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Review Article

Revised historical sources on the eruptive activity and chronology of Vulcano island (Italy)

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ABSTRACT

Vulcano Island has experienced recurrent historical eruptive activity from the La Fossa and Vulcanello cones, including predominantly phreatomagmatic, Vulcanian, and occasionally Strombolian eruptions. It has also produced several effusive events and phreatic explosions. Despite extensive geological investigations and numerous radiometric and palaeomagnetic age determinations, significant gaps persist in the chronology and source attribution of historical eruptions. These gaps largely reflect stratigraphic complexity and the limited availability of reliable tephrostratigraphic markers. This study presents a critical reassessment of the eruptive chronology and vent locations of the La Fossa and Vulcanello cones from the 4th century BCE to the 18th century CE. We employ a multidisciplinary approach integrating historiographical analysis with recent volcanological and stratigraphic data. A systematic review of historical texts and iconographic sources was conducted, using rigorous philological criteria, to assess their reliability and their temporal and spatial resolution independently of existing volcanological interpretations. Key results include:

(1) The identification of the initial emergence of the Vulcanello cone and associated lava platform between 183 and 126 BCE, and its subsequent stabilization in later centuries;

(2) The reconstruction of the definitive formation of the isthmus connecting Vulcanello to the rest of Vulcano, attributed to the progressive accumulation of eruptive material from the La Fossa cone. This likely occurred at the beginning of the 16th century and culminated with the 1525–1526 CE eruption;

(3) The absence of conclusive textual evidence for modern-era eruptions at the Forgia Vecchia crater, despite geological indicators of older explosive phases during the early development of the La Fossa cone;

(4) The refinement of the chronology of the 18th-century Pietre Cotte eruptive cycle, with emplacement of a rhyolitic lava flow in 1739 CE and an associated pumice fallout in 1771 CE, each emitted from different summit vents of the La Fossa cone.

The study outlines five major eruptions or eruptive cycles exceeding the typical intensity and magnitude of vulcanian-type explosions. These occurred in the late 4th century BCE, 1444 CE, 1525–26 CE, 1739 CE, and 1771 CE. No major phreatic eruptions are documented in historical sources, aside from the well known and historiographically transparent Breccia di Commenda eruption. However, geological evidence indicates that numerous (minor) phreatic explosions occurred during initial vent-opening phases. These findings demonstrate the value of historical sources in reconstructing Vulcano's eruptive history and underline their potential to enhance the temporal resolution of probabilistic hazard scenarios for the island.

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1. Introduction

The island of Vulcano (Aeolian Islands, Italy) is characterized by frequent eruptive activity during the Holocene from different eruptive vents located in its northern portion, inside and along the margins of the La Fossa caldera (De Astis et al., 2013; Di Traglia et al., 2024). Over the last millennia, its eruptive history has been characterized by a long-standing sequence of multiple eruptions of the La Fossa and Vulcanello cones, with the latest eruptive cycle at La Fossa in 1888–1890 CE representing the end of a prolonged period of activity (Mercalli and Silvestri, 1891; De Fiore, 1922). Since the last eruption, the La Fossa cone has remained in a fumarolic stage with shallow seismicity and high-temperature fumaroles along the northern crater rim, associated with limited gas-emission points and hot springs on the surrounding La Fossa caldera floor, especially in the Baia di Levante submarine sector (Chiodini et al., 1995; Paonita et al., 2002; Gambino and Guglielmino, 2008). Several unrest phases have occurred in the last century, characterized by increased temperature, gas flux, magmatic gas input, and, occasionally higher seismicity (Granieri et al., 2006), the last in 2021 (Federico et al., 2023). This indicates a high potential for renewed eruptive activity and volcanic risk near the urbanized zone of Vulcano Porto. Vulcano has a permanent population of ~800, which rises to 22,000–28,000 visitors in summer, strongly increasing risk (Galderisi et al., 2013; Bonadonna et al., 2022).

The study of past and historical eruptive activity and the long-term behavior of the La Fossa cone and Vulcanello are crucial for hazard assessment and risk management. They provide information about eruption chronology and size and offer tools to interpret monitoring data. Geological records, however, suffer from limitations: i) complex stratigraphic relationships, ii) gaps caused by erosion, reworking, and volcano-tectonic activity. The La Fossa cone and Vulcanello are mainly characterized by Vulcanian and phreatomagmatic eruptions, with fewer Strombolian and phreatic eruptions and some effusive events, producing a complex stratigraphic succession with few correlatable markers (e.g. De Astis et al., 2013; Di Traglia et al., 2024). Dating is complicated by methodological uncertainties. Erupted products are dated within the last ~5.5 ka by radiometric methods (^{14}C, K—Ar, Ra—Th, U-series) and palaeomagnetism (Keller, 1980; Frazzetta et al., 1984; Gillot, 1987; Gurioli et al., 2012; Voltaggio et al., 1995; Soligo et al., 2000; Arrighi et al., 2006; Zanella, 2006; Malaguti et al., 2022), but often fail to provide unambiguous ages for individual stratigraphic units or eruptions.

To overcome these difficulties, it is essential to combine geological and age data with historical sources, which provide invaluable information on eruption timelines, styles, and vent locations. The Aeolian Islands have been inhabited since prehistoric times due to raw materials (obsidian, alum, and sulfur) and their strategic maritime position. Vulcano, formerly *Hiera* (ancient Greek ἱερά = "sacred offering") and *Therasia* ("hot land"), was considered a forge of Hephaestus (the god of fire) by the Greeks and named *Vulcanus* by the Romans. In the Christian era it was seen as an entrance to hell. Its repeated eruptions made it widely known since antiquity; the name Vulcano became the eponym for all volcanoes (Becatti, 2010) and for the Vulcanian eruptive style (Mercalli and Silvestri, 1891; Walker, 1973). Numerous historical sources report activity of La Fossa cone and Vulcanello, from antiquity to the 19th century, compiled in classic works (Mercalli, 1883, 1891; De Fiore,1922) and the catalogue by Barbano et al. (2017). However, there are historical periods in which little information is available, such as the millennium from antiquity to the Arab domination, and Vulcano was largely uninhabited until the end of the 18th century, apart from the workers in mining activities (Giustolisi, 1995; Barbano et al., 2017). Observers were rarely on Vulcano itself, more often on Lipari or Sicily, and frequently failed to locate the active crater due to the distance of observation and the fact that eruptive activity often resulted in the emission of volcanic clouds that enveloped the island in smoke and ash. Written memory exists mainly when effects reached inhabited areas beyond the island, and when the eruptions were not so violent as to be felt in Sicily and Italy they remained ignored. Thus, most historical eruptions of Vulcano can only be attributed to specific vents and craters through volcanological inference, not textual certainty. Especially in the pre-scientific period, accounts emphasized extraordinary and prodigious events, and their effects on people or places, rather than vent location or morphology. This may introduce a volcanological bias when the phenomena reported in the historical sources are assumed to represent volcanological facts and features based on over-interpretation influenced by current volcanological knowledge, without a critical analysis of the sources and their complexity (Rouwet et al., 2019). Conflicting interpretations often result from partial readings of historical texts (e.g., Mercalli, 1891 vs. De Fiore, 1922), which have strongly influenced later literature.

The aim of this study is to review the available historical sources on Vulcano activity, including newly discovered ones, and select those addressing unresolved issues. We adopt a non-volcanological, historiographical approach, critically analyzing original texts to build a a homogeneous dataset of historically verified and reliable data concerning eruption chronology, phenomenology, and vent localization. Only afterwards are these data interpreted volcanologically within a general framework that integrates geological, stratigraphic and age information from radiometric and paleomagnetic methods. This distinction between historical analysis and volcanological interpretation ensures transparency, reduces interpretative bias, and leaves room for alternative readings while preserving source reliability. By doing so, this paper updates knowledge on Vulcano's historical eruptions beyond the review of Selva et al. (2020), providing an essential tool for hazard assessment and risk mitigation.

2. Geological setting and eruptive history

The island of Vulcano is the exposed summit of a large volcanic complex with a diameter of about 15 km at its base at depths of 1000–1200 m, located in the southernmost sector of the Aeolian Islands (Fig. 1). The Aeolian Islands are an articulated arc-shaped volcanic

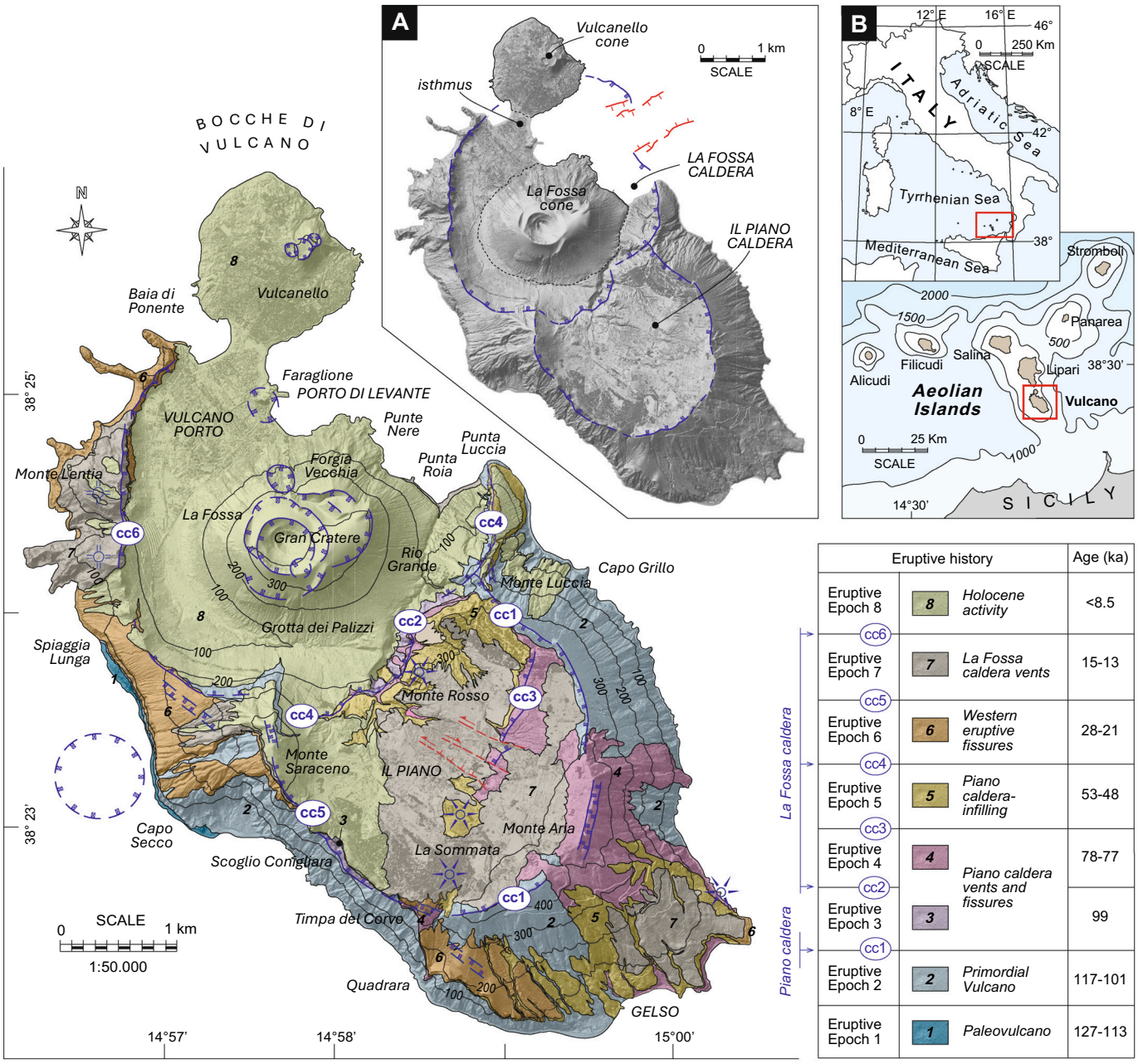


Fig. 1. Simplified geological map of the island of Vulcano merged on a shaded-relief DEM, showing the areal distribution and vents of products related to the main eruptive epochs, as well as the collapse rims associated with the multi-stage formation of the Piano and La Fossa calderas (modified from De Astis et al., 2013). The DEM image is modified from Casalbore et al. (2018). Symbols are the same as in Fig. 2. Age references follow De Astis et al. (2013) and references therein. Coordinates are given in the Gauss-Boaga System (IGM), referenced to the Greenwich meridian. Contour lines are in metres above sea level. In the inset (A), the interpreted geometry of the il Piano and La Fossa caldera structures is highlighted, together with the sketch areal distribution of the La Fossa and Vulcanello cones and the isthmus between the two edifices; data for the submerged northeastern portion of the La Fossa caldera conform to Casalbore et al. (2018). In the inset (B), Vulcano Island is shown within the Aeolian archipelago and the Southern Tyrrhenian Sea.

structure developed in a subduction-related context along the northwestern margin of the Calabrian Arc in the Southern Tyrrhenian Sea, where regional fault systems (NNW–SSE, WNW–ESE, NE–SW) control the structure, distribution, and magmatism of the volcanic centers (see Ventura, 2013, for a review). Vulcano, in particular, forms the southern edge of a tectonically-controlled, NNW-SSE elongated volcanic belt that also includes the islands of Salina and Lipari (Fig. 1B), striking along the major Tindari–Letojanni fault system that transversely intersects the central sector of the archipelago. Accordingly, the structural pattern of Vulcano is dominated by NNW–SSE- to NW-SE-elongated faults, eruptive fissures and volcanic alignments, with additional N—S and NE–SW tectonic lineaments that control vent localization and crater shifting during the younger stages of volcanic development (Mazzuoli et al., 1995; Ventura et al., 1999; Ruch et al., 2016). The volcanic system of Vulcano is underlain by a crustal structure with three main horizons represented by i) Calabrian arc metamorphic basement, ii) felsic granulites of the upper crust, and iii) mafic granulites of the lower crust (Peccerillo et al., 2006). The Moho lies at ~20 km depth beneath the island, reflecting mantle upwelling beneath Lipari–Vulcano and the progressive thinning of the crust towards the Marsili basin (Wang et al., 1989; Ventura et al., 1999).

Referring to the stratigraphy and geological mapping of De Astis et al. (2013), the volcanological history of Vulcano is characterized by eight eruptive epochs spanning approximately 130 ka to historical times (1888–1890 CE), separated by quiescences and erosional stages mostly associated with recurrent volcano-tectonic collapses (Fig. 1). These collapses contribute to the formation of two multi-stage subrounded nested calderas (average diameter 2.5–3 km), known as il Piano and La Fossa calderas (Fig. 1A). The older Il Piano caldera (~100 ka) developed in the central–southern sector, and the younger La Fossa caldera in the northwest, formed through three successive collapse events between ~80 and 8 ka. Volcanism during each eruptive epoch occurred from multiple eruptive centers mostly located along the rims and/or within the successive caldera morphologic depressions, becoming gradually younger through time moving towards the N and NW. They were fed by progressively more evolved magmas whose overall chemical features (both in basalts and rhyolites) mirror progressive temporal changes in evolutionary processes from deep to shallow plumbing systems. The older exposed products are those of the Capo Secco edifice (127–113 ka) offshore the western coast, followed by construction of the Primordial Vulcano stratocone (117–101 ka) and its truncation by the collapse forming the Il Piano caldera (~100 ka). Subsequent eruptive epochs (99–21 ka) produced lava flows, pyroclastic deposits, and dome complexes from vents along the Il Piano and later La Fossa caldera rims, accompanied by multiple collapse events that progressively reshaped the island. The latest epoch of activity during the Holocene, including La Fossa cone and Vulcanello, developed within or along the borders of the final collapse of La Fossa caldera (occurred between 13 and 8.5 ka), whose rims also extend into the submarine areas northeast of the island (Fig. 1A). Subsurface data from geothermal wells indicate that La Fossa caldera experienced asymmetric collapse with a maximum depth in the northern sector, with thick volcanic sequences filling the depression and later capped by La Fossa and Vulcanello products, without any sedimentary intercalations, indicating persistent volcanic activity (Gioncada and Sbrana, 1991).

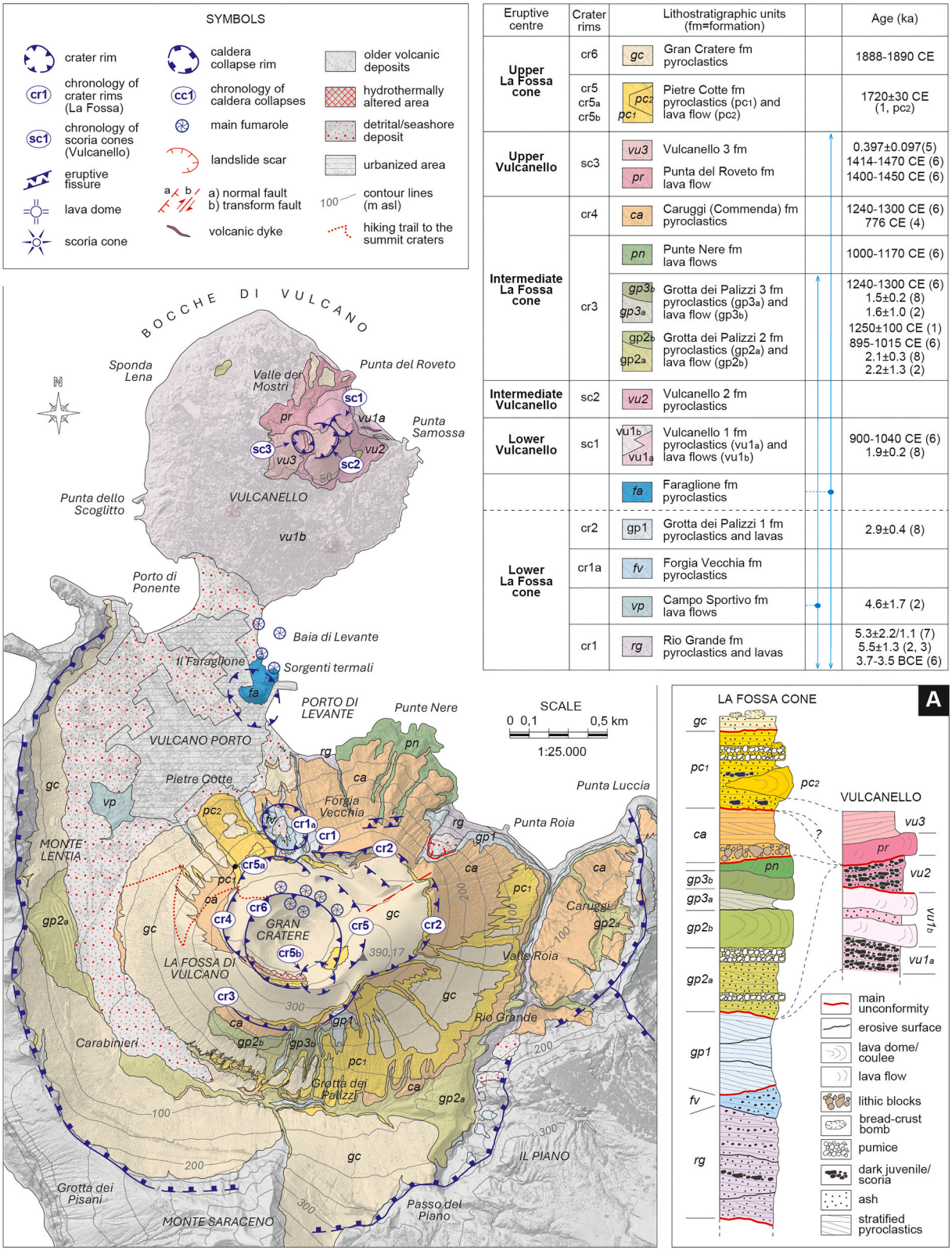
The youngest erupted products are those related to the cones of La Fossa and Vulcanello (and Faraglione) – the subject of the present study - which have been repeatedly active in alternation over the last two millennia. Their eruptive history is described in Fig. 2, taking into account the comprehensive geological reconstruction by De Astis et al. (2013), together with more recent stratigraphic and mapping updates (Lucchi et al., 2024), and the available radiometric and palaeomagnetic age data as well as tephrochronological constraints from the literature. It is worth noting that a revision of the stratigraphy and eruptive history of La Fossa cone and Vulcanello is still currently underway, based on detailed 1:5000-scale mapping of the main volcanic units and morphostructures. The ages and distinctive lithological features and geochemical attributes of the different volcanic units employed in this work are summarized in Table 1, together with their volcanological interpretation. The study of the eruptive activity at La Fossa and Vulcanello cones during the last 1100 years by Di Traglia et al. (2024), based on a combination of stratigraphic analysis and interpretation of historical sources, contains some discordant interpretations and will be discussed further later in the relevant section.

The active La Fossa stratocone (391-m-high, ca. 2-km-wide, average slope angles of 30°) rises within the La Fossa caldera (Fig. 3A) and has been built up during the last 5.5 ka by different pyroclastic products related to fallout and pyroclastic density currents of Vulcanian, phreatomagmatic and Strombolian types, occasional phreatic explosions and a few trachyte-rhyolite lava flows. Radiometric and palaeomagnetic ages and tephrochronological constraints, not always in agreement with each other and with different stratigraphic reconstructions, show important periods of volcanic activity during the Early Middle Ages and during the 18th and 19th centuries (Fig. 2, and references therein). The summit crater area of La Fossa cone is composed of several nested crater rims of different age shifting through time along a rough E/NE–W/SW alignment (Fig. 3B), whereas the Forgia Vecchia crater, whose origin and age are widely debated, is well visible along the northern flank of La Fossa cone (Fig. 3C). The Faraglione stack (56-m-high), located just in front of the Porto di Levante harbour (Fig. 3C), is what remains of a largely dismantled and hydrothermally-altered tuff cone (currently undated), the products of which were extensively exploited in the 18th–19th centuries for the presence of sulfur, alum, alunite and other minerals. Vulcanello is located along the northern border of the La Fossa caldera and consists of a NE–SW-elongated composite cone encircled by a lava platform (Fig. 3D), initially developed as an independent islet and then linked to the main island of Vulcano through the formation of a volcaniclastic isthmus. The early activities of Vulcanello and its emergence are traditionally referred to Roman times (183 or 126 BCE) on the basis of different historical accounts, in agreement with a $^{226}Ra/^{230}Th$ age of approximately 1.9 ka for the Vulcanello platform (Voltaggio et al., 1995), although palaeomagnetic age attributions suggest that its formation dates to the Early Middle Ages (Arrighi et al., 2006; Fusillo et al., 2015; Malaguti et al., 2022). The latest eruptive activities on Vulcanello date to the 16th century (Keller, 1980; De Astis et al., 2013; Malaguti et al., 2022), even if signs of fumarolic activity in its westernmost and most recent crater were noted in some sources until the end of the 19th century (Barbano et al., 2017, and references therein). The last eruptive cycle of La Fossa cone occurred in 1888–90 CE (Fig. 4), and was described in detail by Mercalli and Silvestri (1891) and De Fiore (1922), leading to the definition of the Vulcanian style of eruptive activity (Silvestri, 1889; Mercalli, 1907; Walker, 1973).

3. Methods

We examine and revisit a range of historical sources on Vulcano and its eruptive activity, including numerous classical literary and historical works, chronicles, letters, administrative documents, eyewitness accounts of travelers, photographs and drawings spanning Antiquity to contemporary times. In this context, the selection, critical analysis and relationships between the sources play a key role. These sources are mostly already known, with some references not yet used. Information may be drawn from the analysis of the volcanological historiographic papers of Mercalli (1883, 1891), De Fiore (1922), who provided compilations of eruptions at Vulcano from Antiquity (4th century BCE) through the 18th century. Moreover, we use the extensive catalogue of Vulcano eruptions (together with Aeolian and north-eastern Sicily earthquakes) from the 15th–19th centuries by Barbano et al. (2017), even if it lacks a detailed volcanological interpretation.

For all the selected sources, an important step consists of locating the original texts, in order to verify what information is actually contained in them and identify any potential misunderstandings or interpretative



Eruptive centre	Crater rims	Lithostratigraphic units (fm=formation)	Age (ka)
Upper La Fossa cone	cr6	gc Gran Cratere fm pyroclastics	1888-1890 CE
	cr5 cr5a cr5b	pc2 pc1 Pietre Cotte fm pyroclastics (pc1) and lava flow (pc2)	1720±30 CE (1, pc2)
Upper Vulcanello	sc3	vu3 Vulcanello 3 fm pr Punta del Roveto fm lava flow	0.397±0.097(5) 1414-1470 CE (6) 1400-1450 CE (6)
Intermediate La Fossa cone	cr4	ca Caruggi (Commenda) fm pyroclastics	1240-1300 CE (6) 776 CE (4)
	cr3	pn Punte Nere fm lava flows	1000-1170 CE (6)
		gp3b gp3a Grotta dei Palizzi 3 fm pyroclastics (gp3a) and lava flow (gp3b)	1240-1300 CE (6) 1.5±0.2 (8) 1.6±1.0 (2) 1250±100 CE (1) 895-1015 CE (6) 2.1±0.3 (8) 2.2±1.3 (2)
		gp2b gp2a Grotta dei Palizzi 2 fm pyroclastics (gp2a) and lava flow (gp2b)	
Intermediate Vulcanello	sc2	vu2 Vulcanello 2 fm pyroclastics	
Lower Vulcanello	sc1	vu1b vu1a Vulcanello 1 fm pyroclastics (vu1a) and lava flows (vu1b)	900-1040 CE (6) 1.9±0.2 (8)
		fa Faraglione fm pyroclastics	
Lower La Fossa cone	cr2	gp1 Grotta dei Palizzi 1 fm pyroclastics and lavas	2.9±0.4 (8)
	cr1a	fv Forgia Vecchia fm pyroclastics	
		vp Campo Sportivo fm lava flows	4.6±1.7 (2)
	cr1	rg Rio Grande fm pyroclastics and lavas	5.3±2.2/1.1 (7) 5.5±1.3 (2, 3) 3.7-3.5 BCE (6)

Fig. 2. Simplified geological map of the northern sector of Vulcano, showing the areal distribution of eruptive products and craters of the La Fossa and Vulcanello cones over the past ~5.5 ka, as well as the La Fossa caldera. This map is a simplified version of the 1:10,000 geological map by De Astis et al. (2013), modified according to the most recent update by Lucchi et al. (2024) and new geological field data. See Fig. 1 for geographical location. Contour lines are in metres above sea level. Age references: (1) Arrighi et al. (2006); (2) Frazzetta et al. (1984); (3) Gillot (1987); (4) Keller (2002); (5) Keller (1980); (6) Malaguti et al. (2022); (7) Soligo et al. (2000); (8) Voltaggio et al. (1995). Magma composition labels: Sho = shoshonite; Lat = latite; Tra = trachyte; Rhy = rhyolite. In the inset (A, lower right), a correlation of generalized stratigraphic successions for the La Fossa cone and Vulcanello is shown.

Table 1
List of the lithostratigraphic units of the La Fossa cone and Vulcanello, their distinctive lithological features and geochemical attributes, and summary of the available radiometric and palaeomagnetic ages from the literature. A simplified volcanological interpretation is also provided. Labels: fm, formation; PDC, pyroclastic density current, TRA, trachyte; LAT, latite; SHO, shoshonite; BAS, basalt; AND, andesite; DAC, dacite; RHY, rhyolite, lc, leucite. Composition mostly conform to De Astis et al. (2013) and references therein. References: (1) Arrighi et al. (2006); (2) De Astis et al. (2013); (3) Frazzetta et al. (1984); (4) Gillot (1987); (5) Keller (1980); (6) Keller (2002); (7) Malaguti et al. (2022); (8) Soligo et al. (2000); (9) Voltaggio et al. (1995).

Unit	*Lithological features*	*Crater*	*Interpretation*	*Chemistry*	*Age (ka)*
LOWER LA FOSSA CONE					
Rio Grande fm (Punte Nere fm, 2)	Pyroclastic succession (up to 200–250 m thick) consisting of massive to plane parallel and cross-laminated grey-black to brownish ash (i), with some interlayered beds of well-sorted pumice lapilli (ii). In the upper portion of the unit numerous massive beds containing dark dense juveniles and oxidized blocks are present (iii). Hydrothermally-altered dark lavas crop out along the northern flank of the cone (iv), upon which a m-thick layer of a lava-like welded scoriaceous agglomerate overlies (v).	This unit forms the bulk of the La Fossa cone, bounded by the crater rim cr1 at an elevation of approximately 200 m along the NE side of the cone	PDCs (mostly dry) (i), Strombolian fallout (ii, iii), effusive activity (iv) and hawaiian fountaining (v)	LAT	5.3 (+2.2/−1.1) (1) 5.5 ± 1.3 (1) 3.7–3.5 BCE (1)
Vulcano Porto fm	Aa-type lava flows discontinuously exposed in the area of the village of Vulcano Porto, near the abandoned soccer field.	Undefined eruptive vent		TRA (close to LAT)	4.6 ± 1.7 (1)
Forgia Vecchia fm	Pyroclastic succession (up to approximately 20 m thick) of massive to crudely stratified tuff breccias containing dark juveniles and scoriae. The unit is widely withish to reddish in colour due to intense hydrothermal alteration.	Lateral cone along the northern flank of the La Fossa cone delimited by the crater rim cr1a		LAT	
Grotta dei Palizzi 1 fm	Pyroclastic succession (up to 25 m thick) consisting of very thinly bedded, plane parallel, coherent varicoloured ash with abundant accretionary lapilli (i). Minor layers of grey coarse ash with asymmetrical bedforms are present (ii). This unit is subdivided into three portions by two erosional surfaces. An horizon of porphiritic scoriaceous bombs is present in the basal portion (iii).	This unit builds up the La Fossa cone up to the crater rim cr2 at an elevation of approximately 300 m along the eastern side of the cone		SHO	2.9 ± 0.4 (1)
FARAGLIONE					
Faraglione fm	Highly hydrothermally altered (locally hardened), medium bedded, planar-stratified lapilli-tuffs with relicts of dense and scoriaceous bombs. This unit constitutes the 56-m-high stack of Faraglione, located just in front of the Porto di Levante harbour.	Remains of a tuff cone now almost entirely eroded and dismantled	PDCs and ballistic fallout	Lc-bearing SHO	
LOWER VULCANELLO					
Vulcanello 1 fm	$vu1_a$ member - Pyroclastic succession (tens of metres thick) made up of alternating (i) beds of massive to normal-graded scoriaceous lapilli, bombs and lava spatter, from loose to variably welded, and (ii) subordinate well laminated yellowish ash. Quartzitic and Qz-feldspatic xenoliths are abundant at some stratigraphic levels.	This unit forms the scoria cone sc1 (at elevation of approximately 90 m), which constitutes the bulk of Vulcanello and is currently largely eroded and dismantled on its NE flank	Strombolian fallout (i) and minor PDCs	Lc-bearing SHO	1.9 ± 2.0 (1)
	$vu1_b$ member- Aa to pahoehoe lava flows (interbedded with the vu1a member) which form a compound lava flow field (up to 30 m thick).	Lava platform of Vulcanello originated from the scoria cone sc1	Effusive activity	SHO	900–1040 CE (1)
INTERMEDIATE VULCANELLO					
Vulcanello 2 fm	Pyroclastic succession (8 m thick) consisting of beds of loose black lapilli alternating with beds of reddish scoriae and bombs	This unit forms the scoria cone sc2, nested with the older one and reaching elevation of approximately 120 m	Strombolian fallout	SHO	
INTERMEDIATE LA FOSSA					
Grotta dei Palizzi 2 fm	$gp2_a$ member - Thinly bedded, weakly coherent, massive to planar and cross-laminated grey ash (up to 20 m thick) (i). In the lower portion, an inverse-graded layer of rhyolitic pumice bombs and lapilli and rare obsidian clasts is visible (ii), whereas a 2 m-thick, normal-graded blanket of trachytic pumice lapilli and	This unit forms the crater rim cr3 at an elevation of approximately 200–250 m, which is nested within the southern flank of the La Fossa cone	PDCs (i) and fallout (ii, iii)	LAT to TRA- RHY	2.2 ± 1.3 (1) 2.1 ± 0.3 (1) 895–1015 CE (1)

(*continued on next page*)

Table 1 (*continued*)

Unit	*Lithological features*	*Crater*	*Interpretation*	*Chemistry*	*Age (ka)*
	bombs with isolated breadcrust bombs is present at the top (iii).				
	$gp2_b$ member - Glassy and aphiric, largely obsidianaceous lava coulee (up to 20 m thick) cropping out on the southern flank of the La Fossa cone, and widely hydrothermally altered.	Effusive activity of the crater rim cr3	Effusive activity	RHY (with lava enclaves)	1250 CE ± 100 (1)
Grotta dei Palizzi 2 fm	$gp3_a$ member - Thinly bedded, plane-parallel to cross-stratified tuffs (up to 4 m-thick), including varicoloured tuffs		PDCs		
	$gp3_b$ member - Aa blackish lava flow (up to 8 m thick) cropping out on the southern slope of the La Fossa cone	Late effusive activity of the crater rim cr3		TRA	1.6 ± 1.0 (1) 1.5 ± 0.2 (1) 1240–1300 CE (1)
Punte Nere fm	M-thick, aa lava flows forming a large lobate lava field along the northern flank of the La Fossa cone	Effusive activity of a lateral vent (or fissure) along the northern flank of the La Fossa cone		TRA (close to LAT)	1000–1170 CE (1)
Caruggi fm	M-thick, massive and poorly sorted tuff breccias composed of yellow-reddish ashes and abundant hydrotermally-altered lithic blocks are present at the base of the unit (i.e. Breccia di Commenda unit). Some whitish ash layers from Lipari are interlayered. The upper portion of the unit consists of thinly bedded, coherent varicoloured tuffs (5 m thick) with accretionary lapilli and rare interlayered beds of grey coarse ash with traction structures.	This unit forms the crater rim cr4 (at an elevation of approximately 300 m) along the western side of the La Fossa cone	PDCs and ballistic fallout	LAT	1240–1300 CE (1) 776 CE (1)
UPPER VULCANELLO					
Vulcanello 3 fm.					
$vu3_a$ member	Viscous, m-thick Punta del Roveto lava flow ([11]), characterized by jagged flow front, rough/irregular fractures and roughly clinker top. Lava is vesiculated and porphyric (with cm-sized kf phenocrysts) and in places shows oxidation traces.		Effusive activity from the Vulcanello scoria cone sc3 (the youngest).	LAT-TRA	
$vu3_b$ member	Pyroclastics (up to 18 m-thick) composed of alternating i) thinly bedded, vesiculated, varicoloured tuffs and ii) massive deposits of scoriaceous to vitrophyric lapilli and bombs, the latter increasing towards the top. Some layers contain polygenetic xenoliths. Plant relics are found on a localized erosion surface within the unit, providing a ^{14}C calendar age of 0.397 ka ([11] *).		Strombolian fallout (i) and minor PDC eruption units (ii) building the youngest scoria cone of Vulcanello (sc3).	SHO	0.397 ± 0.097 [11] *
Gran Cratere di La Fossa lithosome *(tuff cone - upper portion)*					
Pietre Cotte fm. (*Unità complessa di Pietre Cotte*, [6])					
pc_1 member	Thinly and plane parallel bedded pyroclastic succession (up to 3 m thick) composed of alternating varicoloured vesiculated ashes and weakly coherent, grey to green coarse ashes. Massive pumiceous layers are locally interbedded (i), particularly at top of the unit where a m-thick, massive layer of pumiceous lapilli and bombs with bread-crust bombs is present.		Dilute PDC eruption units (wet- and dry- type) and minor vulcanian/ strombolian fallout deposits (i).		
pc_2 member (*Pietre Cotte lava flow*, [11])	Stubby and tongue-like, m-thick lava flow cropping out along the NE flank of La Fossa cone. It has a fresh morphology, typically blocky and rough surface, and internal structure characterized by extended obsidianaceous portions, banding with stony and pumiceous layers, flow foliation and folding structures. Several enclaves with variable size (mm÷2-3 dm) and colour (from reddish to grey and white due to alteration) are present, generally aligned along the flow banding, with small lava fragments showing plastic to semiplastic deformations and the coarsest, angular clasts showing sharp edges and contacts.		Latest effusive activity of La Fossa cone (crater rim cr3).	RHY, low porphyritic (plg, px, kf). Enclaves are LAT to TRA.	*1739 9 CE* 1720 CE (±30) [1]

(*continued on next page*)

Table 1 (*continued*)

Unit	*Lithological features*	*Crater*	*Interpretation*	*Chemistry*	*Age (ka)*
Gran Cratere 1 fm. (*Unità piroclastica post-1739*, [6])	Pyroclastic succession (up to 4 m-thick) exposed in discontinuous outcrops mostly localized in the sector of Mt. Lentia reliefs. It mostly consists of thinly to medium bedded ash deposits varying from massive to cross-laminated. Thin, massive beds of pumiceous lapilli with isolated bombs are interbedded in places (i).		Dry-type PDC eruption units (alternating with vulcanian fallout deposits = i)	Pumices are TRA-RHY	
Gran Cratere 2 fm. *(Unità dell'eruzione 1888–90,* [6,15])	Pyroclastics produced during the reknown 1888–90 CE eruptive events (18). They are made up of loose black unvesiculated lapilli-tuffs with isolated bombs and intercalated thinly bedded tuffs. At the top, dense lapilli and blocks and scattered obsidianaceous bread-crust bombs (Ømax>1 m) are present. Isolated bread-crust bombs are reported in the area of il Piano.		Alternating dilute PDC and fallout deposits originated during the latest vulcanian-type eruptions of La Fossa	Bombs are LAT to RHY (with diffused Qz-xenoliths)	*1888–1890 CE*

Notes - Labels conform to the mapped units (cf. *De Astis* et al., *2011): Monte = Mount (Mt.); Vallone = valley. A synthetic description of the lithosomes is given into brackets in the proper spaces. Symbols - Abbreviations: PDC = pyroclastic density current. Composition: TRA = trachyte; LAT = latite; SHO = shoshonite; BAS = basalte; AND = andesite; DAC = dacite; RHY = rhyolite. Mineralogy: plg = plagioclase; cpx = clinopyroxene; kf = k-feldspar; bt = biotite; ol = olivine; lc = leucite. Composition and mineralogy mostly conform to present work (general framework). References for the correlation of stratigraphic units: * Lipari. References: (1)* Arrighi et al., *2006; (2)* De Astis et al., *2013; (3)* Keller, *2002; (4)* Keller, *1980; (5) GIllot, 1987; (6)* Malaguti et al., *2022; (7)* Soligo et al., *2000; (8)* Voltaggio et al., *1995. Ages into brackets are considered to be uncertain because they are in contrast with more precise radiometric ages in our stratigraphic framework or not attributable with certainty to any litostratigraphic units. The original* ^{14}C *conventional ages (*) are here given as calendar ages after calibration by means of the IntCal09 curve of Reimer* et al. *(2009)(see Lucchi* et al., *2013 for further details).*

distortions present in historiographical works and the literature. The sources are critically analyzed from philological and textual perspectives with the aim to trace back to the original source, to highlight what is actually described, and to assess how reliable the description is for dating eruptions and identifying source areas. Particular attention is given to highlight any cross-references between the various sources and any differences in chronology, topographical data and phenomenology provided by each of them. It is important to recognize that historical sources are never neutral or objective but rather reflect the views, perspectives, and intentions of the authors who produced them, and thus a rigorous methodological approach is essential to reconstruct the historical context of the events. Measurements of size and distances are always treated with caution since they were estimated with approximate methods, far from the precision of contemporary times.

The original texts from Greek and Roman authors, between 4th century BCE and 5th century CE, are analyzed through the methods used in specialized historical research and discussed based on historiographical studies of Antiquity. In this regard, the most authoritative specialist historical criticism (Stothers and Rampino, 1983; Panessa, 1991; Rasmussen, 2003; Engels, 2007) is also cited. These sources are mostly easily accessible along with their English translations on different digital platforms (e.g. the Loeb Classical Library – https://www.loebclassics.com - for classical texts). This enables us to highlight any errors and misinterpretations of the data from Antiquity to the 5th century CE in the volcanological literature.

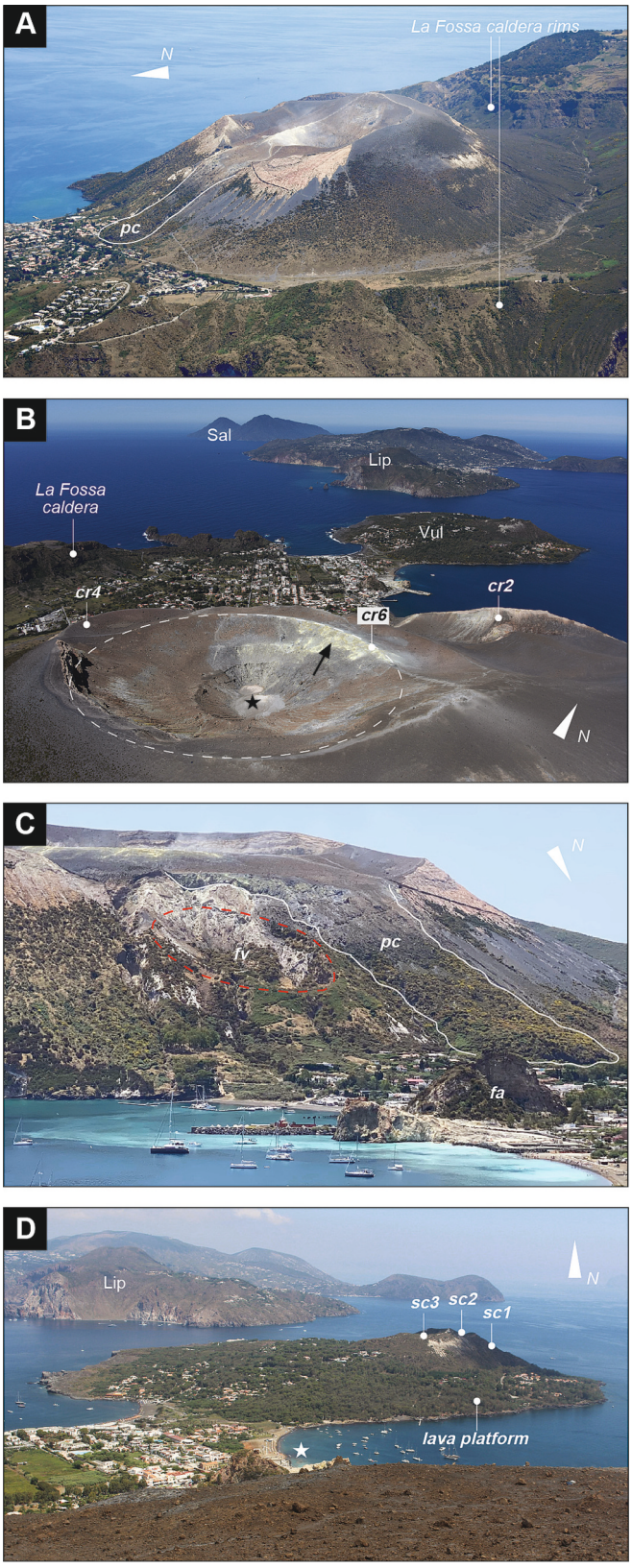
The reading of Arabic sources about Italian volcanoes during the Middle Ages (from the 6th to the15th century CE) is particularly complex due to the reliance of some authors on the works of others. Interpretative pitfalls regarding the correct identification of the cited volcanoes are frequent, also considering the fact that only a few Arab authors who wrote about Sicily actually visited the island and observed the volcanoes in person. In this context, it is especially important to differentiate the terms and toponyms used by the authors to identify either Mt. Etna or the volcanoes of the Aeolian Islands, which can generate confusion and misunderstandings (Guidoboni et al., 2014).

The sources for the Modern Period (16th–18th centuries CE) provide more precise geological descriptions, and information regarding the topography, active craters and the different eruptive and post-eruptive phenomena on Vulcano, so misinterpretation is far less probable. Our review is mostly devoted to recognizing any cross-references among the various works, ascertaining the reliability of each account, understanding the author's point of observation, and determining if they were a direct observer of the phenomena or, instead, relayed accounts from others.

The critical historical analysis of the original texts accounts for the complexity of the sources and delivers historically verified and reliable data concerning eruptive activity on Vulcano. The subsequent volcanological interpretation of what is described in the original texts (and drawings) is particularly focused on the information about the age of eruptions, the eruptive scenario and the localization of the vents, trying to understand whether the eruptions pertain to the craters of La Fossa (and Forgia Vecchia) or Vulcanello. One of the problems, particularly for ancient and medieval texts, is a certain variability in toponyms and their not univocal traceability to a specific volcano or crater in its current state (e.g. Lipari sometimes seems to be mistaken for Vulcano). Moreover, the eruptive phenomena described by writers of the various eras are in most cases not fully consistent with current volcanological terminology and knowledge. We thus focus on the few cases in which the historical accounts are detailed enough to allow an evaluation of the eruptive style or characteristics of the eruptions without an excessive degree of interpretation. Most of the time, however, they refer only to generic eruptive activity without further details. In any case, we believe that the age and location of the eruptions and the described phenomenology are the most important information for the purposes of assessing volcanic hazard.

4. Selected historical sources *(4th century BCE - 18th century CE)*

Here we present a compilation of the historical sources used to conduct our analysis of their historical context and mutual relations, in order to extract information regarding eruption chronology, vent location and eruptive behavior. It is important to clarify that we will not report all the historical sources available to us, but only a broad selection, focusing on those related to the most controversial issues in the eruptive history of La Fossa (and Forgia Vecchia) and Vulcanello cones, for which there is still no full agreement in the volcanological literature.



(caption on next column)

Fig. 3. General geological features of the La Fossa and Vulcanello cones. A) Aerial view of the western flank of the La Fossa cone (photo by C. Steger, Wikipedia), located in the middle of the La Fossa caldera. Caldera rims are indicated. The Pietre Cotte lava flow (pc) is visible along the cone's flank, and overhangs the village of Vulcano Porto, which lies at the base of the cone on its northern side. B) Aerial view of the La Fossa summit crater area (photo by S. Branca, INGV). Multiple crater rims of different age are visibile (see Fig. 2 for more details). Crater rim cr6, formed during the latest eruptive cycle (1888 CE–90), is approximately 500 m wide and nearly circular. It is prominent at the center. Two anastomosed vents are present at its bottom (star) and are surrounded by grey, ash-rich eruptive products. The high-temperature active fumarole field is visible along the northern crater rim (arrow). In the background: the western rim of La Fossa caldera, Vulcanello (Vul), and the adjacent islands of Lipari (Lip) and Salina (Sal). C) Panoramic view of the northern flank of the La Fossa cone (seen from Vulcanello). The Pietre Cotte rhyolitic lava flow (pc) stands out beside the intensely hydrothermally altered and eroded remains of the Forgia Vecchia crater (fv). In the foreground, the highly altered remnants of the Faraglione cone (fa) are visible within the village of Vulcano Porto. Off the village, the Baia di Levante gas emission area is revealed by light-colored seawater. D) Panoramic view of Vulcanello islet (seen from the summit of the La Fossa cone). The lava platform surrounds a composite cone formed by three anastomosed crater rims (cr1-cr3; see Fig. 2 for details). The gas emission area near Baia di Levante harbour is visible in the foreground (star).

Their volcanological interpretation will be discussed in the next chapter.

The selected sources are ordered chronologically according to the date of the eruption or type of event about which they provide information (Fig. 5), starting from ancient Greek and Roman authors up to Arab, Latin and Italian writers and travelers during the Middle Ages (6th–15th AD) and later accounts of historians, naturalists and scientists during the 16th–18th centuries. We do not deal (except in a very marginal way) with the eruptive activity of the 19th century ending with the last eruptive cycle of 1888–90 CE, for which we refer to the complete reconstructions in the catalogs of eruptions provided by Mercalli (1883, 1891), De Fiore (1922), Barbano et al. (2017), and the review by Selva et al. (2020).

A list of the selected historical sources and information extracted from our analysis is given in Table 2. The specific wordings or textual references that are considered most significant for our subsequent analysis and discussion are reported in the text (in italics) together with their translation in English (in quotation marks).

4.1. Ancient period (4th-3rd centuries BCE): two craters on Vulcano

The Greek philosopher Aristotle (384–322 BCE) is among the oldest known historical sources on the eruptive activity of Vulcano. In the work "Meteorologica" (2.8.366 b-367 a) Aristotle (ed. 1982) he discusses the theory of earthquakes and volcanic eruptions generated by winds locked inside the Earth's crust that finally open their way to a point on the earth's surface where they are manifestly released in the form of "hurricanes". He reports that this happened "recently" (relative to his time) in Heraclea Pontica on the Black Sea, and "previously" on the island of Hiera (i.e. Vulcano), one of the Aeolian Islands. In particular, regarding Vulcano he tells us that a part of the ground swelled up and rose ("like a tumor") with a loud noise until it resembled a hill. This relief then fractured and expelled lapilli (*φέψαλον* = burning fragments) and ash (*τέφραν*) that covered the nearby town of Lipari completely and reached even parts of Italy. Moreover, Aristotle emphasizes that the place where this eruption took place was still visible at the time he was writing. Aristotle's description must be considered particularly reliable. This is because on the phenomena observed in the Aeolian Islands he based his model for the genesis of volcanism and earthquakes. He founded an interpretative theory that lasted almost two thousand years (Guidoboni, 1998). On the other hand, the dating of the eruption described at

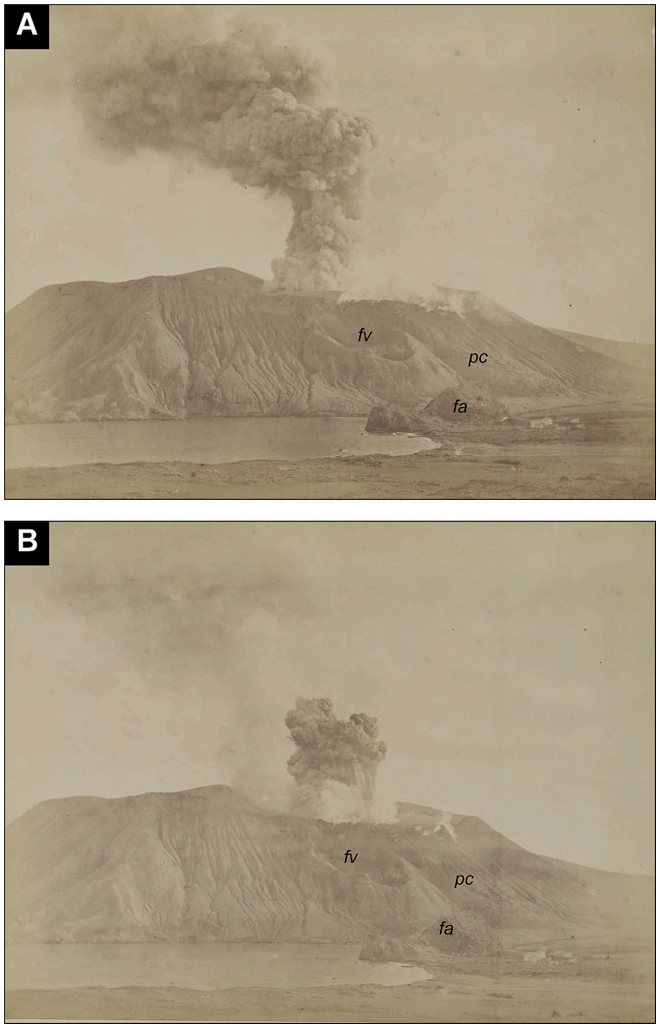


Fig. 4. Photographs of the northern flank of the La Fossa cone during the 1888–90 CE eruptive cycle (photos of O. Silvestri, from Museo Galileo, Florence: "Raccolta fotografica Eruzioni degli anni 1888-1889 all'Isola Vulcano, 1888-1891" - https://bibdig.museogalileo.it/tecanew/opera?bid=967245&seq=1). These images depict typical features of Vulcanian eruptions, characterized by intermittent eruptive plumes and ballistic fallout of large lava blocks and bread-crust bombs. Visible features include the Forgia Vecchia crater (fv), the Pietre Cotte lava flow (pc), and the remnants of the Faraglione cone (fa). A workers' warehouse, struck by ballistic rocks during the eruptions, is also visible.

Vulcano is made uncertain by the two indeterminate temporal terms used by the author (i.e., "recently" and "previously"). Their transformation into plausible dates must take into account the time period in which Aristotle was writing his works, which occurred in several stages. There was also a more indeterminate meaning of the terms that measured time in those days than today's usage. Therefore, in literature and historiography two dates are proposed as more probable for the described eruption: shortly before 360 BCE (Capelle, 1924; Panessa, 1991; Guidoboni et al., 1994) and 330 BCE (Stothers and Rampino, 1983), or more generally the second half of the 4th century BCE (Zunino, 1999).

A few decades later, another source is Callias (ed. 1923-1958), a Sicilian Greek historian who lived between the end of the 4th and the beginning of the 3rd century BCE at Syracuse in Sicily. In his work "History of Agathocles", of which only a few citations by other authors are available, there is a text about Vulcano (Hiera). It is preserved in a scholium (FGrHist 564 F 4) on the works of Apollonius Rhodius, referring to the period in which Callias lived and worked at the court of the tyrant Agathocles (316–289/282 BCE). In this text, Callias mentions the presence of a high volcanic cone where two craters were located. One of them had a perimeter of about 570 m (3 *stadia*) and was characterized by eruptive activity ("emits a lot of fire"), such that it would illuminate everything around for a wide radius, and ejected large burning and incandescent stones, "ferruginous" as a result of combustion, with such a roar that it could be heard for tens of kilometers. This eruptive activity, which is what happens "when the god Hephaestus works", is clearly visible at night, while during the day on the summit of the cone only a nebulous mass can be seen. The other crater is only mentioned without further details.

4.2. 183 BCE: emergence of a new island

Six Latin-speaking authors of the Classical age to Late Antiquity (between the 1st century BCE and the 7th century CE) provide descriptions referring to the possible emergence of a new island in the Aeolian Islands in the year 183 BCE. A careful textual analysis, supported by specialist historiography, defines a philological scheme for these six sources. This scheme identifies two distinct traditions in the transfer of information. Each is handed down by the two authors chronologically closest to the event: Livy and Pliny the Elder.

Livy (ed. 1991) a renowned Latin historian lived between 59 BC and AD 17, reports in the Annales events from the beginning of the year 183 BC when the *pontifex maximus* Publius Licinius Crassus died (Livy, ed. 1991). He says (39, 46.5) that a period of supplication was called because blood had rained for two days in the precinct of the temple of the god Vulcano in Rome. Then (39, 56.6), at the end of the same year – the same year in which Marcus Claudius and Quintus Fabius Labeo were consules and Hannibal died - there was another supplication because of some prodigies: it had rained blood for two days in the sacred area of the temple of the goddess Concordia in Rome. It was announced that not far from Sicily a new island had emerged from the sea, which did not exist before (*nuntiatumque erat haud procul Sicilia insulam, quae non ante fuerat, novam editam e mari esse*). As highlighted by critics (Engels, 2007; Gabrielli, 2007), Livy's work was certainly the source (or one of the sources) of two later authors and epitomators, Julius Obsequens and Paolus Orosius, who lived in the 4th century to early 5th century CE.

Obsequens (ed. 1910), in the *Liber Prodigiorum*, a collection of prodigious events from 190 to 11 BCE, reports (Prod. 4) that during the consulate of Marcus Claudius and Quintus Fabius Labeo in 183 BCE it rained blood for two days in the Vulcano area, and then in the Concordia area for as many days, and in Sicily a new island appeared in the sea (*In area Vulcani per biduum, in area Concordiae totidem diebus sanguinem pluit. In Sicilia insula nova mari nata)*. This is essentially a summary of Livy's original text. However, Obsequens notably introduces a textual contiguity between the term Vulcano and the emergence of an island.

Also, Paulus Orosius (ed. 1889), in the book *Historiae adversus Paganos*, which contains exceptional, often calamitous events, reports (4.20.30) the prodigious events of 183 BCE with words very similar to those used by Livy. He tells us that near the coast of Sicily, the island of Vulcano, which had not existed before, suddenly emerged from the sea and lasted until his own time (*in Sicilia tunc Vulcani insula, quae ante non fuerat, repente mari edita* cum *miraculo omnium usque ad nunc manet*). This outlines that, unlike previous sources, Orosius identifies the island that emerged near Sicily with the island of Vulcano, and he is also convinced that the new island was still visible at the time of writing his book, about 600 years after its early emergence in 183 BCE.

Later, Cassiodorus (ed. 1894), who lived in 490–583 CE c., recalls (3.47.5) the emergence from the depths of an island near Sicily in 183 BCE (i.e. when Hannibal killed himself) with a fearful churning of waves (*hanc insulam ante aliquot annos undarum rupto terrore imitus erupisse)*.

The second historical tradition relative to the 183 BC event originates from Pliny the Elder (ed. 1951) a Roman author, naturalist and naval and army commander of the early Roman Empire, who lived in AD 23-79 and died during the AD 79 eruption of Mount Vesuvius. In his

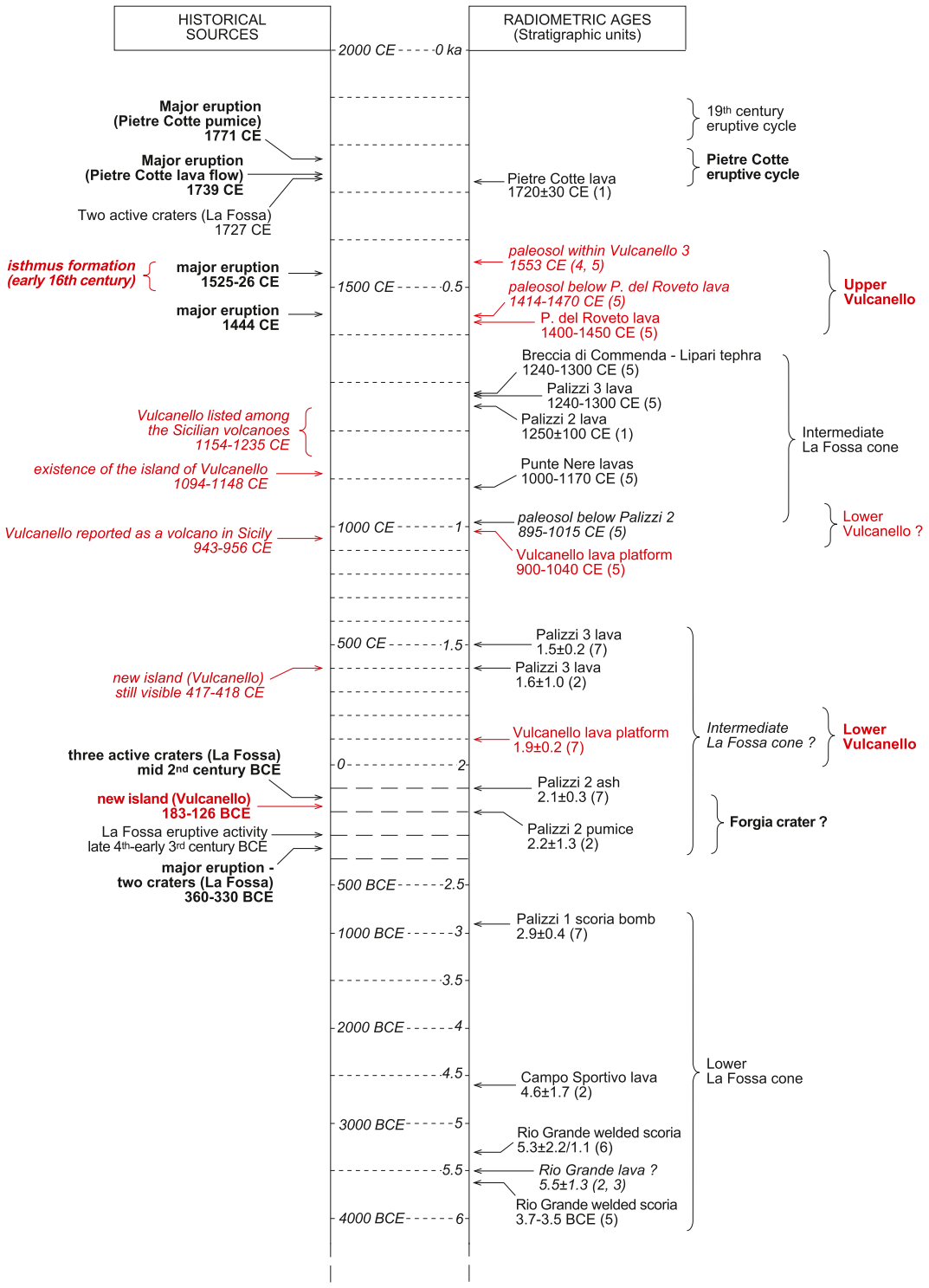


Fig. 5. Schematic diagram showing a compilation of dated eruptions and events relevant to the La Fossa cone (in black) and Vulcanello (in red). These eruptions are derived from the analysis of selected historical sources reviewed in this study. Historical data are integrated with available radiometric and palaeomagnetic ages of the main stratigraphic units (see Fig. 2 for stratigraphic details). Key topics discussed in the subsequent sections are also highlighted. Error bars are shown for the radiometric ages, except for K/Ar dates, which have high analytical uncertainty. Age references: (1) Arrighi et al. (2006); (2) Frazzetta et al. (1984); (3) Gillot (1987); (4) Keller (1980); (5) Malaguti et al. (2022); (6) Soligo et al. (2000); (7) Voltaggio et al. (1995). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

encyclopedic work *Naturalis Historia*, Pliny makes an extensive discussion on the origin and knowledge of earthquakes, volcanoes and the emergence of islands. There, he reports (n. h. II, 202 and 203) that before his time (*ante nos*), near Italy, a new island had arisen in the middle of the Aeolian Islands (*et iuxta Italiam inter Aeolias insulas… emersit…una*), and another island in the 3rd year of Olympiad 163 (126–125 BCE) in the Tyrrhenian sea (*in Tusco sinu*). In this text, unlike what is observed in the tradition linked to Livy, specific reference is made to the emergence of a new island in the Aeolian Islands, and not just generically near Sicily. There are no direct textual references about

Table 2
Summary of selected historical sources regarding eruptive activity on Vulcano. These sources are classified into primary sources, which represent direct descriptions or accounts, and secondary sources, which are transcriptions or quotations of the first ones. The sources are listed according to the chronology of the described events. For each source, we provide a brief description of the content and indicate the relevant volcanic source area, as identified through our historiographical analysis and volcanological interpretation.

Primary historical source			Secondary historical source			Year of the event	Main information	Volcanic source area	Other features	Notes
Author (lifespan)	Book/text	Year of publication	Author (lifespan)	Book/text	Year of publication					
Aristotle (384–322 BCE)	Meteorologica					c. 360 or c.330 BCE	Major eruption producing lapilli and ash that covered the Lipari town and places in Italy	Forgia?	The eruption was associated with swelling and rising of a part of the ground until it resembled a hill	
Callias of Syracuse	History of Agathocles	c. 316–289 BCE?				late 4th – early 3rd century BCE	Continuous eruptive activity	La Fossa	Two craters at the top of a high volcanic cone	
Livy (59 BCE-17 CE)	Annales					183 BCE	New island appeared in the sea	Not far from Sicily		When Gaius Servilius Geminus was elected to the position of pontifex maximus
			Julius Obsequens (4th century CE)	Liber prodigiorum		183 BCE	New island appeared in the sea	In Siciliy		During the consulate of Marcus Claudius and Quintus Fabius Labeo
			Paulus Orosius (c. 380-c. 420 CE)	Historiae adversus Paganos	417–418 CE	183 BCE	Emergence of an island which had not existed before	Island of Vulcano	The island is still visible at the time of writing	
			Cassiodorus (490- c.583 CE)	Variae		183 BCE	Emergence of an island			The year when Hannibal killed himself
Pliny the Elder (23–79 CE)	Naturalis historia					183 BCE	New island arisen	in the middle of the Aeolian islands		
			Ammianus Marcellinus (330–400 CE)	Res Gestae			Island emerged from the sea	Vulcano		
Polybius (c. 208–126 BCE) [in Strabo]	Historiai					mid 2nd century BCE	Three (active) craters on Vulcano	La Fossa, Vulcanello?, Forgia?	One of the craters partially collapsed and the other two are intact	
Posidonius (c. 135–51 BCE) [in Strabo]						126 BCE	Eruption from the sea	Around the Aeolian Islands	"Mud" appeared on the sea surface and solidified becoming hard and solid	The Senate of Rome decided to send a delegation to celebrate expiatory sacrifices on the new islet
Pliny the Elder (23–79 CE)						126 BCE	Emergence of an island	Tyrrhenian Sea	Death of fish and people	3rd year of Olympiad 163 (i.e., 126–125 BCE)

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Table 2 (*continued*)

Primary historical source			Secondary historical source			Year of the event	Main information	Volcanic source area	Other features	Notes
			Julius Obsequens (4th century CE)	Liber prodigiorum	4th century CE	126 BCE	Eruption from the sea causing an extreme boiling of the sea	Sea around Lipari's islands	Death of sailors, of fish, and of people who ate the dead fish.	During the consulate of Marcus Aemilius and Lucius Aurelius
			Paulus Orosius (c. 380-c. 420 CE)	Historiae adversus Paganos	417–418 CE			Island of Lipari and surrounding sea	The heat was so high that it disintegrated the rocks ("*ut adustas quoque rupes dissolverit*") and carbonised the planks of the ships, after having liquefied the wax the wax that held them together	During the consulate of Marcus Aemilius and Lucius Aurelius
Strabo (c. 64 BCE- 24 CE)	Geographia					2nd half 1st century BCE - early 1st cent. AD	Three craters, the lagest of them active ("expels flames with burning masses") Uncertain textual reference to Vulcanello (Jabal al-Burkan) among the volcanoes of Sicily		The erupted material had already filled a significant portion of the strait.	
al-Mas'udi (pre 893-956 CE)	Muruj al-dhahab	943–956 CE						Vulcanello?		
	Platea antiqua bonorum Ecclesiae Pactensis (in Catalioto, 2007)					between 1094 CE and 1131–1148 CE	Existence of the Island of Vulcanello among the territories of the bishpric of Lipari-Patti	Vulcanello	It consists of hunting rabbits	
al-Idrisi (c.1100–1165)	Nuzhat al-mushtaq fi ihtiraq al-afaq	1154 CE				mid 12th century CE	Vulcanello (Jabal al-Burkan) in the list of the small islands near Sicily and Sardinia	Vulcanello	Vulcanello is not mentioned as an active volcano (differently from Vulcano)	Vulcanello = Jabal al-Burkan; Vulcano = al-Burkan
Ibn Jubayr (1145–1217)	Kitab Rihlat	1183–1185				1184 CE, Decembre 8	Nine islands located not far from Sicily		Two of them perpetually emitted fire	
Michel Scot (c. 1175–1235)	Liber particularis	1220–1235 CE				early 13rd cent. AD	Vulcanino among the Sicilian volcanoes	Vulcanino = Vulcanello	Vulcanino is described as erupting (as also Strombolino = Strombolicchio)	Unknown source
Ranzano (1426/27–1492)	Annales omnium temporum		Fazello	De rebus Siculis decades duae	1558 CE	1444 CE	Large eruption (out of ordinary) from the crater in the middle of the island	La Fossa? Forgia?	Very large dfragments fell into the sea at a distance of almost 11 km	
	Lo compasso de navegare	middle 13th cent.				middle 13th cent. AD	Vulcanello (Bolcanino) is an islet located in front of Vulcano, which has an harbour	Vulcanello		Unknown source
	Portolano di Grazia Pauli	2nd half 14th century				2nd half 14th century CE	Vulcanello sometimes erupts fire and flames	Vulcanello	Presence of shoals in different sectors of the stretch of sea between Vulcano and Vulcanello	Unknown source
	Portolano per i naviganti	1490 CE				1490 CE	Vulcanello as a (isolated) rock located to the northeast of Vulcano	Vulcanello		Unknown source
Piri Reis (c. 1465/1470–1553)	Kitab-i Bahriye	1521 CE (1st version)				c. 1521 CE	Vulcano burns constantly. Exposed to the east and to the west winds	Vulcano	Anchorages for ships were on the sides of Vulcano exposed to the west and east winds	

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Table 2 (*continued*)

Primary historical source			Secondary historical source			Year of the event	Main information	Volcanic source area	Other features	Notes
Piri Reis (c. 1465/ 1470–1553)	Kitab-i Bahriye	1525–1526 CE (2nd version)				c.1525–26 CE	Vulcano is a desert island and its two sides burn continually, day and night	Vulcano		
Jérôme Maurand (XVI cent.)	Itinéraire de Jérome Maurand d'Antibes a Constantinople (1544)	1572 CE				1544 CE	Description of the La Fossa crater in a fumarolic stage of activity; information about a major eruption occurred "in the past"		Vulcano and Vulcanello are connected by abundant ash erupted by the crater of Vulcano	
Leandro Alberti	Descrittione di tutta l'Italia	1550 CE; 1561 CE				1525–26 CE	Eruptive activity: incandescent matter coming out at night and smoke during the day	Vulcano		He observed Vulcano from afar
			Domenico Bottone (1641-post 1721)	Pyrologia topographica	1692 CE	around 1524 CE	Strong eruption of ash and rocks that fell into the middle of the sea	Vulcano		
Tommaso Fazello (1498–1570)	De rebus Siculis decades duae	1558 CE				1550–1558 CE	Continuous eruptive activity with large cloud of smoke accompanied by ash, incandescent material and pumice clasts. Reference to a potential activity of Vulcanello.	La Fossa and Vulcanello	Closure of the narrow stretch of sea that separated Vulcano from Vulcanello due to eruption of Vulcano	
Jacques Philippe d'Orville (1696–1751)	Sicula quibus Siciliae	1764 CE				1727 CE (at least May 20–22)	Sequence of Vulcanian eruptions	La Fossa? Forgia?	Two active craters located on two peaks, one larger and higher towards the south an the other to the north of the island	Vulcanello is not mentioned as active. The "island" at his times corresponded to the main island of Vulcano
Mongitore		1743 CE		I Campi Flegrei della Sicilia e delle isole che le sono intorno e descrizione fisica e mineralogica di queste isole						
Gaetano Maria Trovatini Incudine		1882 CE	Ferrara		1810 CE		Various eruptive activities expressly attributed or attributable to Vulcano over a period of at least two and a half months			
	Breve ristretto… (in Alibrandi, 1991–1992)	1991–1992 CE				1739 CE (at least March 29–June 9)			Assocation with earthquakes in north Siciiy	
Guillaume-Antoine De Luc (1729–1812) in Jean-André De Luc	Lettres physiques et morales	1780 CE				1757 CE	Fumarolic activity of La Fossa	Pietre Cotte lava flow	A very porous lava flows (rich in iron) was emitted about ten years earlier than his visit	Vulcanello not active

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Table 2 (*continued*)

Primary historical source	Secondary historical source			Year of the event	Main information	Volcanic source area	Other features	Notes
Gaetano Maria Trovatini	Ferrara	I Campi Flegrei della Sicilia e delle isole che le sono intorno e descrizione fisica e mineralogica di queste isole	1810 CE	1771 CE	Vulcanian eruption forming an eruptive cloud and fallout of ash in February; other eruptions in March, April and mid-May	La Fossa	The ash eventually piled up in Lipari to form a considerable layer several inches (or centimeters) thick	
Déodat de Dolomieu	Voyage aux Iles de Lipari		1786 CE	1771 CE	Large eruption with emission of large rock fragments and blocks of glassy lava	La Fossa	Whitish ash reached as far as Lipari and Sicily	A black, glassy lava flow (Pietre Cotte?) emitted a few years earlier than his visit in 1786 ADCE

the age of the emergence event in the Aeolian Islands, but it can be reasonably attributed to 183 BCE considering that Pliny refers to "before his time", while the second emergence event in the Tyrrhenian sea is explicitly dated to 126–125 BCE (see below in paragraph 4.4).

Pliny was likely the source of Ammianus Marcellinus (AD ca. 330–400), a Roman historian and military man. In his book, the Rerum gestarum quae exstant (Ammianus Marcellinus, ed. 1978), he mentions (17.7.3) Vulcano in the Tyrrhenian Sea (*et apud Tyrrenos Vulcanus*) as an example of an island emerged due to the so-called *brasmatiae*, a type of earthquake that raises the ground from the bottom and pushes up enormous masses, correlated by the author to volcanic activity. It is notable that in the passage of information from Pliny to Ammianus, the event is localized by the latter in Vulcano, a toponym absent from the older source.

The combined analysis of all these six sources indicates unambiguously that in 183 BCE in the Aeolian Islands, likely around the volcanic complex of Vulcano, a small island suddenly appeared, where none had existed before. The year of appearance of this new island is unquestionably the one accepted by historiography and literature. This agress with the year when the pontifex maximus Publius Licinius Crassus died and the correct conversion of the year of the consulate of Marcus Claudius and Quintus Fabius Labeo as given by Livy and Julius Obsequens. This date is consistent with the year of Hannibal's death, cited by Livy and Cassiodorus, and it is also "before the times" of Pliny the Elder. The 183 BCE event is reported by all sources briefly, without any detailed description of the associated phenomenology, except for the text of Cassiodorus (ed. 1894) who recalls "waves that were torn apart". That event is described as the sudden emergence of an island (*edita* = "sent out" in Livy and Orosius; *erupisse* = to "be thrown out" in Cassiodorus; *nata* = "born" in Julius Obsequens; *terrae..emersit..una* ="land emergence" in Pliny the Elder and Ammianus) at a sea point where previously there was no land. However, the textual elements provided by the sources for a precise localization of the event and the identification of the new island are vague and not well constrained. Regarding this, the early two authors who handed down the information, Livy and Pliny the Elder, did not identify precisely the island that emerged within the Aeolian archipelago. Livy's indeterminate localization "not far from Sicily" can be somewhat complemented by the more precise "in the midst of the Aeolian islands" by Pliny the Elder. However, Livy's wording is later taken up by Julius Obsequens ("in Sicily"), and it becomes in Orosius "the island of Vulcano". The specific historiographical studies on the prodigies of classical Roman times list the extraordinary event of the emergence of a new island, using the sources mentioned above. While Rasmussen (2003) does not raise the question regarding the precise identification of the island, Engels (2007) suggests - in agreement with Hillen (1993) - that the island that emerged may have been Vulcanello, originally an island. Borca (2000) also cautiously accepts the hypothesis that there could have been an exchange of Vulcano for Vulcanello.

Gabrielli (2007) convincingly argues that, probably following the 183 BCE event – although it is not possible to determine exactly when - a regulation was created to govern the "abnormal status" of a new island. He refers to a rule contained in the *Digesta*, a collection of books that include ancient Roman legal material from the 1st century BCE to the 4th century CE, part of the *Corpus Iuris Civilis* issued by the emperor Justinian I in 533 CE. In the section dedicated to the acquisition of ownership of goods (Dig. 41,1,7,3), the rare case (*quod rare accidit*) of a new island born in the sea (*insula quae in mari nascitur*) is recalled. It clarifies that its ownership belonged to the first occupant because the island did not belong to anyone (*nullius enim esse creditur*). Gabrielli (2007) underlines that the sudden appearance of an island in a stretch of sea frequently travelled by navigators was perceived as a negative and disturbing element, perhaps because it was generated by an impressive volcanic phenomenon. The appearance of a new land foreign to the territorial structure must have created difficulties regarding its ownership and borders. In line with the ideas of traditional Roman republican

culture, therefore, this unwelcome and prodigious event was necessarily followed by an institutional initiative of a religious nature (the atonement), the need for a naturalistic explanation (the one provided by Pliny the Elder) to rationalize and reduce men's fear in the face of such an extraordinary natural phenomenon, and, finally, the need to regulate the anomalous legal status of a new island. Based on these considerations, it can be believed that this interest of Roman jurists was aroused by a real event. This event reasonably corresponds to the formation of the new island in the Aeolian Islands in 183 BCE (and later eruption in 126 BCE), assuming that the lexicon used surprisingly follows that of the historical sources for this event.

4.3. Mid-2nd century BCE: three craters on Vulcano

A later, well-known account about Vulcano is that of Polybius (c. 208–126 BCE), a Greek historian who travelled throughout Italy and Sicily. He narrated most events as a contemporary source, which makes him authoritative and reliable. In his historical work *Historiai*, book no. 34, of which only a few fragments have remained, he describes the countries he visited and defines measurements and distances. Polybius (ed. 1967) was widely referenced by Strabo (c. 64 BCE-24 CE), a well-known Greek geographer and historian, in his work *Geography,* which includes a description of Sicily and the volcanic phenomena of Etna and the Aeolian Islands. The measurements provided by Polybius are not free from errors: for example, he estimated the distance from Gibraltar to Messina at ca. 3300 km (i.e., 18700 *stadia*), whereas the actual distance does not exceed 1900 km. In particular, Polybius (34.11.12–20, in Strabo 6.2.10) provides information of volcanological interest about the state of activity and general morphology of Vulcano in the middle of the 2nd century BCE. During the years of his stay in Italy (167–150 BCE), he or one of his direct sources was probably able to observe the Aeolian Islands from the sea. According to Polybius, Vulcano (*Thermessa*) had three craters, one of which was partially collapsed and the other two intact. The largest of the three craters had a circular rim, with a circumference of ca. 900 m (5 *stadia*), which gradually reduced to a diameter of only 15 m in its internal part, and a height of ca. 180 m (1 *stadium*) above sea level. This height made it visible from afar in calm weather. Polybius says that the eruptive activity of the largest crater was visible only under conditions of northern wind and clear visibility. Under these conditions, flames rose very brightly from the crater and louder rumblings were heard. The other two craters looked similar, although Polybius does not give any specific dimensions. However, the "violence" of their eruptions was less.

4.4. 126 BCE (or 91–88 BCE): submarine eruption

Six authors report on a large underwater eruption with notable gas exhalation in the year 126 BCE or, less probably, in 91–88 BCE.

The oldest, most detailed, and most contemporary source of this event, is a text by Posidonius (ed. 1967), likely based on a contemporary account of his master Panezio di Rodi (c. 185-c.109 BCE), according to Senatore (2018). Posidonius (c. 135-51 BCE) had a huge literary production in many fields of knowledge. He had a particular interest in natural phenomena, such as earthquakes and volcanic eruptions, as the result of travels across the Mediterranean coastal regions (Vimercati, 2004). Unfortunately, none of his works is available; only a few fragments of text are preserved in the writings of later authors.

In particular, Strabo considered Posidonius to be the main and reliable source for most of the geographical information in his work *Geography* (Lasserre, 1967). Strabo travelled for a long time in Egypt, Asia, Italy and Greece. He was able to acquire direct information or personally observe the places he describes. He states (6.2.11) that several times the fire had "run on the water" around the Aeolian Islands, after it had "escaped from an underwater opening" which then emerged at the surface. Then he reports a text of Posidonius (Fragment 227, Edelstein-Kidd = F 43, Theiler = A 146) about an eruption when the sea was "raised to an extraordinary height by a sustained blast" and remained there for a considerable time before subsequently falling again. People on a small boat - who dared to approach the area where the uprising had occurred - saw many dead fish dragged by the currents. They were forced to flee due to humanly intolerable smelly fumes and the emanation of great heat that was unbearable to them. For these reasons, some of the men in the boat died, while the other members of the crew managed to take refuge in Lipari. However, they were struck by periodic attacks resembling epileptic fits, alternating with periods of normal lucidity. Many days after this event, mud appeared on the surface of the sea, associated with flames, smoke and "murky fire" (λιγνύας = ash?), which solidified, becoming "hard and solid like millstone". Strabo's transcription of the original text of Posidonius makes clear that this event greatly impressed the contemporaries. It was so striking that the governor of Sicily, Titus (Quinctius) Flaminius (then identified with Titus Flamininus, see later in the text), reported it to the Senate of Rome. The Senate decided to send a delegation to celebrate expiatory sacrifices both on the new islet and on Lipari.

As mentioned in paragraph 4.2, Pliny the Elder also in his work *Naturalis Historia* reports (2.203) the emergence of an island in the Tyrrhenian Sea occurring in the 3rd year of Olympiad 163 (i.e., 126–125 BCE), with a phenomenology of emission of an incandescent and violent blast (*flagrans haec violento* cum *flatu*) and the death of those who had fed on the fish that were floating around in abundance.

Obsequens and Orosius, the two Roman authors who lived in the 4th century CE, provide very similar accounts about an eruption that occurred in 126 BCE, i.e. during the consulate of Marcus Aemilius and Lucius Aurelius. It is hypothesized that both sourced the news from Livy, whom they epitomized, even if it cannot be confirmed since the books of his work containing the facts after 167 BCE have been lost. In particular, Obsequens (Prod.29) recalls an extremely intense "boiling of the sea" (*mare efferbuit*) that "burned ships, stifled several mariners with fumes and scattered about a large amount of dead fish" (*et quibusdam adustis navibus vapore plerosque navales exanimavit, piscium vim magnam exanimem dispersit*). Orosius (5.10.11) adds that "the heat was so strong that it disintegrated the rocks" (*ut adustas quoque rupes dissolverit*) and "carbonised the planks of the ships after having liquefied the wax that held them together" (*tabulata navium liquefactis ceris extorruerit)*. The death of numerous people from Lipari has also been reported because of damage to vital organs due to prolonged breathing of fiery air and intestinal poisoning of those who had fed on the dead fish. More synthetic and similar references to the 126 BC event are also given byAugustine (ed. 1955; 3.31), lived in AD 354-430, and in the book Chronicon by Eusebius of Caesarea (ed. 1956), lived in AD 265-340, according to the Latin version translated (146e) by Gerolamus (AD 347-419).

Regarding this event, the vaguest chronological attribution is precisely that of Posidonius, who nevertheless provides the most accurate description. He is very precise about the day and the hour. In fact, the event occurred "in his time", therefore in the time between 135 and 51 BCE, at the dawn of June 21 (summer solstice), the day after the start of an eruption of Etna (Guidoboni et al., 2014). All the other sources converge on a chronological attribution of both eruptions (the one at Etna and that of Vulcano) to 126 BCE, which is the year of the consulate of Marcus Aemilius and Lucius Aurelius recalled by Obsequens and Orosius. This is in agreement with the references to the 3rd year of the 163rd Olympics (i.e. 126/125 BCE) by Pliny the Elder and Eusebius. Notably, there is another text passage from Pliny the Elder in the *Naturalis Historia* (2.238) that accounts for the islands of Vulcano (Hiera) and Lipari burning in mid sea for several days, as did the sea itself (*in medio mari Hiera et Lipara insulae Aeoliae iuxta Italiam* cum *ipso mari arsere)*, until a deputation from the senate of Rome performed a propitiatory ceremony, even if it is dated to the era of the social war in 91–88 BCE. On this, Stothers and Rampino (1983) and Engels (2007) independently refer the described event to 126 BCE. There is no unanimity on this interpretation (Rasmussen, 2003; Cavalier and Basile, 2012). In any case, it should be noted that the textual elements essentially reflect

the information contained in all the sources related to the 126 BCE event. Thus, we consider it acceptable that the eruption which entered the volcanological tradition with the date of 91–88 BCE is a duplication of the 126 BCE event, and not really a distinct eruption.

Part of the historiography (e.g. Pagliara, 1995), taken up in the volcanological literature even recently (Manni and Rosi, 2021), dates and attributes the eruptive event described by Posidonius to 183 BCE. This is based on the reference to Titus Quinctius Flaminius (229–174 BCE) as the governor of Sicily. It must be made clear that there never existed a governor of Sicily with this name, much less in the period in which Posidonius lived. The name of Titus Quinctius Flaminius is instead used in the year 183 BCE to refer to the ambassador in Bithynia to obtain the delivery of Hannibal. Some most authoritative editors and commentators think that the reference made by Posidonius was to Titus Flamininus (Panessa, 1991; Engels, 2007; Cavalier and Basile, 2012), who was praetor of Sicily in 123 BCE. This would be consistent with the year 126 BCE for the event provided by most sources, considering a certain approximation, or assuming that the expiatory rite was celebrated three years after the emersion of the new island. This could signal approximately three years of inaccessible conditions there.

In terms of localization of the event, the sources for the 126 BCE eruption converge on the Aeolian Islands, sometimes with more precise indications. Posidonius, the oldest and most contemporary source, locates the event between *Hiera* (Vulcano) and *Euonimo* (Panarea). This could be read as referring to the side of Vulcano that looks towards Panarea. In the two texts of Pliny the Elder this event is identified first in the Tyrrhenian Sea and then in the islands of Vulcano and Lipari and the surrounding sea. In substantial agreement with Pliny the Elder, a location near the island of Lipari is indicated by Orosius (*Lipara insula et vicinum* circa) and Obsequens (*ad insulas Liparas*). Only Eusebius goes so far as to identify, evidently erroneously, the island that emerged with that of Vulcano (*Hiera*).

Notably, Strabo in his work *Geography* provides interesting information about the geomorphology and state of activity of Vulcano at the time he was writing (second half 1st century BCE - early 1st century CE). He refers to the island of Vulcano - named *Thermessa* and at his time ("now") *Hiera* of God *Hephaestus* (i.e. island sacred to *Hephasteus*) - as rocky, desert, and fiery, and characterized by three vents rising from three openings "which one might call craters". The largest of them expelled flames together with red-hot masses (bombs) which had already filled "a considerable part of the strait", although it is not specified whether this is the strait between Vulcano and Lipari or between Vulcano and the island of Vulcanello (which had likely already formed).

4.5. High Middle Ages (1000–1300 CE): Vulcanello islet

There is a long and almost complete gap in the written sources on the Aeolian Islands throughout most of the first millennium until the middle of the 12th century CE. The reason is that after the fall of the western Roman Empire in the 5th century CE the archipelago became a site of recurring disputes. It was widely devastated by the Muslims towards the end of the first millennium, leading to an almost total depopulation (Iacolino, 1996). Exceptions are very few accounts of Arab or Latin travelers who provide brief information about the eruptive activity on Vulcano and the possible presence of the islet of Vulcanello as a stable geographic entity. As for the Arabic sources, it is important to differentiate the terms and toponyms used by the authors to identify Mt. Etna or the volcanoes of the Aeolian Islands (i.e. Vulcanello). Despite the interpretative uncertainties that characterize the individual sources, most authors describe the volcanoes of Sicily with expressions such as "the mountain of fire" (*Jabal al-nar*) or "the mountain of flowing fire" (*Jabal al-nar al-giariya*) to indicate Mount Etna. Vulcano is called "the volcano" (*al-Burkan*) or the "island of Vulcano" (*Giazirat al-Burkan*), while Vulcanello is called "the mountain of Vulcano" (*Jabal al-Burkan*) (Guidoboni et al., 2014).

As far as is known, the Arabic form *Jabal al-Burkan* was used for the first time by the historian and geographer al-Mas'udi (pre-893 CE-956 CE) in his work *Muruj al-dhahab* ("The Golden Meadows") written in 943 CE and revised in 956 CE (al-Mas'udi, ed. 1966-1979). He refers twice to the volcanoes of Sicily using the term *Jabal al-Burkan*, and on a third occasion he uses the term *al-Burkan* alone. This could be the earliest textual evidence of a toponym used to identify the Vulcanello islet. However, despite an in-depth analysis, several uncertainties remain both rearding the identification of the Sicilian volcanoes reported with the form *Jabal al-Burkan* (whether Etna, Vulcano or Vulcanello), and regarding the chronology and reliability of the information reported by al-Mas'udi (Johns, 1989; Guidoboni et al., 2014).

About two centuries later, there is another report of the Arabic term *Jabal al-Burkan* used almost unequivocally to indicate Vulcanello. This appears in the text *Kitab Nuzhat al-mushtaq fi ihtiraq al-afaq* ("The Book of Pleasure for Those who Desire to Visit Faraway Places") or *Al-Kitāb al-Rujārī* ("The Book of Roger") written in 1154 CE by al-Idrisi (ed. 1970-1984), who lived between ca. 1100 and 1165 CE and was for a long time at the court of the kings of Sicily. He gave a list of the small islands near Sicily and Sardinia. He mentions between Stromboli and Lipari first *Jabal al-Burkan* and then *Jazîrat al-Burkân*, respectively identified and translated as Vulcanello and Vulcano in most translations starting from Amari and Schiaparelli (1883) up to the French edition of Bresc and Nef (1999). Further on, al-Idrisi focusing on some of the listed small islands, cites Vulcano (*Jazîrat al-Burkân*) several times as a point of reference compared to other locations, but no longer mentions Vulcanello. This suggests it was of less interest due to the lack or scarcity of eruptive activity, even if this cannot be proven unequivocally. Vulcano is described as an island not large, full of wild goats, with a very high mountain which sometimes emits a great fire and burns with short intermittent pauses, and when it erupts, ejects incandescent stones and emits frighteningly loud booms heard at long distances.

Another source in this period is the Andalusian geographer, traveler and poet Ibn Jubayr (1145–1217 CE), who observed the volcanoes of the Aeolian Islands during the return journey from his pilgrimage from Spain to Mecca in Arabia (Ibn Jubayr, ed. 1963). This occurred on 8 December of 1184 CE, which corresponds to Tuesday 12 of the month of Ramadan of the year 580 CE of Hegira according to the Islamic calendar use by the author. Specifically, Ibn Jubayr saw from afar the "nine" islands that are located not far from Sicily. Two of them perpetually emitted fire, as in fact he observed smoke coming out of those two and red flaming tongues at night, even if they are referred to with no clear toponyms or geographical indications. This text presents several interpretative problems concerning the translations available starting from the end of the 19th century, particularly regarding the names of the two volcanoes that the author saw as active. These have been interpreted differently in the available translations. No toponyms or geographical indications are present in the first translation from Arabic to French made by Amari (1845–1846), while the same author, in his translation of Ibn Jubayr's work from Arabic to Italian (Amari, 1880), subsequently inserted in round brackets the toponyms Vulcano and Vulcanello in relation to the two active volcanoes, without providing precise locations. About the same text, no toponyms were suggested or hypothesized in the translation by Schiaparelli (1906), while Broadhurst (1952, from Arab to English) and Calasso (2022, from Arab to Italian) suggest that the two active volcanoes were Vulcano and Stromboli, as this would be likely to be seen from afar considering their recurrent eruptive activity.

A document of peculiar interest for the High Middle Ages is the *Platea antiqua bonorum Ecclesiae Pactensis* ("Ancient inventory of the property of the Church of Patti") that is preserved in various copies in the Archivio Arcivescovile (i.e. Archbishop's Archive) of Patti, Sicily (Catalioto, 2007, 2017). This reports a long and precise list of the assets (lands and possessions) of the newly established diocese of Lipari-Patti at that time, along with the related income rights. As far as we are interested, there is a specific mention of the island of Vulcanello (*Item Insulam Vulcanelli),* in the genitive form (*Vulcanelli*) of the Latin toponym

Vulcanellus (i.e. "small Vulcano"), noting that this is an area where "rabbit hunting" (*in venatione cuniculorum*) is practiced. The original document (now lost) is not directly dated. However, its age can be reconstructed by considering that the creation of the diocese of Lipari-Patti occurred in 1094 CE as the final action of the progressive control over the Aeolian Islands from the Normans. They were engaged from 1061 CE in the reconquest of Sicily by the Arabs. The extension of the owned territory and the economic importance of this unified monastic nucleus expanded considerably in the following decades. Therefore, the bishop Giovanni da Pergana decided to transcribe the *Platea antiqua bonorum Ecclesiae Pactensis* to avoid any claims for privileges and properties of the diocese (Catalioto, 2007). This transcription dates back to between 1131 CE and 1148 (Garufi, 1928; Girgensohn and Kamp, 1965; Catalioto, 2007, 2013), meaning the year of drafting of the original document is antecedent. Therefore, the document was written between 1094 CE, the year in which the diocese of Lipari-Patti was created, and 1131–1148 CE. It should be considered erroneous the dating of this document to 1247 CE proposed by Manni and Rosi (2021), as well as its incorrect archival reference in the "Historical Archive of Sannio", and the mistaken citation in Catalioto (1996).

A source hitherto unknown to historiography and volcanological literature is the book *Liber particularis* by Michel Scot (AD c. 1175–1235), an Arabic-Latin translator, philosopher, encyclopedist, astrologer and naturalist at the Sicilian court of the king of Sicily, Frederick II of Swabia, starting from 1220 CE. In the second of the three books of the *Liber introductorius* (1220–1235 CE) (Scot, ed. 2014), he dedicates a long passage to Sicilian volcanoes, among which he lists Stromboli (*Strongulus*), "Strombolino" (*Strongulinum*), corresponding to the Strombolicchio islet, Vulcano (*Vulcanus*) and "Vulcanino" (*Vulcaninus*), corresponding to Vulcanello, Etna (*Moncibel*) and Lipari. Note that "Vulcanino" is a variant for Vulcanello that is present in some sources of the 13th–14th centuries CE. He specifies that the eruptive activity at the summit of Stromboli and "Strombolino" is continuous, while Vulcano, "Vulcanino", Etna and Lipari erupt occasionally, particularly "only when the southern wind blows", emitting a large amount of smoke, when the summit flame ceases, and ejecting stones, burnt wood and pumice. In other passages of his work Scot mentions the Sicilian volcanoes, but does not mention Vulcanello ("Vulcanino") again.

Important information about the islet of Vulcanello as a well-known geographical and topographical entity to sailors in the High Middle Ages is obtained from the "portolans": specific types of texts that appeared in the 13th century. Written portulans were navigation manuals that listed the distances between coastal locations, including the directions to follow to travel from one location to another. They contained warnings about navigation conditions, particularly regarding the presence of rocks and shoals, currents and prevailing winds, and methods of making landfall. They also described routes, coasts, ports, seabeds; suitable or dangerous points for passage and docking. The written portulans were nautical tools regularly used onboard in the Middle Ages, together with nautical charts, to ensure accurate navigation at sea. They were in close relationship due to the involvement of pilots in their making (Campbell, 1987; Gautier-Dalché, 1995). Thus, they are very reliable historical sources. The oldest Italian portolan, entitled *Lo compasso de navegare* (ed. 2011), was written around the middle of the 13th century, and has not yet been used in historiography and volcanological literature (Motzo, 1947; Debanne, 2011). Its anonymous author points out that on the island of Vulcano there was a good port with the islet of Vulcanello (*Bolcanino*) in front of it (*En la dicta isola de Bulcano è bom porto, et à denamti sè una isolecta, che à nome Bolcanino*), and advises accessing it from the west between Vulcano and Vulcanello (*Et à entrata lo dicto porto da ver lo ponemte, e entre Bolcano e Bolcanino*) by sailing closer to Vulcano than to the Vulcanello islet itself (*E se venissi a lo dicto porto, estrengite de ver Bolcano*). The reason why the vessel should sail nearer to Vulcano, as noted in the portolan *Lo Compasso de navegare,* is clarified by reading the later portolan entitled *Portolano di Grazia Pauli* (Anonymous, ed. 1977), written in the second half of the 14th century and still unused in the historiography and volcanological literature. This clarifies that the stretch of sea that separated Vulcano and Vulcanello, referred to as the "mouth" (*boccha*), was about 200 m wide ("almost a crossbow throw"), but there was a shoal in the middle, creating a shallow seabed. Therefore, instructions were given to stay close to Vulcano (*istrengeti a Bolgano*) if one was between Vulcano and Vulcanello (*se ti trovi intra Bolgano e Bolganello*), and instead to approach Vulcanello if one entered the port from the west or from the east (*Et se tue verai da la parte di ponette al ditto portto, istregeti a Bolganello chà, i mezo de la bocha, à secha una. E se tue verai da partte di levante, similementte istrigete a Bolganello*). The portolan also warns sailors to disentangle themselves and to be cautious even when approaching the port entrance (*paligola*) because there was a passage with a shoal only about 2 m deep (8 palms). Further, if one was unable to enter the port of Vulcano with a west wind, it was better to go to the current *Cannitello beach (chapo Chanetello), in the south of the island,* where there was a good landing place *(e locho è sorgitoro)*. In conclusion, the portolans highlight that towards the end of the 14th century the stretch of sea between Vulcano and Vulcanello had some shoals with shallow depth, sometimes insufficient for the passage of boats.

4.6. Late Middle Ages (15th–16th century CE): La Fossa cone activity and isthmus formation

The historical sources for the Late Middle Ages are related to eruptive activity on Vulcano, particularly to the definitive formation of the isthmus that currently connects Vulcano to Vulcanello (which had formed previously as a separate islet).

The Sicilian theologian and humanist Pietro Ranzano (1426 CE/27–1492) is the most direct witness of an eruption that occurred on February 5, 1444 CE, considered the first of its kind in the Late Middle Ages (Ciuccarelli et al., 2019). This eruption is known in the volcanological tradition starting from Bottone (1692) onwards. It is based on the work *De rebus Siculis decades duae* published in 1558 CE by the Sicilian historian Tommaso Fazello (1498–1570 CE). Actually, Fazello drew almost verbatim from Ranzano, n.d. (15th century), as uncovered by Ciuccarelli et al. (2019). In 1444 CE, Ranzano was evidently informed of the eruption at Vulcano while he was still very young in Catania. He later included this information in his *Annales omnium temporum* (Biblioteca Comunale of Palermo, Ms. 3 Qq C, 60), along with the description of an eruption of Etna that occurred in the same year, of which he was an eyewitness. In Ranzano's account the eruption is described as "out of the ordinary" (*praeter solitum*), compared to the known activity on Vulcano. It generated an eruptive cloud with incandescent fragments (*flammarum atque ardentium saxorum globos*), four of which of very large size fell into the sea at a distance of almost 11 km - i.e., 6 miles (*ut quatuor ex ijs admirandae magnitudinis, ultra sex ab insula p.m. in mare*). A few days after the eruption, strong earthquakes were felt throughout Sicily without causing damage to people (according to Fazello, these earthquakes were also felt in the Aeolian Islands).

Information about Vulcanello is taken from the portolan entitled *Portolano per i naviganti composto per un gentiluomo veneziano (Anonymous, 1490)*, not yet cited in historiography and volcanological literature. This anonymous manual for navigation states that around that time "to the northeast of Vulcano" - where the north-east wind, called *Grecale* or *Greco*, blows from (*dala parte de greco de bolcham*) - there was a rock named Vulcanello (*e un scoieto ditto bolchanello),* thus revealing that the sea still separated the previously formed islet from Vulcano. It is notable that the term *scoieto* ("little rock") does not refer to a smaller size of Vulcanello than we know today. It is a term that portolans used to define generically small islands (even the island of Giglio, in Tuscany, which is larger than the entire Vulcano island, is defined there as a *scoieto*).

Some geographic information about the area – possibly including Vulcanello - is provided by the maps and written accounts of Pîrî Re'îs (c. 1465 CE/1470–1553), an Ottoman sailor and geographer. He drew a

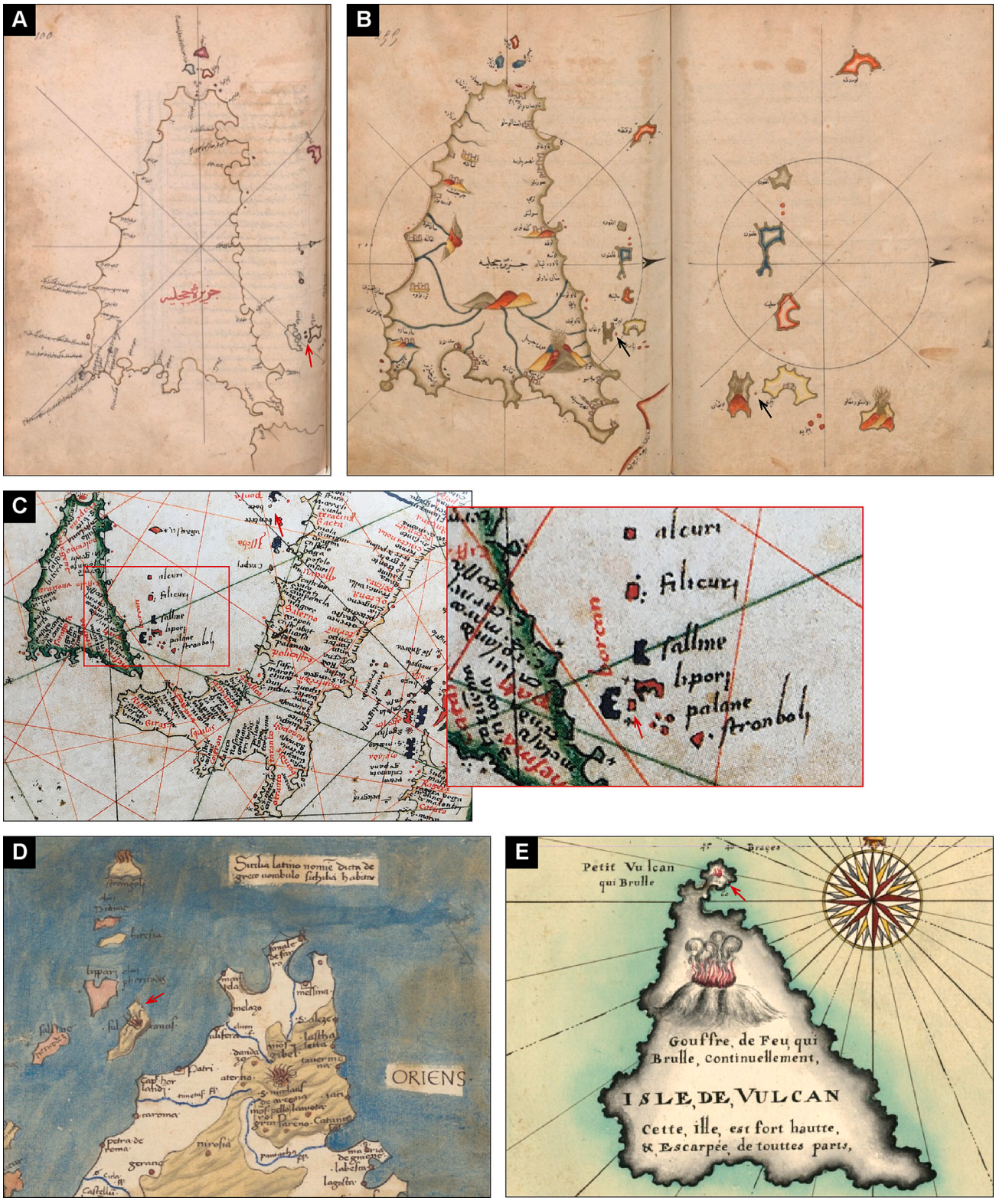

Fig. 6. Maps and pictures of the Late Middle Ages showing different representations of Vulcano and Vulcanello. A) Map of Sicily and the Aeolian Islands in the codex that refers to the first version of the book *Kitab-i Bahriye* by Piri Reis, dated 1521 CE (Bibliothèque nationale de France, Supplement Turc 220). In this map, the presence of the Vulcanello islet is not obvious to the north of Vulcano (arrow). B) Maps of Sicily and the Aeolian Islands in the second version of the *Kitab-i Bahriye* by Piri Reis (from Bacqué-Grammont and Bresc, 2009), dated 1526 CE (Bibliothèque nationale de France, Supplement Turc 956), where Vulcanello is shown as a separate islet (arrow). C) Nautical atlas by Vesconte Maggiolo, dated 1512 CE (Biblioteca Palatina, Parma, ms. 1614). The Vulcanello islet (arrow) is still visible to the north of Vulcano. D) Detail from the map *Liber Insularum Arcipelagi* by Cristoforo Buondelmonti (Bibliothèque Nationale de France), from the first half of the 15th century. Vulcano is depicted without any graphic evidence of Vulcanello (arrow), either as a separate islet or detached from the main island. E) Extract from Henry Michelot's map (1699; Bibliothèque Nationale de France). This shows the islands of Vulcano and Vulcanello connected by the isthmus, with a graphic representation suggesting that both La Fossa cone and Vulcanello (arrow) were active.

map of the entire known world in 1513 CE, of which only a small portion has survived. This portion of the map includes the Atlantic Ocean and the western coasts of Europe and Africa, but neither Italy nor Sicily appear (McIntosh, 2000). Later, Pîrî Re'îs wrote a navigation treatise and drew an atlas of the coasts of the Mediterranean and its islands, named *Kitab-i Bahriye* ("Book of the Sea"), accompanied by information on the places described, reference points, distances, routes and landings. He compiled two different versions of this book in 1521 CE and 1525–26. These were transcribed in different manuscript copies, almost all of them accompanied by maps, but the original autographs of Pîrî Re'îs' have been lost. Most scholars have considered the manuscript *Ayasofya 2612*, compiled in 1574 CE and now preserved in the Süleymaniye Library of the Topkapı Sarayı Museum in Istanbul, as the copy closest to the original version of 1525–26 CE (Lepore et al., 2011, 2013). A critical edition of the entire Pîrî Re'îs' work has not yet been published, although the in-depth and authoritative study of Bacqué-Grammont and Bresc (2009) compared different manuscripts of the book *Kitab-i Bahriye* (in both the known versions). They identified the toponyms on the available maps, highlighting small differences between the various transcriptions. From this study we learn that in the first version of 1521 CE Pîrî Re'îs inserted only the map of Sicily and the nearby archipelagos, including the Aeolian Islands. In the second version of 1525–26 CE there is also a specific map of the Aeolian Islands. In some manuscript copies of the maps, Vulcanello might appear as a small island separated from Vulcano (Fig. 6A-B), though this is not always clear, and the toponym Vulcanello is never reported, only that of Vulcano (with some variations). Considering the complexity of the different textual and cartographic transcriptions of Pîrî Re'îs work, these maps cannot unequivocally support the presence or absence of a connection between Vulcano and Vulcanello in his times. In general, we think that the analysis of geographical maps and other cartographic documents of the time can be misleading in providing information on the age of specific events (such as an eruption) or details on morphostructural evolution. In fact they are not always precise, despite the high level of precision achieved in some coastal measurements. It is also unclear whether the cartographic representation corresponds exactly to the situation in the year of its elaboration or to what was observed by the author (or others) in the years preceding it (Fig. 6C-D). On the other hand, in the accompanying text to the 1521 CE version of the book *Kitab-i Bahriye*, Pîrî Re'îs states that two miles from Lipari there is an island called Vulcano that burns constantly (*la susdite Vulcano brûle en tout temps* in the French translation from Arab by Bacqué-Grammont and Bresc, 2009), and the anchorages for ships are on the side exposed to the east wind and on the side exposed to the west wind (*les lieux de mouillage de cette Vulcano pour les navires sont du côté du vent d'est et du côté du vent d'ouest*). This suggests that at that time the two islands were already connected by an isthmus, on the sides of which it was possible to land depending on the prevailing winds. In the second version of 1525–1526 CE Pîrî Re'îs reports that Vulcano is a desert island where "both sides burn continually, day and night" (*les deux côtés de cette île brûlent continuellement, nuit et jour*), so much that "no one has ever seen this fiery place extinguish" (*Nul n'a jamais vu ce lieu enflammé s'éteindre*).

Leandro Alberti (1479–1552 CE) is a historian from Bologna who wrote a book of history and geography of Italy (*Descrittione di tutta l'Italia*), published in a first edition in 1550 CE and a second posthumous edition in 1561 CE. In it, he described the islands surrounding Italy and provided information about Vulcano (and Vulcanello) and its eruptive activity. In both editions, Alberti mentions Vulcano twice while describing what he observed during his journey along the western coast of Calabria in 1526 CE. While travelling along the Bivona shore (Alberti, 1550; p.182), he saw a large quantity of pumice clasts that he believed were erupted from the crater of Vulcano and had been pushed there by the sea waves. Then, after passing Tropea's shore (p.183) and following the Apennine ridge (p. 90) from Seminara to Solano, Alberti saw all the Aeolian Islands (he counts seven), including Vulcano, from which he saw smoke and incandescent material emitted. Only in the second edition of his book published in 1561 CE, Alberti adds a description of the islands of Italy, including Sicily. He had travelled to between the autumn of 1525 CE (in October of this year he was in Palermo) and the beginning of 1526 CE. He specifically deals with the seven Aeolian Islands (also called *Isole Liparee o di Vulcano*), though he did not visit them directly (Redigonda, 1960; Di Matteo, 1999). Moreover, Alberti (p. 74) provides a translation into Italian of the entire text of Polybius (as cited in Strabo, ed. 1967; see above), referring to the presence of three craters on Vulcano during the 2nd century BCE, one of which had collapsed. He mentions the eruptive activity of Vulcano in his time. Alberti states that he saw (*anche io ho veduto*) incandescent matter coming out of Vulcano at night and smoke during the day. We do not know whether Alberti witnessed Vulcano erupting once (from Calabria's coast in February 1526) or twice (both from Sicily at the end of 1525 and then from Calabria). Nevertheless, the strong eruptive activity to which he refers likely dates to around 1525–1526 CE. As suggested by Barbano et al. (2017), it is plausible to assume that the eruptive activity of Vulcano documented by Alberti in 1525–1526 CE matches that described by Bottone (1692). Bottone, without making his sources explicit, refers to a strong eruption of ash and rocks that fell into the middle of the sea about eighty years after the eruption of 1444 CE, i.e. around 1525–1526 CE.

An important source for that period is the work "Itinerary from Antibes to Constantinople of 1544", written by the French priest Jérôme Maurand in 1572 CE (in vernacular Italian; Maurand, ed. 1901). This work describes the journey he took following the Franco-Ottoman fleet commanded by the corsair Khair ad-dīn (Barbarossa) in 1544 CE. Maurand reports his stop in Lipari and his excursion to the crater of Vulcano. This was completed on 2 July, 1544 CE. He also reports some information he gathered from inhabitants of Lipari about past events. Before climbing the crater of Vulcano, he recalls that the two islands of Vulcano and Vulcanello, which he saw united in 1544 CE, had been separated in earlier times (*in altro tempo*), and explains that the abundant ash erupted by the crater of Vulcano (*le habondante cenere che sono usite di la bocha di Volcano)* had closed that arm of the sea. That had had previously divided the islands and allowed ships to pass (*hano serrato il passo dove uno brasso di mare passava et divideva le doe insole)*. Regarding the ascent to the summit crater (i.e. La Fossa cone), Maurand describes its active crater, about 100 m wide ("half a shot from an arquebus") and just over 200 m long, from which he observed very hot sulfurous fumes coming out. Then, he reports the story he heard from the people of Lipari about a very large eruption that had occurred "in a certain time in the past" (*uno certo tempo*). This eruption was characterized by the ejection of incandescent material. The material fell back still incandescent on the island of Lipari, igniting wooded areas and reaching the vicinity of the town, which had risked being destroyed. On that occasion the women of Lipari had expressed a vow to walk barefoot and not drink wine to obtain the survival of the city. They were still doing so when Maurand visited the island in 1544 CE. Given the uncertain temporal term he uses, it is not possible to define precisely which eruption Maurand referred to. It must be assumed that, being a piece of news passed down orally by the locals, it was not an eruption that occurred too far back in time. In this sense, it is worth remembering that the major known eruptions that occurred in the hundred years before Maurand's visit were those of 1525–26 CE (reported by Alberti) and 1444 CE (reported by Ranzano).

In his work *De rebus Siculis decades duae*, Fazello also provides evidence for the eruptive activity of Vulcano in his time (*hodie*), which means the period in which he was writing his work (*hodie*), presumably between 1550 CE and 1558. Or more broadly during his lifetime, between 1498 CE and 1558. The La Fossa cone is assumed to have erupted almost continuously, since from the crater that opens in the middle of the island (*ex voragine, quæ in medio patet*) a large cloud of smoke was emitted without interruption, sometimes accompanied by ash, incandescent material (*ignis*) and pumice clasts (*pumices*). Vulcanello is also probably described as active. From time to time it erupted incandescent material (*quæ & ignem ipsa aliquando evomuit*). Moreover, Fazello recalls that a substantial quantity of ash and clasts erupted from the crater of

Vulcano closed the very narrow stretch of sea (*nunc interiecta ex Vulcaniae caminis cinerum, ac lapidum mole praeclusus est*) that separated Vulcano from Vulcanello. This stretch had offered shelter to sailors until then (*tertia insula Vulcanellus tenuissimo euripo a Vulcania recedit*).

4.7. 1727 CE: two active craters of La Fossa cone

Eruptive activity of La Fossa cone in 1727 CE is documented by Jacques Philippe D'Orville (1696–1751), a Dutch philologist and historian of Antiquity, who landed on the Aeolian Islands during his study trip to Sicily when Vulcano was in eruption. He provided a detailed description of this eruption in his work written in Latin, *Sicula quibus Siciliae* (pp.19–21), published posthumously (D'Orville, 1764). This account is among the few direct eyewitness testimonies, aside of the well-known eruptions of the 19th century. He left Messina on May 20, 1727 CE. That day, he observed that the eruption was already underway. While passing near the promontory of Rasocolmo along Siciliy's northern coast, he saw the Aeolian Islands shrouded in thick smoke from his boat. The eruptive activity continued the following day (May 21). This is evident from the strong detonations he heard during the trip, even at distances of 14–18 km (8–10 miles). That night, he was kept awake in Lipari by the noise from Vulcano. On May 22, he made an excursion to Vulcano, probably under the guidance of local experts, travelling by boat from the eastern coast of Lipari. He skirted the narrowest point between Lipari and Vulcano for a distance of about 1500 m ("just over a thousand paces"), which corresponds to the arm of the sea from the cape of Punta della Crapazza on Lipari to Vulcanello. Then, D'Orville passed along the eastern coast of Vulcanello, explicitly noting its double name, Vulcanello or "small" (*piccola*) Vulcano, and the morphology of its connection to Vulcano through "a strip of land", with no reported eruptive activity. He landed on the northern side of the island (*in latere septemtrionali insulae*), where he tested the surprising change in water temperature. The water changed from cold at the shore to warm at a distance of about 3–4 m ("two or three steps"), and became very hot at about 25 m ("twenty steps"). These indications make it possible to locate the landing point (and therefore the starting point of D'Orville's field excursion) near the current Spiaggia delle Acque Calde, most likely at Porto di Levante. Furthermore, it can be deduced that D'Orville, when referring to the northern sector of Vulcano, excludes Vulcanello and refers instead to the northern side of the present-day La Fossa cone. D'Orville witnessed an eruption characteristic of a typical Vulcanian cycle. Notably, he described Vulcano as having two craters on "on two peaks" (*duobus jugis*), both active (*quae ambo continuis incendiis exeduntur*). The climb to the top of the main crater, on a "larger and higher relief" (*in majorem collem*) "towards the south" (versus *meridiem*), was very tiring because of the steep slope and the soft, ash-rich ground. D'Orville estimated that the circumference of this major crater was just over 2 km (1500 paces) and very deep (*baratrum vastum*). Inside, the surface was yellow in colour and characterized by exhalations of very hot steam, and there was a hill-shaped structure formed by the accumulation of erupted volcanic material, lowered by about 60 m (200 ft) with respect to the edge of the crater. At the summit, D'Orville and his companions witnessed renewed activity: first an increase in the "volume of detonations" (*strepitus adeo increbuit*), followed by a very hot exhalation of dense smoke (*atque igneus* cum *fumo spisso vapor*), and then a sudden eruption of incandescent bombs (*lapidumque candentium jactus derepente*). D'Orville described the second crater as lower in elevation and smaller in size (*minus jugum),* "towards the northern part of the island" (versus *septemtrionales insulae partes*). This crater was characterized by "more frequent" eruptive activity and "greater luminosity" (*crebrioribus & clarioribus*), almost continuously expelling rocks, burning ash and black smoke (*fere continue saxa, favillas & fumum atrum eructat*). According to D'Orville, this was due to a lower depth of the crater floor compared to the rim, so that all the eruptive activity was visible outside the crater itself giving the impression of a greater frequency and quantity of erupted incandescent material. Differently, the major (higher) crater was characterized by such a depth that part of its activity remained internal and was not visible from the outside.

4.8. 1739 CE: major eruption (and earthquakes)

Another eruption well-known in the volcanological literature is that of 1739 CE. At the current state of knowledge, there are no direct witnesses from Vulcano or Lipari. The eruption was observed only from the northern coasts of Sicily through some contemporary testimonies. The richest in detail is the text by Mongitore (1743) based on two distinct accounts by two priests who directly observed the phenomena respectively from San Marco d'Alunzio and from Naso, two villages along the northern coast of Sicily. Further information is contained in an anonymous text drawn up in San Marco d'Alunzio in 1739 (Anonymous, 1739) and published by Alibrandi (1991–1992), which was used for the first time in volcanology by Barbano et al. (2017). The text by Incudine (1882) is also remarkable regarding the history of the Naso village. It is based on documentation from the municipal archive, which is no longer available today. Another source is that of Ferrara (1810), who mentions the activity of Vulcano in that period based on the in-depth and detailed descriptions of the island of Vulcano and its eruptions contained in the writings of the erudite priest of Lipari Gaetano Maria Trovatini. In these contemporary sources, various eruptive events expressly attributed or attributable to Vulcano are recorded over a period of at least two and a half months, from March 29 to June 9. No more precise topographical indications are given beyond simply referring to island of Vulcano. This information is closely connected with the memory of the seismic sequence which occurred in May 1739 and affected the Naso area in northern Sicily (Barbano et al., 2017; Guidoboni et al., 2019), and an earthquake in the area of Mt. Etna (Azzaro and Castelli, 2014). Therefore, one must try to separate the information relating to eruptive phenomena from that relating to the earthquakes. We can summarize the main features of the Vulcano eruption(s) deduced from those sources as follows:

- March 29, around 9:15 p.m. GMT - In the sky north of Naso an intense redness appeared that faded into black, with incandescent clouds dissolving into the shapes of "palm trees", columns and "burning beams". From San Marco d'Alunzio anomalous flashes ("beams of fire") were seen.
- May 4, between 15:30 and 16:30 GMT - At the same time as very strong and frequent detonations, a whitish, crackling and incandescent column was seen rising from the island of Vulcano. It was pushed by the wind towards the coasts of Sicily. From this column, rock fragments, even of large dimensions, fell into the sea and onto the coasts. One rock fragment was collected while still warm on the beach near Piraino, along the north coast of Sicily southwest of Vulcano. It appeared "heavy, dark in colour, composed of a mass of shiny stone fragments with a sulfurous smell" (*ponderoso, di color fosco, composto di molte pietruccie lucide ammassate con odore sulfureo;* Mongitore, 1743). The volcanic cloud then moved from north to south-southwest, maintaining "its incandescent appearance" (*scintillando sempre fuoco*), and passed the villages of Naso, San Marco d'Alunzio, Longi, Alcara Li Fusi, Tortorici and Randazzo, until it disappeared near Mt. Etna.
- May 9 - Very strong detonations from Vulcano were felt in Naso and San Marco d'Alunzio, accompanied by the strong earthquakes that occurred that day.
- May 10–15 - From San Marco d'Alunzio extended lead-colored "nebulous masses" were seen from time to time in the sky and above the islands in front of the coast (i.e. the Aeolian islands), alternating with emissions of yellow sulfur-colored vapor.
- June 5 - In San Marco d'Alunzio a "prodigious" burning light was seen in the atmosphere (*apparve gran fuoco nell'aria che sembrava volesse consumare il mondo*). It dissolved towards the south around the Randazzo and Bronte villages.

- June 9 - In Naso and San Marco d'Alunzio a low fog was seen, exuding the smell of bitumen and antimony. It was dense and very dark, so dense that nearby people could not see each other.

4.9. 1757 CE: crater morphology of La Fossa cone and lava flow

A later indirect source on the 1739 CE eruption is the work of the physicist and geologist Jean-André De Luc (1727–1817). In his book titled *Lettres physiques et morales* published in 1780 (vol.2, pp.431–441), he reports verbatim the testimony of his brother, the Swiss scholar Guillaume-Antoine De Luc (1729–1812), who visited the Aeolian Islands and Vulcano in 1757 CE and climbed the summit of the La Fossa cone. His account provides information about Vulcano and the morphology of La Fossa crater, together with useful elements for deducing the characteristics of eruptive activity in 1739 CE. Guillaume-Antoine De Luc approached the visit to Vulcano with a wealth of information and previous observations of other Italian volcanoes (Mt. Etna, Vesuvius and Campi Flegrei). Although little is known of his biographical data, he was an extremely curious and careful observer with considerable geological and volcanic knowledge for that period. On March 31 he landed at Porto di Levante (Vulcano) and provides a detailed account of the morphology of the island and La Fossa cone. It is not explicitly named, but described as "new", "recent" or "current" compared to ancient volcanic edifices, whose names are not specified. According to De Luc, the La Fossa cone had a regular conical shape. It was formed by two different craters (*a été formé par deux bouches différentes*), "extending up to its apex" (*propongées jusqu'à fon fommet*), which could be distinguished from a certain distance (*on les distingue lorsqu'on en eit à quelque distance*). The cone was surrounded by a high circular "bastion" open to the northeast (i.e. the La Fossa caldera), similar to that of the Mount Somma caldera surrounding Vesuvius. He also observed the remains of an ancient vent, not very high above sea level, probably corresponding to the Faraglione di Levante, the low relief currently visible near Vulcano Porto. Towards the north, he recognized Vulcanello (*le petite Volcano*; i.e. the little Vulcano), which " no longer burns today". Then he decided to climb the most active La Fossa cone starting from the narrow gulf between it and the Faraglione remains, accompanied by one of the Lipari boatmen (*conduit par un de nos Marinieress qui étoit Liparotes*). After half an hour of climbing up a very steep slope completely cut by deep ravines, De Luc reached a narrow gorge (*gorge étroite)* entirely occupied by dense sulfur smoke, connected to the summit crater area. Aware of the fragility of the ground, as indicated by the deep echo of his footsteps, he measured directly the diameter of the main crater as varying between approximately 400 and 700 m (500 to 900 "steps", i.e. *pas* in their French meaning) and the height of the crater rim at approximately 50–65 m (150 to 200 "feet", i.e. *pieds* in French) with respect to its bottom. On the opposite side from where he had climbed onto the crater, he saw a roughly 50 m wide (60 "steps") funnel-like vent emitting a distinctive column of smoke (*une ouverture d'où partoit la plus grande quantité de fumée*), situated "at the foot of one of the highest sides of the crater rim" (*au pied d'un des cotés les plus élevés de l'enceinte*). On the way back, De Luc gave a description of the volcanic products observed along the route, with grey ash along the flanks of the cone and surrounding plains. This was generally less heavy and less hard than the rocks observed on Vesuvius and Etna, and whitish, tasteless, sulfur-soaked rock material at the summit, similar to that found in other volcanic areas (mainly at Solfatara). Along the slope he found "lava material" that was harder, more compact and with more perfect vitrification than those observed by him on Vesuvius and Mt. Etna, and similar to the black "*filex*" (i.e. flint) of the chalk hills in England. De Luc described another lava, which, unlike the others described above, "was very porous and contained a lot of iron, like all those of Vesuvius and Etna" (*Une autre Lave, descenduë du sommet depuis une dizaine d'années, est au contraire très poreuse: celleci contient beaucoup de Fer, comme toutes celles du Véfuve & de l'Etna*). This lava, according to De Luc, flowed down from the summit about ten years earlier (*depuis une dizaine d'années*). This chronological indication was imprecise, likely due to vague information from the guides who passed it to De Luc. The emission of that lava flow can only be assigned to a recent year before his visit, though the date cannot be defined more precisely. It is notable that most of the previous literature has attributed this lava flow to the 1739 CE eruption.

4.10. 1771 CE (sometimes misattributed to 1731 CE or 1775): Major eruption (eruptive cycle) of the La Fossa cone

A prolonged eruptive cycle in 1771 CE is attested by two sources. One is the testimony of the priest of Lipari Gaetano Maria Trovatini, as reported by Ferrara (1810). The other is the Anonymous manuscript (19th century), partly used previously by Mercalli (1881, 1883) and transcribed more extensively by Barbano et al. (2017), who claimed to have obtained it from Iacolino (1996). However, we checked directly Iacolino (1996) verifying that the manuscript is not mentioned, which suggests it comes from another work by Iacolino. Both sources describe an eruption observed from the island of Lipari. The eruption began on February 17 (or 15) with an earthquake, felt very strongly in Lipari, followed by a prolonged detonation and the expulsion throughout the night of a large quantity of smoke and incandescent material. This moved over Lipari in the form of a "flashing cloud" pushed by a southerly wind, accompanied by copious fallout of ash "in the form of rain". Similar explosions were repeated almost every day during February, always preceded by strong earthquakes and detonations. On February 21 the ash eventually piled up in Lipari to form a considerable layer several inches (or centimeters) thick, covering the grass, causing considerable damage to livestock. Sometimes very large scoriae were erupted, spreading fear among the inhabitants of Lipari. Also in the following months of March, April and almost until mid-May, there were further explosions, accompanied by strong detonations, but no longer by earthquakes. In some cases, the quantity of smoke and the fallout of ash, i.e., "ashy rain" (*pioggia terrosa*), was so great in Lipari that it obscured the daylight and prevent people from seeing each other even at short distances. The last very strong eruption occurred on May 13, when the violence of the explosion (*crepolò*) was so great it broke almost all the windows of the houses of Lipari, greatly frightening the inhabitants.

A further important source on Vulcano in the 18th century is the account of a journey to the Aeolian Islands made in 1781 CE by the well-known geologist and mineralogist Déodat de Dolomieu (1750–1801), published in 1783. He made the journey personally and, given his significant scientific preparation, is considered a highly reliable source, also quoted by Mercalli (1891), De Fiore (1922), Barbano et al. (2017) and most of the available volcanological literature. In the text, de Dolomieu (1783) provides some information on past eruptions of Vulcano, probably acquired from previous studies. For example, he mentions the eruption that filled the stretch of sea between Vulcano and Vulcanello, which he dates to around 1550 CE, and the eruption that occurred in 1739 CE during the earthquakes in the area of Naso (Sicily). According to some testimonies collected by him, the last eruption of Vulcano before his visit was that of 1775 CE, characterized by the emission of large rock fragments and blocks of glassy lava, while whitish ash reached as far as Lipari and Sicily. We believe that this eruption actually corresponds to that of 1771 CE, as already pointed out in much of the historiography (Ferrara, 1810; Mercalli, 1883; Mercalli, 1891; De Fiore, 1922; Barbano et al., 2017). Considering that de Dolomieu (1783) does not mention eruptions in 1771 CE, despite several existing testimonies, and that he attributes to 1775 CE a phenomenology very similar to that described for the 1771 CE eruption by different sources, we may assume that he reported the date incorrectly. On this, it should be noted that the information about the eruption was provided to de Dolomieu by locals, based on oral transmission, which can sometimes be imprecise in details. De Dolomieu (1783) also provides a detailed report of his visit to Vulcano on July 13, 1781. He landed on the beach of Porto di Levante between the present La Fossa cone and the Faraglione remains, and describes in detail the morphology of the island. This is described as an

old mountain forming a circular rocky enclosure (i.e. the wall of La Fossa caldera) which encloses a newer, more regular cone topped by the active crater (i.e. La Fossa cone). De Dolomieu climbed up along the northern slope of the cone, describing it as very steep and covered with loose ash, into which one "sinks up to the knees", and with ash agglutinated by various salts, which formed a crust on which the foot has no grip. Once on the top of the volcano, he describes the active crater, which does not occupy the very centre of the cone but is located a little further south, on the highest but also "thinnest" slope. In the crater he describes a sort of 6 m (20 ft) deep crack from which a few years earlier a black, glassy lava flow was emitted, still visible on the side of the mountain. De Dolomieu says that this lava had reached the base of the cone without entering "the valley" (without defining this valley more precisely), and that the crater was filled with lava, overflowing through its lowest part.

In relation to the 1771 CE eruption, we intend to discuss the possible occurrence of an additional eruption of Vulcano in 1731 CE, which is reported in a work written by Trovatini in 1785 and published in 1786, entitled *Analisi dell'Acqua del Bagno a Vulcano*. An eruption of Vulcano in 1731 CE is also reported by Ferrara (1810), and subsequently cited by Mercalli (1883, 1889, 1891) and De Fiore (1922), without adding further information. Barbano et al. (2017) considered already the 1731 CE eruption dubious based on the many textual similarities and comparable phenomenology with that of 1771 CE, going so far as to hypothesize a copying or reading error. Ferrara (1810) actually states that he had two texts by Trovatini at his disposal: one was the manuscript letter (whose location and possible preservation are currently unknown) from which he took the information on the eruptions of 1739 CE and 1771 CE, and the other was the work published in 1786, from which he evidently deduced the information on an eruption in 1731 CE. After reading this published text directly, we note that according to Trovatini (1786) the last eruption of notable magnitude that he remembers, described as "the last fire" (*l'ultimo incendio*), was that of 1731 CE, and he makes no mention of an eruption in 1771 CE, which is instead well described in other sources. Moreover, the author provides a brief description of the possible eruption in 1731 CE with a phenomenology and circumstances that are almost identical to those of 1771 CE. Therefore, by reading and comparing the texts available, some elements emerge that lead us to believe that the eruption reported as 1731 CE by Trovatini (1786) is, probably due to a printing error, actually that of 1771 CE. Accordingly, we suggest that in 1731 CE there was no explosive eruption at Vulcano.

From our analysis we consider the eruption of 1771 CE as the last one in the 18th century for which reliable historical accounts exist. There are other important indications of eruptions in 1780 CE and 1786 CE (e.g., Mercalli, 1891; Spallanzani, 1793), the latter described by Spallanzani as featuring an indescribable overflow of pyroclastic material mixed with vortices of smoke and fire (*un indicibile straboccamento di arene miste a vortici di fumo e di fuoco)*. However, in this regard, there is also contradictory information from Ferrara (1810), based on the accounts of the priest Trovatini who lived in Lipari, who states that from 1771 CE to the time of writing (i.e., the beginning of the 19th century) the volcano had been in a state of quiescence. Therefore, recalling the careful discussion by Barbano et al. (2017) on these issues, we must consider these eruptions, including the 1786 CE one, as not certain.

5. Volcanological interpretation of historical data

In the next sections, we volcanologically interpret selected historical sources, spanning from the 4th century BCE to the 18th century CE. Our goal is to extract information on eruption chronology, eruptive scenarios, and vent localization, all of which are useful for hazard assessment and risk mitigation (Fig. 5). Our volcanological interpretation of the phenomena deduced from the analyzed sources and their dating is presented and discussed. It is then compared with the reference works of Mercalli (1883, 1891), De Fiore (1922), the eruption catalogue of Barbano et al. (2017), and other volcanological studies. Additional elements for the discussion come from the geological and stratigraphic knowledge of the La Fossa and Vulcanello cones (see chapter 2). We also consider available radiometric and palaeomagnetic ages, and new geological findings regarding the most recent deposits of the La Fossa cone (Lucchi et al., 2024).

We do not aim to correlate all the eruptions derived from the analysis of the selected historical sources with specific deposits or tephra packages observed in the field. This differs from the approach of Di Traglia et al. (2024) who propose correlations based on interpreted duration and intensity of the eruptions, deposit dispersal patterns, physical features, and vent locations. We believe that this approach is not entirely satisfactory, as it requires an extended and potentially misleading degree of interpretation. This applies even when contemporary sources are very detailed (e.g. Mercalli, 1891; De Fiore, 1922) and also when the stratigraphic reconstructions of the erupted products are well studied. The deposits related to the last Vulcanian eruptive cycle of 1888–90 CE are an exception, as they were directly observed by Mercalli and Silvestri (1891). It is generally accepted that the La Fossa cone and Vulcanello have exhibited a homogeneous eruptive behavior during most of their history, with many eruptions of limited magnitude and low to moderate intensity. These eruptions often occurred in cycles lasting months or a few years. A few eruptions displayed a greater-than-average magnitude (Selva et al., 2020). In the geological record, this eruptive behavior is reflected in the presence of numerous lithologically similar tephra layers, often of limited thickness and areal distribution. These layers are sometimes difficult to preserve and tend to recur in different stratigraphic intervals. Moreover, it must be assumed that many (small) eruptions are likely unknown or undocumented. Even when written or iconographic records exist, the witnesses rarely had the opportunity to observe the eruptive activity up close, so their descriptions are often very generic and do not clearly define the activity type or erupted products. For all these considerations, we believe that the risk of introducing an interpretative bias when attempting to correlate an eruption directly with a specific deposit or sequence of strata is too high. Therefore, in most cases we do not attempt this correlation. We make exceptions only for a few particular cases (discussed below) of very well described eruptions or deposits clearly distinguishable from others.

Our discussion has a particular focus on some issues that still remain unresolved and not universally accepted regarding the eruption chronology, vent location and eruptive behavior of La Fossa and Vulcanello. In particular, this concerns:

i) the emergence and definitive stabilization of Vulcanello;
ii) its connection with the main island of Vulcano;
iii) the type of activity and the age of the eruptions in the Forgia Vecchia area;
iv) the age and source areas of the Pietre Cotte eruptive cycle in the 18th century.

Finally, we discuss the analyzed historical data in order to improve the characterization of the eruptions and the evaluation of the size of the potential impact area with reference to the classification into five main eruptive categories proposed by Selva et al. (2020) for the purpose of hazard quantification and risk mitigation.

5.1. Emergence and stabilization of Vulcanello

The combined analysis of the historical sources relative to the Classical age and Late Antiquity indicates that, in 183 BCE, a small island appeared in the Aeolian Islands, as accepted in the volcanological historiography (Mercalli, 1883, 1891; De Fiore, 1922). In agreement with Stothers and Rampino (1983), we do not have textual evidence that it was Vulcanello that emerged. However, we can assume this with some uncertainty. The fact that the new island was exactly Vulcanello is completely consistent with the geological knowledge that it was the only island (now a peninsula) formed in the Aeolian archipelago in historical

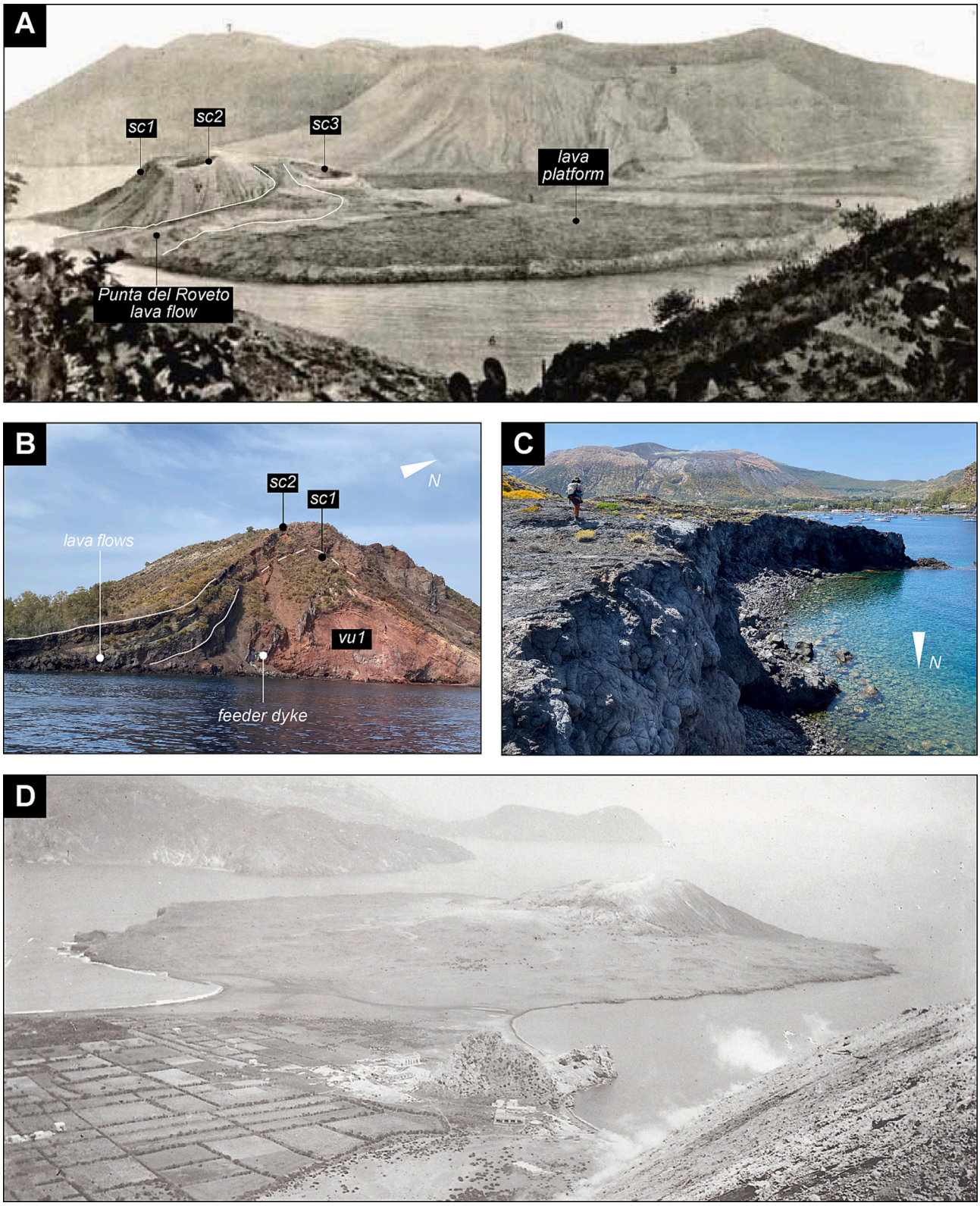

Fig. 7. Vulcanello emergence and stabilization. A) Photograph of the northern side of Vulcanello (seen from Lipari) in 1888 CE (photo by O. Silvestri; from Mercalli e Silvestri, 1891). This image shows the likely appearance of the islet following the emplacement of the lava platform from the oldest cone (crater rim sc1). The youngest cone (crater rim sc3) and the Punta del Roveto lava flow, both associated with Late Middle Ages activity, are also visible. B) View of the northeastern side of Vulcanello. A natural cross-section of the Vulcanello 1 cone (vu1) and its crater rim (sc1) is exposed due to intense marine erosion and probable tectonic activity. Lava flows originating from this cone - and from a feeder dyke - form the present-day lava platform. The Vulcanello 2 cone (crater rim sc2), of unknown age, is visible in the background. C) View of lava flows forming the western side of the Vulcanello lava platform. D) View of Vulcanello from the south in 1923 CE (photo by I. Sicardi; Giustolisi, 1995). The image clearly shows the isthmus (arrow), composed of volcaniclastic deposits, that now connects the original islet to the main island of Vulcano.

times. Moreover, from the reported sources we have sufficient information to assume that a further explosive (submarine) eruption occurred in the Vulcanello area in 126 BCE. Its precise location, however, remains uncertain. Again, this is geologically reasonable because Vulcanello was the only area where shallow submarine eruptions have occurred in historical times in the Aeolian Islands, in a sector close to Vulcano and Lipari. We do not consider it probable that another eruption occurred in this area in 91–88 BCE, even if there is no unanimity on this interpretation (i.e., Rasmussen, 2003; Cavalier and Basile, 2012). It is therefore reasonable to assume that the early activities of Vulcanello and its emergence date to the Roman ages (183 and 126 BCE), in agreement with the most authoritative specialized historical critique (Stothers and Rampino, 1983; Panessa, 1991; Rasmussen, 2003; Engels, 2007).

Then, the question arises of understanding what happened to Vulcanello after its emergence during the eruptions of 183 and 126 BCE (and possibly others not intercepted by historical sources). Did it form permanently and stabilize (Fig. 7A), assuming the capacity to remain in place over time? Or was it rapidly submerged again due to marine erosion of poorly consolidated volcanic material? Modern volcanology has now acquired the evidence that a newly formed volcanic island can be rapidly eroded (partially or entirely) until it is submerged again (e.g. in the case of the Ferdinandea Island in 1831 CE), unless there is emission of lava flows capable of consolidating and stabilizing the emerged cone. Therefore, the key point of controversy for Vulcanello is establishing when the lava platform that encircled its composite pyroclastic cone was formed. There is in fact a $^{226}Ra/^{230}Th$ radiometric age of c. 1.9 ka for the Vulcanello platform by Voltaggio et al. (1995), which is consistent with a calibrated ^{14}C age of 1722 ± 97 years BP obtained by Todman (2012) for charcoal collected in a trench dug into pyroclastic deposits above the lava platform. In palaeomagnetic age attributions indicate that the Vulcanello platform formed at 899–1044 CE (Malaguti et al., 2022). It is beyond the scope of this paper to address which of the two dating methods may provide the more accurate ages, or whether either may be affected by specific analytical issues in this case study. Thus, we carefully checked the original historical sources to try to extract information on the presence of Vulcanello as a stable island in the years following its initial emergence, and thus obtain useful information to clarify the age of formation of the lava platform.

Particularly significant in this regard is the account by Posidonius, who describes the release and consolidation of "mud with flames" onto the surface of the sea following the eruption of 126 BCE, until it became hard and solid. It is reasonable to think that this consolidated "mud" could correspond to the lava emitted from the early cone of Vulcanello until it formed (at least partially) the lava platform currently visible (Fig. 7B-C). The presence of Vulcanello as a stable island is also supported by the request of the Senate of Rome to send a delegation there to celebrate sacrifices of expiation for these very unusual events. Also, the mention of a newly formed island and its ownership in the *Digesta*, a collection of Roman jurisprudential material from the 1st century BCE to the 4th century CE, gives credit to the formation and probable persistence of the Vulcanello islet after many years since its early emergence. This new island, although small, must have had a morphology and extension sufficient to lead Roman jurists to raise questions relating to its legitimate ownership. The stabilization of the Vulcanello islet after its early emergence is also confirmed by the accounts of Orosius, who was convinced that the new island emerged in 183 BCE was still visible in his time in 417–418 CE, about 600 years after the early observed eruptions. There are therefore useful historical elements to think that the island of Vulcanello stabilized following the formation of the lava platform already in relation to the eruptions that occurred in 183 and 126 BCE. This would be in agreement with the $^{226}Ra/^{230}Th$ age of c. 1.9 ka of the lava platform by Voltaggio et al. (1995), and also with the ^{14}C age of 1722 ± 97 years BP of charcoal within the overlying pyroclastic deposits (Todman, 2012).

A different reconstruction is that Vulcanello stabilized only after the formation of the lava platform in the Early Middle Ages, as indicated by the palaeomagnetic ages of 899–1044 CE (Arrighi et al., 2006; Fusillo et al., 2015; Malaguti et al., 2022). To support this historically, Manni and Rosi (2021) assume that only starting from the dawn of the 2nd millennium CE an islet with an autonomous name (i.e. Vulcanello) was recalled in the works of Arab geographers, but they do not adequately discuss the above mentioned sources or simply ignore some of them. As for the Arab authors, we think that the toponym Vulcanello is referred to as *Jabal al-Burkan* (see paragraph 4.4), while *Jazîrat al-Burkân* indicates Vulcano, even if we know that there are interpretative uncertainties regarding the terms and toponyms used by them to identify the Sicilian volcanoes (Johns, 1989). If the term *Jabal al-Burkan* equates to Vulcanello, it would have been first mentioned by al-Mas'udi in the middle of the 10th century, much earlier than suggested by Manni and Rosi (2021). Then, the terms *Jabal al-Burkan* (Vulcanello) and *Jazîrat al-Burkân* (Vulcano) are used by al-Idrisi in 1154 CE, as outlined by most of the editors and translators from Arab starting from Amari and Schiaparelli (1883) to Bresc and Nef (1999). More uncertain is the source of Ibn Jubayr about two active volcanoes in the Aeolian Islands in 1184 CE, which are identified as Vulcano and Vulcanello in part of the volcanological historiography starting from De Fiore (1922). This was later resumed in Manni and Rosi (2021) based on the translation of Amari (1880). Our analysis of the available translations highlights that Ibn Jubayr did not specify any toponyms referring to the two active volcanoes he observed. We found no indication in Amari (1880) or in other translations that the two active islands observed by Ibn Jubayr were the southernmost ones of the archipelago, as instead reported by Manni and Rosi (2021). Moreover, various translators, over time, have interpreted and attributed that activity to Vulcano and Stromboli (more probably) rather than to Vulcano and Vulcanello.

In addition to the Arab sources, we have identified the toponym of Vulcanello in different types of texts and within distinct linguistic traditions – Latin and early Italian vernacular - related to the time period between the 10th and 12th centuries. The source of the diocese of Lipari-Patti cited by Catalioto (2007, 2017) and dated between 1094 CE and 1138 is the first written testimony of the Latin toponym *Vulcanellus* (i.e. small Vulcano), and its genitive form *Vulcanelli*, then transformed into Vulcanello in the vulgar form. Accordingly, the Latin wording *insulam Vulcanelli* has to be translated as "island of Vulcanello", and in no case can it be wrongly interpreted as a plural form, which would indicate the presence of more volcanic cones as suggested by Manni and Rosi (2021). Despite the fact that many toponyms contained in the document are introduced by phrases such as "which is called" (*qui dicitur*) or identified by making explicit the boundaries or proximity to better-known orographic or hydrographic elements (Catalioto, 2007), the term Vulcanello is used without fear of misunderstandings in the same way as all the names of the other islands of the Aeolian archipelago. This is an indication that the toponym had acquired a stable and recognized form through prolonged use, most likely because the islet had already existed for a long time before then. Given the official nature of that document with legal value, it was essential that the toponyms reported were easily identifiable by everyone, because their precise identification was fundamental in defining and guaranteeing property rights. This tells us that at the beginning of the 12th century Vulcanello was a long-lasting, well-identified and separate geographical entity. The term Vulcanello, in its variant *Vulcanino*, is also referred to an islet in the Aeolian archipelago by Scot (ed. 2014) in 1220–1235 CE, even if it cannot be established whether it was active during that period or not. He includes Vulcanello among the active volcanoes of his time (even if not continuously). However, we note that also the Strombolicchio islet (named *Strombolino*) would be described as active, which is completely unlikely because it is an old extinct lava plug (Francalanci et al., 2013).

This strengthens us in thinking that the island of Vulcanello was well present to contemporaries in their knowledge of the Sicilian area, and that it has likely existed since the early eruptions and emergence as well as the (probable) formation of the lava platform in 183–126 BCE. The

absence of the term Vulcanello or of information relating to its existence during most of the first millennium CE should not be surprising because in that period the written sources (and maps) are generally silent, not only on Vulcano but also on the other Aeolian Islands (Bernabò Brea, 1988; Maurici, 2008). These islands were substantially uninhabited, with only a few dozen inhabitants at the beginning of the 2nd millennium (Arena, 1991; Iacolino, 1996). Only some pilgrims travelled across the Mediterranean and were attracted by the active volcanoes (Garbini, 2010; Guidoboni, 2013).

Alternatively, Manni and Rosi (2021) propose that Vulcanello emerged in the Roman times and was subsequently erased by the sea to create a shallow seabed on which the lava platform currently visible was formed by means of volcanic activity in the Early Middle Ages (899–1044 CE; Malaguti et al., 2022). In this regard, to our knowledge, there are no historical sources documenting in any way this evolution. There are also no written accounts that unequivocally indicate effusive activity on Vulcanello around the end of the 1st millennium CE. Interestingly, the document of the bishopric of Lipari-Patti datable between 1094 CE and 1131–1148, analyzed and transcribed by Catalioto (2007), reports that the island of Vulcanello (*insulam Vulcanelli*) was characterized by an abundance of wild rabbits, to the point of representing a substantial income. This suggests a favorable habitat for animals eating vegetation. It may lead one to think of a well-established supporting-life territory and of the absence of intense volcanic phenomena in the previous decades or centuries. The only source where there is mention of (intermittent) eruptive activity on Vulcano in that period is that of al-Idrisi around the middle of the 12th century CE ("during the period in which he wrote"). However, he does not provide specific indications as to whether it was Vulcanello in eruption (or rather La Fossa), or further details on its state of activity. As an additional note, we need to clarify that the eruptive regime of Vulcano in that period was not of "strong activity" as reported by Di Traglia et al. (2024). They probably confused al Idrisi's text talking about "occasional eruptions" with that of Pîrî Re'îs who accounts for a "continuous activity" (see paragraph 4.6) during the first decades of 16th century CE (both quoted in Yilmaz, 2016). We must also note that historical sources are not unequivocal in describing eruptive activity on Vulcanello in the following centuries. In fact. Neither the book *Kitab-i Bahriye* by Pîrî Re'îs, in its second version of 1525–1526 CE, nor the accounts of Fazello in 1558 CE and Maurand in 1572 CE contain direct textual references to eruptions of Vulcanello (as also discussed by Barbano et al., 2017).

In conclusion, to bring together i) the evidence from our critical analysis of the historical sources regarding the emergence of Vulcanello in 183–126 BCE and its stabilization in the following centuries after the formation of the lava platform, consistently with the $^{226}Ra/^{230}Th$ age of c. 1.9 ka of the lava platform (Voltaggio et al., 1995) and the ^{14}C age of 1722 ± 97 years BP of the overlying pyroclastic deposits (Todman, 2012), and ii) the palaeomagnetic ages which indicate the development of the lava platform in 899–1044 CE, we should assume that this lava platform was built in two different steps. An initial phase could have occurred in the Roman age (around 2000 years ago), and a final one took place in the Early Middle ages (around 1000 years ago). This would be the only way to keep together all the available ages for the lava platform, which are mostly contrasting, without raising questions regarding the greater reliability of one method over the other. However, an evolution of the Vulcanello platform in two phases so distant in time should be documented in the field by some stratigraphic or volcanological evidence for a prolonged interval of quiescence (c. 1000 years) and renewed effusive activity within the succession of stacked lava flows forming the platform. At the present state of knowledge, this is lacking. The lavas of the Vulcanello platform are traditionally attributed to the activity of the older Vulcanello 1 cone (De Astis et al., 2013; Fusillo et al., 2015; Di Traglia et al., 2024), while Keller (1980) had proposed that the lava platform had formed in relation with the intermediate (younger) cone called Vulcanello 2. It should be noted that further stratigraphic and dating studies are underway by the authors to try to clarify the relationships between the lavas that form the platform and the different phases of construction of the composite cone of Vulcanello. However, based on the current state of knowledge we must say that the question of the age of formation of the Vulcanello lava platform has yet to be definitively solved.

5.2. Formation of the isthmus between Vulcano and Vulcanello

The definitive connection of the Vulcanello islet with the main island of Vulcano occurred through the formation of the currently visible isthmus, formed by accumulation of pyroclastic material (Fig. 7D). Its dating and the source producing this pyroclastic material are not yet unequivocally defined in historical and volcanological literature. Our critical analysis of the available historical sources provides insights on this topic.

The formation of a thin strip of land between the two islands can be traced back to the timespan of Fazello's life, i.e. between 1498 CE (or 1490 CE in those authors who make an erroneous dating of his birth) and 1570, as already established in the volcanological historiographical tradition from Mercalli (1891) to Barbano et al. (2017). Fazello (1558) informs us know that the narrow stretch of sea that separated Vulcano and Vulcanello up until that time was closed by ash and rocks erupted by the "crater of Vulcano". This likely corresponds to the La Fossa crater, even if also Vulcanello is described as occasionally active during that time. Fazello does not specify when exactly the corresponding eruption (or eruptions?) occurred. However, he makes clear that the sea strait between Vulcano and Vulcanello was navigable until his time. This expression can be understood as until the period of his life, or until his generation, or even until his historical era.

The unpublished anonymous book "Portolano per i naviganti" (paragraph 4.5) gives us the possibility to attest unequivocally that Vulcanello was an independent islet still in 1490 CE. Moreover, we infer from Maurand (1572; ed.1901) that in 1544 CE the isthmus already existed, formed by the abundant ash produced by "the crater of Vulcano", probably coinciding with that of La Fossa cone. Maurand does not specify when the eruption that caused the formation of the isthmus occurred, or whether this was the result of multiple eruptions over time. Therefore, his testimony provides, as already highlighted by Barbano et al. (2017), only the date *ante quem*, that is, before which the isthmus was created. Thus, the time interval in which the isthmus between the two islands formed can be constrained between 1490 CE and 1544 CE. This excludes that the stretch of sea between Vulcano and Vulcanello was closed during the major eruption in 1444 CE.

In the defined time interval, a major eruption (or eruptive cycle) occurred between the summer or autumn of 1525 CE and February of 1526 CE (Barbano et al., 2017), based on what was described by Alberti (1561). This is consistent with the strong eruption of ash and rocks that fell into the middle of the sea described by Bottone (1692) as having occurred about eighty years after the 1444 CE eruption, therefore around 1525–26 CE (Barbano et al., 2017). Accordingly, we believe that the eruption dated to 1550 CE by De Dolomieu (1783)) and by part of the historiography (Mercalli, 1891) should be backdated to 1525–26 CE. One of the eruptions that occurred between 1525 CE and 1526 could correspond to the strong eruption that Maurand says he heard about before his visit to Vulcano in 1544 CE. However, it is not possible to place it chronologically based on textual elements alone. Barbano et al. (2017) assume that the isthmus between Vulcano and Vulcanello was definitively formed precisely during the eruptive cycle of 1525–1526 CE. A critical cross-reading of the sources, particularly that of Alberti (1561), shows that there are no details about the source area and effects of the 1525–26 CE eruption(s). There are also no certain indications that the isthmus was definitively formed in that period. Moreover, in the 1521 CE version of the Pîrî Re'îs' work *Kitab-i Bahriye* it is reported that different anchorages for ships existed on Vulcano on the sides exposed to the east and to the west winds. This could mean that the isthmus was already present at that time, before the eruptive cycle of 1525–1526 CE.

Thus, the interval in which it was formed could be further constrained between 1490 CE and around 1521 CE. It must be said that the Pîrî Re'îs' source does not provide a direct textual reference to the existence of the isthmus, because the two landing places on both sides could also have existed in the presence of a narrow residual stretch of sea. On the other hand, there is a lack of unequivocal evidence that the closure of the strait occurred exactly in correspondence with a specific eruption. Thus, we hypothesize that the isthmus was formed as a result of the progressive accumulation of pyroclastic material erupted during one or more past eruptions by the action of the sea in the strait between Vulcano and Vulcanello, rather than in relation to one specific eruption. This would also be supported by what is written in the manual for navigation called *Portolan of Grazia Pauli*, according to which already towards the end of the 14th century there were some shoals at shallow depths, insufficient

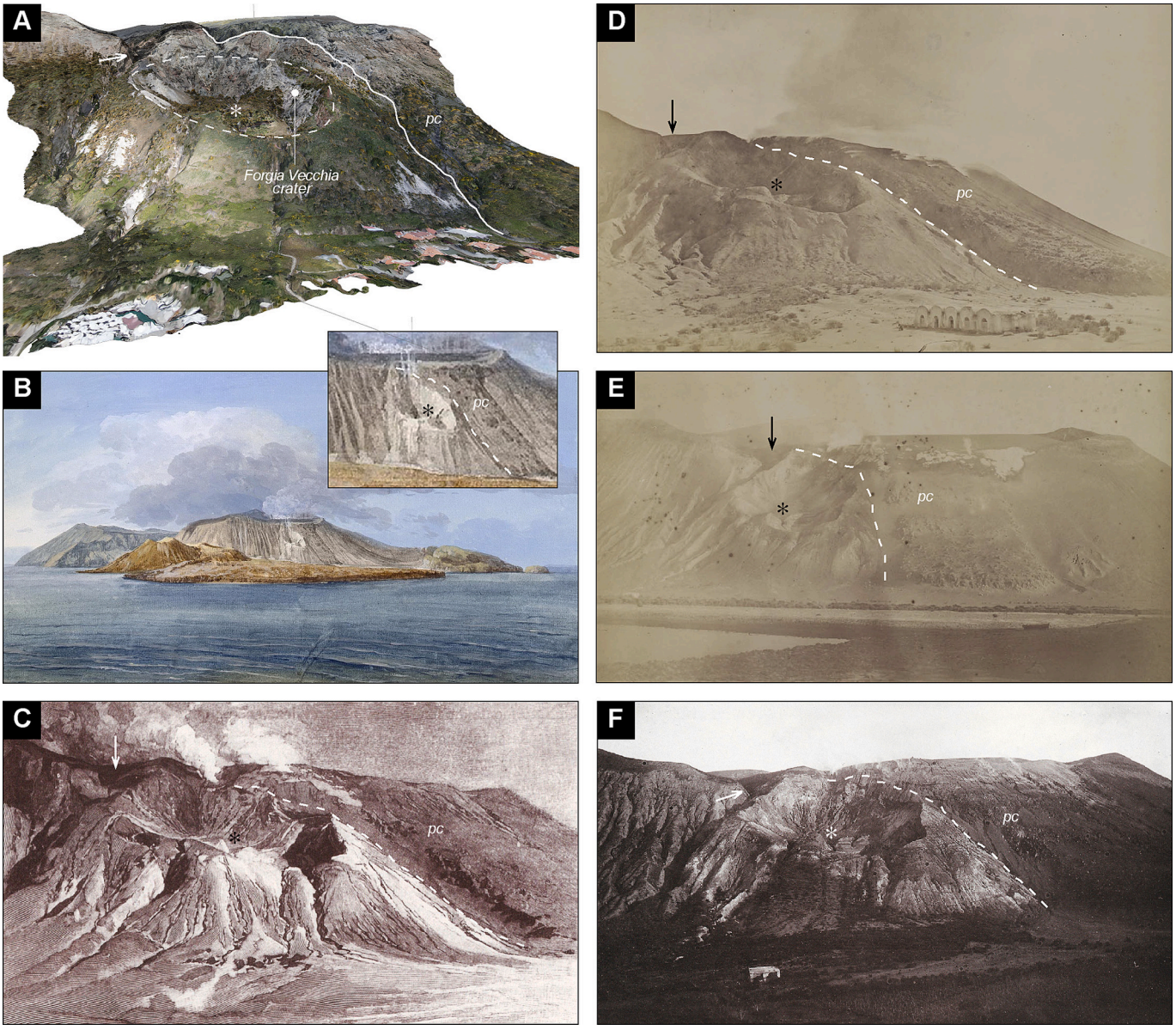

Fig. 8. Photographs and pictures of the Forgia Vecchia area over time. A) UAV-based photogrammetric digital outcrop model (courtesy of J. Natale, University of Bari), showing the remnants of the Forgia Vecchia lateral cone, its large crater, and its highly hydrothermalized and largely eroded flanks. The Pietre Cotte lava flow (pc) is also clearly visible next to the cone. B) Painting by Jean-Pierre Houel in 1776–1779 CE, depicting a view of Vulcano island from the north (Hermitage Museum, St. Petersburg). The inset shows a close-up of the Forgia Vecchia area. C) Drawing by Vuillier (1896). D-E) Photographs of O. Silvestri, showing different views of the northern flank of La Fossa cone in 1889 CE (Museo Galileo, Florence, "Raccolta fotografica Eruzioni degli anni 1888-1889 all'Isola Vulcano, 1888-1891", https://bibdig.museogalileo.it/tecanew/opera?bid=967245&seq=1). F) Photograph by I. Sicardi in 1920 CE (Giustolisi, 1995). In all the images, the original morphology of the Forgia Vecchia cone (and its crater) is clearly visible. The cone was constructed along the northern flank of La Fossa cone, rather than excavated into it. Although erosion has widened and lowered the structure, its main shape remains recognisable. The lack of significant morphological changes since (at least) 1776 CE suggests that erosion had already been active for a long period before the time covered. The positive morphology of the Forgia Vecchia cone is further highlighted by the deflection of the Pietre Cotte lava flow (pc), which was emitted from a vent located just above the Forgia Vecchia crater depression. At first glance, some images might suggest the presence of two nested craters, as proposed in much of the literature. However, the apparent intersection between the two craters actually corresponds to a vertical cliff (marked by an asterisk) where pyroclastic deposits infilling the bottom of the crater crop out. These deposits include materials related to the older and intermediate stages of La Fossa cone (i.e., the Grotta dei Palizzi 1 and Commenda units), and they post-date the formation of the Forgia Vecchia crater (see text for more details). At the top left of the images (arrows), the "narrow gorge" – which we infer was the route De Luc took to reach the summit of La Fossa cone - is visible.

for the passage of boats. This attests to a gradual decrease in depth of the stretch of sea between the two islands in relation to the progressive accumulation and reworking of the volcaniclastic material by the sea. Something like this is also hypothesized by Di Traglia et al. (2013) according to whom the isthmus emerged from the sea gradually due to both coastal processes and volcaniclastic sediment inputs. We think that the definitive formation of the isthmus could have occurred in the early part of the 16th century, and the eruptive cycle of 1525–1526 CE could have played the role of concluding the process. As for the source of the erupted material accumulated in the isthmus, we consider it more likely that the main source had been the cone of La Fossa, from which much larger volumes of volcaniclastic material were erupted in the previous centuries than from Vulcanello. This is entirely reasonable because, if we consider the typical eruptive behavior of the La Fossa cone, characterized by Vulcanian eruptive cycles of low to moderate magnitude with few major eruptions (see paragraph 5.5), it is difficult to think that a single eruption (or eruptive cycle) was able to determine by itself the closure of the stretch of sea between Vulcano and Vulcanello.

The time interval for the isthmus formation was further restricted to before 1513 CE by Manni and Rosi (2021), as they consider a map of the Aeolian Islands and northeast Sicily of that year by Pîrî Re'îs, quoted in Cheshire (2018), where the islet of Vulcanello is apparently still separated from Vulcano. We were unable to verify the original source, as in Cheshire (2018) the Pîrî Re'îs' map is not cited anywhere. We also verified that in the Pîrî Re'îs' map of 1513 CE Sicily does not appear (McIntosh, 2000). We therefore assume that the map cited by Manni and Rosi (2021) is that of Sicily included by Pîrî Re'îs in one of the two versions of his work *Kitab-i Bahriye* of 1521 CE and 1525–26 CE (Fig. 6A-B), and later transcriptions. In any case, in none of the maps reported in the in-depth and authoritative study of Bacqué-Grammont and Bresc (2009) the toponym Vulcanello is reported, and the presence of Vulcanello as a separate islet is not always clearly distinguishable in either Pîrî Re'îs' maps. For this reason, we do not think that the maps of Pîrî Re'îs, as other maps of that period and further on (Fig. 6A-D), can be adopted to assess unequivocally the age of eruptions or to have very precise information on any other geographical or morpho-structural elements. Moreover, a critical historical analysis of the iconographic sources is nonetheless always necessary to derive reliable data from them. In this regard, for example, we suggest that Michelot's map from 1699 CE (Fig. 6E) should be used with caution. This map seems to indicate eruptive activity at Vulcanello in the late 17th century, whereas this is unlikely based on volcanological knowledge and available written sources.

5.3. Age and features of the Forgia Vecchia crater

The type of activity and the age of eruptions that occurred in the Forgia Vecchia area, along the N flank of the La Fossa cone, are questions of primary importance in the hazard assessment and risk mitigation on the island of Vulcano. Forgia Vecchia is, infact, a potential source area of eruptions located immediately behind and at a short distance from the inhabited area of Vulcano Porto. However, there is still debate in volcanological literature without having reached a shared vision, so far. The entire area is characterized by intensely active erosion, dismantling processes and pervasive hydrothermal alteration, which obliterate most of the original characteristics of the volcanic products visible along the slopes. This situation partly explains the uncertainty in the definition of the outcropping units and their respective stratigraphic relationships (Fig. 8A).

In the area of Forgia Vecchia two eccentric phreatic craters are traditionally located. These are generically attributed to the younger stages of development of the La Fossa cone. The first crater (Forgia Vecchia I) has an undefined age (Frazzetta et al., 1983; Keller, 1980). Alternatively, it is attributed to the eruption of 1444 CE on the basis of a reading of historical reports (Di Traglia et al., 2013, 2024; Malaguti et al., 2022). The second crater (Forgia Vecchia II) is generally attributed to the eruption of 1727 CE always on the basis of historical sources (Frazzetta et al., 1983; Keller, 1980; Di Traglia et al., 2013). There are no measured ages for the volcanics referable to either of these two hypothetical craters.

A different geological and stratigraphic reconstruction was initially proposed by De Astis et al. (2013) and then partially modified and integrated by Lucchi et al. (2024). This reconstruction identifies the Forgia Vecchia area as the remains of a lateral cone and its crater built up on the northern flank of La Fossa cone (Fig. 8A). This crater is referred to a constructive morphology, although largely eroded and dismantled, and is not dug into the substrate (as would be in the case of a phreatic crater). The Forgia Vecchia crater is pre-dated by the occurrence on its floor of a crater-filling sub-horizontal succession of pyroclastic deposits related to the lower and intermediate portions of La Fossa cone – including the well-known Commenda pyroclastics - dated at between c. 2.9 ka and 1240–1300 CE. These deposits also crop out along the sides of the crater, unconformably covering the remains of the cone's flanks. There are also patches of pyroclastics relative to the Pietre Cotte activity and the 1888–90 CE eruption(s). Based on these stratigraphic relationships the Forgia Vecchia cone and its crater must be referred to the lower La Fossa cone, dated to more than 2.9 ka. In particular, it represents a lateral cone nested on the northern flank of the larger cone. The Forgia Vecchia crater is also filled by thick accumulations of volcaniclastic material derived from the erosion and reworking of the steep slopes of the La Fossa cone (Fig. 8).

To try to shed light on this issue, we reviewed all the historical sources, trying to isolate those that were supposed to contain useful information or those that had been cited by other authors in reference to the Forgia Vecchia area. We then discuss the data they provide from a volcanological point of view. In this regard, we must point out that there are no historical accounts where the source area of Forgia Vecchia is explicitly mentioned. Nor are direct topographical references ever provided that allow its identification.

First, we consider the attribution of one of the Forgia Vecchia craters (Forgia Vecchia I) to the 1444 CE eruption proposed by Di Traglia et al. (2013, 2024). This is based on their reading of the written source of Ranzano, then used by Fazello. It must be noted that in the original source there are no textual references nor other geographic or geomorphological indications about the location of the 1444 CE eruption. Thus, there is no way to prove that it may be linked to the Forgia Vecchia source area. Ranzano only says that the eruptive activity refers to "a filled crater" (*dalla bocca colma*), but there is no indication of which crater was active specifically. On the other hand, Fazello mentions the "crater in the middle of the island", which is most probably the main one of La Fossa cone (Barbano et al., 2017). However, it was meant to indicate the source of the eruptive activity ongoing in the years he was writing, between 1550 CE and 1558, and not in relation to the 1444 CE eruption. To support the link between the Forgia Vecchia I crater and the 1444 CE eruption, Di Traglia et al. (2024) suggest that the ejected ballistic blocks up to distances of c. 11 km reported in Ranzano's chronicle reflect a laterally-directed component of the eruption that is consistent with the N-oriented geometry of the Forgia Vecchia crater. We consider this interpretation unlikely and speculative. Even considering the reported fall distance as realistic (and it probably isn't), it would only make sense if the clasts were thrown predominantly northwards during the 1444 CE eruption, thus reflecting the asymmetric shape of the crater. Instead, in the original written source there are no indications of the point from which the eruption was observed, neither from where or from whom the information came, nor where or in what direction the volcanic clasts fell into the sea. They could have fallen into the sea in all directions with respect to the source area, and there is no reason to think that they were headed preferentially northward. We conclude that, based on historical sources, the Forgia Vecchia crater cannot be considered the source of the 1444 CE eruption. We think, instead, that this was produced by the main crater of La Fossa cone, as it was the one characterized by the most frequent eruptive activity on Vulcano in that

period.

The second point of discussion concerns the attribution of the younger crater of Forgia Vecchia to the 1727 CE eruption by some previous authors, on the basis of their interpretation of the historical account of D'Orville (1764). During his ascent to the summit of La Fossa cone, he described two active craters located on "two peaks", the larger and higher one towards the south and the minor one towards the northern part. On the identification of the larger and higher crater, the volcanological historiography converges on the main crater of La Fossa. The identification of the other (minor) one is instead more debated. There have been proposed attributions to the Forgia Vecchia area or to Vulcanello (Mercalli, 1883, 1891), or to one of the Forgia Vecchia craters (De Fiore, 1922, then quoted by Frazzetta et al., 1983; Keller, 1980; Di Traglia et al., 2013; Barbano et al., 2017). Also, Spallanzani (1793) wonders what were the double active craters, about which only a few of the oldest people in Lipari in his times preserved some obscure memory. We underline that in the original written source by D'Orville there are no toponyms for the two active craters, nor any textual references that allow us to unequivocally identify them among the craters currently preserved on Vulcano. Volcanologically, we agree that the larger and higher one is the main crater of La Fossa. This is because the descriptions of the morphology and type of activity reported by D'Orville are largely consistent with its behavior and characteristics. As regards the minor (active) crater located further north, on a textual basis we can only exclude that it is Vulcanello. This is because D'Orville (1764) does not specify that he saw any eruptive activities in that area while he was sailing around it. Moreover, when he talks about the "northern part of the island", he refers to the island of Vulcano, excluding the peninsula of Vulcanello, as usual for the authors of that time. Consistently, when he lands on Vulcano, in an area characterized by hot emissions corresponding to the Porto di Levante bay, he refers to the "northern side of the island", that is to the north of La Fossa cone. Thus, the second crater described by D'Orville (1764) was likely located in the northern sector of La Fossa cone. Our preferred reading of the text is to exclude that it corresponds to the Forgia Vecchia crater. This is because the Forgia Vecchia crater is large, flared, and at a much lower altitude than the main crater of the La Fossa cone (Fig. 8), and this does not fit well with the description by D'Orville of a crater on the top of a relief or mound. Nor can it be assumed that since 1727 CE a relieved crater morphology in the Forgia Vecchia area has been intensely eroded to the point of its current state. We will discuss further the possible attribution of this second crater active in 1727 CE later in the section regarding the Pietre Cotte eruptive activity.

Recently, Di Traglia et al. (2024) have proposed a different attribution of the younger crater of Forgia Vecchia to an eruption that occurred in the time interval between the first half of the 15th century and 1550 CE. This view is based on their assumption that Alberti (1550) described the state of activity of Vulcano in his time as characterized by the presence of three distinct vents, compatible with the ones of Vulcanello, La Fossa and the eccentric crater(s) of Forgia Vecchia. By checking the original source, we have verified that Alberti's account is reported only in the 1561 edition of his book (the one that includes the description of the islands near Italy), and the following ones. Moreover, he did not report observations made by himself in the times in which he wrote (i.e., the 16th century). Instead, he drew almost literally the text of Polybius – later quoted by Strabo (ed. 1967) - relative to the state of activity and general morphology of Vulcano in the middle of the 2nd century BCE (see paragraph 4.3). It can be easily verified that the original texts of the sources of Polybius and Alberti are entirely similar (as Alberti also explicitly states). By the way, Alberti did not visit the Aeolian islands during his journey in 1525–1526 CE (Di Matteo, 1999). Therefore he was able to observe the activity of Vulcano only from a great distance (from Calabria) without being able to describe its crater morphology in detail. Thus, the use of Alberti's source as the evidence that in the area of Forgia Vecchia there was an active crater in the 16th century is erroneous.

In summary, from the available historical sources there is a lack of compelling evidence for eruptive activity in the area of Forgia Vecchia in the modern age. Therefore, an alternative chronological attribution is possible. This goes to strengthen the geological and stratigraphic reconstruction where the Forgia Vecchia crater is only one (not two) and displays a much older age, most likely during the older stages of construction of the La Fossa cone (De Astis et al., 2013; Lucchi et al., 2024). In this regard, we have decided to carefully check whether in the historical sources of the Roman Republic age there could be any textual references useful to obtain information on the eruptive activity in that area.

The text of Aristotle is quite effective in describing the phenomenology of a major eruption that occurred in the second half of the 4th century BCE. This was associated with notable and permanent topographical variations in the volcanic edifice active at that time on the island. This edifice must reasonably be identified with the La Fossa cone, recognized as such throughout the volcanological historiographical tradition (Mercalli, 1891; De Fiore, 1922). It seems particularly interesting to us what Aristotle describes about an eruption that occurred after a "sudden swelling of the ground" and "rising of a mass like a hill". This seems to recall the growth of a "new" volcanic cone (or lava dome). However, there are no textual references useful for locating this new volcanic morphology. We certainly exclude that it refers in some way to the Vulcanello island, because we verified that it emerged later towards the end of the 2nd century BCE. We also exclude the bulk of the La Fossa cone, because it had already formed in the previous eras. Mercalli (1891) hypothesized that the new cone described by Aristotle was the north-western (more recent) portion of the La Fossa cone. We cannot exclude that Aristotle's description referred to the construction of a portion of the main crater of La Fossa cone, because geological data show that during its various phases of activity several craters were sometimes activated. However, we focus on what is described by Aristotele as a "new cone". We think this is more likely to indicate a distinct morphological entity, separate from the main edifice of La Fossa cone, and not just a different crater in its summit portion. Therefore we think it is possible that what Aristotle had documented was the growth of the Forgia Vecchia lateral cone along the northern flank of the La Fossa cone. This "old" cone would then have been progressively eroded and dismantled in subsequent periods by the processes of reworking of its steep slopes. Leading to the current conformation of the crater, which appears widely flared and lowered than when it was formed (Fig. 8). The possibility that Aristotle could have described the construction of the Forgia Vecchia cone was always discarded in the previous literature (e.g. De Fiore, 1922 and following authors quoting him). This is because the eruptive activity in that area had been traditionally considered more recent and referred to the Late Middle Ages based on interpretation of historical data. However, we have demonstrated that this age attribution has no direct references in historical sources. Moreover, we are referring to a different geological framework, in which the Forgia Vecchia cone is stratigraphically older, relative to the older stages of development of La Fossa cone, and this would be perfectly consistent with Aristotle's account.

This reconstruction could be consistent also with the account of Callias about the existence of two craters at the beginning of the 3rd century BCE, shortly after the period described by Aristotle. About these two craters, we have to exclude, even in this case, the Vulcanello area as a possible counterpart. One of them, described as more active and roughly over 500 m large, seems to match well the main crater of La Fossa cone. The other crater (not described in greater detail) could correspond to the crater of the just formed Forgia Vecchia cone, as accounted by Aristotle. This correspondence between the new cone described by Aristotle and one of the two craters described by Callias was already suggested by Stothers and Rampino (1983). Finally, there is the source of Polybius, quoted by Strabo (ed. 1967), who describes three craters on Vulcano in the middle of the 2nd century, one of which partially collapsed and the other two intact. From what Polybius writes

Fig. 9. Features relevant to the Pietre Cotte eruptive cycle. A) Distinctive fallout pumice layers of the Pietre Cotte succession (see C for location). Foliated lava lithic clasts, interpreted as derived from the Pietre Cotte lava flow, are circled in the basal portion. B) Aerial view of the La Fossa summit crater showing the hypothesized location of three craters active during the Pietre Cotte activity (photo by S. Branca, INGV). Crater $cr5_a$ corresponds to the vent of the Pietre Cotte lava flow (lf). Crater $cr5_b$ is located as shown in panel C. These craters lie on either side of the main crater cr5, and are currently only partially visible. Their preservation has been reduced due to major morphological changes associated with the formation of the main crater (cr6) during the 1888–90 CE eruptions and its erupted products. C) UAV-based photogrammetric digital outcrop model (courtesy of J. Natale, University of Bari) of the southwestern rim of the present-day Fossa crater. The Pietre Cotte succession overlies the Commenda pyroclastics (co) and older units - not identifiable due to intense hydrothermal alteration. The entire outcrop is unconformably covered by ash and ballistic clasts from the 1888–90 CE eruptive activity (gc = Gran Cratere unit). The inferred position of crater rim $cr5_b$ is based on the observed thickness decrease of the Pietre Cotte succession (pc) and its distinctive pumice layers, outlined by dotted lines. The $cr5_b$ crater area is partially infilled by deposits from the 1888–90 CE eruptions. D) Photograph showing the basal portion and carapace of the Pietre Cotte lava flow (from Piochi et al., 2009). The image highlights its internal foliated structure. E) Detail of the Pietre Cotte lava flow (photo by F. Lucchi), showing its typical internal foliated texture. Alternating bands of grey-pinkish rhyolite lava, minor obsidian and vesicular ("pumiceous") material are present. Grey to reddish lava enclaves are also visible. F) Detail of the Pietre Cotte lava flow (photo by F. Lucchi), showing a portion dominated by grey-pinkish rhyolite lava with numerous enclaves.

it is not possible to obtain specific indications to attribute unambiguously the three craters at the time of his observations to those that are currently visible on Vulcano, specifically those relative to La Fossa and Vulcanello (at that time almost certainly emerged). No further elements are provided by Strabo. We hypothesize that Polybius made his observations from the north-east of Vulcano. This is the only sector from where you can have complete visibility of the most recent volcanic edifices. In the volcanological historiography the three craters described by Polybius have been identified differently. Mercalli (1891) hypothesizes that they were the three craters currently preserved in Vulcanello. However, we think differently because we know from the available radiometric ages of erupted products that (at least) the most recent crater of Vulcanello was formed in the Late Middle Ages. Instead, we agree with Stothers and Rampino (1983) in thinking that one of the

craters observed by Polybius was that of Vulcanello emerged in 183 BCE. The other two must be located in the area of the La Fossa cone. We consider it very unlikely that Polybius was referring to the Faraglione cone, now largely destroyed by erosion. Thus, the largest crater, with a diameter of c. 900 m, could correspond to the main crater of the La Fossa cone. The other could be referred to the Forgia Vecchia cone, if we accept that it was formed in the previous centuries. In this view, let us take up literally the description by Polybius, in which two of the craters are intact and well preserved, probably coinciding with those of La Fossa cone and Vulcanello (just formed). The other one, described as partially collapsed, would preferably be the Forgia Vecchia crater, which has a wide and deep appearance, derived by intense processes of erosion and dismantling after its formation (at least one century before the times described by Polybius). This still gives it the appearance of a "collapsed" area (Fig. 8).

In conclusion, the critical review of available historical sources allows us to exclude any clear indications about eruptive activity in the area of Forgia Vecchia in the Late Middle Ages or later. On the other hand, the sources of the ancient age contain some references to an additional cone, and its crater, with respect to those of La Fossa and Vulcanello in an interval between the 4th and 2nd centuries BCE. This additional cone could correspond with the Forgia Vecchia cone (and its crater), in agreement with the stratigraphic reconstruction recently proposed by Lucchi et al. (2024). This reconstruction assigns it to the older stages of development of the La Fossa cone.

5.4. Source areas and ages of the Pietre Cotte eruptive cycle

The Pietre Cotte eruptive cycle is traditionally referred to distinctive whitish pumice fallout deposits (Fig. 9A) and a rhyolitic lava flow (Fig. 9B) produced by the La Fossa cone during the 18th century (Frazzetta et al., 1983; Keller, 1980; De Astis et al., 2013; Di Traglia et al., 2013, 2024). The tephra deposits are exposed in the summit crater area and its southern flanks. The lava flow, instead, stands out along the

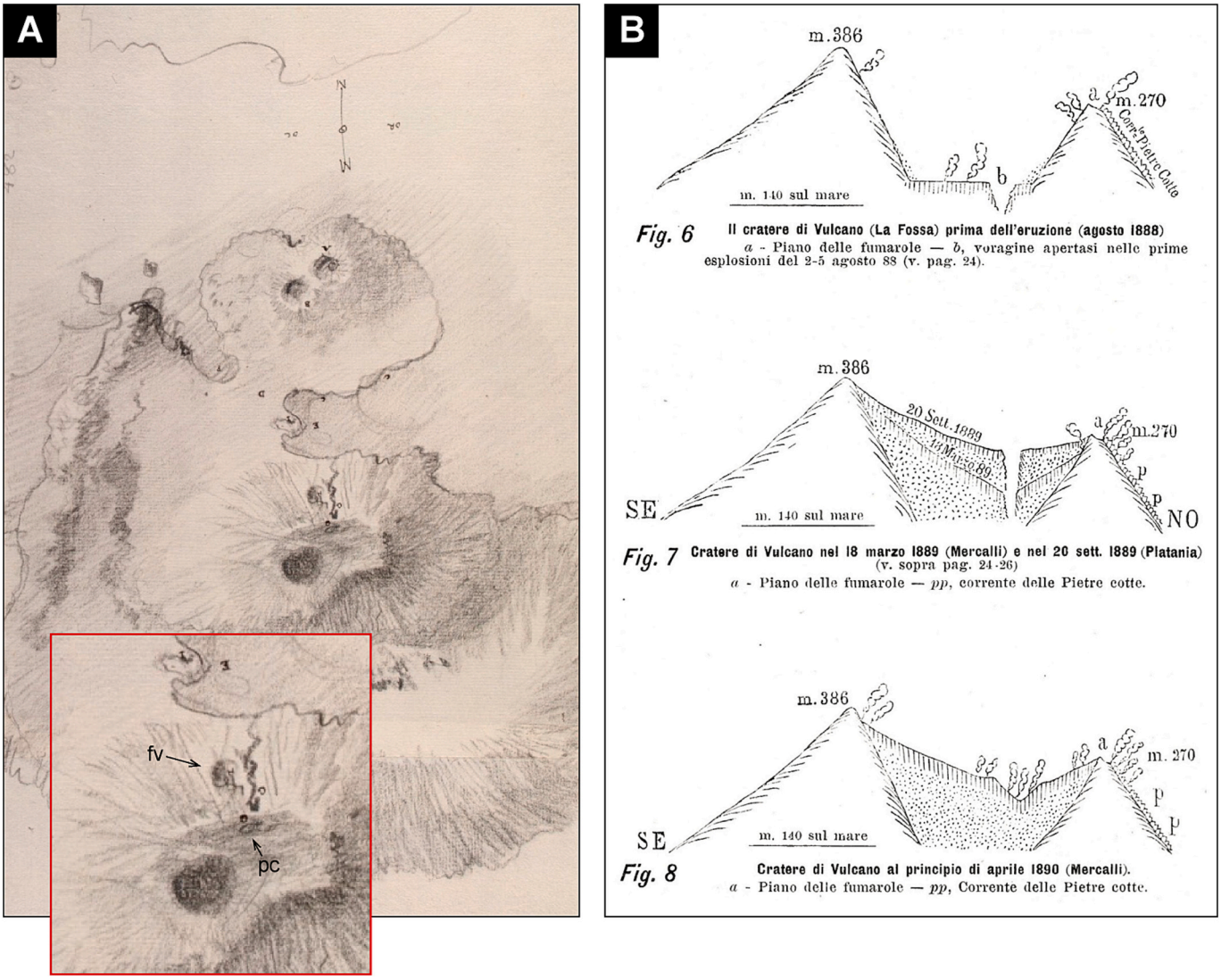

Fig. 10. Iconographic sources documenting the activity of the La Fossa cone during the 18th century. A) Plain-view drawing of Vulcano and Vulcanello by Jean-Pierre Hoüel, dated to 1776–79 CE (Hermitage Museum, St. Petersburg). The illustration shows the Vulcanello peninsula, including two well-preserved craters. The third crater, towards the north-east, is almost entirely eroded on its seaward site. The image also depicts a path ascending towards the summit of the La Fossa cone, adjacent to the Forgia Vecchia crater (fv). A secondary vent is visible on the northern side of the La Fossa summit crater. This vent is likely associated with the source of the Pietre Cotte lava flow (pc). Although the lava flow is not clearly depicted, it had already been emplaced by that time. Its absence is probably due to the stylized and non-realistic nature of the artwork. B) Drawings showing the morphology of the La Fossa summit crater before the 1888–90 CE eruption (top), during the activity (middle), and at its end (bottom) (from Mercalli and Silvestri, 1891). In the pre-eruption (top), an eccentric vent is visible along the northern crater rim, at an elevation of 270 m. This vent is shown emitting the Pietre Cotte lava flow.

northwest flank of La Fossa cone. The problem is that, despite their very recent age, the outcrops of the tephra deposits are rather discontinuous. This is due to i) limited areal distribution, ii) intense erosion and reworking processes on the steep sides of the cone, and iii) coverage (although not uniform) by the deposits of the last eruptive cycle of 1888–90 CE. Moreover, the lava flow has little direct stratigraphic contacts with most of the pyroclastic deposits. This complicates the reconstruction of the internal stratigraphic relationships among the different portions of the Pietre Cotte tephra succession and between these and the lava flow. It also helps explain the considerable discrepancy in the literature about their chronology. Basically, the relative chronology between the pumice deposits and the lava flow, and the age of emission of the lava flow itself, are controversial. The lava flow has been dated either to 1739 CE (De Fiore, 1922) or 1771 CE (Mercalli, 1891) based on a different reading of the contemporary historical chronicles. An archaeomagnetic age of 1720 CE ± 30 also exists (Arrighi et al., 2006). The lava flow has been generally considered the final event of the Pietre Cotte eruptive cycle (Frazzetta et al., 1983; Keller, 1980; De Astis et al., 2013). In any case, it is generally assumed that the lava flow was emitted after the pumice deposits (Di Traglia et al., 2024). A different reconstruction, according to which the lava flow is older than the pumice deposits, emerges from a recent geological fieldwork (Lucchi et al., 2024). This outlines the occurrence of lithic clasts of foliated lava with enclaves lithologically similar to the Pietre Cotte lava flow in the strata immediately below the pumice deposits. This most likely indicates that the lava flow had already been emitted and was involved at the time of the corresponding explosive activity and fractured into lithic clasts. Moreover, this new reconstruction highlights different craters in the summit area of La Fossa cone during the Pietre Cotte eruptive cycle. One (crater $cr5_a$) is that referred to the lava flow on the north-west side of the crater rim (crater cr5 in Fig. 9B). Another was located along the southeast crater rim (crater $cr5_b$ in Fig. 9B) and is assumed to represent the source area of the pumice deposits (and other tephra material) as indicated by their progressive *E*-to-W thickness and grain size decrease (Fig. 9C).

Given these open questions, the volcanological interpretation of historical data regarding eruptive activity on Vulcano in the 18th century may provide insights into the definition of the source areas and the ages of erupted products during the Pietre Cotte eruptive cycle.

5.4.1. *The Pietre Cotte lava flow (1739 CE)*

The account of De Luc (1780) about his visit to Vulcano in 1757 CE is particularly important because it has traditionally been used to date the emission of the Pietre Cotte lava flow to 1739 CE. His description is quite detailed, but there are no textual indications that allow us to ascertain from which of the sides of the La Fossa cone ("the new cone") he made the ascent after his landing at the port of Porto Levante. Moreover, it is difficult to locate that "narrow gorge" crossed by him along the way. This applies even admitting that it existed at the time and is no longer preserved in the current state of the volcano. However, establishing from which side he climbed onto the cone is of particular importance to correctly interpret the information he provides. It is notable that in the past the ascent to the crater of La Fossa was carried out along an old path leading up the north side of La Fossa cone, running alongside the crater of Forgia Vecchia. A new one along the northwest flank of the cone was established only in the second half of the 19th century (Baltzer, 1875). The current path along the western side of the cone was developed at the end of the 80s of the 20th century, due to the fact that a landslide had interrupted the old path. We thus assume that in the 18th century, when De Luc visited the island, the ascent to the cone was commonly carried out along the northern path of Forgia Vecchia. This is confirmed by a drawing by Houel in 1776–1779 CE, where the path is located right to the east of the Forgia Vecchia crater (Fig. 10A). The description of the climb carried out by De Luc along a very steep slope crossed by narrow and deep gorges is entirely consistent with the morphological characteristics of the northern side of the cone inside the Forgia Vecchia crater. If this is correct, the "narrow gorge" that De Luc had followed to enter the summit crater area could correspond to the narrow valley located at the top of the ridge that delimits to the east the Forgia Vecchia crater (Fig. 8). This is the probable path followed by him. There are no other indications regarding the path taken to descend from the cone.

On the way back, De Luc describes the presence of two lava flows, without specifying where precisely he observed them. From what has been said previously, we assume they are located along the northern side of the cone. One of the lava flows is described as "hard, compact and perfectly vitrified", with an appearance similar to that of "black flint". These characteristics alone do not allow for an unequivocal attribution to one of the lava flows emitted from the La Fossa cone. We note that some dark trachytic (glassy) lava flows emerge along the northern side of La Fossa cone, forming the wide fan-shaped promontory of Punte Nere. He could have observed them while climbing up or descending. However, there is little evidence to support this attribution. It must be said that the description of this first lava can recall the lithological aspect of obsidian. Therefore, it could be hypothesized that it corresponds to the (rhyolitic) Pietre Cotte lava. We feel it is appropriate to exclude this hypothesis because the Pietre Cotte lava is not homogeneously obsidianaceous. Instead, it is characterized by alternating bands of grey-pinkish rhyolite lava and obsidian and light grey vesicular portions (Piochi et al., 2009; Bullock et al., 2019; Costa et al., 2021) (Fig. 9D-F). These features seem consistent with the description given by de Luc for the other lava observed during his visit, which is "very porous" and contains "a lot of iron". The "porous" appearance may correspond to the vesicular (pumiceous) portions of the lava. The high iron content may indicate its widespread reddish-colored portions due to surface oxidation, like observed in many rhyolitic lavas (e.g. Furukawa et al., 2010). Considering that De Luc did not carry out chemical analyses, it can be assumed that the reddish colour of the lava suggested to him a high iron content, which is plausible for a geologist of that time. The Pietre Cotte lava flow stands out along the northwest flank of La Fossa cone, a short distance from the landing area at Vulcano. Therefore, it would have been clearly visible to De Luc. It is important to note that he recalls the emission of this lava flow as occurred "about ten years before" his visit in 1757 CE. This is an indication that De Luc must have acquired from the Lipari boatman who accompanied him in the excursion. This is not a precise indication of age, but it is nevertheless a clear testimony of an eruption occurred not long before. Therefore, we think that it is entirely reasonable to attribute the outpouring of the Pietre Cotte lava flow to the 1739 CE eruption (or eruptive cycle), for which we have collected several testimonies. There are no direct textual indications of effusive activity during this eruption. However, all the accounts are based on observations of Vulcano from afar, and thus it is absolutely likely that any lava flow would not have been seen. Moreover, at the current state of knowledge no other eruptions are known to have occurred on Vulcano in the period between 1739 CE and 1757 CE, time of the visit of De Luc. Our attribution of the Pietre Cotte lava flow to 1739 CE agrees with the part of volcanological tradition (Frazzetta et al., 1983; Keller, 1980; De Astis et al., 2013) which refers to De Fiore (1922). It is also coherent, within the analytical error, with the archaeomagnetic dating of this lava flow to 1720 CE ± 30 (Arrighi et al., 2006).

An alternative interpretation is that the Pietre Cotte lava flow was emitted in 1771 CE, referred to by the volcanological tradition that follows Mercalli (1883, 1891). This is based on the account of de Dolomieu (1783) on his visit to Vulcano in 1781 CE. While climbing to the summit of the La Fossa cone, he had always skirted a black, glassy lava flow that he refers to an eruption occurred a few years before his visit. This most likely corresponds to that of 1771 CE (identified erroneously by him in 1775 CE; see paragraph 4.10). It is not entirely clear which side of the cone de Dolomieu climbed from. He says he went up from the northern side of the cone, "low and wide". However, his description of a very steep slope covered by loose ash, into which one "sinks up to the knees", and with ash agglutinated by various salts, which "have made it a crust on which the foot has no grip", fits perfectly

with the characteristics of the western side of the cone. This is in proximity to where there is the current path to the active craters. This would be an anomaly, since, as previously mentioned, it is conceivable that the most used path to climb the volcano at that time was in the Forgia Vecchia area. But de Dolomieu climbed without a guide, and it is therefore possible that he took a different path from the most common one. All the previous literature has assumed that the one observed by de Dolomieu was the Pietre Cotte lava flow. However, we note that its black and glassy appearance does not exactly match that of this peculiar rhyolitic lava (as mentioned above).

This dating of the Pietre Cotte lava flow highlights a clear discrepancy with respect to the possible attribution to 1739 CE based on the interpretation of De Luc (1780)'s account, then reflected in all the subsequent historiography and volcanological literature. It is notable that de Dolomieu (1783) did not consider what De Luc had reported about that lava flow during the 1757 CE excursion, even though he shows that he knows the previous account very well. For example, de Dolomieu says that the narrow gorge crossed by De Luc to enter the summit crater no longer existed at his time. This is precisely one of the elements used by Di Traglia et al. (2024) to attribute the Pietre Cotte lava flow to 1771 CE (our correction of 1775 CE). In fact, they assume that the gorge was buried and obliterated by the lava flow, which should then post-date 1757 CE. However, we have verified that there are no textual references in de Dolomieu (1783) to support this hypothesis, which thus is entirely speculative. De Dolomieu only says that the lava flow reached the base of the cone after filling the "crater depression", without entering "the valley". It is not specified which valley it is. Moreover, de Dolomieu himself explains the absence of the narrow gorge described by De Luc, hypothesizing that there was a recurrent landsliding of the crater rim.

Considering the available historical data, we are inclined to think that the attribution of the Pietre Cotte lava flow to 1739 CE based on De Luc's account is the most correct. This is also because the description given by De Luc appears much more coherent with the lithological characteristics of that lava. We cannot completely exclude that de Dolomieu's attribution of the lava flow to 1771 CE is possible. However, we note that de Dolomieu (1783) essentially attributes the lava flow to the last eruption he knew about before his visit to Vulcano (erroneously referred by him to 1775 CE). He does not clarify from whom or where he got this information or whether it is just his supposition based on the fresh appearance of the lava. We can therefore assume that he did not receive correct information about the age of the eruption during which the lava flow was emitted. Furthermore, the lava flow, if issued in 1739 CE, could still have had a fresh appearance at the time of de Dolomieu's visit, leading him to an incorrect chronological attribution.

5.4.2. *The Pietre Cotte pumice deposits (1771 CE)*

In 1771 CE, an eruptive cycle lasting about three months with recurrent explosive eruptions is attested by the accounts of the priest Gaetano Maria Trovatini, reported in Ferrara (1810). The first (major) eruption formed an eruptive plume moving north towards the island of Lipari. This island was overall covered by thick amounts of ash, causing extensive damage to vegetation and livestock. A very similar description is given by Dolomieu (1783) for this major eruption, although he places it erroneously in 1775 CE. He adds that the ash fell both in the direction of Lipari and Sicily, documenting a distribution of the eruptive plume(s) also towards the south. Moreover, de Dolomieu specifies that the ash that covered Lipari was whitish. This seems peculiar, because the ash produced by the recent eruptions of Vulcano is typically grey to blackish in colour, given its dominant latite to trachyte composition (e.g. De Astis et al., 2013). The eruptive cycle of Pietre Cotte is instead characterized by distinctive fallout layers of white rhyolitic pumice. Thus, we consider it probable that the eruption in 1771 CE is the one that produced precisely these deposits. If so, the Pietre Cotte pumice layers would have been emitted after the lava flow. This is in agreement with the most recent geological evidence, that lithic clasts of the Pietre Cotte lava are stratigraphically located immediately below the pumice layers (Fig. 9A) (Lucchi et al., 2024). This reconstruction is different from what was hypothesized in much of the previous volcanological literature.

5.4.3. *Different craters through time*

The historical accounts relative to the 18th century also provide information on different source areas activated through time during the Pietre Cotte eruptive cycle. This is consistent with the new geological data proposed by Lucchi et al. (2024) (Fig. 9B).

The account of D'Orville (1764) is about (at least) three days of eruptions in 1727 CE (from 20 to 22 May), even if neither the beginning nor the end of this eruptive activity are known. These eruptions occurred from two active craters. As already mentioned previously, we agree with most of the volcanological historiography that the larger and higher crater is the main one of La Fossa. However, doubts remain about the minor and lower one. We have excluded that it could be in the Vulcanello area and assumed as unlikely that it could correspond to the Forgia Vecchia crater. Therefore, it seems reasonable to us to hypothesize that in 1727 CE there were more active craters in the summit area of La Fossa cone. The minor crater described by D'Orville, "further north" than the main crater, could correspond to the vent from where the Pietre Cotte lava flow would later have been emitted (Fig. 10A). This is actually located along the northern edge of the summit crater rim of La Fossa cone ($cr5_a$ in Fig. 9B). What D'Orville observed during his visit could have been quite similar to the morphology of the crater area hypothesized by Mercalli and Silvestri (1891) before the 1888–90 CE eruptive cycle. The vent from which the Pietre Cotte lava flow was emitted was located on the northern crater rim (Fig. 10B). This setting would also justify D'Orville's indication that the minor (northern) crater seemed more active, since the vent of the Pietre Cotte lava flow is actually more visible from the observation point of the Porto di Levante beach than the main central crater, which is instead deeper.

Further information on the state of activity of La Fossa cone in 1757 CE is provided by De Luc (1780). First, he observed two different craters of La Fossa cone, which "extend up to its apex" and "can be distinguished only from a certain distance". These could still correspond to the main central crater and the one from which the Pietre Cotte lava flow had been issued in 1739 CE (cr5 and $cr5_a$ in Fig. 9B), assuming that this minor vent had continued its (explosive) activity even after the lava flow was outpoured. It is unlikely that one of the craters is that of Forgia Vecchia. We have shown before that there is a lack of historical (and geological) evidence that the Forgia Vecchia crater was active in the modern age. Moreover, this crater is clearly visible from the base of the La Fossa cone, and not only from a certain distance as underlined by De Luc. When he reaches the summit area of La Fossa, De Luc makes a detailed description of the main central crater. This had dimensions, between 400 and 700 m in diameter and 50–65 m deep, completely similar to the one corresponding to the 1888–90 CE eruption. Then he observes another funnel-like vent located on the opposite side from where he climbed onto the crater, lower than one of the highest sides of the crater rim. Since it is likely that he ascended from the north side, this (minor) vent must have been located along the southern crater rim of La Fossa, somewhat lower than its maximum elevations. We hypothesize that this vent corresponds to the one from which the pumice layers of the Pietre Cotte succession were fed in 1771 CE ($cr5_b$ in Fig. 9B-C). This is located along the southern crater rim of La Fossa, slightly lower than its highest portions. This hypothesis is also in agreement with the observation by Dolomieu in 1781 CE of an eccentric crater located a "little further south" than the centre of the cone, on the "highest and thinnest slope".

5.5. *Hazard scenarios for the La Fossa cone*

In this section, we aim to extract from the selected historical reports analyzed for the last c. 2400 years the information useful to define the eruptive behavior of La Fossa cone and eruptive scenarios for the

purpose of quantifying the hazard and impact areas. We refer to the classification proposed by Selva et al. (2020) into phreatic eruptions (Type 0), effusive and Strombolian eruptions (Type 1), Vulcanian eruptions (Type 2), accompanied or not by the development of pyroclastic density currents, and (Sub-Plinian?) sustained eruptions (Type 3). Each one is identified by representative eruptions best observed in the field or studied in the past. It must be considered that most of the eruptions were not described in detail by the historical sources, and many others are likely unknown due to the lack of evidence or documents. Moreover, even when written (or iconographic) records exist, the witnesses rarely had the opportunity to observe the eruptive activity up close. The descriptions are often very generic and do not allow a certain definition of the type of activity. This is why in most cases we cannot provide information on the characteristics of the eruptions, on the possible sequence of events preceding them to assess what occurred during the unrest phases, or on the timeline of the eruption itself.

The historical sources document explosive activity of La Fossa cone at least from the end of the 5th century BCE (as reported in De Fiore, 1922). It is not generally possible to evaluate the eruption recurrence. This is because the historical sources are an archive of point-by-point reports, and there is not always the certainty that in the time intervals for which we do not have accounts there was truly no eruptive activity. The 19th century activity is an exception, because there are detailed chronicles documenting the sequence of eruptions (Mercalli and Silvestri, 1891; De Fiore, 1922), but it is out of the purpose of the present paper. Moreover, the precise and repeated accounts of the priest Trovatini (reported in Ferrara, 1810) document a period of quiescence characterized by continuous fumarolic activity lasting (at least) 30–40 years after the 1771 CE eruption(s) (see also Trovatini, 1786). However, the analyzed sources suggest that the activity of the La Fossa cone was relatively continuous. Or, in any case, it was frequent enough to make the volcano appear active in a recurrent manner. After all, precisely because of its recurrent eruptive activity, the volcano was known to the Greeks and Romans. It was regarded as the "link between the kingdom of the dead and the living" (*Hiera*), the "hot land" (*Therasia*), and finally the forges of Hephaestus, the god of fire. Almost certainly, due to its frequent eruptive activity, the island was identified in the Middle Ages as one of the gates to Hell.

When present and detailed enough, particularly in the Modern age accounts, the descriptions of the type of activity fit perfectly with what is known as the typical eruptive behavior of the La Fossa volcano (Selva et al., 2020). It shows recurrent cycles of small volume and low to moderate Vulcanian explosive eruptions (Type 2). These are separated by intervals of quiescence of varying duration. These Vulcanian eruptions are characterized from time to time by ejection of clasts, discontinuous ash-rich plumes, detonations, and underground rumblings and noises. They are sometimes preceded or associated with earthquakes felt on the nearby islands. We did not find any textual evidence for the generation of pyroclastic currents, or documentation of the outpouring of lava flows (except for the Pietre Cotte lava flow). There are not even textual references that allow us to define some of those eruptions as Strombolian (Type 1), even though there is clear evidence of scoriaceous deposits of this type in the corresponding stratigraphic windows.

We highlight some eruptions that had a magnitude greater than average and therefore were likely capable of impressing observers. These eruptions were characterized by the formation of higher eruptive columns, transported by the winds in different directions and capable of causing the fallout of ash and larger clasts over considerable distances. They are considered to be of a higher rank than typical Vulcanian eruptions, and thus classified in the Type 3 category of Selva et al. (2020). We are unable to say whether they were sustained (Plinian or Sub-Plinian) eruptions or not from the point of view of the sole interpretation of historical accounts. We define generically these eruptions as "major" eruptions. Major eruptions occurred in the 4th century BCE, 1444 CE, 1525–26 CE, 1739 CE and 1771 CE. The eruption described by Aristotle in the second half of the 4th century BCE was characterized by the widespread fallout of ash and lapilli that covered the town of Lipari completely. It also reached some places in Italy. The eruption of 1444 CE, according to Ranzano (quoted by Fazello), is described as out of the ordinary compared to the typical eruptive behavior of Vulcano. It emitted an eruptive cloud with ballistic clasts of very large dimensions falling into the sea at a distance of almost 11 km (6 miles). Since the maximum fallout distance in Vulcanian eruptions of La Fossa is typically set around 3 km (Biass et al., 2016), such a greater fall distance would indicate an eruption of much greater magnitude than average. In any case, the fall distance of ballistic clasts reported by Ranzano (and Fazello) could be likely overestimated. Another eruption of magnitude above average could be one of those that occurred in the eruptive cycle of 1525–26 CE. According to Bottone (1692), there was an eruption characterized by the fallout of ash and rocks into the middle of the sea. It is interesting to recall the account of Maurand about a major eruption that occurred before his visit in 1544 CE. It was characterized by the fallout of clasts on the island of Lipari, large enough to remain hot and set fire to wooded areas, threatening the town of Lipari. This eruption cannot be precisely dated. We think it more probable that it corresponds with one of the eruptions of 1525–26 CE (or that of 1444 CE). Regarding the eruptive cycle of 1739 CE, we have collected several historical sources that describe, on different days, the formation of eruption plumes. These plumes had the typical shape of a "maritime pine" or "palm tree". One of them moved south towards Sicily (on May 4th and 9th) due to the action of the winds. It eventually reached the area of Mt. Etna, and launched large rock fragments apparently up to the Sicilian coast (although this seems very doubtful). The 1771 CE eruptive cycle was characterized by a series of explosive eruptions that formed eruptive plumes moving north and, to a lesser extent, southwards. These deposited thick amounts of (whitish) ash on the island of Lipari and even in smaller quantities in Sicily. Occasionally, large rock fragments and blocks of glassy lava (scoria?) were launched. These eruptions were associated with detonations able to break the windows of the houses of Lipari (de Dolomieu, 1783; Ferrara, 1810). The erupted ash was likely carried by a westerly wind and fell on the city of Constantinople, according to the news that reached Lipari in the following period (Anonymous manuscript, n.d., 19th century). We note that on May 14, 1771, a notable eruption of Vesuvius began, of a predominantly effusive nature, but also with emission of ash. Therefore, it is not certain if the ash that fell at a great distance is actually due to the eruption of Vulcano.

Through these data it is possible to integrate the database of major eruptions (Type 3) at Vulcano defined by Selva et al. (2020). In this regard, there is no historical evicence for the two major eruptions occurred within the Palizzi cycle (c. 1000–1250 CE), testified by two distinctive layers of fallout pumice lapilli, named Palizzi rhyolitic and Palizzi trachytic.

5.5.1. *Phreatic eruptions*

A particular aspect in the evaluation of eruptive scenarios for the La Fossa cone in Vulcano is the possibility of generating phreatic (or hydrothermal) eruptions. These eruptions are caused by the sudden vaporization of hydrothermal or groundwater due to the transfer of heat or hot fluids from the magma, with no direct involvement of the magma itself (Barberi et al., 1992; Browne and Lawless, 2001; Stix and de Moor, 2018). They are typical of volcanoes that host active hydrothermal systems (Montanaro et al., 2022). These eruptions are among the most hazardous volcanic phenomena. This is because they are generally unpredictable and can impact inhabited areas or tourist sites. This was seen at the Biscuit Basin geyser at Yellowstone Caldera in 2024, as well as during the 2016 Ontake and 2019 Whakaari/White Island eruptions (Global Volcanism Program). The problem in assessing their recurrence in the eruptive history of a volcano is that the corresponding deposits, essentially characterized by the absence of juvenile material, are difficult to preserve in the geological record. Here we want to check whether historical accounts can provide some information. We also aim to discuss previous reports of historically defined phreatic eruptions. Let us

start by saying that we do not consider it probable that historical accounts, even considering the most recent ones, have noticed the peculiar characters of phreatic eruptions. This is because these eruptions are usually of low-magnitude and exhibit phenomena similar to magma-driven explosions. It is a fact that phreatic eruptions had not even been defined at least until the middle of the last century (e.g. Stearns and Macdonald, 1946).

On Vulcano, Selva et al. (2020) identified three large phreatic explosions (Type 0) based on erupted products and/or historical accounts. One is referred to the well-known Breccia di Commenda (Caruggi), archeomagnetically dated to 1240–1300 CE. The other two, related to the Forgia Vecchia craters, occurred in 1444 CE and 1727 CE. The latter was recently re-dated by Di Traglia et al. (2024) to between the first half of the 15th century CE and 1550 CE. About these two (phreatic) eruptions, we have already discussed them previously (paragraph 5.3). We demonstrated that no textual evidence exists for (major) phreatic eruptions from the Forgia Vecchia craters in the modern age. Nor are there geological deposits unequivocally referring to them. As a side note, Di Traglia et al. (2024) tentatively attribute a date of 1403 CE to a Vulcanian and phreatic eruption. However, this date is not supported by any reference in the text, nor is its origin clarified—there is no indication whether it derives from historical records or geological evidence. No documentary or published historical source we consulted reports an eruption at Vulcano in 1403 CE, as confirmed by a thorough review of the entire volcanological historiography.

The Breccia di Commenda is instead a metre-thick, widespread, lithic-rich deposit. It is traditionally considered the result of a large phreatic eruption (Rosi et al., 2018). Even if it is not possible to exclude definitively that fresh magma – trachytic to rhyolitic in composition - was involved in some way in the eruption (Gurioli et al., 2012). In any case, the metric thickness and occurrence of large ballistic blocks over wide distances from the crater (up to a few kms) are clear evidence of a major eruption. This is above the standard levels defined for La Fossa cone activity. Considering these characteristics, the Breccia di Commenda fits perfectly with what is described in historical sources for the eruption of 1444 CE. However, this is not consistent with the recently defined palaeomagnetic age of 1240–1300 CE for that deposit (Malaguti et al., 2022). Therefore, alternatively, it must be assumed that the eruption that produced the Breccia di Commenda is not recorded in historical accounts.

Recently, Giansante et al. (2025) have defined a deposit, named Breccia De Fiore, which is referred to a cycle of phreatic eruptions of La Fossa cone in September–October 1873. This is mostly based on historical accounts (Mercalli and Silvestri, 1891; De Fiore, 1922). Although this eruptive activity does not fall within the time interval target of the present study, we believe it is useful to make an exception. This helps to verify the effectiveness of our approach, which is based on a clear distinction between historical data and their volcanological interpretation. We do not want to discuss whether the Breccia De Fiore has the geological characteristics of a phreatic deposit, but only the historical evidence of such eruptions. First of all, it should be clarified that all the historical sources relative to the eruptive activity of 1873 CE refer to the observations of Ambrogio Picone, quoted by Mercalli (1883). He lived on the island of Vulcano from 1868 to 1874 as the director of mining works, and had the opportunity to directly observe the eruptive phenomena. He describes a period of 44 days of eruptive activity. This was characterized by numerous explosions of varying magnitude, lasting from a few seconds to a few hours. These were generally characterized by the ejection of ash, stones, and incandescent material, and associated with underground rumbles. There are no textual references that allow us to interpret these eruptions as phreatic. Indeed, most of the characteristics fit perfectly with those of a cycle of Vulcanian eruptions. These were completely similar to others in the past and also to the ones that occurred a few years later in 1888–90 CE. The presence of "incandescent material" is particularly important, because it gives clear indications of high temperatures of the clasts ejected during those eruptions. This is a distinctive feature of magma-related eruptions and not of phreatic ones. Only in the first eruption that opened the 1873 CE eruptive cycle, on 7 September, was the emission of white ash with tridymite observed. However, this was always in association with incandescent material. The presence of white ash with tridymite suggests the involvement of the shallow hydrothermal system in the onset phase of the eruption. This is entirely reasonable for a volcanic system like that of La Fossa cone. The presence of incandescent material is clear evidence that magma played a fundamental role in the eruptive dynamics. Therefore, this was not a purely phreatic eruption. Ultimately, the interpretation proposed by Giansante et al. (2025) of a sequence of phreatic eruptions in 1873 CE capable of producing the deposit called Breccia De Fiore is at least questionable.

This discussion confirms that, at the current state of knowledge, the available historical sources are ineffective for identifying major phreatic eruptions that occurred in the history of the La Fossa cone before the 1888–1890 CE eruptions. We believe that it was characterized by several small phreatic (or hydrothermal) explosions. These are visible in the field as layers rich in hydrothermally-altered lithic clasts. They are particularly recognized within the best-preserved Pietre Cotte succession and the more recent deposits. These phreatic eruptions may be interpreted as initial phases of magma-related eruptions (such as the one preceding the 1888–90 CE eruptive cycle). In these cases, the shallow hydrothermal system is involved and the conduit is opened. Their evidence, however, is geological. They can hardly be distinguished on the basis of historical chronicles. For these reasons, we cannot exclude that other phreatic eruptions have occurred in the history of La Fossa cone without being preserved in the geologic record or documented by historical sources.

Conclusive remarks

In this study we have revised the available historical sources on the activity of La Fossa cone and Vulcanello covering the Ancient period (4th to 2nd centuries BCE) to the 18th century following a rigorous method that includes an initial phase of purely historiographical evaluation. This was followed by the interpretation of the main elements within a volcanological framework and by their discussion in relation with earlier studies. The main outcomes for geological reconstruction and hazard assessment of the La Fossa cone and Vulcanello are the following.

1) Early eruptions and emergence of Vulcanello occurred in 183–126 BCE. This likely led to the development of a small island, through the formation of a lava platform, that persisted in the following centuries. The latest activities of Vulcanello most likely occurred in the middle of the 16th century.
2) The islet of Vulcanello was connected to the main island of Vulcano by an isthmus likely formed through the progressive accumulation of erupted material. This material was mostly from the La Fossa cone and remodeled by the action of the sea at the beginning of the 16th century. Historical evidence also suggests that its completion occurred during one of the major eruptions in 1525–1526 CE.
3) In the written sources of the modern age there is no unambiguous textual reference indicating eruptive activity in the area of Forgia Vecchia. However, some indications regarding the formation of a new cone and the presence of a crater in this area are highlighted between the 4th and 2nd centuries BCE. This is in line with most recent stratigraphic and volcanological data.
4) Two different eruptive vents were likely active during the Pietre Cotte eruptive cycle in the 18th century on the sides of the main crater rim of La Fossa cone. The well-known rhyolitic lava flow, most likely dated to 1739 CE, was outpoured from a vent on the northern crater rim. The pumice (fallout) layers were emitted during the 1771 CE eruption from a vent located along the southern side of the summit crater.
5) Major eruptions with a magnitude greater than the average of typical Vulcanian eruptions (e.g. in 1888–90 CE) occurred at La Fossa cone

in the second half of the 4th century BCE, in 1444 CE, 1525–26 CE, 1739 CE and 1771 CE.

6) No phreatic eruptions are documented by historical accounts before the 1888–90 CE eruptive cycle. There is also no historical documentation of the violent eruption that formed the well-known Breccia di Commenda.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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