fractures and caves carved by the sea at the base of Capo Miseno cone are predisposing factors that favour rock falls and toppling. This is a common feature that the Capo Miseno cone shares with sea-cliffs carved in pyroclastic deposits along the entire coastal stretch of the Campi Flegrei (Di Crescenzo *et al.*, 2021). The last rock fall occurred in 2015 (figs 12 and 13), whose volume has been estimated in 130,000 m^3 by comparing pre- and post- event digital elevation models derived from UAV investigation (Valente *et al.*, 2019). Geomorphological analysis allowed Valente *et al.* (2019) to reconstruct the original size of the cone and, thus, to evaluate the long-term coastal retreat rate, which resulted to be of 0.135 m/year.

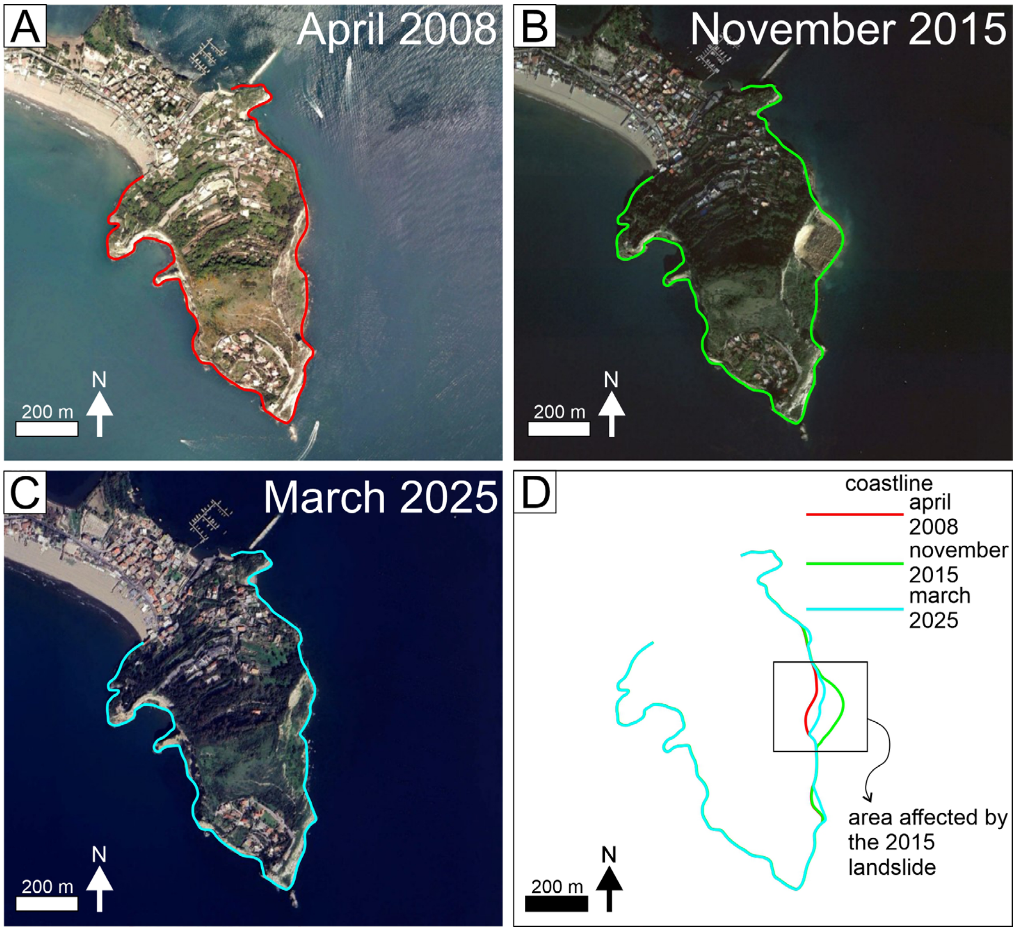

Figure 12 - Google Earth view of the Capo Miseno area with indication of the coastline in April 2008 (A), November 2015 (B) and March 2025 (C). Panel D shows coastline evolution from A to C with indication of the area where the 2015 landslide occurred. Location of the geosite is shown in fig. 3.

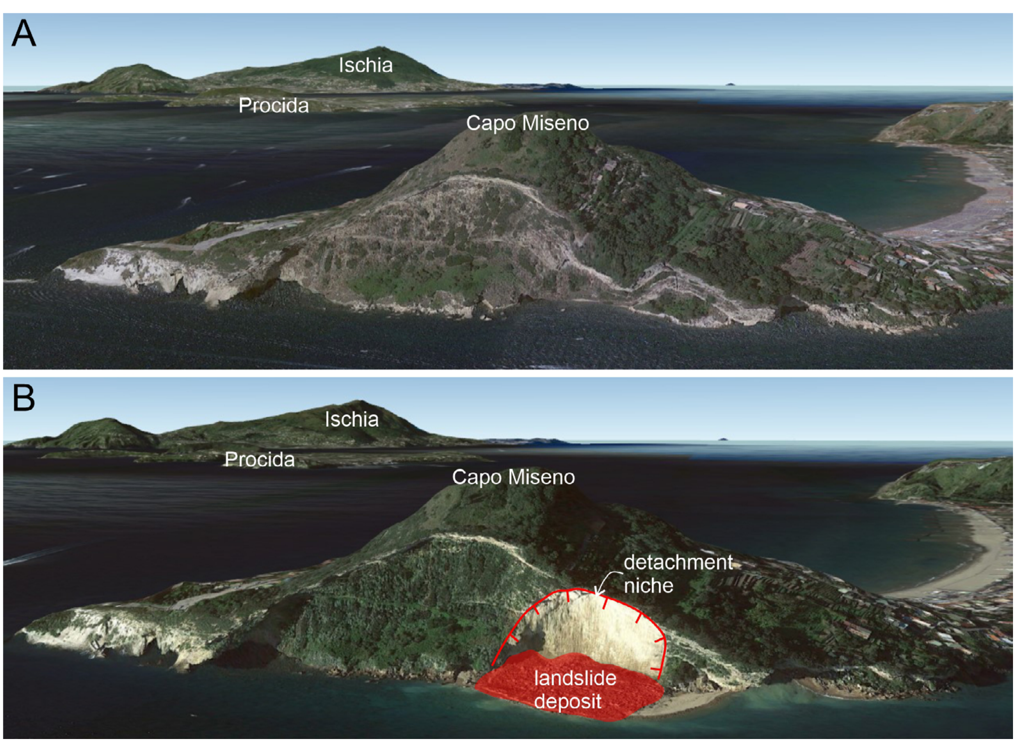

Figure 13. 3d view of Google Earth before (A) and after (B) the 2015 landslide.

Capo Miseno is crossed by a small road that allows visitors to reach the southernmost point of the volcanic edifice. Here, it is possible to admire a breathtaking landscape that encompasses the entire Gulf of Naples. Furthermore, an active sea lighthouse is present but visiting is limited by restrictions and it is allowed only during special occasions (https://www.prolococittadibacoli.it/faro-di-capo-miseno-2/). To overpass this limit, it is possible to have boat trips along the entire perimeter of the tuff cone, which would lead geotourists discover the fascinating landscape of Capo Miseno, with possible entrance in some of the largest coastal caves.

DISCUSSION

Campi Flegrei as a complex geosite

The term Campi Flegrei refers to the ring-shaped caldera formed by the collapse related to the Campania Ignimbrite (39 ka; Giaccio *et al*., 2017) and the Neapolitan Yellow Tuff (15 ka; Deino *et al*., 2004) eruptions. The recognition of the Campi Flegrei as one of the first 100 IUGS Geosites depends on the role that the area played in the history of geosciences, as «the site had a major role in the European debates that created the modern science of geology in the 18th and 19th centuries. Naturalists were attracted to the area to record evidence directly in the field regarding both active and extinct volcanoes and their products preserved in the landscape» (https://iugs-geoheritage.org/publications-dl/IUGS-FIRST-100-SITES-WEB-BOOK.pdf). Despite being considered as a unique geosite by the IUGS, the Campi Flegrei exhibits landforms and deposits formed by different geological and geomorphological processes, which have been classified as geosites each self (Esposito, 2006; Armiero *et al*., 2011). This make the Campi Flegrei suitable to be classified as a complex geosites. Complex geosites are larger geosites exhibiting geosite subtypes representative of different geoscience topics (Bruno *et al*., 2014; Filocamo *et al*., 2019; Mikhailenko *et al*., 2019; Habibi *et al*., 2022). Bruno *et al*. (2014) pointed out that a prevailing topic must be defined for a complex geosites. For the Campi Flegrei, the main topic is volcanology but geosites representative of processes such as bradeysism, coastal modification and geoarchaeology are present. This is a feature that the Campi Flegrei share with another iconic volcanic area of Italy, i.e. Mt. Etna in Sicily (Pasquarè Mariotto *et al*., 2023).

The promotion and management of a complex geosite may be challenging and requires both a large-scale overview of the area and detailed analysis of individual geosites within it (Forno *et al*., 2022). Concerns must be addressed to assess the degradation risk of a complex geosites (Fernandez-Martinez *et al*., 2022). The creation of geomorphological maps at different scale may significantly contribute to this topic and play a crucial role in the dissemination of knowledge and in a promotion plan for complex geosites (Coratza *et al*., 2021). Promotion and management of the Campi Flegrei is a crucial task that must be considered in geotourism promotion as the Campi Flegrei hosts hundreds of thousands of inhabitants and human frequentation has been continuous since Greek and Roman times due to the fascinating landscape, climate and fertility of the soils. For this reason, we proposed a geoitinerary in the western part of the Campi Flegrei by selecting, through the Brilha (2016) method, geosites already included in the official catalogue of the Campania Region ((https://sit2.regione.campania.it/documenti/mappatura-geositi#overlay-context=content/download). The evaluation of the Educational (EV) and Potential Touristic (PTV) values provided objective data representative of the potential of each geosites in terms of dissemination of geoscience topic (EV) and attractiveness for both specialistic and non-specialistic tourists (PTV).

Geosites and human settlements

Human settlement in volcanic areas, such as Campi Flegrei, may seem counterintuitive given the potential risks of eruptions, earthquakes, and ground deformation. Yet, as our geosites demonstrate, throughout history – and continuing into the present – people have chosen to live in these regions for a variety of compelling reasons rooted in geography, culture, and economy (Costa *et al*., 2022; Leone *et al*., 2022).

One of the primary attractions is the remarkable fertility of volcanic soil. The comminution of pumice fragments and the fine grain-size of ash deposits make them prone to the alteration, which enriches the soil with microelements, making it ideal for agriculture. Around Campi Flegrei, vineyards, orchards, and vegetable farms flourish, feeding both local populations and markets (see Alberico *et al*., 2023). This agricultural productivity has supported settlements here since ancient times. The western Campi Flegrei is one of the territories in Italy that's well-known for its volcanic wines, specifically the Falanghina, the white variety, and Piedirosso, the red variety. The hot climate of Campi Flegrei and the presence of pumice in the volcanic soil, which is capable to retain moisture below the surface during the hot summers, strongly influence the quality of the wines. Furthermore, the volcanic activity has provided useful building material, the most important of which is the *Pulvis Puteolana* (Pozzolana), used for hydraulic mortars, numerous quarries of which were exploited in Roman age in the Baia area (Rispoli *et al*., 2024). Another prominent factor is the availability of fresh water and geothermal resources. Volcanic regions often host natural springs and underground aquifers. In the western Campi Flegrei, the presence of thermal springs historically led to the development of Roman bath complexes, especially in areas like Baiae, which became famous for its luxurious resorts and therapeutic waters. Today, geothermal energy remains a potential asset for sustainable development in such areas (Iorio *et al*., 2024).

Proximity to the coast is also significant. The choice of the Greek founders of Cuma was not trivial. They settled where the presence of the lava dome offered a topographic high close to the sea, both difficult to attack and easy to defend. Moreover, it also allowed inhabitants to avoid the negative effects of the marshy plain, which was occupied only later, in Roman age (Città Bassa). Most of the geosites here presented lie along a natural bay, which historically allowed cities like Pozzuoli to thrive as trade hubs. Maritime access brought wealth, cultural exchange, and strategic importance, especially during the Roman Empire, when Pozzuoli was second only to Ostia as a major port. The role of Serapeum as the "Forum", a sort of market square for the Roman Puteoli, is a good testimony of the trading activity in the area. The geography, though shaped by volcanic activity, offered more opportunities than dangers for much of the population's history.

Cultural and historical significance also plays a role in why people continue to live in these areas. Campi Flegrei has long been shrouded in mythology. The ancient Romans considered Lake Avernus the entrance to the underworld. Settlements grew around religious, military, and civic landmarks, many of which still stand today. These connections foster a strong cultural identity and continuity, binding modern communities to the past.

Tourism is another major draw. Volcanic landscapes are unique and beautiful, attracting visitors from around the world. In western Campi Flegrei, destinations like the submerged ruins of Baiae, and the Serapeum in Pozzuoli provide not only historical interest but also economic opportunities through tourism-related jobs.

The Campi Flegrei area has been experiencing a bradyseismic crisis since 2005, with ground rise currently in the order of 1.5-2 cm per month, high CO_2 emissions and several seismic shocks felt by the population (Chiodini *et al.*, 2021). Despite the known hazards, many people remain in place because of deeply rooted communities and existing infrastructure. Generations of families have lived in the area, and relocation would not only be a financial burden but also an emotional loss. In some cases, the risks are accepted as a normal part of life, especially with modern monitoring systems managed by the ING-Vesuvian Observatory that guarantee early warning and contingency planning. Ultimately, the decision to settle in volcanic zones reflects a complex balance of benefits and risks. For the people of Campi Flegrei, the richness of the land, the historical legacy, and the economic possibilities continue to outweigh the dangers.

SWOT analysis

To evaluate the potential of the geoitinerary for both education and touristic activities, we carried out a SWOT (Strengths, Opportunities, Weaknesses, Tzreats) analysis.

Strenghts

Campi Flegrei attracts tens of thousands of tourists each year. People are attracted by the fascinating landscape sculpted by volcanism and modelled by the sea and by diffuse archaeological sites (e.g., Cuma, Baia Sommersa), some of which are worldwide known (Serapeo). The recent bradeysismic crisis affecting the Campi Flegrei increases local people awareness about volcanic processes and landscape modification, thus making the geoitinerary an ideal instrument to disseminate these concepts. Visiting the geosites of Serapeo, La Starza marine terrace and Baia Sommersa could help the tourists being familiar with bradeysism, both in historical times and since the Holocene. Furthermore, Campi Flegrei are easily accessible by car being served by a highspeed way (i.e., Tangenziale di Napoli). The closeness of an international airport just 20 minutes away from the area could also favour tourist traffic through each period of the year.

Weaknesses

The geoitinerary is at an initial stage and deserves further initiative to be developed. The creation of didactic panels describing the main feature of each geosites has not carried out yet, but it will be crucial for a dissemination strategy. The geoitinerary is a personal initiative by the authors and lack of collaboration with local administration, which could provide logistics and economic funding for the creation and promotion of the geoitinerary. Furthermore, a management policy is necessary to preserve the geoitinerary through years, and this should be demanded to local administration.

Opportunities

Campi Flegrei are close to sites already attracting tens of thousands of tourists each year, such as Naples and the Vesuvius. For this reason, the geoitinerary could be integrated in a wider tour that include also these sites, thus favouring the increase of tourist traffic In the Campi Flegrei. Increase of tourist traffic could not be a problem as the area is served by many accommodation facilities that can host a large amount of people. Furthermore, the geoitinerary could be split in two or more days, allowing geotourists to enjoy local landscape, climate, food and hospitality.

Threats

As the geoitinerary is at an initial stage, it still lacks financial supports for its development. Furthermore, intense tourist traffic during summer, which is due to local people and people from the surrounding areas moving towards the beaches, could reduce the attractiveness of the geoitinerary in this period of the year.

CONCLUSION

The Campi Flegrei's unique geological and cultural landscape presents a valuable opportunity for the development of geotourism that promotes sustainable development, environmental education, and cultural preservation. Recent initiatives and researches underscore the potential of geotourism to enhance public awareness of geological heritage, improve community resilience to natural hazards, and stimulate local economies. Addressing challenges related to risk management, environmental conservation, and community involvement will be essential to realize the full benefits of geotourism in the Campi Flegrei. Through collaborative and sustainable approaches, geotourism can serve as a catalyst for the region's socio-economic and environmental well-being.

While the Campi Flegrei offers immense potential for geotourism, several challenges must be addressed to ensure its sustainable development. The area's active volcanic nature necessitates careful risk management and communication strategies to ensure the safety of both residents and tourists. Collaborative efforts between scientists, local authorities, and tourism operators are essential to develop comprehensive emergency plans and educational programs that inform visitors about volcanic risks and appropriate safety measures.

Balancing geotourism development with environmental conservation is crucial. The delicate ecosystems and geological features of the Campi Flegrei require protection from potential negative impacts of increased tourist activity. Implementing sustainable tourism practices, such as regulated access to sensitive sites, promoting off-peak visitation, and encouraging eco-friendly transportation options, can help mitigate environmental impacts.

Integrating local communities into geotourism initiatives presents significant opportunities for socio-economic development. By involving residents in the planning and operation of geotourism activities, communities can benefit from job creation and the revitalization of local crafts and traditions. Furthermore, fostering local pride and stewardship of geological heritage can enhance the overall visitor experience and contribute to the preservation of the area's unique character.

AUTHORS CONTRIBUTION

Alessandra Ascione (writing original paper; revision; description of the La Starza marine terrace geosite); Pietro Aucelli (writing original paper; revision; description of the Baia sommersa and Serapeo geosites); Claudia Caporizzo (writing original paper; revision; description of the Baia sommersa and Serapeo geosites); Carlo Donadio (writing original paper; revision; description of the Averno lake geosite); Gaia Mattei (writing original paper; revision; description of the Baia sommersa and Serapeo geosites); Paola Petrosino (writing original paper; revision; description of the Cuma and Mt. Nuovo geosites); Elda Russo Ermolli (writing original paper; revision; description of the Cuma geosite); Nicoletta Santangelo (writing original paper; revision; description of the La Starza marine terrace geosite); Ettore Valente (writing original paper; revision; supervision; description of the Capo Miseno geosite).

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DATA AVAILABILITY

Data are available on request to corresponding author.

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