Geological Field Trips and Maps

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Sistema Nazionale per la Protezione dell'Ambiente

2023

Vol. 15 (2.1)

ISSN: 2038-4947

When tectonics and climate take over: Quaternary depositional history of extensional Tuscan basins

POST-2 – Post-congress Field Trip of the XXI Inqua Congress "A Mediterranean perspective on Quaternary Sciences", Rome 14th-20th July 2023

https://doi.org/10.3301/GFT.2023.06

GFT&M - *Geological Field Trips and Maps*

Periodico semestrale del Servizio Geologico d'Italia - ISPRA e della Società Geologica Italiana
Geol. F. Trips Maps, Vol.**15** No.2.1 (2023), 60 pp., 36 figs. (https://doi.org/10.3301/GFT.2023.06)

When tectonics and climate take over: Quaternary depositional history of extensional Tuscan basins

POST-2 – Post-congress Field Trip of the XXI Inqua Congress "A Mediterranean perspective on Quaternary Sciences", Rome 14th-20th July 2023

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Cover page Figure: Panoramic view of the "White whale" travertine depositional system at Bagni san Filippo (Siena). Photo courtesy of Enrico Capezzuoli.

ISSN: 2038-4947 [online]

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ABSTRACT

The investigation of the tectono-sedimentary evolution of the extensional basins of southern Tuscany plays a key-role to understand the settings into which sediments are deposited in response to the interaction among eustatism, climate and tectonic activity. Indeed, during the Quaternary, the extensional basins of southern Tuscany hosted thick successions of continental and marine sediments whose deposition was strongly controlled by tectonic activity, volcanic and climatic processes. In this view, such basins can unveil detailed records of Quaternary climatic changes and tectonic processes leading to significant changes of this portion of the Apennine belt. Spectacular examples of this interaction, occurred during the last 3 Ma, will be illustrated in different depositional settings: marine - Radicofani Basin; fluvio/lacustrine - Valdarno Basin; volcanic - Monte Amiata Volcano and Radicofani; travertines - Rapolano Terme and Bagni San Filippo. The field trip is nestled in the historical and scenic view of the Tuscan landscape.

Key words: tectonics, climate, sedimentary successions, terrestrial carbonates, sedimentology, palynology, Northern Apennines, glacial/interglacial cycles, UBSU.

PROGRAM SUMMARY

First day

Day 1 – The Radicofani Basin and the Monte Amiata Volcano		
Departure from Rome at 7:40. Transfer to Radicofani		
Stop 1.1	10:00 – 11:00	Radicofani Basin: its Neogene evolution and architecture
Stop 1.2	11:00 – 12:30	Radicofani: the Volcanic Neck (Pleistocene)
Stop 1.3	12:30 – 14:00	Lunch. Transfer to Bagni San Filippo
Stop 1.4	14:30 – 16:00	Bagni San Filippo: evolution of the Monte Amiata Volcano (Pleistocene)
Stop 1.5	16:00 – 17:30	Bagni San Filippo: travertine of the Fosso Bianco Creek (Holocene)
Departure from Bagni San Filippo around 17:30 (arrival in Rapolano Terme at 18:30)		

Second day

Day 2 – The Rapolano Terme Area during the Plio-Quaternary		
Departure from the Hotel at 8:30, at Rapolano Terme		
Stop 2.1	08:30 – 09:30	Rapolano Terme: Introduction to the local geology
Stop 2.2	09:40 – 10:30	Sentino Basin: Piacenzian marine and Quaternary continental deposits
Stop 2.3	10:30 – 12:30	Armaiolo: fluvio-palustrine and travertine deposits (Pleistocene)

Stop 2.4	12:30 – 14:30	Lunch
Stop 2.5	14:30 – 16:30	Serre di Rapolano: the fossil travertine system (Mid-Late Pleistocene)
Stop 2.6	16:30 – 18:00	Serre di Rapolano: the Terme San Giovanni fissure ridge (Holocene)
Return to Hotel around 18:00		

Third day

Day 3 – The Upper Valdarno Basin (UVB)		
Departure from the Hotel at 7:40		
Stop 3.1	08:30 – 09:30	Castelnuovo: visit to Mine Museum and introduction to the UVB basin
Stop 3.2	09:40 – 11:00	The Santa Barbara site: lacustrine deposits (Piacenzian)
Stop 3.3	11:20 – 12:50	Borrassole quarry: fluvio-palustrine deposits (Gelasian-Calabrian)
Stop 3.4	13:10 – 15:10	Accademia Vald. Poggio: lunch and visit to the Palaeontological Museum
Stop 3.5	15:30 – 17:30	“Balze”: alluvial fans at the NE edge of the basin (Calabrian-Chibanian).
Departure from Castelfranco around 17:30 (arrival in Florence at 19:00)		

SAFETY

The stops are generally easily accessible. Hiking shoes and comfortable clothing are necessary; in addition, high-visibility jackets must be worn for the road stops, and protective helmets only for some stops (they will be made available to you at the start of the excursion). Outcrops are close to localities where there are both shops and pharmacies. July is one of Tuscany’s hottest months of the year, with a range of 82-95°F (28-35°C). Sunscreen protection and water are thus needed. General Emergency contact number: 112 (Carabinieri, Police, Ambulance, Firefighters)

HOSPITALS

Day 1 – The nearest hospital is the Ospedale Amiata Val d’Orcia - Abbadia San Salvatore; Phone: (+39) 0577 7821; 800613311.
Day 2 – The nearest hospital is the Azienda Ospedaliera Universitaria Senese V.le Mario Bracci, 11, 53100 Siena; Phone: (+39) 0577 767676; 800613311.
Day 3 – The nearest hospital is the Ospedale Valdarno “La Gruccia” – Montevarchi; Phone (+39) 0575 2551; 800613311.

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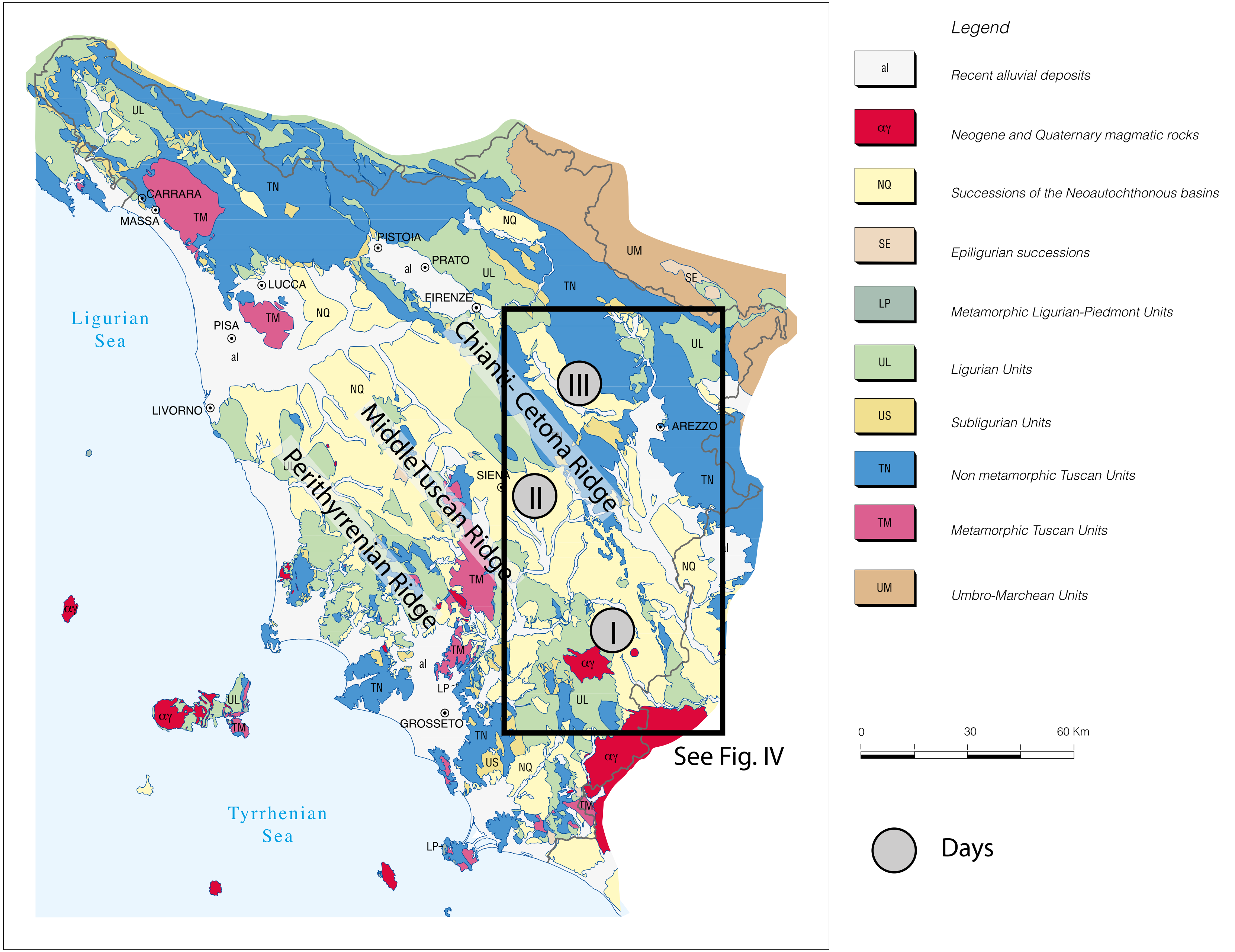

Fig. 0.1 - Sketch map of the stratigraphic and tectonic units present in Tuscany and indication of the different areas visited during the three field trip days.

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ACCOMMODATIONS IN FIRENZE

The last stop before your leaving is in Firenze. Useful telephone numbers: - Florence airport information: +39(0)55 3061300; - 24-hour Pharmacies: Santa Maria Novella Station (Via Calzaiuoli, 7r, Piazza San Giovanni, 20); Hospital: Santa Maria Nuova (Piazza Santa Maria Nuova, 1); - Emergency Medical Service (Guardia Medica): Via della Pergola, 1 A, +39(0)57 3454545. - Travel from Florence is via several International Airports: Florence "Amerigo Vespucci", Pisa "Galileo Galilei", Bologna "Guglielmo Marconi", Rome-Fiumicino "Leonardo da Vinci", Milan Malpensa Airport, and more. - By Train: The city's main railway station is Firenze SMN (Santa Maria Novella). Italian railway services: Trenitalia (FrecciaRossa – FrecciaArgento: high speed trains) and Italo. Main tourist information about the city as maps, accommodations, transports, places of interest and monuments can be found at e.g.: https://www.feelflorence.it/; https://en.comune.fi.it/city/culture_and_tourism/tourist_information.htm.

GEOLOGICAL OUTLINE

The Apennines chain is a fold-thrust belt crossing Italy from NW to SE, which developed from the convergence and collision (Late Cretaceous-Early Miocene) of the Adria promontory (of African plate pertinence) and the European plate, represented by the Sardinia–Corsica massif (e.g., Vai and Martini, 2001). The northern portion (i.e., the Northern Apennines) is mainly formed by stacked tectonic units deriving from different palaeogeographic domains corresponding to (i) the Ligurian-Piedmont Ocean (Ligurian Domain); (ii) the transitional crust at the boundary between the ocean domain and Adria continental margin (Sub-Ligurian Domain); and (iii) the Adria continental margin (Tuscan and Umbria-Marche Domains) (e.g., Vai and Martini, 2001). In the inner zone of the Northern Apennines (Fig. 0.1), only the tectonic units belonging to the Ligurian, Sub-Ligurian and Tuscan domains are exposed. These units are, from the top (Carmignani et al., 1994) (Fig. 0.2):

(a) the Ligurian units (Ligurian Domain), consisting of remnants of Jurassic oceanic crust and its Upper Jurassic-Cretaceous, mainly clayey, sedimentary cover;
(b) the Sub-Ligurian units (Sub-Ligurian Domain), made up of Cretaceous-Oligocene turbiditic successions;
(c) the Tuscan units, represented by metamorphic and non-metamorphic units stacked in duplex systems (Pandeli et al., 1991; Brogi, 2005). The metamorphic units were affected by blue-schist and green-schist facies metamorphism (Jolivet et al., 1998; Rossetti et al., 2002; Brogi and Giorgetti, 2012), related to the collisional event (Brunet et al., 2000; Bianco et al., 2015, 2019) and derive from a succession ranging from Palaeozoic to Early Miocene (Pandeli et al., 1991; Carmignani et al., 1994). The Ligurian units were involved in the eastward accretionary prism during the progressive convergence of the continental margins. The accretionary prism was overthrust on the Adria margin (i.e., the Tuscan Domain) during late Oligocene-Early Miocene causing the formation of the duplex systems of the Tuscan units. Since Early Miocene the inner zone of

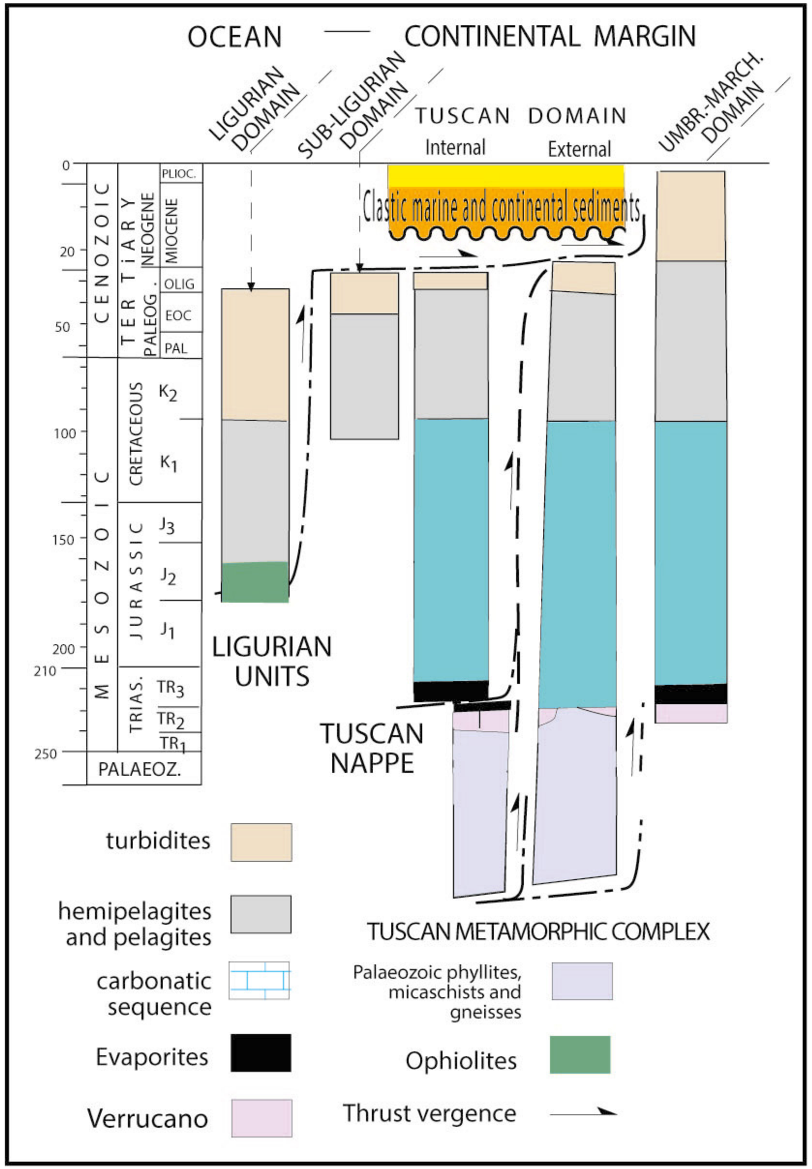

Fig. 0.2 - Relations among the different tectonic units of Northern Apennines and related palaeogeographical domains (after Carmignani et al., 1994 modified).

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the neo-formed Northern Apennines was affected by extensional tectonics which dismantled the previously developed orogenic pile (e.g., Liotta et al., 1998) (Fig. 0.3).

The development of structural depressions (i.e., basins) in the Tyrrhenian area is one of the main consequences of this process (Bartole, 1995; Carmignani et al., 1995; Costantini et al., 2009). These basins started to develop since middle/late Burdigalian (Carmignani et al., 1995; Pascucci et al., 1999; Cornamusini et al., 2014) in the Tyrrhenian area, and progressively migrated toward East, inland (i.e., southern Tuscany), until Pleistocene (Martini and Sagri, 1993). Basins have a main NNW-orientation and are delimited by almost orthogonal transfer zones (e.g., Liotta, 1991; Martini and Sagri, 1993; Pascucci et al., 2007). According to several authors (e.g., Bertini et al., 1991; Baldi et al., 1994; Carmignani et al., 1994; Liotta et al., 1998; Brogi and Liotta, 2008; Brogi, 2011; 2020) extension developed by means of superposed events framed in the progressive migration of the extensional tectonics toward East: (a) the first event (Early to Late Miocene) produced an extension of at least 120% (Carmignani et al., 1994; Brogi, 2006) and gave rise to low-angle normal faults (e.g., Bertini et al., 1991; Dallmeyer and Liotta, 1998; Brogi, 2008; Brogi and Liotta, 2008); (b) the second event (Zanclean to Present) formed high-angle normal faults that crosscut the previous structures (Liotta et al., 2010; Brogi, 2020), and determined tectonic depressions where Plio-Pleistocene continental and marine sediments deposited (Martini and Sagri, 1993; Pascucci et al., 2007; Brogi, 2011; Martini et al., 2021). The amount of extension related to these faults is estimated in about 6-7% (Carmignani et al., 1994). Transfer zones, represented by NE-trending brittle shear zones, played the role of structures separating crustal sectors with different amount of extension and interrupt the continuity of the normal faults

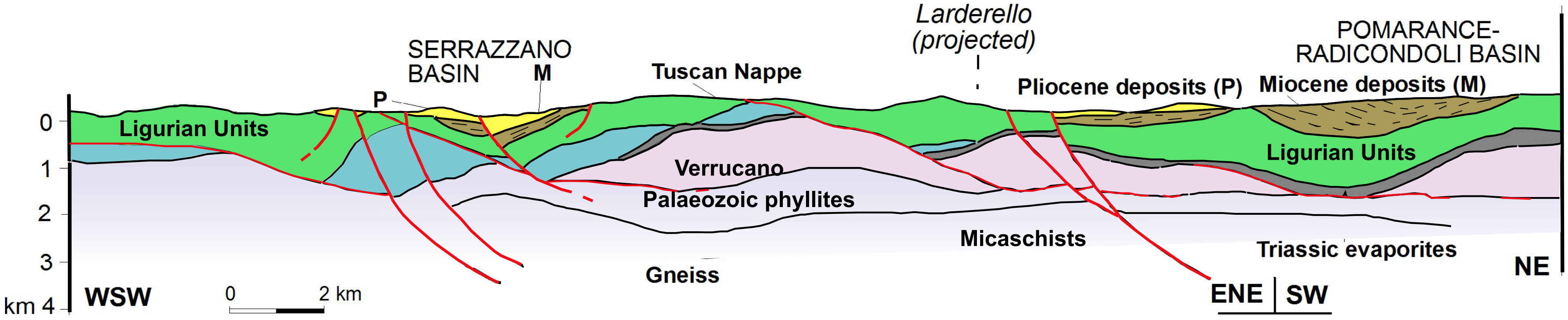
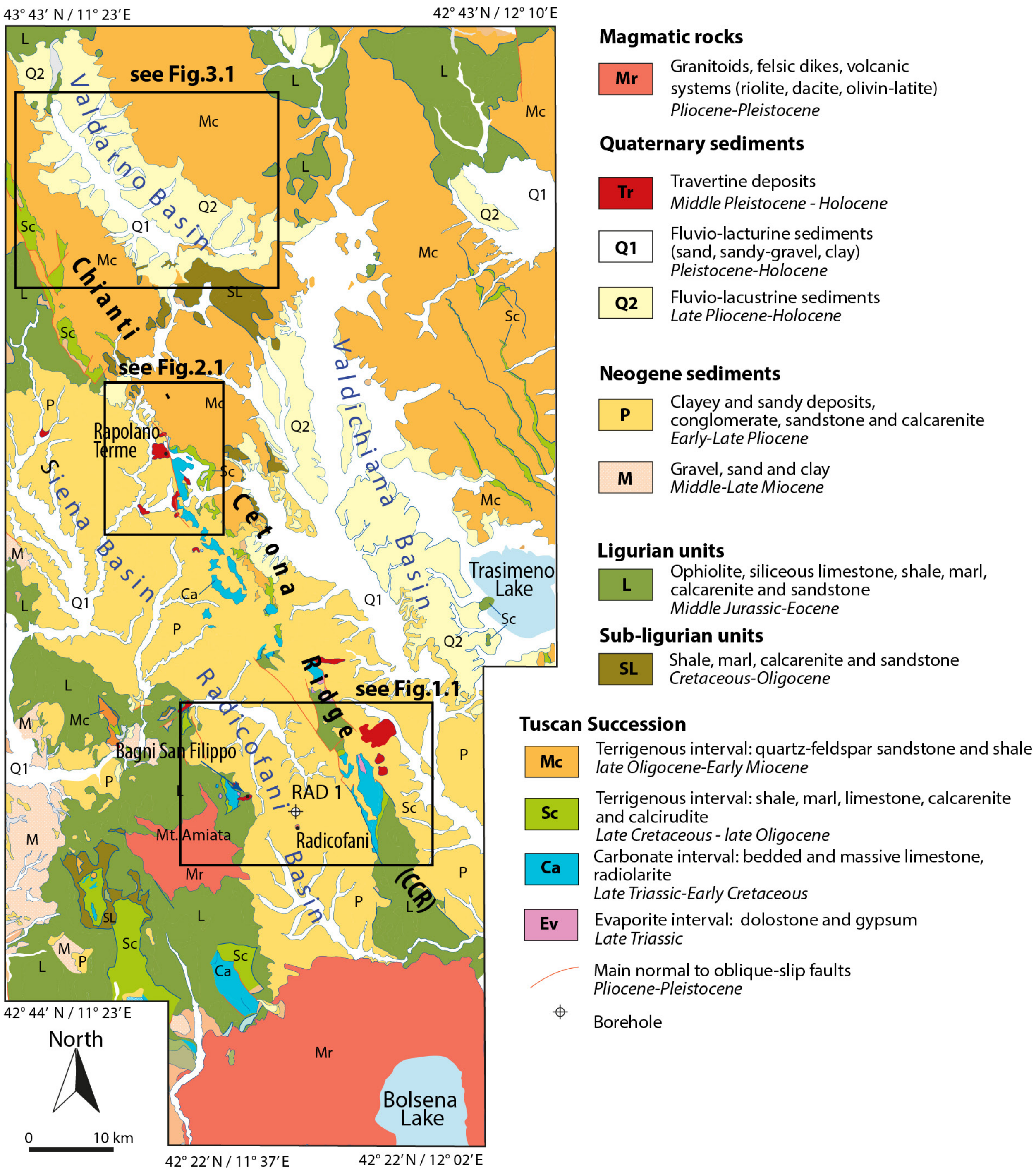


Fig. 0.3 - Geological section across the Larderello-Travale geothermal area in southern Tuscany, highlighting the geological process which gave rise to the thinning of the overthickened continental crust and the lateral segmentation of the previously stacked tectonic units (after Baldi et al., 1994 modified).



and related structural depressions (Liotta, 1991). The whole extensional process produced a basin-and-range structure clearly recognisable in southern Tuscany, where major NNW-SSE trending ridges occur. These are (from the west): the peri-Tyrrhenian Ridge, the Middle Tuscan Ridge (MTR) and the Chianti-Cetona Ridge (CCR) (Figs. 0.2, 0.4).

These ridges developed during the Late Miocene and separate basins filled by syn-tectonic deposits (Brogi et al., 2005; Brogi and Liotta, 2008; Brogi, 2011), which substratum is mainly characterised by the Ligurian units directly overlying the Upper Triassic evaporites and/or the Palaeozoic succession (i.e., "*serie ridotta*" *Auct*., e.g., Decandia et al., 1993). Since the Zanclean, marine sediments filled these relict structural depressions, which were also affected by normal faults until Quaternary (Sagri et al., 2004; Brogi, 2011, 2020; Martini et al., 2021).

The Tuscan Neogene basins differ in age, as well as in their depositional sequences. Those located SW of the MTR (named "central" basins by Martini and Sagri, 1993) developed since Late Miocene and contain thick (up to 2000 m) continental and marine deposits. Those NE of the MTR (named "peripheral" or "intermontane" by Martini and Sagri, 1993; Martini et al., 2001) have developed since Pliocene and Pleistocene, to the west and east respectively. They

Fig. 0.4 - Geological map of the central-eastern sector of Tuscany (redrawn from Carmignani et al., 2004).

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contain relatively thin (about 600 m) continental successions. Over a basal continental, gravelly, peat-bearing succession, the "central" basins contain marine, gypsum-bearing, Upper Miocene deposits, in turn overlain by marine Pliocene sediments. The "peripheral" basins have similar basal succession overlain by continental Upper Miocene deposits, in turn overlain by marine Pliocene sediments. During the Quaternary, all basins were characterised by a widespread, fluvial-lacustrine terrigenous deposition, especially in the "peripheral" basins. In southern Tuscany these sediments are often interbedded with carbonate deposits (lacustrine limestone, calcareous tufa and travertines). This deposition is strictly linked to the regional karstic groundwater circulation that characterises the Tuscan carbonate-rich formations, and by the geothermal fluids that in some cases flow up at the surface and which are related to the widespread magmatism (Brogi et al., 2016). In fact, Late Miocene-Pleistocene magmatism (mainly anatectic with minor contributions of deeper origin) migrated toward East from the Tyrrhenian Sea to Tuscany-Northern Latium (Peccerillo et al., 2001) as the basin development (Martini and Sagri, 1993). In this framework, shallow granitoids and volcanic complexes took place, making the continental crust of the inner zone widely intruded by felsic plutons (Serri et al., 1993; Westerman et al., 2004; Dini et al., 2005). Presently, the crustal and lithospheric thickness of the inner Northern Apennines (i.e., Tyrrhenian area and southern Tuscany) results strongly thinned (22–26 and 40–50 km, respectively; Calcagnile and Panza, 1981; Di Stefano et al., 2011); high heat-flow and geothermal anomalies (Della Vedova et al., 2001) are also present, with local peaks climaxed in the Larderello and Monte Amiata geothermal areas (Batini et al., 2003).

Large fluxes of crustal and mantle-derived CO_2 released in geothermal and volcanic areas, caused by large scale metamorphic processes in the pluton-hosting rocks (Minissale and Sturchio, 2004) and in the upper mantle, confirming the western Central Italy as a globally relevant source of (mantle and crustal derived) carbon (e.g., Mancini et al., 2019b). Many thermal springs of southern Tuscany deposit travertine due to the $CaCO_3$-oversaturation, occurring when the thermal water flows out at the surface, due to the CO_2 leakage (e.g., Luo et al., 2022). Travertines are still depositing in correspondence of active thermal springs or occur in "fossil" hydrothermal systems (Minissale, 2004).

Main climatic and environmental changes

The cooling from the late Eocene explains the passage from the so-called "Greenhouse" to an "Icehouse" world and to concomitant major modifications in land and ocean biota, at a global scale (e.g., Zachos et al., 2001; Westerhold et al., 2020). In the Mediterranean area, changes in the values of both temperature and precipitation, associated to the maximum expansion of the Arctic ice at 2.6 Ma, together with the new topography resulting from the rise of the Apennines, are factors certainly inter-related in the process that produced a progressive disappearance of tropical and subtropical taxa, the spread of both altitudinal arboreal taxa and herbs, and the creation of new competition patterns in the biological communities, as pointed out by palynological analyses (e.g., Bertini, 2010; Combourieu-Nebout et al., 2015, Magri et al., 2017; Bertini and Combourieu-Nebout, 2023).

Cooler climatic conditions, typical of the Pleistocene, gradually started to appear in the course of the warm Pliocene, which includes the short-lived 'warm blip' centred close to 3.0 Ma, referred to as the "mid-Piacenzian" warm interval (e.g., Dowsett et al., 2013). In fact, from about 2.8 Ma Glacial/Interglacial (G/I) cycles, at 40-kyr band (obliquity-dominated), started in coincidence with the expansion of the Arctic ice. During glacials, cyclic arid conditions favoured the expansion of open vegetation such as steppes, especially along the Mediterranean coasts. However, in Northern Italy, glacials were mostly typified by an increase in montane coniferous taxa (e.g., Lona, 1950; Lona and Bertoldi, 1972; Bertini, 2001, 2010) – the same as in elevated sites – without significant expansion of open vegetation in space and time. The progressive disappearance of subtropical to warm temperate taxa became more evident from the Gelasian under the effects of G/I cycles. The transition to the Middle Pleistocene was marked, during the so-called Early-Middle Pleistocene transition (Head and Gibbard, 2015), by a drop in temperature and by a change in the dominant orbital cyclicity, from 40 kyr to quasi-100 kyr (eccentricity-dominated). The effects on the flora of such increasing long-term average global ice volume, and the establishment of strong asymmetry in global ice volume cycles were amplified. Taxodioideae, *Cathaya* (plus *P. haploxylon* type), *Tsuga*, *Cedrus*, *Carya*, *Pterocarya*, along with other taxa, progressively disappeared throughout the Pleistocene (Bertini, 2010; Magri et al., 2017). Their different timing of extinction was explained by the presence of climate gradients linked to the latitudes, altitudes, and physiography of the sites. During the Middle and Late Pleistocene vegetation communities were marked by conifer forest expansion in the north and the expansion of deciduous *Quercus* forest, with *Fagus* and *Betula*, in the south. Herbs including steppic taxa expanded especially during glacial stages. Further cooling occurred at 0.4–0.5 Ma, with decreasing precipitation and winter temperatures during glacials. Interglacials remained relatively humid. Modern-day Mediterranean summer drought was established during the Holocene after 4.2 ka, following humid Early- to Middle-Holocene climates (Combourieu-Nebout et al., 2015).

During the three-days excursion we will discover the importance of the selected basins for the reconstruction of the complex environmental and climate changes during the Piacenzian and Quaternary, in central Italy. The study of the effects of both climate and tectonics as well as their interactions is indispensable for a comprehensive interpretation of the depositional environments. In particular, the palynological evidence allows the description, in high detail, of the effects of the last Pliocene warm interval and the instauration of G/I cycles after 2.6 Ma on lacustrine to fluviatile depositional systems of the intermontane Upper Valdarno Basin (see day 3) (e.g., Bertini, 2013). At the same time, palynological studies in the terrestrial carbonates of the Rapolano area (Ricci, 2011) provide an impressive palaeovegetational and palaeoclimatic documentation for the last ca 130 ka, including the Eemian (see day 2).

DAY 1 - THE RADICOFANI BASIN AND THE MONTE AMIATA VOLCANO

Leaving Rome, we follow the E35 (A1) highway towards Florence. Exit at "Chianchiano- Chiusi", then follow the SP478 to Sarteano and successively arrive to Radicofani (Stops 1.1-1.2). In the afternoon we move towards Bagni San Filippo (Stops 1.4-1.5) following the SP478, reaching the SS2 (direction to Siena) and the SP61. At the end, we will retrace the SP61 to the SS2 (Cassia Road) toward Siena, reaching Rapolano Terme after Torrenieri, San Giovanni d'Asso (SP14) and Asciano (SP60) (Fig. 1.1).

Monte Amiata is the largest volcano of Tuscany. Its volcanic products are effusive and of silicic composition (Peccerillo, 2003). They cover an area of about 90 km^2 and lie on the Ligurian and Tuscan units. According to Ferrari et al. (1996) and Cadoux and Pinti (2008), volcanic activity developed in three main phases between 303 and 190 ka (Fig. 1.2): 1) the Basal Trachydacitic Complex unit (BTC); 2) the Domes and Lava flows Complex (DLC); and 3) the Olivine Latitic Lava flows (OLL).

The BTC is the most voluminous volcanic unit of the volcano (between 13.5 to 18 km^3); it extends on 90 km^2 and its average thickness is 150-200 m. Ferrari et al. (1996) distinguished two sub-units: a thick massive basal unit (Lower BTC) and a blocky upper unit concentrated in two linguoids elongated NW and SE (Upper BTC).

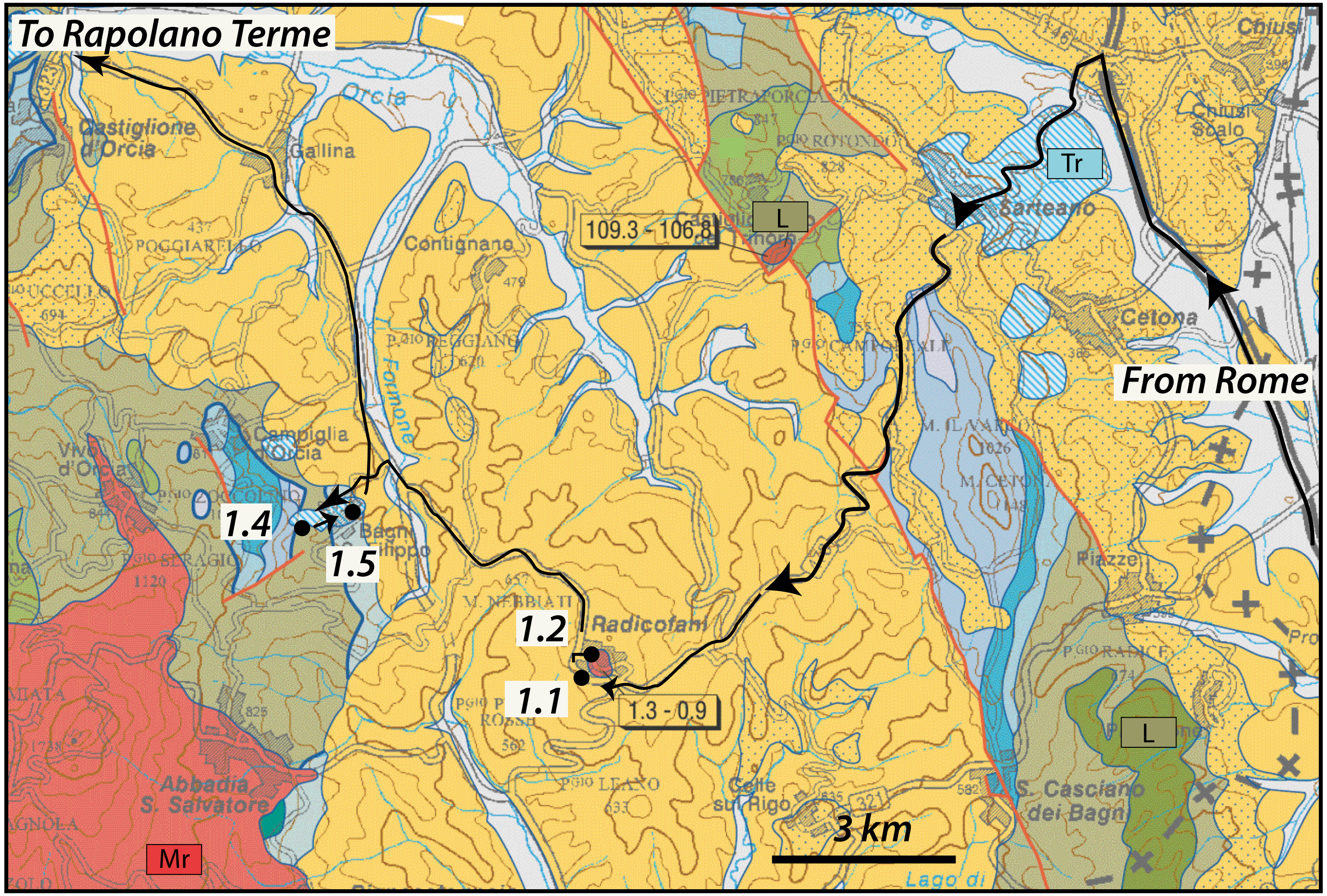

Fig. 1.1 - Itinerary of the first day field trip (redrawn from Carmignani et al., 2004).

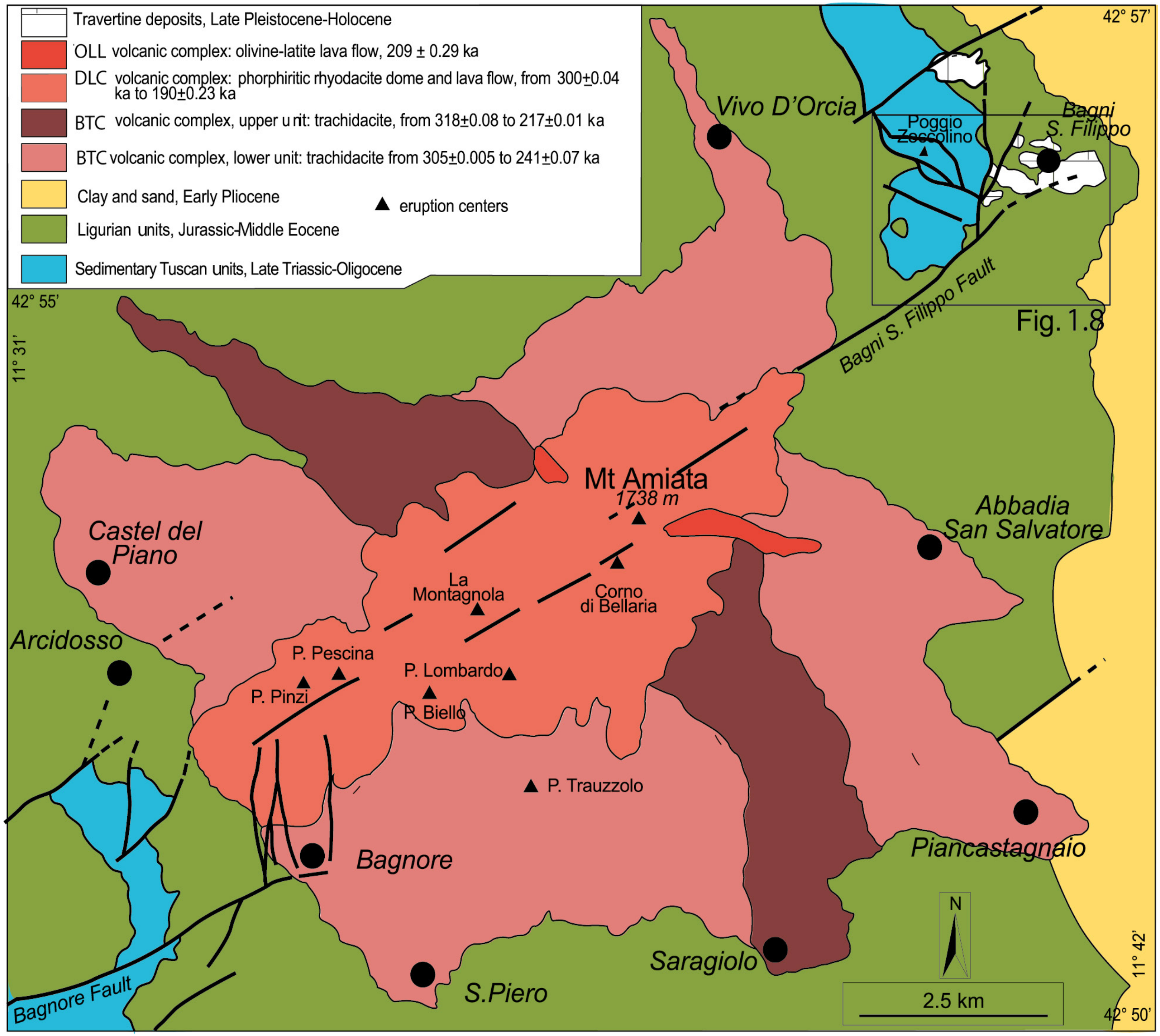

Fig. 1.2 - Geological map of the Monte Amiata and surroundings indicating the location of eruption centres (modified from Brogi et al., 2010a).

Contrasting views exist about the nature and eruption style of the BTC. Indeed, this unit displays equivocal field characteristics between an ignimbrite and a simple lava flow (for more details, see Ferrari et al., 1996). According to Mazzuoli and Pratesi (1963), the BTC is a rheomorphic ignimbrite implying therefore an explosive-type eruption, while Barberi et al. (1971) identified it as a simple silicic lava flow (i.e., effusive emplacement). Ferrari et al. (1996) proposed an initial weak explosive activity, rapidly decreasing and producing a final stage dominated by blocky lava flows. Whatever its origin, all the Authors agree about the high-temperature emplacement of the BTC. The extrusion of summit lava domes and a few lava flows discharging from the domes characterise the second phase of activity (DLC). Finally, two small latitic lava flows (OLL) («Ermeta» and «Pian delle Macinaie» lava flows) were emplaced at the summit. All these volcanic products were controlled by a main NE-SW striking crustal structure named as the Monte Amiata Fault (Brogi, 2008) corresponding with a brittle shear zone with left-lateral oblique-slip

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movement (Brogi and Fabbrini, 2009). The north-eastern prosecution of the Monte Amiata Fault has also been indicated as Bagni San Filippo Fault controlling a widespread circulation of hydrothermal fluids (Brogi et al., 2010a).
The Monte Amiata volcano developed on a N-S trending ridge separating two Late Miocene-Pliocene basins: the Cinigiano-Baccinello and Radicofani basins, to the west and east, respectively. The Radicofani Basin was the result of a polyphase tectono-sedimentary evolution (Liotta, 1996; Martini et al., 2021) and is characterised by widespread Zanclean-Piacenzian marine sediments (Bossio et al., 1993; Liotta, 1994, 1996; Liotta and Salvatorini, 1994; Pascucci et al., 2006) overlying Middle–Upper Miocene deposits (Fig. 1.3) never exposed in the basin, but drilled by the Radicofani 1 and Paglia 1 boreholes (Bossio et al., 1993; Liotta, 1996). On the contrary, part of the Miocene succession is exposed in the eastern shoulder of the basin (Brogi, 2020), where the filling sediments are juxtaposed with the Tuscan and Ligurian Units by a regional normal fault active during the Zanclean (Liotta, 1996).
The Monte Amiata Fault also influenced the development of the Cinigiano-Baccinello and Radicofani basins. Its activity continued until late Quaternary as indicated by the post-190 ka tectonically controlled cinnabar mineralization and the Present travertine deposition. Such a main

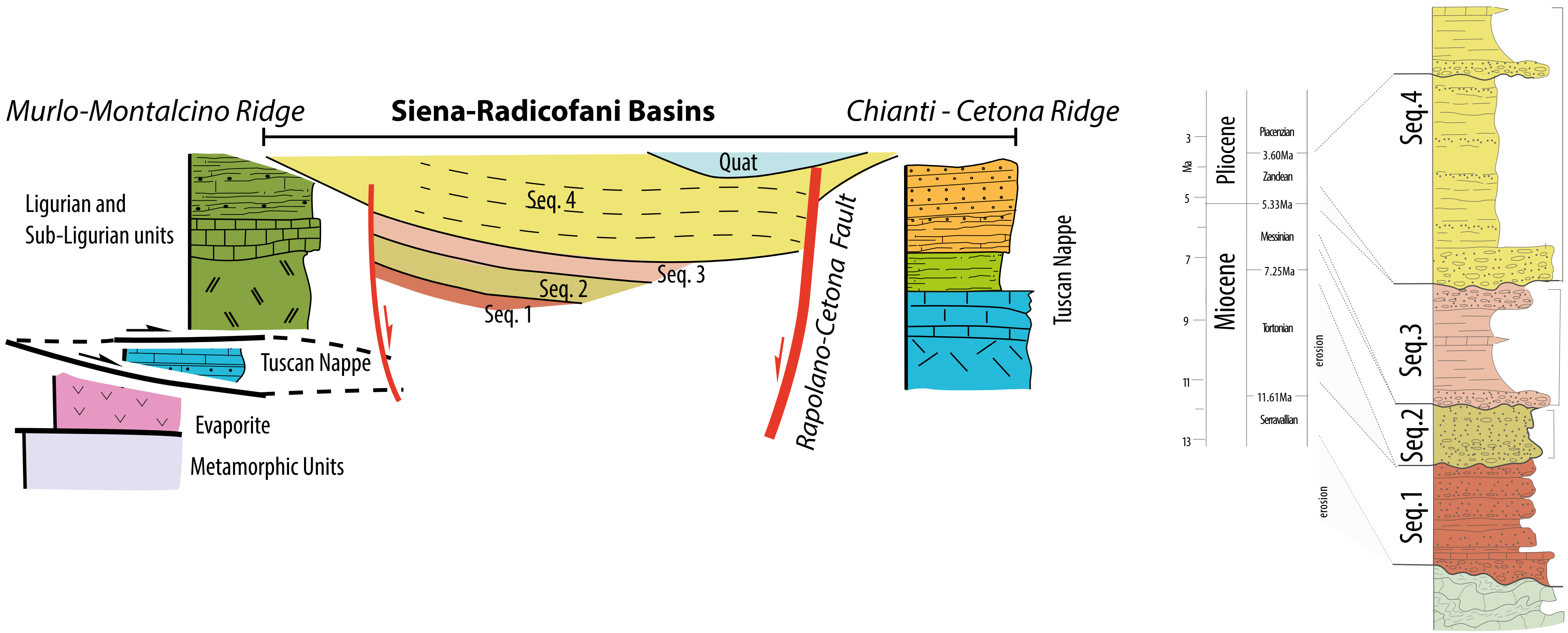

Fig. 1.3 - Schematic geological section and stratigraphic columns of the Neogene sedimentary infill of the Siena-Radicofani Basin.

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fault shows its lateral extension in two minor faults affecting the substratum of the volcano, referred to as the Bagnore Fault and the Bagni San Filippo Fault, to the south-west and north-east of the volcano edifice respectively (Brogi et al., 2010a). In addition, the Bagni San Filippo Fault has a parallel segment to the north, in the Campiglia d'Orcia area. The Bagni San Filippo Fault and the northern one, both trending SW-NE and steeply dipping to the SE, are linked through a releasing step-over zone (Brogi and Fabbrini, 2009; Brogi et al., 2010a) where widespread post-volcanic hydrothermal phenomena (gas vents, thermal springs, travertine deposition and Hg-As sulphides epithermal mineralisation) are concentrated since Late Pleistocene-Holocene. Travertine deposition and gas vents are still active. Abundant CO_2 emissions, very dangerous (total singular emission can exceed 10-20 T/day) are located along the Bagni San Filippo Fault. The linkage zone connecting the two main faults is about 2 km wide. Hg sulphide was mined along the Bagni San Filippo Fault (Pietrineri Mine) for almost a century (Arisi Rota and Vighi, 1971), suggesting its importance as a structural conduit for hydrothermal fluid flow also during latest Pleistocene. The faults within the linkage zone have three different orientations. The main trend is SW-NE, with a dominant left-lateral transtensional displacement. Kinematic indicators are mostly given by striae with calcite fibres and Riedel fractures. The other two groups of faults strike N160° and N10° with normal and left-lateral and right-lateral transtensional displacement, respectively. A mutual overlap of transtensional and near-normal kinematic indicators is often observed on the shear surfaces, suggesting the activation of the pre-existing fault planes in a temporary extensional context. Widespread hydrothermal circulation and related travertine deposition are strictly related to permeable conduits related to the two main SW-NE trending left-lateral strike- to oblique-slip faults and their linking structures.

STOP 1.1 - Radicofani Basin: Neogene evolution and architecture

Coordinates: Lat. 42°53'45.58"N, Long. 11°46'0.92"E

TO OBSERVE:

- Panoramic view of the basin and interaction with volcanic features.

TO DISCUSS:

- Tectonic versus climate depositional control of the Radicofani Basin.

The Radicofani Basin developed mainly during the Late Miocene—Early Pliocene. Its eastern margin is bounded by a normal fault system that cut a thrust anticline affecting the Tuscan and Ligurian units. To the north, the Radicofani Basin is delimited by a NE-SW trending threshold (the so called "Pienza high"), corresponding to a transfer zone. To the west it is delimited by a normal fault system that juxtaposes the filling sediments against the Ligurian units (mainly), whereas to the south the Radicofani Basin is covered by Quaternary volcanic units.
The basin is a polyphase extensional basin, which experienced differential tectonic and associated sedimentation. It originated as a bowl-shaped structural depression during late Serravalian-Zanclean extensional tectonics and was subsequently deformed by high-angle normal

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faults (HANFs) whose activity started in the Zanclean and more specifically during a time interval between 5.08 and 4.52 Ma. These HANFs provided the accommodation space for the total, ~2700 m thick basin fill. Sea level fluctuations that led to the repeated development of the cross-sets may also have been influenced by climatic or eustatic changes. The tectonic-induced signatures are recognizable in the Pliocene marine and continental successions. In marine-dominated successions, tectonic influence is expressed by: (i) local abrupt facies superimposition (Martini et al., 2021) indicative of relative sea-level drops that are not coeval with climate and eustatic fluctuations recognised in other nearby basins; and (ii) transgressive settings (Martini et al., 2021) characterised by high sediment yields, in contrast to sediment starvation as classically expected for climate-induced transgressive phases.

Fig. 1.4 - Panoramic view of the Radicofani area and of the Monte Amiata.

Continental successions are mostly exposed in eastern basin margin, where thick (~600 m) alluvial fans developed in relay areas between boundary faults and transverse faults and transfer zones (Pascucci et al., 2006) suggesting changes in accommodation/sediment supply ratio during times (Martini et al., 2021). Both marine and continental successions commonly record the creation of accommodation space (tectonic control) combined with an increase in sediment supply, while phases during which climatic factors dominate accommodation space generation (i.e., transgressions) are typically characterised by sediment starvation (Fig. 1.5).

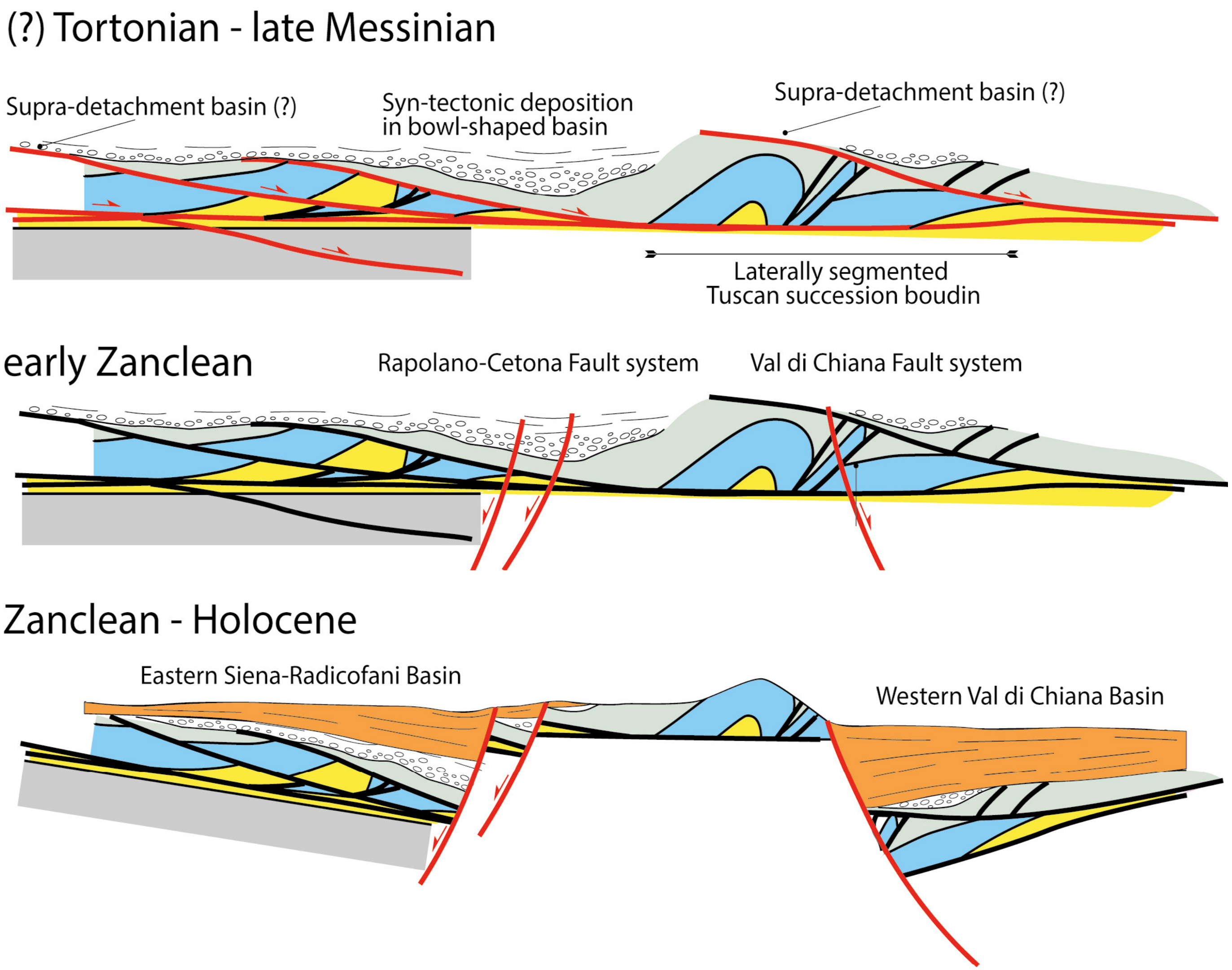

Fig. 1.5 - Cartoon showing the evolution of the Siena-Radicofani Basin and of the close Monti del Chianti - Monte Cetona ridge and Valdichiana Basin: from (?) Tortonian to late Messinian the detachment evolution produced the segmentation of the previously stacked units and the development of syn-tectonic bowl-shaped tectonic depressions filled by continental to brackish deposits. Since early Zanclean, west- and east-dipping high-angle normal faults dissected the previously developed structures and deposits. During early Zanclean-Piacenzian, the Siena-Radicofani and Valdichiana Basin developed being separated by the Monti del Chianti-Monte Cetona horst. From Piacenzian, orthogonal faults (i.e., transfer faults related to younger tectonic activity in the eastern sector of the Northern Apennines) interrupted the continuity of the Pliocene normal faults (modified after Brogi, 2020 and Martini et al., 2021).

STOP 1.2 - Radicofani: the Volcanic Neck (Pleistocene)

Coordinates: Lat. 42°53'56.74"N, Long. 11°45'59.08"E

TO OBSERVE:

- Characteristic of the magmatic rocks.

TO DISCUSS:

- Interaction of magmatic activity, with tectonic and basin evolution.

The Radicofani volcano (1.3-1.0 Ma; $^{40}Ar/^{39}Ar$ and K-Ar by: Barberi et al., 1971; Pasquaré et al., 1983; D'Orazio et al., 1991) belongs to the Tuscan Magmatic Province (Peccerillo, 2003) and consists of a mantle-derived basaltic body developed on top of the Pliocene sediments filling the Radicofani Basin (Disperati and Liotta, 1998; Bonini and Sani, 2002; Acocella et al., 2002). Radicofani is a small volcano formed by a 90 m-high well-preserved volcanic neck and by several lava flows scattered around the neck (Fig. 1.4). Remnant of original volcanic edifice, probably a cylinder cone a few hundred meters high and now completely eroded, consists of thin layer of red scoriae preserved on the edge of the top of the neck. Columnar jointing is present in the middle and lower portions of the neck, affecting grey and dark grey aphyric to sub-aphyric basalt (Conticelli et al., 2011) (Fig. 1.6).

Fig. 1.6 - Outcrop of the Radicofani neck, with its columnar jointing affecting grey and dark grey aphyric to sub-aphyric basalt.

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STOP 1.3 - Bagni San Filippo: evolution of the Monte Amiata Volcano and its geothermal system (Pleistocene)

Coordinates: Lat. 42°55'35.59"N, Long. 11°41'38.40"E

TO OBSERVE:

- Late Pleistocene travertine deposits: geometry and lithofacies.

TO DISCUSS:

- Interaction between volcanic activity, tectonic and travertine deposition.
- Evolution during Pleistocene.

The Monte Amiata volcano-geothermal area, where Bagni San Filippo is located, developed in a severely extended continental crust sector (Brogi, 2008) where a magmatic body emplaced at mid-upper crustal level. The depth of the intrusion roof was estimated at about 6-7 Km (Gianelli et al., 1988). Based on stratigraphic and regional considerations, emplacement is related to the Early Pliocene (Jacobacci et al., 1967; Pasquarè et al., 1983). The emplacement of the magmatic chamber, as well as the volcanic eruptions were controlled by extensional faults developed in an extensional setting. Since Middle Miocene, extension in the Monte Amiata area gave rise to the lateral segmentation of the Tuscan Nappe, which resulted in three main "boudins" (Fig. 1.7). The Bagni San Filippo is located in the eastern margin of a Tuscan Nappe boudin (Poggio Zoccolino Mt.) in an area where the Ligurian units directly overlie Upper Triassic evaporites, near the junction zone between the eastern ramp crossing the Mesozoic carbonate and the basal detachment.

Travertine bodies are located on the eastern slope of the Poggio Zoccolino Mt., ranging at different quotes between about 670 and 500 m a.s.l. It is possible to distinguish two sub-areas: an upper

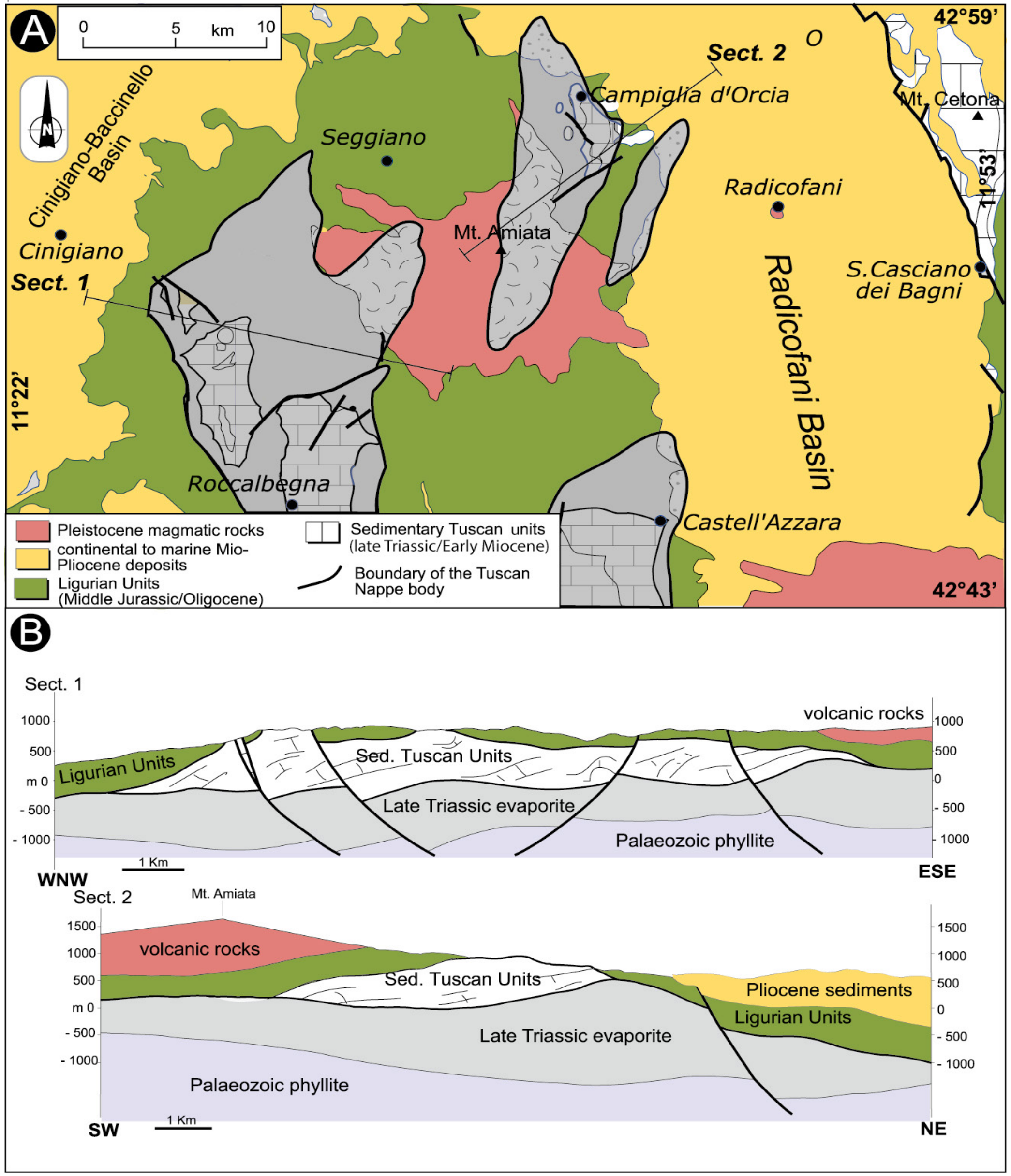

Fig. 1.7 - A) Geological sketch map of the Monte Amiata volcanic complex and its surroundings showing the location of the laterally segmented sedimentary Tuscan Units. The buried boundaries of the Tuscan Units were reconstructed through geothermal boreholes and reflection seismic lines (modified from Brogi et al., 2005). B) Geological cross-sections through the Monte Amiata area (modified from Brogi et al., 2010a).

area where all travertine deposits are fossil, and a lower one where travertine deposition and CO_2 emissions are active (Fig. 1.8).

The upper travertine, in correspondence of the Pietrineri village, is a fan-shaped body, with a top, sub horizontal surface located at a quote of 652 m a.s.l. Several abandoned quarries evidence its internal geometry with sub horizontal-to gentle inclined bedding composed of monotonous sequence of microbialites alternated with centimetric crystalline crust boundstones. Local unconformities and palaeosol evidence interruptions of the sedimentation. These lithofacies, present in varying proportions, are characteristic of a very gentle slope depo-environment (Mancini et al., 2019a) flowing toward east, locally evolving to small vertical terrace walls, pool and rims confining the margins of the pools (Terraced Slope depo-element) (Fig. 1.9). A radiometric dating of the upper area (Minissale and Sturchio, 2004) refers it to the Late Pleistocene (55 ka).

To the east, this travertine body only apparently insists in another E-W elongated body, about 25 m thick, located in correspondence of the San Filippo retreat. Original morphology of this latter is obliterated by an intense quarry activity and a partial erosion in its southern side due to the presence of the Rondinaio Creek that delimit it. Crystalline crusts boundstone of a Slope depo-element (Mancini et al., 2019a) are the dominant travertine lithofacies evidencing a main discharge towards South and East. Secondly, palustrine facies (coated bubble, reed travertine, pisoids, microbialite deposits) are also present. Remarkable is the presence of lenticular layers of fluvial conglomerates interbedded in the travertine vertical, and observable preferentially in the lower portion of the westernmost travertine sequence, while in the eastern and southern area (near the Rondinaio Creek) they are interbedded even in upper portion. In correspondence of the axial portion of the body, E-W oriented, vertical calcite veins (Capezzuoli et al., 2018) testify for local area of upwelling thermal waters, identifying a fossil fissure ridge body. As to other Apennine areas (see Janssen et al., 2020, as example), distribution of the travertine bodies at different quotes evidence that the hydrological circuit of the thermal waters has changed over time. The rising of older travertine and/or the lowering of the emergence elevation of the thermal water can be due to several reasons, such as isostatic uplift, changes in the base level of the regional karstic circulation, and changes in the sea level.

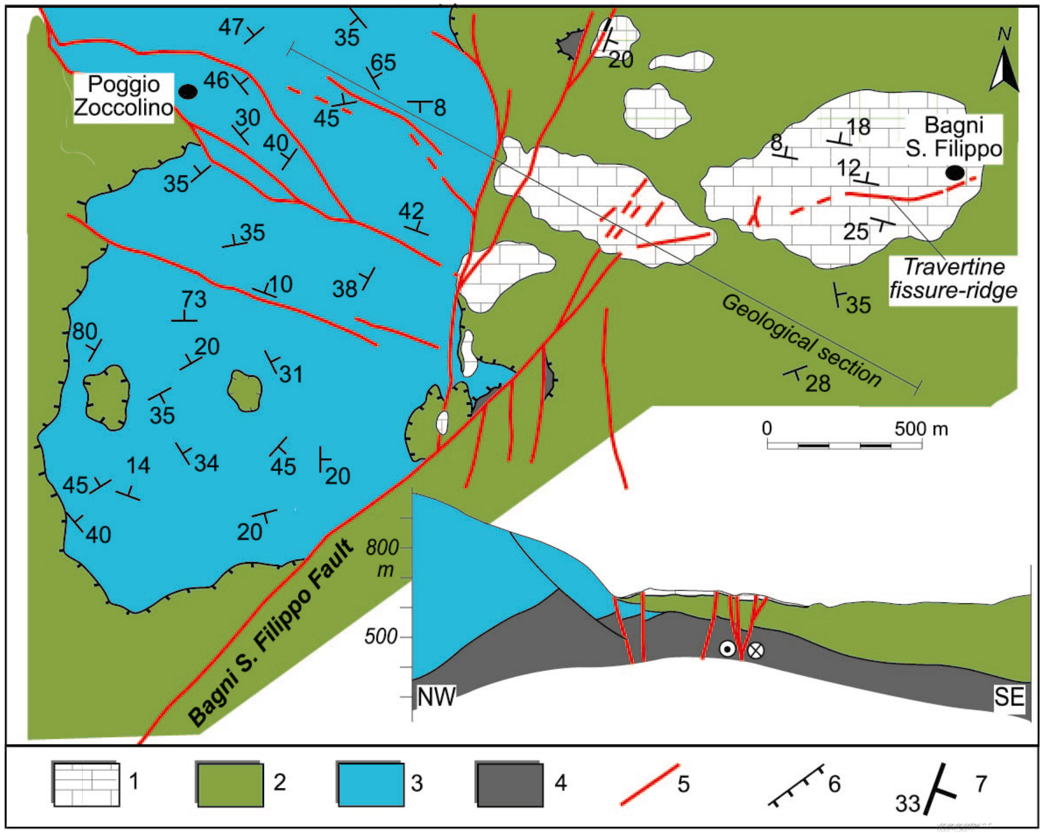

Fig. 1.8 - Geological sketch map and cross-section of the Bagni San Filippo Fault and surroundings. The horse-tail splays and the en-echelon array of minor faults are shown. Their arrangement indicates a left-lateral displacement along the master fault (modified from Capezzuoli et al., 2011).

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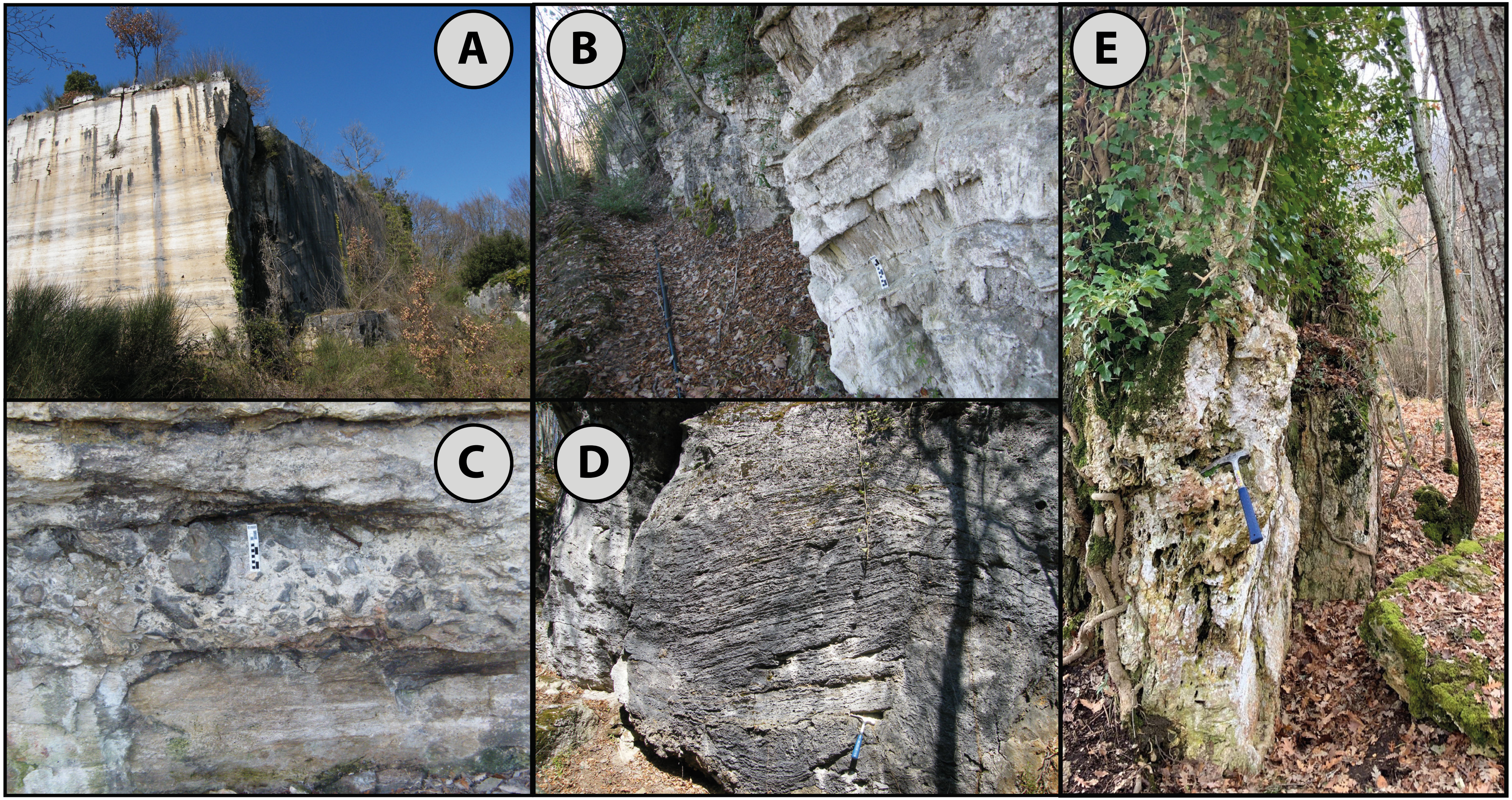

Fig. 1.9 - A) Abandoned quarry in the upper part of the travertine system with sub-horizontal bedding of a very gentle slope environment; B) thick sequence of crystalline crusts in the lower part of the system; C) layers of conglomerates intercalated to the travertine deposits near the San Filippo retreat; D) laminated microbial mats of gently-inclined slope system near the San Filippo retreat; E) vertical banded travertine testifying for the upwelling conduit of the thermal water.

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STOP 1.4 - Bagni San Filippo: travertine of the Fosso Bianco Creek (Holocene)

Coordinates: Lat. 42°55'44.54"N, Long.11°42'11.47"E

TO OBSERVE:

- Active travertine morphologies and interaction with a fluvial environment.

TO DISCUSS:

- Active travertine deposition, lithofacies and their distribution.

The Rondinaio Creek delimits the upper fossil travertine bodies from the lowest and active body. The latter is represented by an extensive, around 90 m long, E-W elongated fissure ridge (Brogi et al., 2010a), with the Bagni San Filippo village located in correspondence of its eastern termination. The external morphology is characterised by an elongated, sub-horizontal top terrace mound shape at a quote of about 580 m and slope depositional systems mainly developed and flowing to the north (toward the Rondinaio Creek) and to the South and East (toward the Fosso Bianco Creek). Active thermal springs are located at the tips of the fissure ridge, in correspondence of its higher (western tip – Il Bollore spring) and lower portion (eastern tip – Bagni San Filippo spa). Between these two springs, the ridge is evidently fractured at the surface, forming a prolonged, E-W oriented fissure, up to 30 cm wide, with presence of thermal emission and left-lateral recent movement (also evidenced by cracking on a building located exactly along its trace). Thermal waters are naturally issuing from the western tip, while in the eastern one they are piped and then collected in the Fosso Bianco Creek, a small northeast-flowing stream with a length of about two kilometres and finally joining the Rondinaio Creek where travertine deposits are locally active (Fig. 1.10).

The most impressive portion is located immediately under the local spa, where after having served for the many spa activities, waters are discharged forming a large range of flowing-water depositional sub-environments. In the so-called White Whale, it is possible to observe a variety of these (waterfall, terraced to smooth slopes, stalagmite travertine). The interaction with the cold, karstic water of the creek offers a complete variety of the complex, rapid lateral variability of facies in distal portion of a thermal system. Many parameters (e.g., morphology, water discharge, plant colonization, water geochemical variations, flooding episodes) determine the resulting depositional sub-environment and its brief existence (Luo et al., 2021).

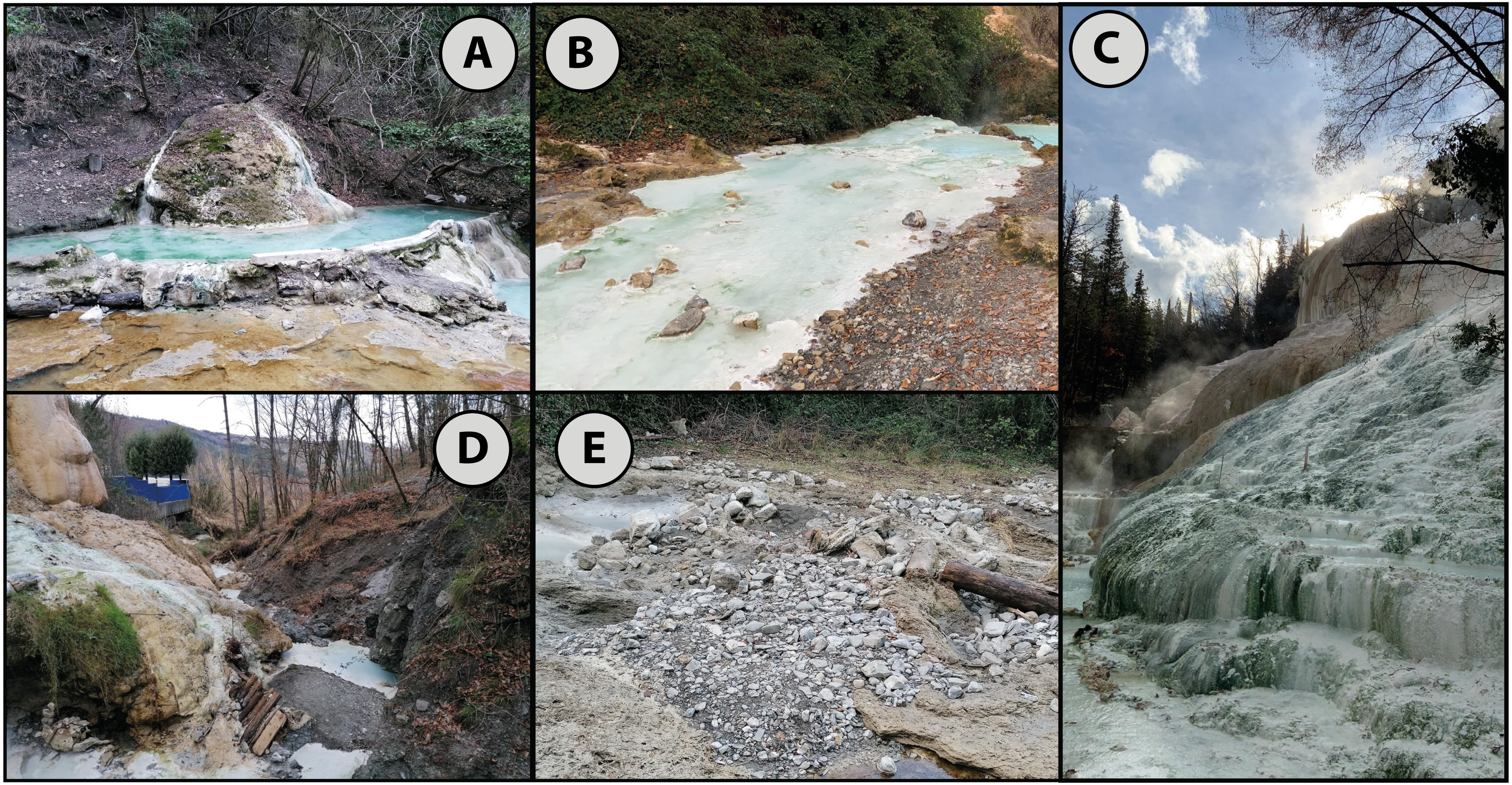

Fig. 1.10 - A) one of the thermal resurgences on the left bank of the White Creek; B) travertine deposition along the White Creek; C) view of the White Whale from the east; D) evidence of erosion occurring on the right bank of the White Creek during flooding event; E) pebble-to-boulder deposits accumulated along the White Creek during flooding events. These deposits will be successively binded and covered by new travertine deposition.

DAY 2 - THE RAPOLANO TERME AREA DURING THE PLIOCENE-QUATERNARY

We move in the surrounding of Rapolano Terme, between the small village of Armaiolo (to North) and Serre di Rapolano (to South) (Fig. 2.1).

Rapolano Terme stands along the Chianti-Monte Cetona Ridge (CCR), on the eastern margin of the Siena Basin, one of the biggest structural depressions of Tuscany, with a basin-fill succession ca. 100 m thick, consisting of Miocene continental deposits covered by a Pliocene marine succession ended up in the latest Piacenzian-early Gelasian (cf. Martini et al., 2016). In the area of Castelnuovo Berardenga (few km north of Rapolano Terme area), marine sedimentation mainly occurred in a coastal environment and presents three major relative sea-level changes occurred during the Piacenzian (Martini and Aldinucci, 2017). At the top, Quaternary terrestrial deposits (fluvial-lacustrine to travertine) are developed mostly on the eastern side (Fig. 1.3).

In the CCR, Upper Triassic–Lower Miocene successions belonging to the Tuscan succession, strongly affected by contractional and extensional structures, are widespread exposed. Late Oligocene–Early Miocene East-verging folds and associated reverse faults developed during stacking of the tectonic units. Since Middle Miocene the structures were crosscut by low angle normal faults that gave rise to local tectonic elisions within the Tuscan Nappe and Ligurian units. The low-angle normal faults were crosscut by high-angle normal faults one of which is the Rapolano Fault, corresponding to the northern prolongation of the fault system bounding the eastern margin of the Radicofani Basin (to the south of the Siena Basin). The Rapolano Fault (Zanclean–Piacenzian) juxtaposes Neogene sediments filling the Siena Basin against pre-Neogene carbonate

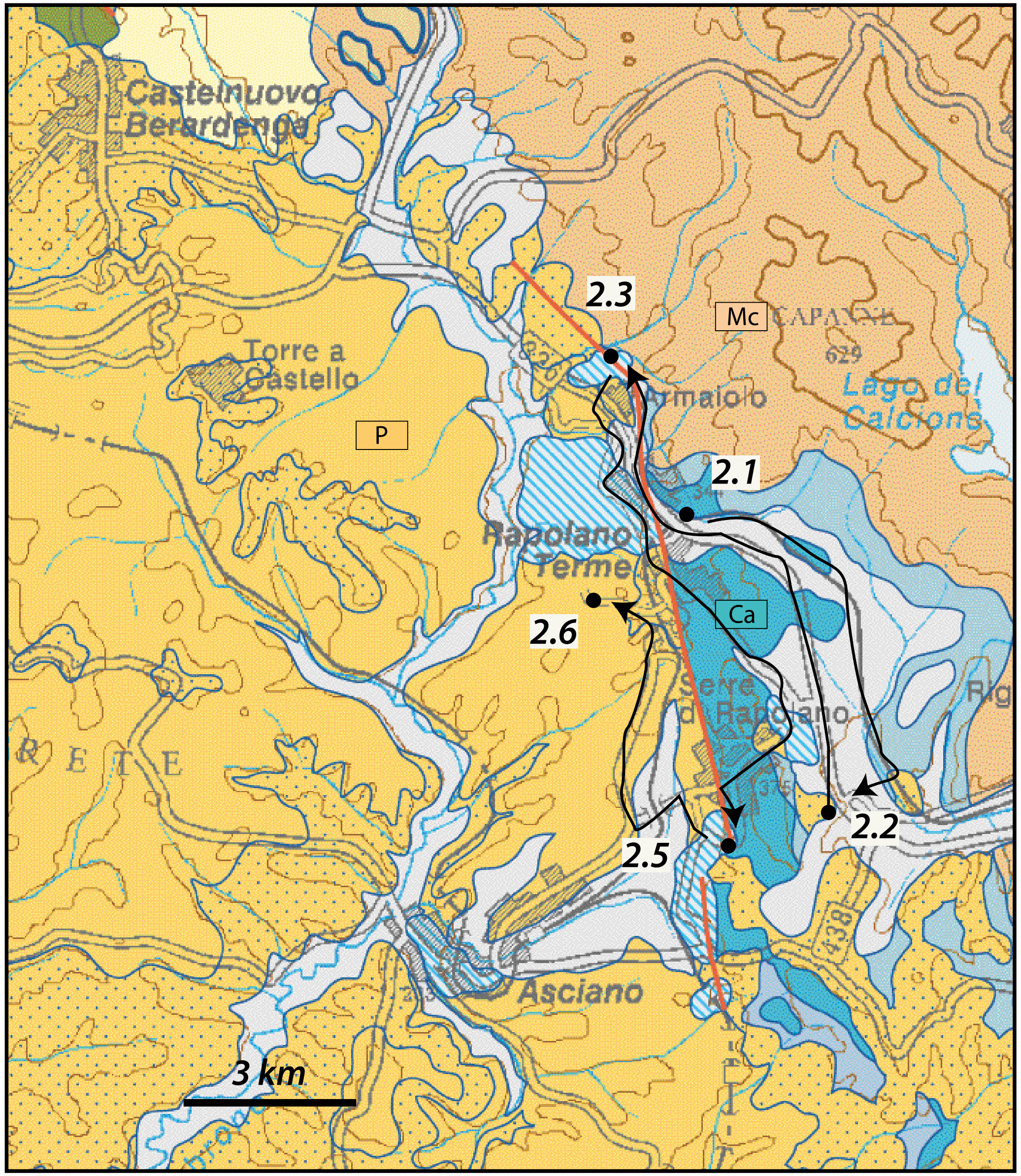

Fig. 2.1 – Itinerary of the second day field trip (redrawn from Carmignani et al., 2004).

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successions. Other minor faults, interrupting the continuity of the Rapolano Fault, are considered active during the latest Quaternary, and play(ed) a fundamental role for hydrothermal fluids circulation and discharge, as well as travertine deposition.

To East, the CCR delimits the Valdichiana Basin (Fig. 2.2).

This basin is filled up with a 1500–2000 m thick sedimentary succession, consisting of marine and alluvial deposits accumulated between the Pliocene and Pleistocene. In the northern sector of the Valdichiana Basin, marine sedimentation took place until late Piacenzian, and it was replaced by alluvial sedimentation during the Gelasian to Calabrian. The alluvial succession includes two major unconformity-bounded units consisting of sand and mud accumulated by a southward directed palaeo-drainage (Fig. 2.3).

To the North, the Valdichiana Basin continues in the Upper Valdarno Basin, and it is separated from the latter one by a 10-km-wide rocky ridge. The Upper Valdarno Basin is located about 35 km SE of Florence, between the CCR and the Pratomagno Ridge, and it is filled with a few hundred metres of palustrine, lacustrine, and alluvial deposits with three major unconformity-bounded stratigraphic units accumulated between the Piacenzian and the Late Pleistocene (for more detail, see Day 3).

The tectonic setting of these extensional basins is related to the Neogene-Quaternary structural evolution. The Pliocene-Pleistocene high-angle faults controlled the configuration of the current structural depressions (i.e., Siena, Valdichiana and Upper Valdarno Basins) and their Pliocene-Quaternary infill. In these areas, these faults can be categorised in three main systems depending on age, geometry, and kinematics: (i) Zanclean-Piacenzian N-S normal faults; (ii) Neogene-Quaternary NE-striking faults; and iii) Neogene-Quaternary NW-striking faults. Zanclean N-S normal faults are mainly represented by the Rapolano Fault, partially covered by Piacenzian marine sediments. It juxtaposes, in several places, the pre-Neogene succession of the CCR (Tuscan Nappe) with the Zanclean-Piacenzian marine sediments filling the Siena Basin. Similar features characterise also minor faults associated to the Rapolano Fault. The maximum vertical offset of the Rapolano Fault was estimated in about 400 m on the basis of seismic profiles interpretation. These N-S faults are interrupted by NE- and NW-striking faults, dissecting the Piacenzian marine sediments and Late Pleistocene-Holocene travertine deposits and supporting the hypothesis of active tectonics in the whole area. Furthermore, NE- and NW-striking faults play a role in controlling the geothermal fluid circulation, as well as the location of thermal springs and travertine deposits. These faults controlled also the late geomorphological evolution of the study area, mainly characterised by the Ambra Valley and Sentino Basin.

In particular, the Ambra Valley crosses the CCR, linking Siena and Upper Valdarno basins and its trace is mostly controlled by NE-striking fault system that is part of the so-called “Arbia-Valmarecchia Line”, a brittle shear zone characterised by anastomosed fault segments, which interfered with the continental sedimentation during the Quaternary. The Sentino Basin connects the Siena and Valdichiana basins and developed in response of the activation of several NW- and NE-trending faults. Their interplay gave rise to the peculiar zig-zag shaped structural depression, controlling the continental sedimentation as illustrated in the next paragraph. Both NW- and NE-striking faults are characterised by a dominant left- and right-lateral oblique-slip kinematics.

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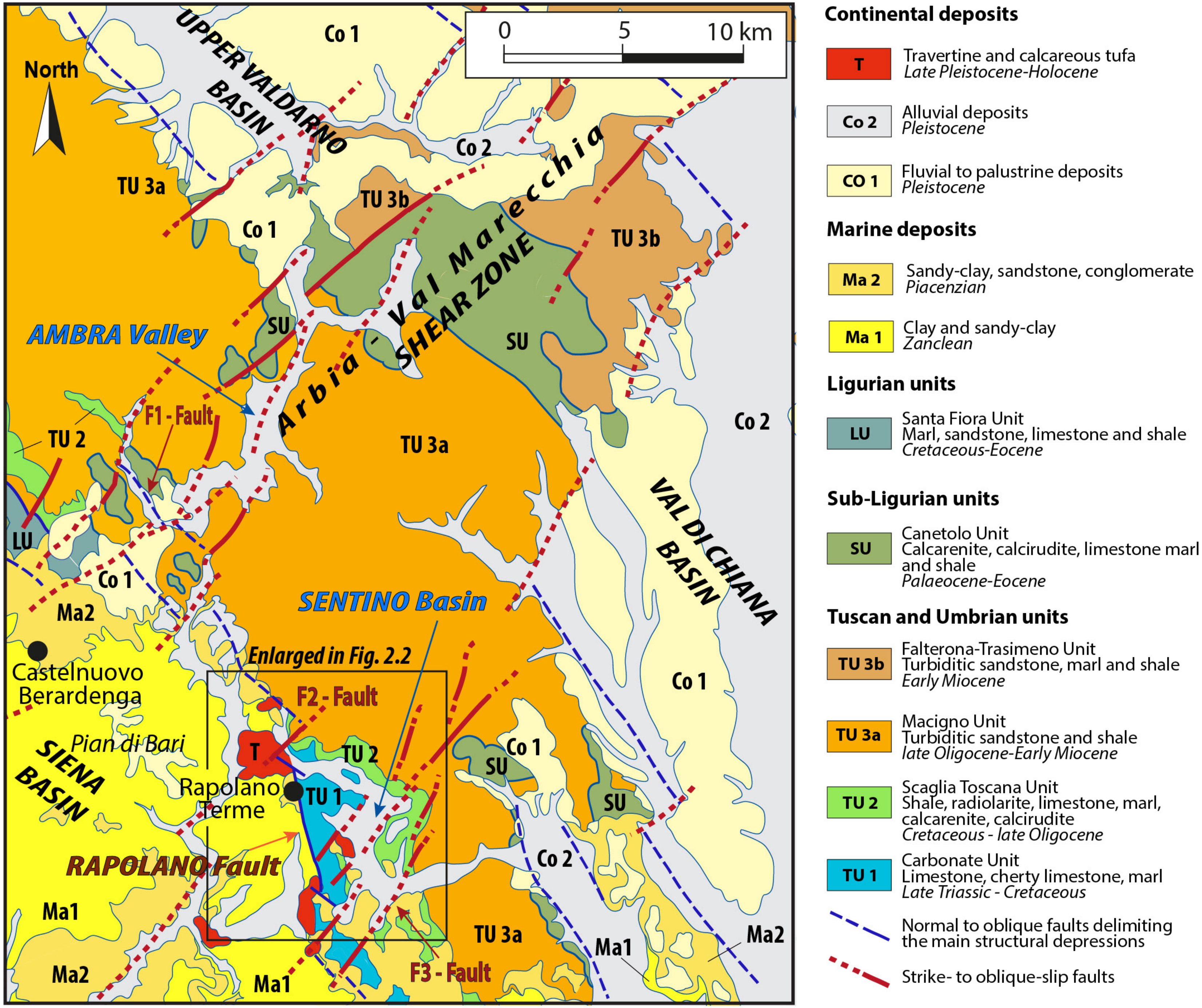

Fig. 2.2 – Geological map of the Rapolano Terme area with indicated the enlarged area of Figure 2.4 (modified from Ghinassi et al., 2021).

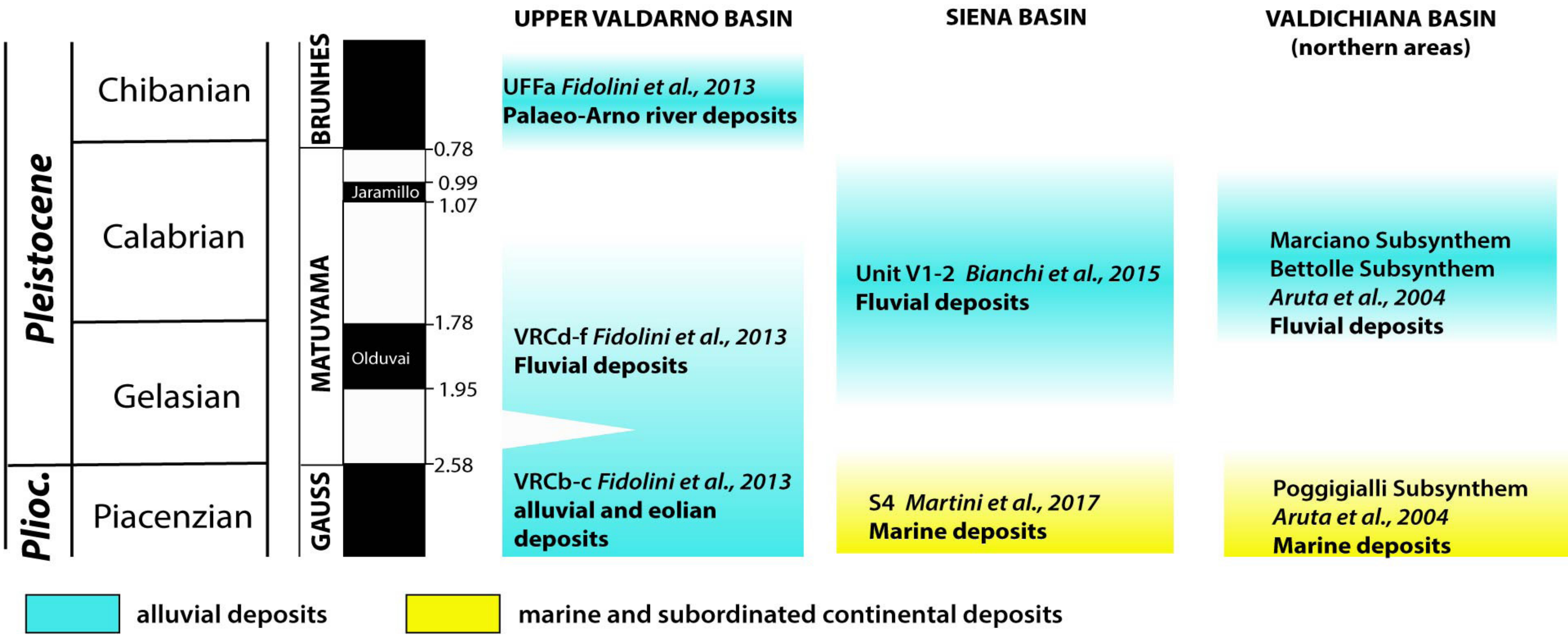

Fig. 2.3 – Age of deposits filling the Upper Valdarno, Siena and Valdichiana basins during Plio-Pleistocene (modified from Ghinassi et al., 2021).

STOP 2.1 - Rapolano Terme: introduction to the local geology

Coordinates: Lat. 43°17'29.38"N, Long. 11°36'42.08"E

TO OBSERVE:

- Substrate of the Neogene-Quaternary deposits (Tuscan Nappe).
- Morphology of the area.

TO DISCUSS:

- Introduction on the Pliocene-Quaternary evolution of the area.

Rapolano Terme is located in a key area for the observation of the Quaternary evolution of the region, along the Monti del Chianti – Monte Cetona ridge (CCR) and drained by hydrographic systems pertaining to three major intermontane Neogene-Quaternary basins: Siena, Valdichiana and Upper Valdarno basins. CCR in the Rapolano Terme area forms a narrow, elongated belt where Upper Triassic–Lower Miocene successions belonging to the Tuscan succession are exposed. For sake of simplicity, the Rapolano area has been divided into three sectors based on the occurrence of three major faults (F1 to F3 in Fig. 2.2). Sectors 1 and 2 are sited within the Quaternary drainage system pertaining to the Upper Valdarno and Siena Basins, respectively, whereas sector 3 is sited in the drainage of the Valdichiana Basin. Sector 1 is drained by the Ambra River which after flowing southward for a few kilometres bends northward to join the Arno River in the Upper Valdarno Basin. Sector 2 is drained by the southward-flowing Ombrone River, which cuts Pliocene marine deposits of the Siena Basin. Sector 3 is drained by the Foenna Creek, located at the bottom of a wide plain within the Sentino Basin (Figs. 2.2, 2.4). The Foenna Creek is sourced from the Rapolano area and drains eastward toward the Valdichiana Basin.

STOP 2.2 - The Sentino Basin: Piacenzian marine and Quaternary continental deposits

Coordinates: Lat. 43°14'56.88"N, Long. 11°38'16.12"E

TO OBSERVE:

- Marine Piacenzian and overlying continental Pleistocene deposits.
- Local tectonic deformation.

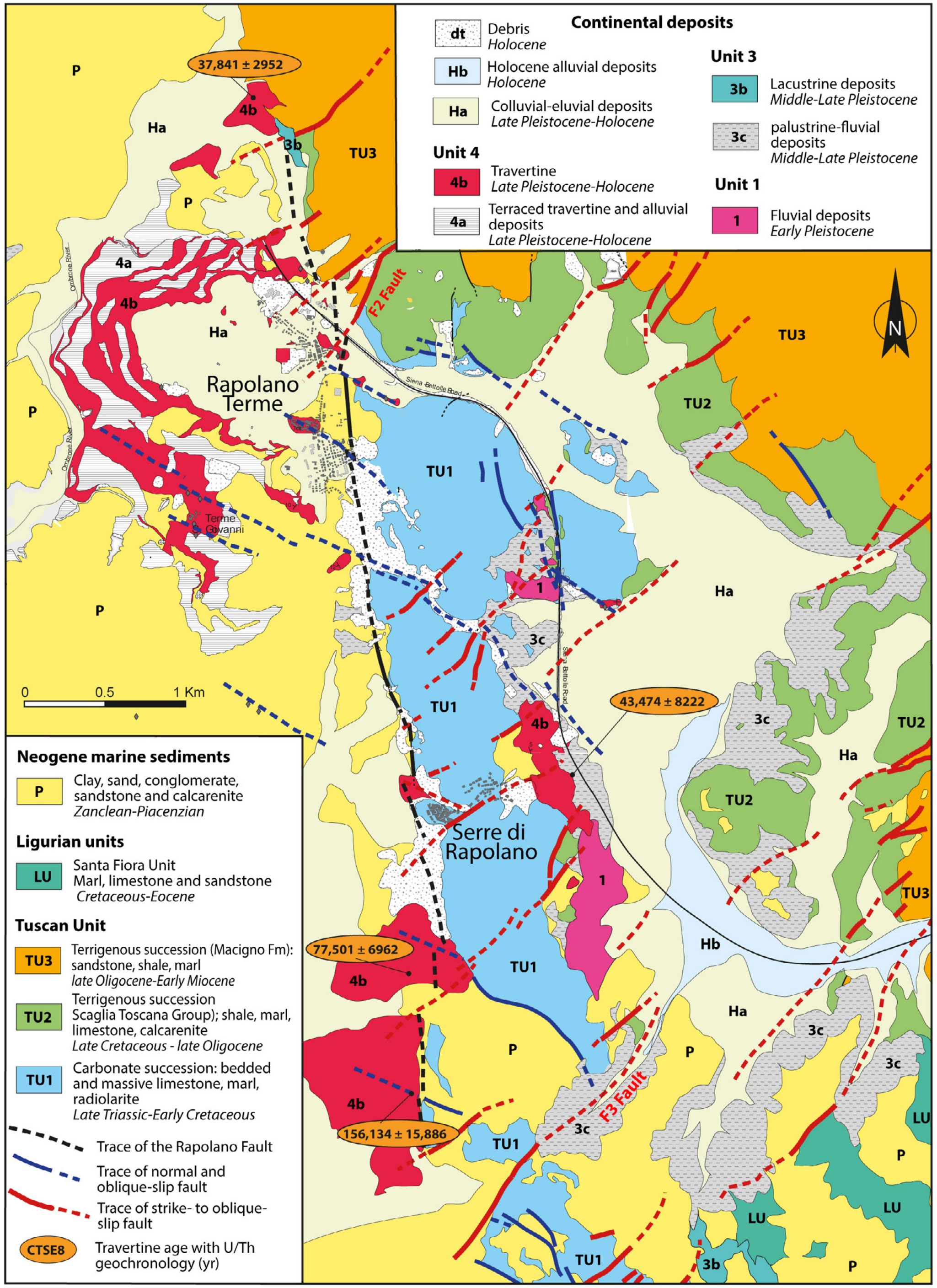

Fig. 2.4 – Geological map of the Sentino Basin (modified from Ghinassi et al., 2021).

TO DISCUSS:

- Evolution of the basin during the Late Pliocene-Pleistocene.

The Sentino Basin is a structural depression definitively configurated during the Quaternary by the interplay of NE- and WNW-trending faults. Faults control both the eastern and western margins of the basin. The Sentino Basin preserves memories of Piacenzian marine deposits and of the later continental evolution of the area. This latter is testified as an isolated, N-S trending lithosome overlying the pre-Neogene bedrock and Pliocene marine deposits in the east to Rapolano Terme. This sedimentary body is thick at least 20 m and it consists of clast-supported gravels grading southward into sand with subordinate gravels. Gravels occur above Mesozoic bedrock and they consist of moderately to well-rounded boulders of metric size. They are poorly organised exhibiting a gravelly to sandy matrix. Sandstone clasts from the Macigno Fm. are deeply weathered, as those occurring in the sector 2. Sandy deposits occur above Pliocene marine sand and they are 4-m-thick channelised bodies. These bodies are made of medium-grained sand with sets of large-scale inclined beds dipping at 5° to 20°. Inclined beds are characterised by a plane parallel and ripple cross-lamination. These beds are floored by channel lag gravels, which include deeply weathered sandstone pebbles of the Macigno Fm. Tectonically, the continental deposits are affected by NE- and NW-striking faults characterised by dominant left-lateral oblique-slip movements (Fig. 2.5).

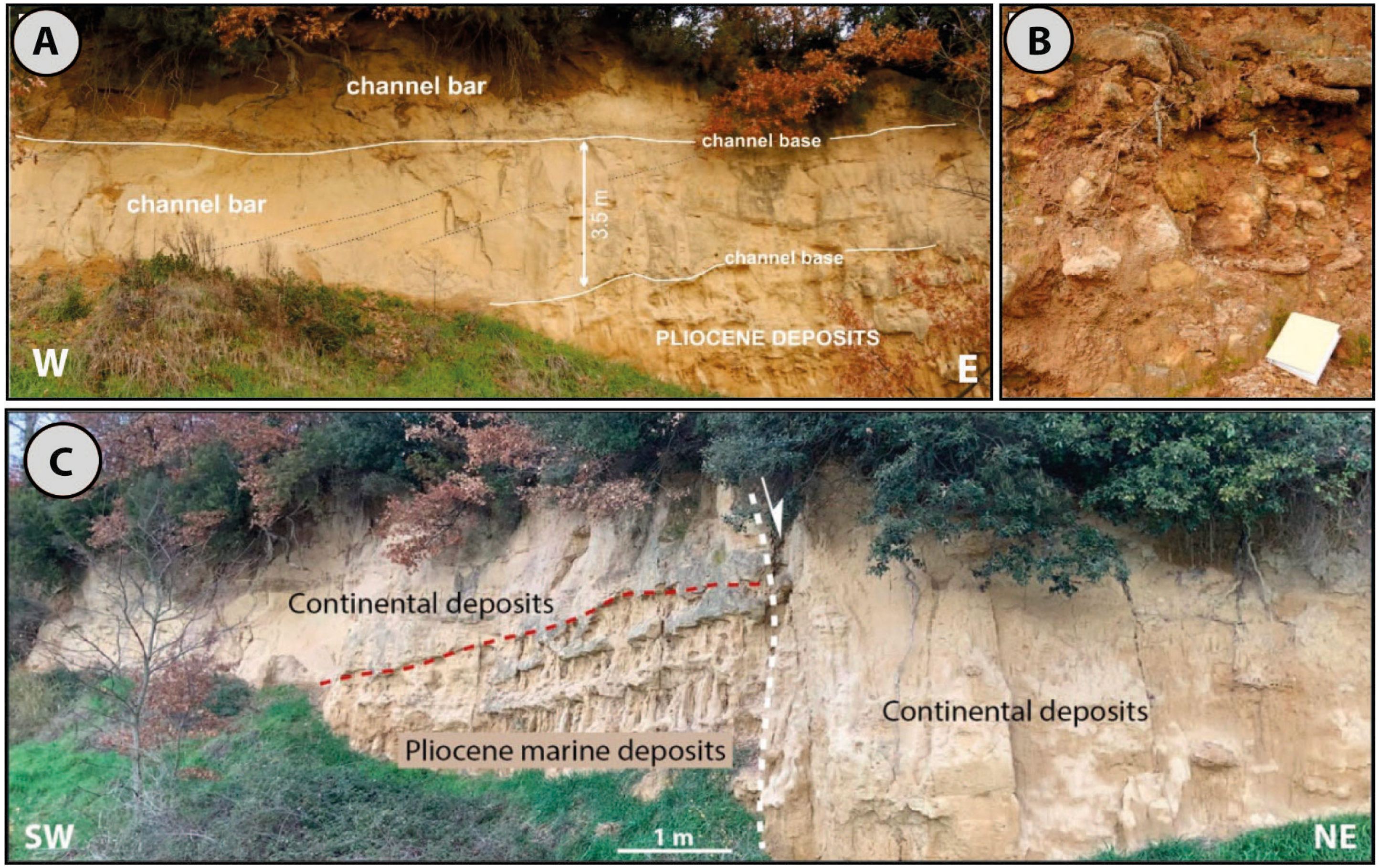

Fig. 2.5 – Detail of the marine and overlying continental succession filling the Sentino Basin: A) channelised sand overlying marine Pliocene deposits; B) poorly organised continental gravels; C) detail of the NW-striking normal fault dissecting Late Pleistocene continental sediments (modified from Ghinassi et al., 2021).

STOP 2.3 - Armaiolo: fluvio-palustrine and travertine deposits (Pleistocene)

Coordinates: Lat. 43°18'37.01"N, Long. 11°35'53.60"E

TO OBSERVE:

- Pleistocene continental clastic and carbonate deposits.

TO DISCUSS:

- Evolution of the area during Pleistocene.

In the Armaiolo area the Quaternary continental deposits unconformably overlay Pliocene marine deposits which consist of lacustrine mud grading upward into deltaic sandy beds (Ghinassi et al., 2021). Lacustrine mud is tightly laminated including layers of well-sorted fine sand. These lacustrine layers are intensely deformed by dewatering structures, and they are cut by syn-sedimentary normal faults. Overlying deltaic sandy beds are mainly tabular and characterised by widespread plane-parallel stratifications with local 0.5 to 1.5 m thick channelised bodies, which are paved by gravelly lags; they developed as distributary channels of small-scale deltaic systems locally sourced from the Rapolano Terme area.
To the top, the area is characterised by the presence of thick successions (up to 50 m) of continental carbonates and subordinate fluvial terraces. These carbonates (mostly travertine, secondarily calcareous tufa and lacustrine deposits) are widely exposed along all the basin margins. Facies association highlights a large variability of depositional environments, generally evolving from proximal systems (typically close to vents, like mounds and fissure ridges), to intermediate (slopes and channels) up to distal (marsh, shallow lakes and transitional to alluvial plains). Local sections show the direct superposition of the carbonates to alluvial/fluvial clastic deposits. In some areas, the carbonate deposits occur at different elevations corresponding to at least three depositional terraces (Ghinassi et al., 2021) (Fig. 2.6).

STOP 2.5 - Serre di Rapolano: the fossil travertine system (Middle-Late Pleistocene)

Coordinates: Lat. 43°14'50.63"N, Long. 11°36'59.40"E

TO OBSERVE:

- Panoramic view of a travertine quarry.
- Internal geometry of a travertine body.

TO DISCUSS:

- Morphology and depositional architecture of a travertine body.
- Relation between travertine deposits and basin development.

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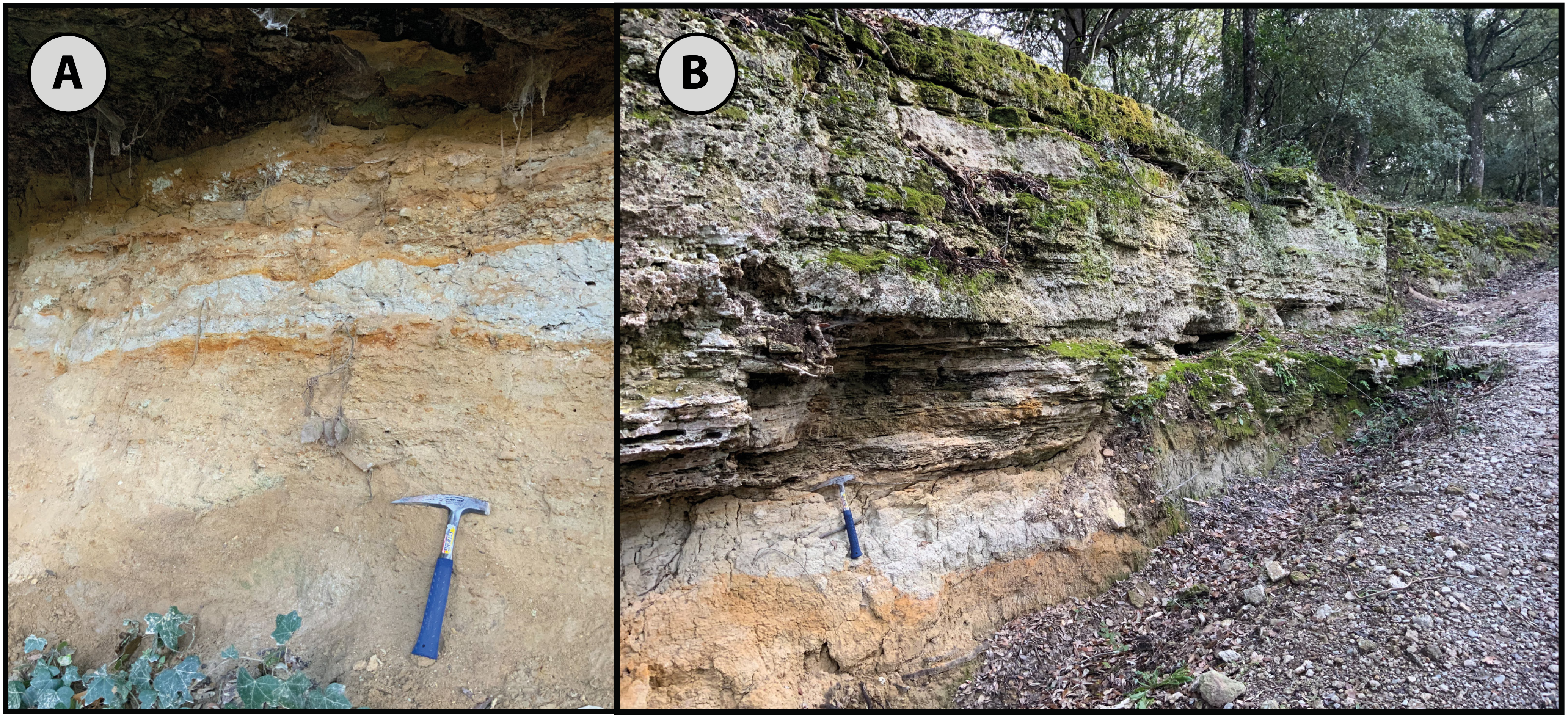

Fig. 2.6 – A) Pleistocene lacustrine sandy silt deposits; B) Late Pleistocene travertine deposits unconformably overlying lacustrine sand (modified from Ghinassi et al., 2021).

The Monti del Chianti – Monte Cetona ridge (CCR) in correspondence of the central Rapolano area is composed of Mesozoic and Cenozoic rocks belonging to the non-metamorphic Tuscan succession which are buried by banks of Middle-Upper Pleistocene travertine and gravel. It was the abundance of travertine, together with the presence of the thermal springs, which dictated Rapolano's celebrity and notoriety. Quarrying activity from the Etruscan period is documented since the XVI century, as witnessed by a document of 1597 concerning Noceto quarry, which provided the church of S. Maria in Provenzano in Siena with much of its constructional material. Mainly linked to commissions concerning the building of single mansion, the extraction of the travertine peaked between the last years of the XIX century and the first

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years of the XX century. In particular, the twenty years of fascism saw the erection of a celebrative architecture inspired by the monuments of the Roman empire and these were often built in travertine. New techniques and technologies to extract quality stone, and especially machines to saw blocks into slabs ensured that the demand was met. These were good years, in which travertine was exported all over Europe, and prestigious projects were carried out, both abroad and in Italy. The development of modern building techniques ensured a high demand for polished travertine for stairs, doors, and windowsills. After a crisis during the 1980's production continued at a somewhat slower pace until today. Travertine is magnificently exposed in the machine cut Rapolano quarry faces and Sant'Andrea quarry is one of the most spectacular (Fig. 2.7). Here, a succession of depositional episodes separated by colluvial sediments and angular unconformities are recognisable. The travertine bodies, generally reflecting fan-slope depositional geometries (Mancini et al., 2019a), form distinct masses controlled by resurgent hydrothermal waters along fracture zones located at the intersection between two fault systems which developed during the Neogene- Quaternary extensional tectonics characterising the evolution of the inner Northern Apennines. Palynological analyses have been carried out in different lithofacies of the travertine bodies outcropping in two quarries (i.e., Cava Oliviera and Cava Le Querciolaie) at Serre di Rapolano (Ricci, 2011; Bertini et al., 2014). Floristic and vegetational evidence permitted to infer the main climate changes (including stadial and interstadials), especially for the MIS 5 and MIS 3 time-intervals. The role of climate vs tectonics will be discussed.

Fig. 2.7 – Aerial view of the Sant'Andrea Quarry at Serre di Rapolano.

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STOP 2.6 - Serre di Rapolano: the Terme San Giovanni fissure ridge (Holocene)

Coordinates: Lat. 43°16'45.36"N, Long. 11°35'32.38"E

TO OBSERVE:

- Travertine Fissure-ridge depositional morphology and the related depositional environments.

TO DISCUSS:

- Travertine lithofacies and their distribution.
- Travitonics: the intimate relation between travertine deposition and tectonics.

Terme San Giovanni is currently the most active travertine-depositing site in the area, even though most of the water is diverted for use in thermal baths at the hotel health spa adjacent to the fissure ridge. Water is piped off and circulated through the baths before returning along artificial surface channels, whose courses are changed through time, to natural streams in adjacent valleys. The water has a high calcium, bicarbonate, and sulphate contents, with pH of 6,2-6,9 and temperatures of 41 °C (Kele et al., 2015). The travertine fissure ridge (Brogi et al., 2021), about 250 m long, 30 m wide and maximum 10 m high, grown on a fluvial terrace linked to the morphological evolution of the Ombrone River, running about 1 km west of the study area (Brogi and Capezzuoli, 2009) (Fig. 2.8).

Fig. 2.8 – Aerial view of the Terme San Giovanni fissure ridge.

The base of this fissure ridge has been drilled to increase the hot water inflow in the nearby thermal resort. The stratigraphic log indicates that the travertine fissure ridge overlies Pleistocene terraced alluvial deposits (about 20 m) with

encrusting limestones embedded, in turn with overlying marine Piacenzian clayey sediments. Furthermore, the occurrence of a carbonate reservoir at shallow depths can be presumed. The present day Terme San Giovanni fissure-ridge consists of a calcareous body resulting from the coalescence of small cones. It is characterised by intermediate depositional slopes (Mancini et al., 2019a) with flanking bedded travertine asymmetrically distributed with respect to the fissure (wider in the southern part than in the northern one) and dipping gently away from the crest. Small quarries excavated in the past, cut along the transverse profile of the ridge, reveal its internal structure which appears to be formed by superposed thin crystalline crusts parallel to the depositional surface. The different travertine lithofacies recognised in the bedded travertine have been interpreted as derived by superposed depositional events also attested by numerous angular unconformities (Guo and Riding, 1999). The profile of the ridge is asymmetric: the northern slope is higher than the southern one by about 10 m. At the top of the ridge, along its crest, a continuous fissure with a maximum width of 30 cm occurs. The width of the fissure decreases towards its extremities, where it becomes about 1 mm wide. At the western and eastern ends of the ridge, the fissure is apparently missing because it is concealed by new travertine deposited by hot waters issuing from small cones aligned along the crest. The cones, commonly rising tens of centimetres high and decimetres in diameter, bubble vigorously when active and deposit thin, white, and dense micritic layers. The internal fabric of the cones is mainly characterised by superposed crystalline crust boundstones (Gandin and Capezzuoli, 2014), forming a thin-layered structure reflecting the growth of the cone surface. Active fissuring is documented by the dilation fracture across the cones and by the displacement of a man-made artefact, constructed in the 1950s, located at the top of the ridge. Evidence of such historical fissuration and induced deformation (seismites) has been also evidenced in local quarries (Brogi et al., 2017, 2018) and after recent seismic events (Brogi and Capezzuoli, 2014). The age of this fissure ridge can be determined as it lies on an erosional surface cutting the FT2 terrace. Consequently, the fault dissecting both travertines and the fluvial terrace must be related to the hypothetical older age of faulting to 24±3 ka (Late Pleistocene) (Fig. 2.9).
On the left, we will follow the path of water discharge to see the morphologies and sedimentological structures created by the thermal water flowing to the local Borro Cantoppa Creek. Previously spring water reached the valley along a drainage channel from the ridge, depositing thick masses of valley slope travertine and stream-fill deposits. Diversity of these Recent and sub-Recent travertines near Terme San Giovanni offers a mosaic of the facies normally seen on a much larger scale in older travertines bodies in the area (see Guo and Riding, 1998, 1999). At the confluence between the thermal water discharge channel and the fresh-water Canatoppa Creek, the mixed paludal environmental gives rise to the distal travertine facies merging in calcareous tufa.

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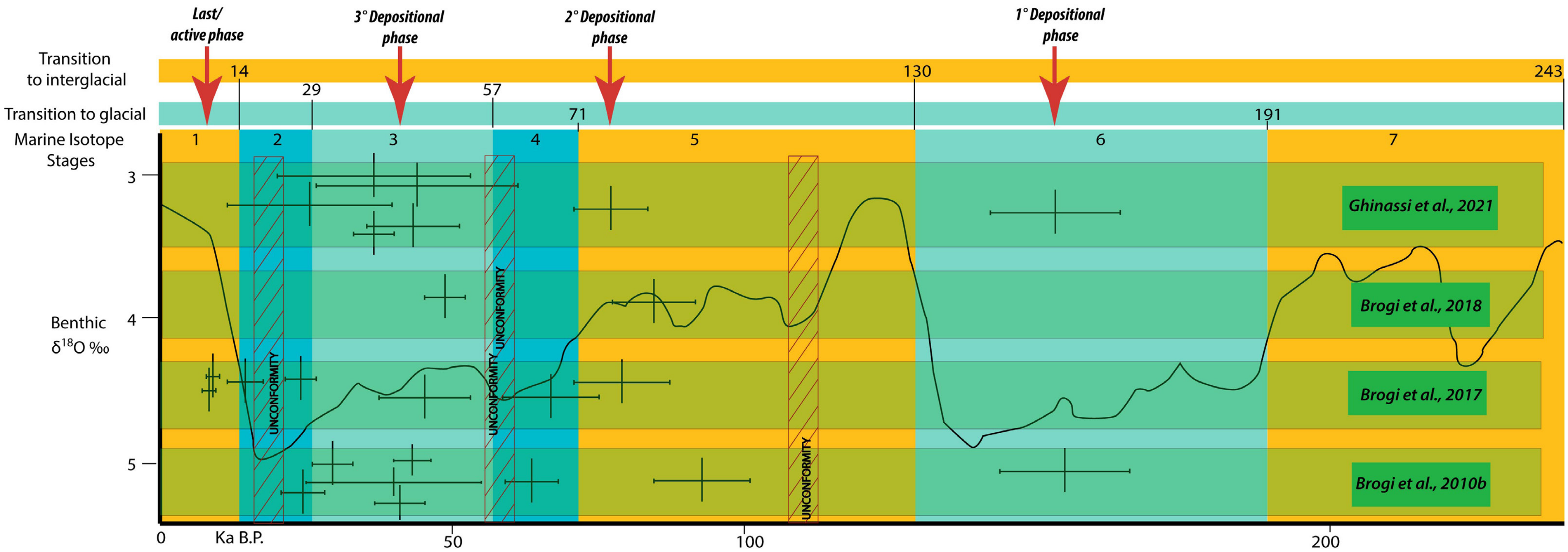

Fig. 2.9 - Comparison between available palaeoclimate and travertine data of Rapolano Terme area. All the available travertine radiometric data here achieved are compared and recognised unconformities highlighted. Black line is the SPECMAP marine palaeoclimatic $\delta^{18}O$ record (Martinson et al., 1987) during Late Pleistocene time (modified from Ghinassi et al., 2021).

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DAY 3 - THE UPPER VALDARNO INTERMONTANE BASIN (UVB)

From Rapolano Terme, move towards Siena following the SS715 highway. At "Colonna del Grillo" exit, follow indications to Ambra (SP540) and reaching the Valdarno Basin. San Giovanni Valdarno (stops 3.1 and 3.2) and Montevarchi (Stops 3.3 and 3.4) are located on the western side of the basin, while Castelfranco di Sopra (Stop 3.5) is on the eastern one. From the last stop, follow the E35 (A1) highway to reach Florence (Fig. 3.1).

The third and last day of this excursion (Fig. 3.1) is devoted to the Upper Valdarno, one of the most extended and well-known Pliocene-Pleistocene intermontane basins of the Apennines. The UVB has been studied since the Renaissance for its rich fossil record including a rich fauna and different floral remains (leaves and seeds); moreover, especially since 2000, an impressive geological-stratigraphic record was produced thanks to several sedimentological, palaeomagnetic, palynological and palaeontological researches (e.g., Gaudin and Strozzi, 1858-1859; Ristori, 1885; Bertini and Roiron,1997; Bertini, 2003, 2010, 2013; Napoleone et al., 2003; Ghinassi et al., 2004, 2013; Fidolini et al., 2013 cum biblio; Mazza and Bertini, 2013; Rook et al., 2013 cum biblio). Different depositional systems (e.g., lacustrine, fluvial, palustrine) were described and their changes through the time traced within a quite good chronological framework (Late Pliocene - Middle/Late Pleistocene) (Figs. 3.2, 3.3).

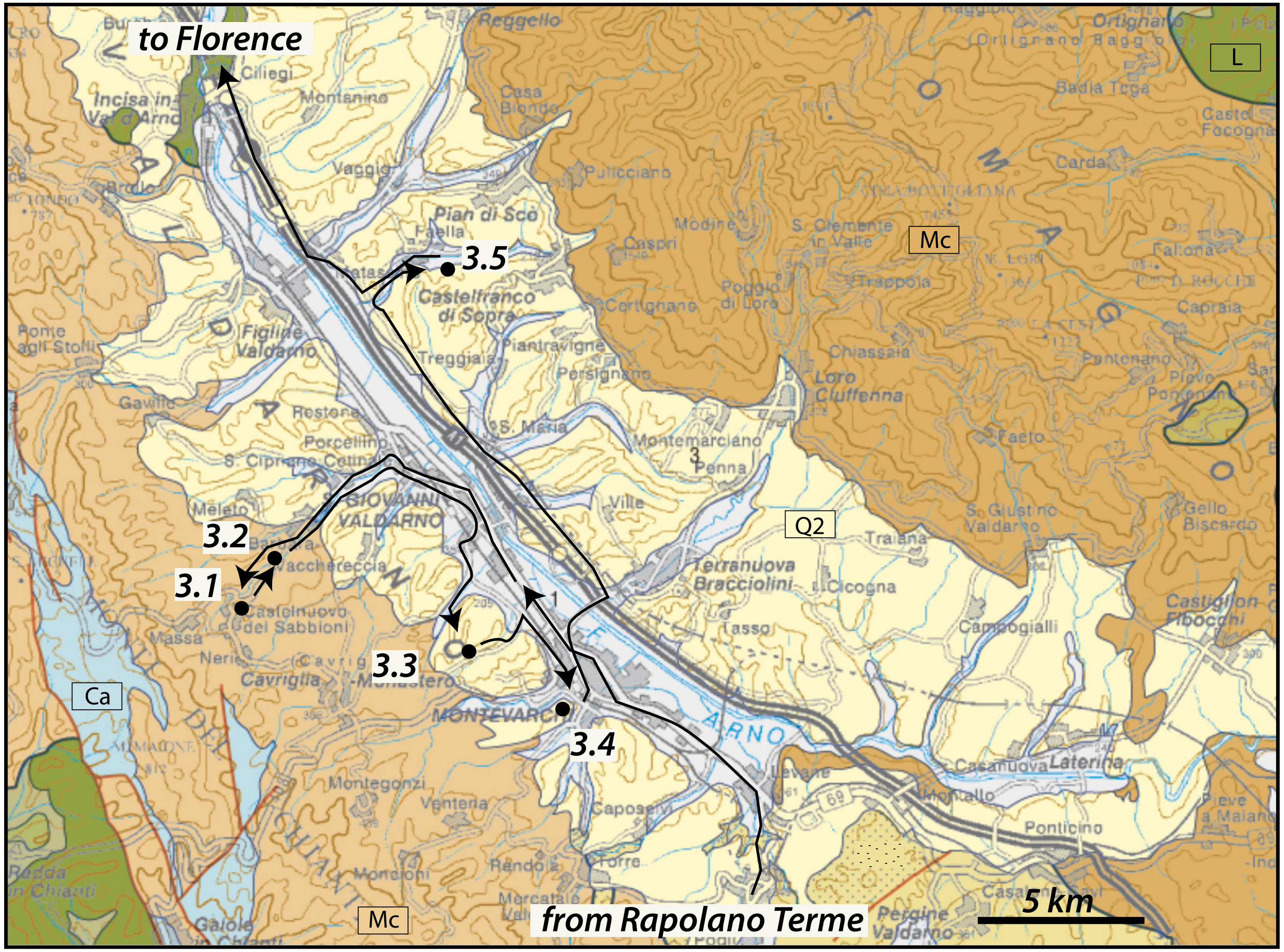

Fig. 3.1 – Itinerary of the third day field trip (redrawn from Carmignani et al., 2004).

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The previous rich documentation from the UVB, whose formation dates to about 3.3 Ma (Piacenzian), constitutes a crucial contribution for the understanding of the main changes affecting terrestrial environments in the Mediterranean area, in response to both global and regional events. During the excursion we will have the opportunity to discuss on:

- the uplift phases of the Neogene-Quaternary Northern Apennines;
- the last warm Pliocene phase still today considered a good analogue for the study of the greenhouse effect (e.g., Haywood et al., 2016);
- the transition from the Piacenzian subtropical-temperate warm world to the "post-Gelasian" temperate one, coinciding with the maximum expansion of the Arctic ice cap, around 2.6 Ma.

Geological-stratigraphic framework of the UVB

The UVB has traditionally been interpreted as a graben/half-graben developing in a post-collisional extensional context affecting the internal part of the Northern Apennines, from the Late Miocene (Martini and Sagri, 1993; Martini et al., 2001; Brogi et al., 2013). However, alternative hypotheses identified the main cause of basin formation in a compressive regime (Bonini et al., 2013 cum biblio).

The UVB occupies an asymmetric tectonic depression, 15 km wide, extending for 35 km in a NW-SE direction, drained

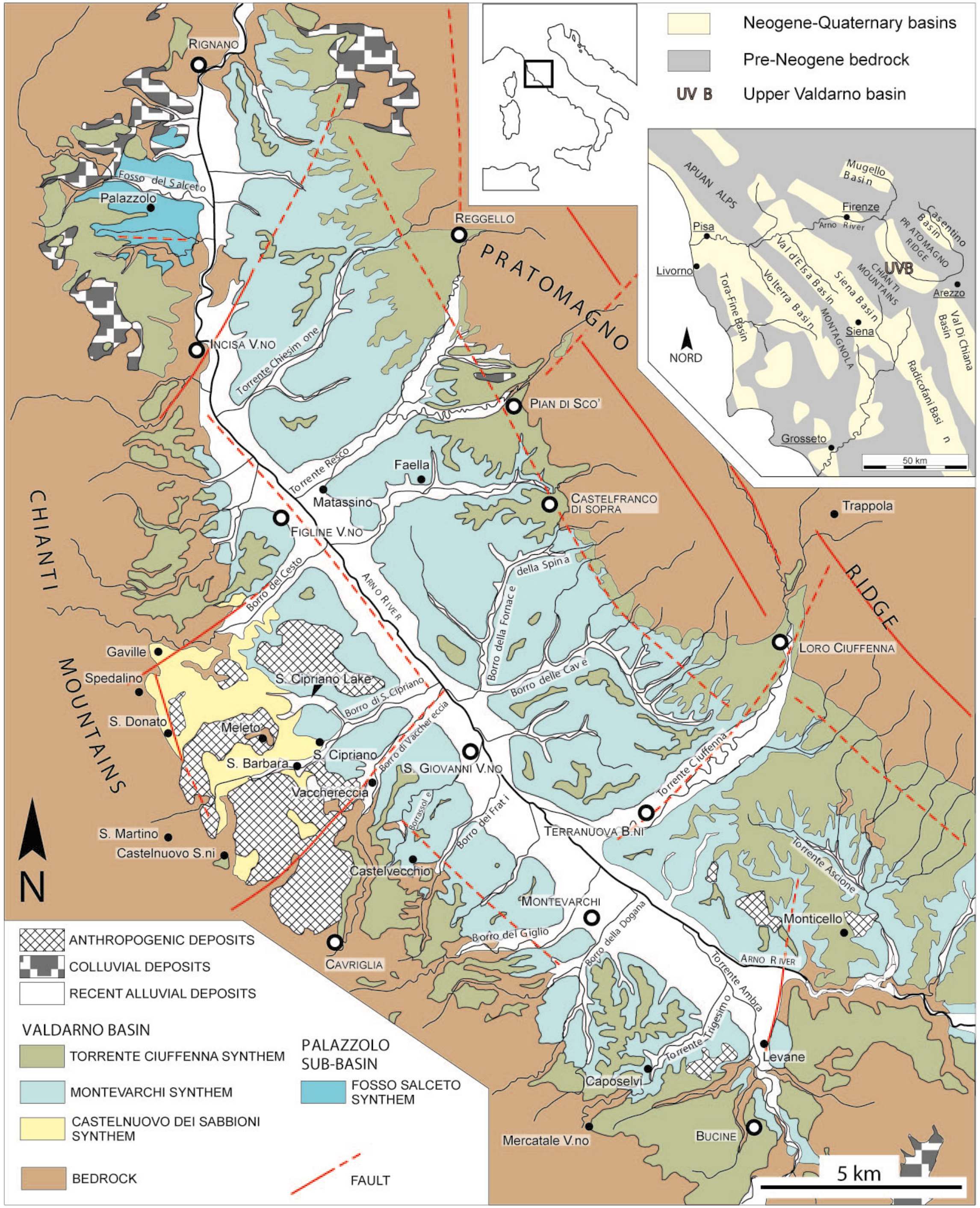

Fig. 3.2 – Location and geological sketch map of the Upper Valdarno Basin (modified from Fidolini et al., 2013).

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from SE to NW by the Arno River (Fig. 3.2). The depression was filled, starting from the end of the Late Pliocene (e.g., Napoleone et al., 2003), by alluvial and lacustrine deposits (e.g., Martini et al., 2001). The substratum consists of Oligocene-Miocene sandy turbidites, locally covered by intensely deformed deep-marine, muddy deposits (Ligurian units, Cretaceous to Eocene). Substratum uplift, along transversal faults to the basin, has given rise to some peripheral sub-basins (for example the Palazzolo sub-basin, Figs. 3.2, 3.3), which have occasionally experienced an independent depositional history. As already mentioned in the introduction, a good chronological definition of the UVB has been developed through a close integration between magnetostratigraphy, vertebrate faunas, palynology and radiometric datings (e.g., Napoleone et al., 2003; Ghinassi et al., 2004; Bertini, 2013; Fig. 3.3).

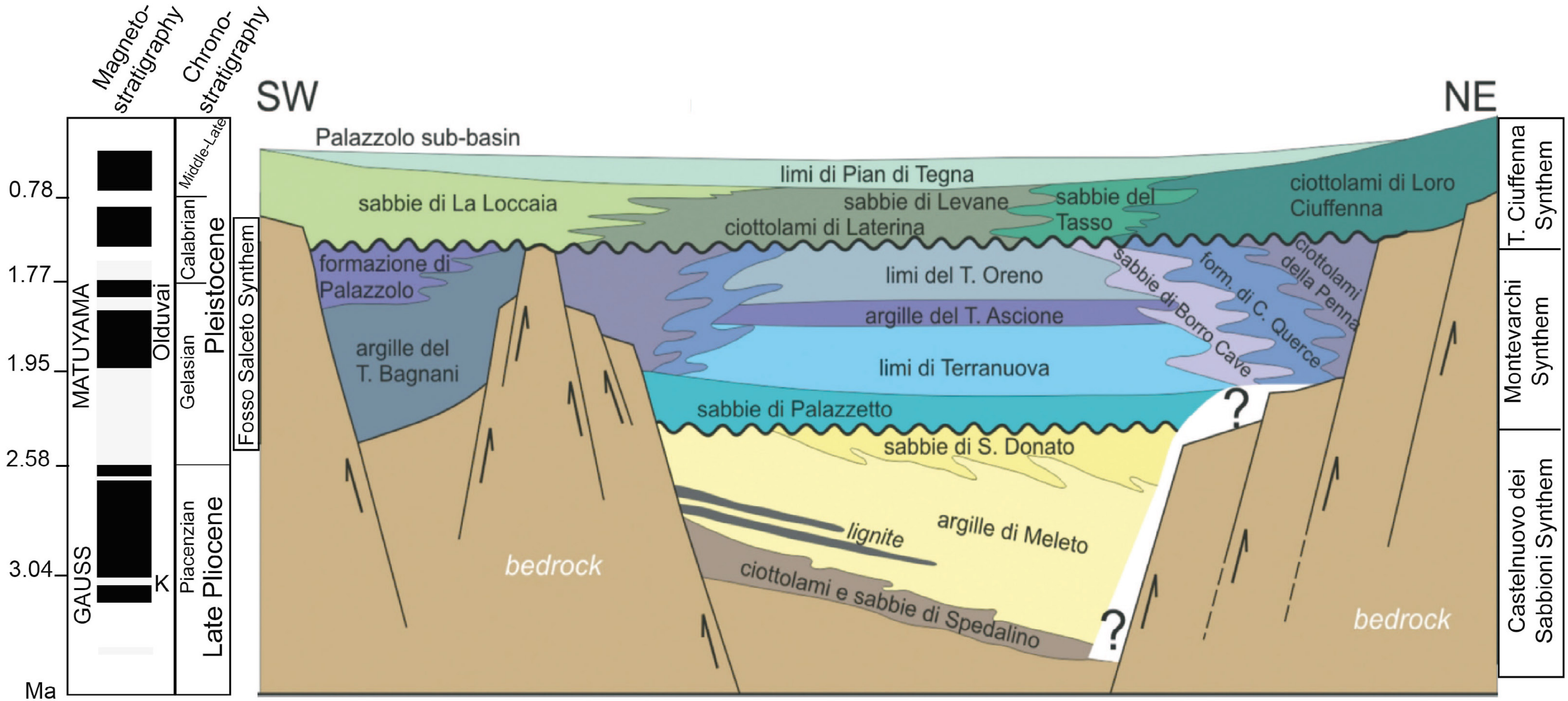

Fig. 3.3 – Stratigraphic scheme of the UVB; informal lithostratigraphic units are also specified (modified from Fidolini et al., 2013).

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Depositional phases

The filling of the UVB, made up of over 500 m of Pliocene-Pleistocene alluvial and lacustrine deposits, took place during three main depositional phases, to which correspond four distinct sedimentary successions separated by stratigraphic discontinuities (Figs. 3.2, 3.3). According to the classification criteria based on the Unconformity Bounded Stratigraphic Units (UBSU), four synthems were distinguished: Castelnuovo dei Sabbioni Synthem, Montevarchi Synthem, Fosso Salceto Synthem (in the Palazzolo sub-basin) and Ciuffenna Torrent Synthem (Figs. 3.2; 3.3; Fidolini et al., 2013).

Castelnuovo dei Sabbioni Synthem (Piacenzian)

These deposits (Figs. 3.2-3.4), about 200 thick, are exposed only on the south-western margin of the basin and consist, starting from the bottom, of fluvio-deltaic gravel and sand (*ciottolami e sabbie di Spedalino*) which pass, laterally and upwards, to lacustrine silty clays, with lignite strata at the base, (*argille di Meleto*), in turn covered by fluvio-deltaic sand (*sabbie di San Donato*). These deposits, generally north-eastward inclined and deeply eroded, are unconformably overlain by the deposits of the Montevarchi Synthem.

Montevarchi Synthem (upper Piacenzian-Calabrian)

This synthem covers unconformably the deposits of the Castelnuovo dei Sabbioni Synthem (Fig. 3.3). Its deposition starts after a reactivation of tectonics which produced a widening and a renewed subsidence of the basin. The Montevarchi Synthem includes a lower portion, about 40 m thick, outcropping only along the SW margin of the basin. The latter consists of coarse sediments of alluvial fans (*ciottolami e sabbie di Caposelvi*) which pass laterally to fluvial and aeolian sands (*sabbie di Palazzetto*) where palynological analyses were also carried out (Fig. 3.5). The upper portion of the Synthem crops out at the basinal scale. Its thickness varies from 30-35 m in the SW sector of the basin and reaches 70 m in the central sector, where however its base is not outcropping. The upper portion consists, in the most central part of the basin, of mainly silty-sandy sediments, deposited in an alluvial plain environment, which include isolated sandy river channels (*limi di Terranuova* and *limi e sabbie del Torrente Oreno*). A rich peat horizon characterised the intermediate portion of this sedimentary succession (*argille del T. Ascione*). Previous deposits host several important fossil sites that have yielded a rich vertebrate fauna, for example at Poggio Rosso (Fig. 3.6) (Mazza et al., 2004; Mazza, 2006; Rook et al., 2013 cum biblio) as well as palynological records (Bertini et al., 2010; Bertini, 2013). The central-basin deposits pass laterally to the coarse deposits of the alluvial fans (*ciottolami della Penna*, *ciottolami* and *sabbie di C. la Querce*, *sabbie del Borro Cave*) coming from the margins of the basin.

Fig. 3.4 – Summary pollen diagrams from the deposits of the Castelnuovo dei Sabbioni Synthem (modified from Bertini, 2010, 2013). A) The Santa Barbara section (Allori quarry) in the *argille di Meleto* with the main lignitiferous bed on the left bottom (modified from Bertini, 2010); at the top a residual outcrop with the *sabbie di San Donato*. B) The San Donato Est and Case Bolcavo sections in the *sabbie di San Donato*. Legend of pollen groups: 1) Subtropical humid forest taxa; 2) Temperate broad-leaved deciduous forest taxa; 3) *Cathaya* + *Pinus haploxylon* t.; 4) *Pinus* + Pinaceae saccatae indeterminable; 5) *Tsuga* + *Cedrus*; 6) *Abies* and *Picea* + *Fagus* and *Betula*; 7) local arboreal plants with the exception of *Salix* + *Alnus* (8) and the sclerophyll forest taxa (9); 10) non arboreal taxa with the exception of steppe taxa (11).

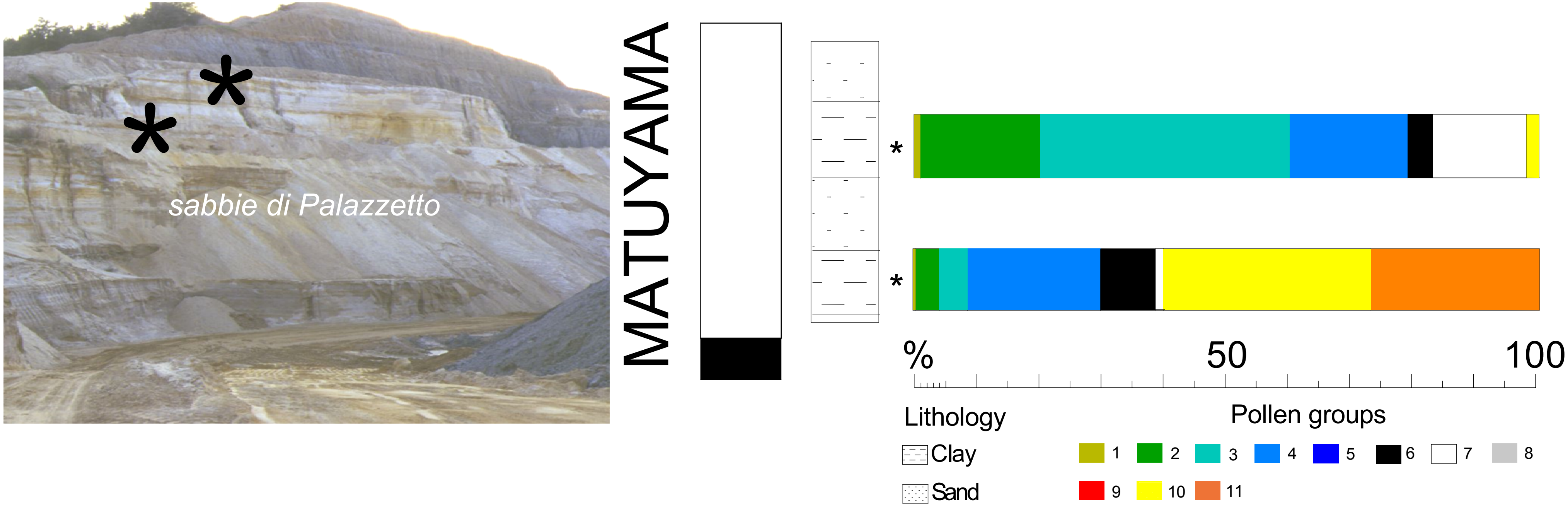

Fig. 3.5 – Summary pollen spectra of the Rena Bianca section, in the Silva quarry (Montevarchi Synthem) (modified from Bertini, 2010, 2013). The expansion of herbaceous plants, in particular of the steppe taxon, *Artemisia*, above the Gauss-Matuyama boundary, has been associated with the first glacial/interglacial cycles from ca 2.6 Ma, marked in the sedimentary succession by spectacular lithological change. The latter is expressed by sandy deposits characterised by a distinctive aeolian component (Albianelli et al., 1995). Legend of the pollen groups: 1) Subtropical forest taxa; 2) Temperate broadleaf forest taxa; 3) *Cathaya* + *Pinus haploxylon* t.; 4) *Pinus* + Pinaceae saccate indeterminable; 5) *Tsuga* + *Cedrus*; 6) *Abies* and *Picea* + *Fagus* and *Betula*; 7) Local tree plants except *Salix* + *Alnus* (8) sclerophyll forest taxa (9); 10) non-arboreal taxa with the exception of steppe taxa (11).

T. Ciuffenna Synthem (Middle to Upper Pleistocene)

It constitutes the final filling of the basin and is separated from the underlying Montevarchi Synthem by an important erosive surface (Fig. 3.3). It has a thickness of 30-40 m and emerges at a basin scale, in a sub-horizontal position. It includes fluvial deposits deposited along the axis of the basin, laterally interdigitated with the marginal deposits of alluvial fans. In the south-eastern area of the basin, the axial fluvial deposits consist of gravel (*ciottolami di Laterina*) and sandy deposits (*sabbie di Levane*) which towards the west pass to predominantly sandy sediments (Fig. 3.7). The marginal alluvial fan deposits, which reach thicknesses of more than 35 m along the Pratomagno ridge, consist of pebbles, even very coarse, of the proximal facies (*ciottolami di Loro Ciuffenna*) and mainly sandy distal deposits (*sabbie del Tasso*).
Along the Chianti ridge, where the typical fan facies are absent, alluvial deposits dominated by sandy-gravelly lithologies (*sabbie di C. Loccaia*)

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Fig. 3.6 – Overview of the sedimentary succession of Poggio Rosso (Montevarchi Synthem) in the SOLAVA brick quarry. The *Balze* and the Pratomagno ridge are visible in the background. Numerous remains of vertebrates come from here, the most famous of which are part of the "den of the hyenas" (Mazza et al., 2004) now exhibited in the Palaeontological Museum of Florence.

can be observed (Fig. 3.3). At the top of the Synthem there are alluvial deposits, up to 15 m thick, consisting mainly of pedogenised silts of variable colour from grey to reddish-brown, which contain sands and gravels in isolated tabular or lentiform layers (*limi di Pian di Tegna*). They represent the final filling deposits of the basin forming the large terminal morphological surface (*Pianalto*), today deeply engraved by erosion. Towards the end of the Middle Pleistocene, the Arno and its tributaries begin to erode and dismantle the fluvial-lacustrine deposits giving rise to the current hydrography and morphology (Bartolini and Pranzini, 1981).

Fig. 3.7 – T. Ciuffenna Synthem at Cava Chiusuri; *ciottolami di Laterina* (CL) and *sabbie di Levane* (SB).

The control of tectonics versus climate on the UVB sedimentary facies

In the UVB, the effects of global climate changes, including its interactions with local to regional factors including tectonics, are well evident throughout the sedimentary succession.

a) The basin developed during the late Piacenzian, at around 3.3 Ma, after a tectonic damming of a north-eastward flowing drainage attested by fluvial, valley-fill gravels.

b) Lignite formed in swamps of a lacustrine system during the last major shift to a warmer global climate (the so-called “mid-Piacenzian” warmth) close to 3.3 Ma. (Figs. 3.2-3.4). The *argille di Meleto* deposition developed in coincidence with the deepening of the basin; progressively more sandy episodes matched a cooling (but still under moist conditions) phase since ca 2.8 Ma. The shift to the predominantly sandy deposition of the *sabbie di San Donato*, in a deltaic system, is associated to a prevalently subtropical-warm climate, between ca 2.65 and 2.6 Ma (Fig. 3.4).

c) A significant tectonic event, just before 2.6 Ma, which caused the uplifting of the Monti del Chianti and the Pratomagno along the two borders of the basin (e.g., Bonini et al., 2013; Brogi et al., 2013), predates the onset of the prevalently fluvial(-palustrine) sediments of the Montevarchi Synthem, which accumulated between ca 2.6 Ma and 1.7 Ma (Napoleone et al., 2003) (Figs. 3.5, 3.6). At the same time a major global climatic event, i.e., the maximal expansion of the Arctic ice, leaves its signature in both the UVB pollen and the sedimentary records, as attested by the first notable increase of steppe vegetation (i.e., the *Artemisia* acme phase) in the aeolian/fluvio-aeolian sands of the *sabbie di Palazzetto* (e.g., Rena Bianca site, Figs. 3.3, 3.5), during the first glacial expansions, after 2.6 Ma (e.g., Albianelli et al., 1995; Bertini, 2010, 2013).

d) The basal sedimentary succession of the Montevarchi Synthem attests a marked basin broadening and re-equilibrium of the morphological profile as a response to the previous tectonic deformation which leaded to the establishment of an axial fluvial drainage and marginal alluvial fans. A further subsidence pulse triggered a new morphological disequilibrium along the margins and subsidence in the axial portion. The alluvial fans progradation, which stemmed out as response to the morphological disequilibrium, led to development of small, isolated fan-delta systems.

e) The sedimentary record of deposits of the third synthem, the T. Ciuffenna Synthem, is preceded by an intense and significant erosional phase which has been related to the entrance of the palaeo-Arno River into the basin (Fidolini et al., 2013). The emplacement of the T. Ciuffenna Synthem occurred during the so-called Early-Middle Pleistocene transition which produced significant climatic changes at global scale. In the UVB, the interaction of different factors, i.e., the diversion of the palaeo-Arno, regional tectonics, and global climatic changes, seems responsible for the lack, in the sedimentary record of, at least, 600 kyr, throughout the Calabrian. During the Late Pleistocene the palaeo-Arno River and its tributaries cut down through the basin fill forming terraced deposits and allowing the basin to reach the modern configuration.

STOP 3.1 - Visit of the Mine Museum at Castelnuovo with introduction to the geology and stratigraphy of Upper Valdarno Basin

Coordinates: Lat. 43°32’45.93’’N, Long. 11° 27’15.09’’E

TO OBSERVE:

- Current geomorphological arrangement of the basin.
- Exhibition rooms at the Mine Museum.

TO DISCUSS:

- Geological-stratigraphic overview of the basin.
- Mining activity vs redevelopment of abandoned mines according to the principles of environmental, economic and social sustainability.

From the panoramic terrace of the Mine Museum, at the base of the northern ridge of the Chianti Mountains, a magnificent view overlooking the UVB, permits to observe (Fig. 3.8):

- *In the foreground*: what remains of the mining area for the extraction of xyloid lignite, which developed between the 1950s and 1990s. In this area, the sediments of the Castelnuovo dei Sabbioni Synthem, including the lignite horizons (Figs. 3.3, 3.4), were splendidly exposed until the end of 1990. During the works for the recovery of the mining areas, the Pliocene deposits were, unfortunately, almost completely covered by fill material or occupied by water reservoirs (Fig. 3.9).

Fig. 3.8 – Overview on the Upper Valdarno Basin from the Mine Museum at the base of the northern ridge of the Chianti Mountains.

- *at North-East*: (facing the observer, in the background) the Pratomagno ridge, at the base of which is the main fault system on which the sinking of the basin occurred. At the foot of the ridge, the alluvial fan systems are visible, which developed during the deposition of the sediments of the Montevarchi and T. Ciuffenna Synthems (Fig. 3.3).
- *In the centre*: what remains of the top filling surface of the basin (*Pianalto*), considerably engraved by the late Quaternary erosion.

Before to reach the Santa Barbara quarry, we will discover several documents, photographs, and the collected memories of the elderly, in the Mine Museum. They attest the profound changes in this territory, including the abandonment of some settlements, especially due to the mining activity, since the end of the 19th century. In the museum seven rooms are dedicated to

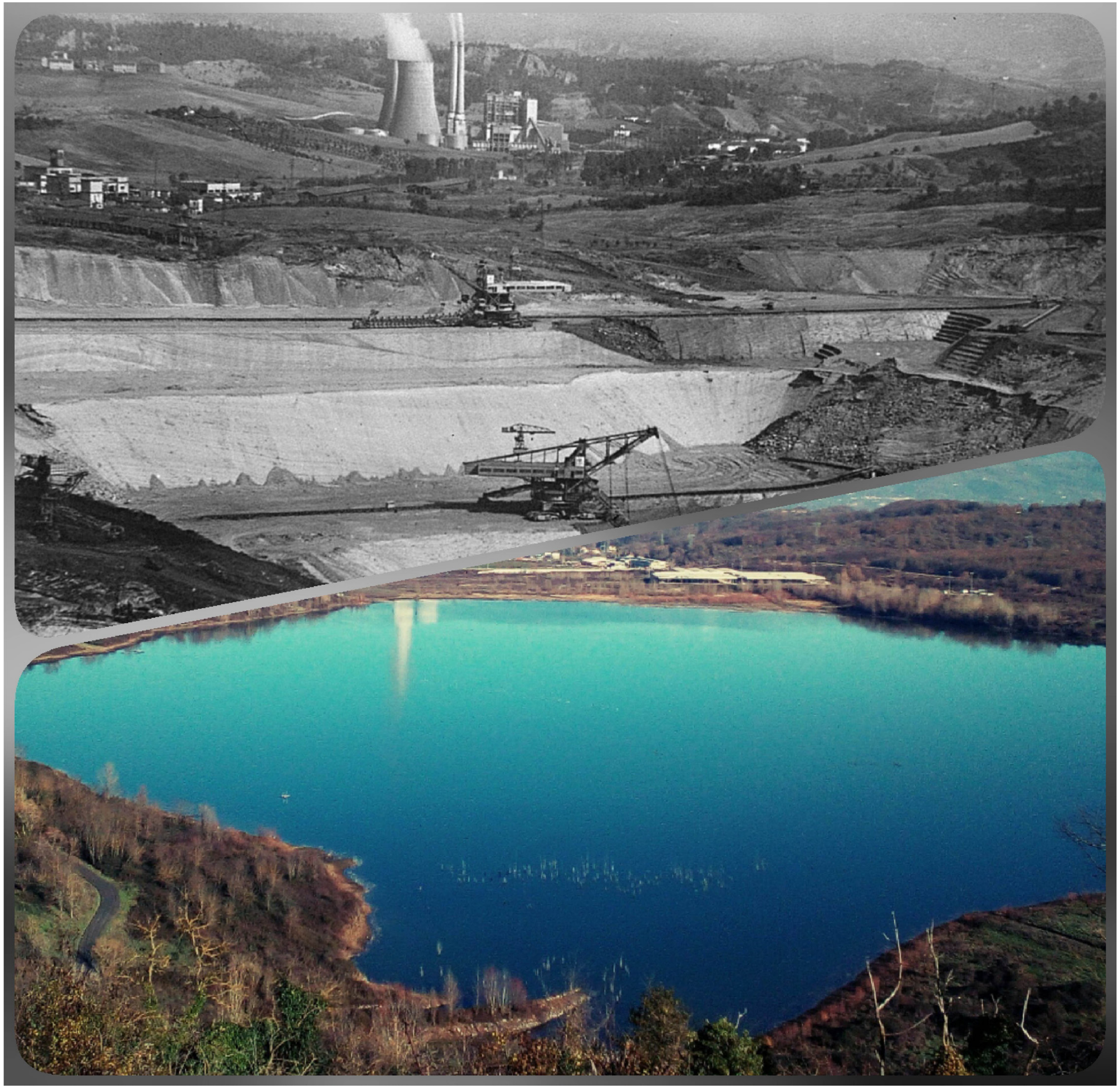

Fig. 3.9 – Reconstruction of the Santa Barbara area «before» i.e., during the excavation period of the lignite and «after» the phase of recovering of the mining area. (Photo courtesy of Mine Museum).

the history and mining events according to an itinerary from the first documented news on the lignite deposit to the development of mining including the first struggles of the miners. The exhibition focuses on excavation techniques and on the life of the miner, on the sounds and smells of the tunnel. A small section also recalls the tragic events of the Nazi massacres that took place in July 1944. The narration resumes by dealing with the changes that took place after the Second World War and related to excavation techniques: from tunnel mines to open-air mines. Our visit ends with a film that collects testimonies and voices of those who lived these events. In 2022, Borgo Castelnuovo d'Avane was the winner for Tuscany of the *PNRR Borghi Linea A*: the project provides for the complete regeneration of the village that survived the mining excavation with new uses beyond the museum and with the establishment of tourist activity - accommodation, recovery of historic buildings, artist residences and artisan workshops.

STOP 3.2 - The Santa Barbara site

Coordinates: Lat. 43°33'36.90''N, Long. 11° 26'44.08''E

TO OBSERVE:

- Piacenzian lacustrine deposits.
- Scenic stop at the transition between the *ciottolami di Spedalino* and the *argille di Meleto.*

TO DISCUSS:

- Flora and vegetation just before the instauration of glacial/interglacial cycles in an intermontane basin of central Italy.
- Comparison with marine and other continental successions of the late Neogene and Quaternary of Italy.

In the Santa Barbara area, we have unique and last possibilities to observe the last outcrops of the basal deposits of the Castelnuovo dei Sabbioni Synthem (Figs. 3.2-3.4). We will observe the lignite used as fuel in the Thermoelectric station of ENEL (the Italian National Energy Company) from 1950 to ca 1993. Since this date the lignite was no more extracted, and the thermoelectric station was converted in order to use coal and gas in the frame of an intervention of environmental re-setting. The environmental recovery of the area does not now allow the observation of the spectacular quarry fronts clearly visible before the 2000s (Fig. 3.4). The about 200 m thick sedimentary succession yield rich vegetal micro-and macro-remains assemblages and permit by the integration of palaeomagnetism and mammal fauna to define a quite good chronologic frame. Some large stumps and trunks in growth position (Fig. 3.10A, B), embedded within dark grey muds, allow to characterize the plant assemblage as a fossil forest.
The carpological and palynological analyses indicated a flora dominated by arctotertiary elements, but also containing palaeotropical elements. *Glyptostrobus europaeus*, *Nyssa disseminata* and *Alnus* sp are the most abundant taxa among carpoflora. The lignites and the overlying silts yielded a scanty mammalian fauna assemblage including *Anancus arvernensis*, *Zygolophodon borsoni*, *Tapirus arvernensis*, *Stephanorhinus*

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jeanvireti, *Leptobos stenometopon*, *Ursus minimus*, which are typical components of the Triversa faunal unit. Previous mammal fauna identified the normal polarity of the palaeomagnetic record from the *argille di Meleto* with the Gauss Chron C2An.1n. The continuity of the succession, the high reliability of the magnetic signature and the sampling resolution allowed the local mammal assemblage to be placed within the Kaena subchron (C2An.1r) at ca 3.1 Ma (Fig. 3.3; Napoleone et al., 2003).

Fig. 3.10 – Basal portion of the Castelnuovo dei Sabbioni Synthem. Large trunks in life position (T: Taxodioideae) are visible along the outcrop (A, B).

STOP 3.3 - Cava Borrassole

Coordinates: Lat. 43°33' 3''N, Long. 11° 30'58''E

TO OBSERVE:

- Basal deposits of the Montevarchi Synthem.
- *sabbie di Palazzetto* included the Rena Bianca sands.
- Fluvial and aeolian deposits (Rena Bianca sands) of the *sabbie di Palazzetto.*
- Erosive boundary between the *sabbie di Palazzetto* and the *limi di Terranuova.*
- Sedimentary structures in aeolian and ephemeral streams deposits.

TO DISCUSS:

- Glacial-interglacial cycles since 2.6 Ma.
- Sedimentological signatures.
- Floristic-vegetational/climatic signatures.

The Borrassole quarry offers a good exposure (about 25-30 m) of the lower portion of the Montevarchi Synthem. Starting from the bottom, the sedimentary succession includes the *sabbie di Palazzetto* (SPs) and the base of the overlying *limi di Terranuova* (LT) (Fig. 3.11).
The SPs consist of fluvial deposits with associated aeolian sediments (Rena Bianca sands). At the base and at the top of the outcrop, a few metres of white or yellowish sand can be observed, of aeolian origin (Rena Bianca sands), well selected and rich in quartz and feldspar

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granules. The sands are organised in tabular strata, 20 to 150 cm thick, and internally characterised by plane-parallel to trough cross-lamination, and by ripple. Palaeocurrents indicate a flow from E-SE. The fluvial deposits include sands, medium to poorly sorted, of a yellowish brown or light grey colour, arranged in tabular or lentiform layers, 20-80 centimetres thick. The sands are predominantly structureless, sometimes graded, plane-parallel to trough cross-laminations are less frequent. The base of the strata is generally flat and slightly eroded. At the top, the strata are often reddened by weathering and sometimes retain minute traces of roots. Palaeocurrents indicate flows mainly from W-NW.

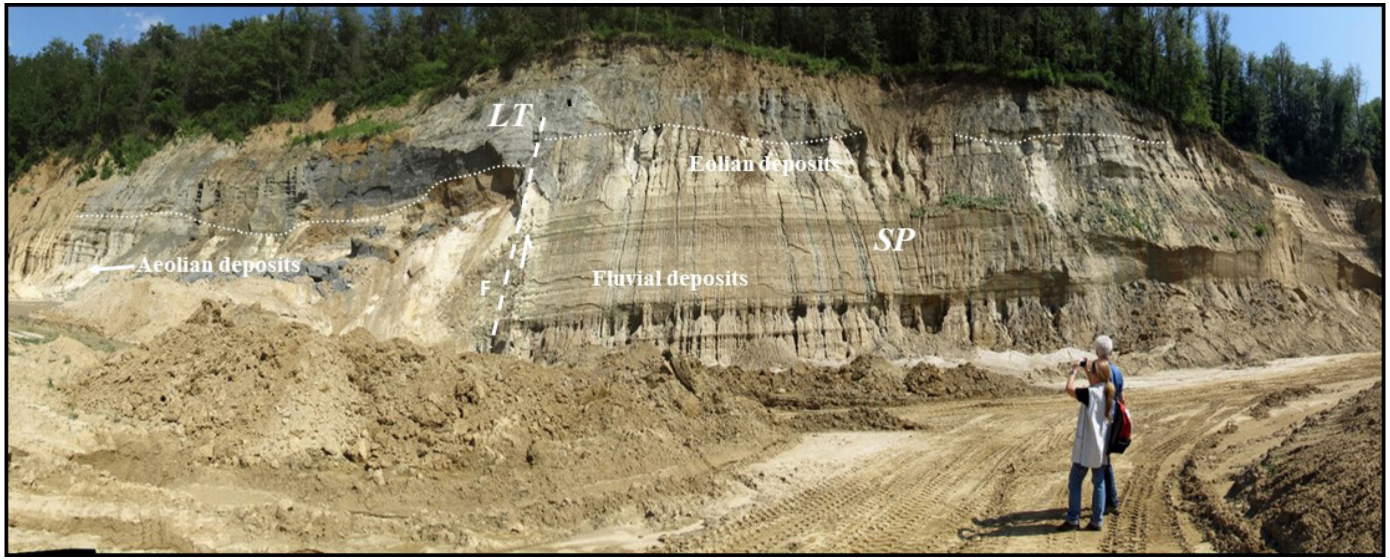

Fig. 3.11 – Overview of the deposits at the base of the Montevarchi Synthem. From the bottom: the *sabbie di Palazzetto* (SP), including the Rena Bianca sands, and the overlying *limi di Terranuova* (LT) are visible. F: fault.

The sedimentary succession of the SPs represents the deposition of modest ephemeral water courses, coming from the Chianti Mountains, which, by means of unconfined flows, left their load on the surface of a sandy alluvial plain or in the middle-distal part of alluvial fans. During periods of prolonged drought, the wind was able to rework and transport alluvial sands and deposit them in the form of aeolian sediments. In the stratigraphy of the basin, the SPs rest, with erosive and discordant contact, on the fluvial-deltaic deposits of the *sabbie di San Donato*, belonging to the underlying Castelnuovo dei Sabbioni Synthem. Upwards, the SPs pass to the fluvial-marshy deposits of the upper portion of the Montevarchi Synthem, represented here by the *limi di Terranuova*. This unit is mainly made up of clayey and/or grey sandy silts, often pedogenised, with interbedded layers of medium-fine sands, sometimes silty-clayey, which contain isolated lenticular sandy or sandy-gravel fluvial bodies. The passage that we observe in the quarry (Fig. 3.11), is represented by a well-defined erosion surface. Moving towards the centre of the basin, the passage occurs gradually through the interposition of fluvial deposits (*sabbie e limi di Montecarlo*), rich in the remains of freshwater molluscs (Esu and Ghinassi, 2013; Ghinassi et al., 2013). Palaeomagnetic investigations (Albianelli et al., 1995) and the $^{40}Ar/^{39}Ar$ dating of an ash layer (Ghinassi et al., 2004), outcropping in a nearby quarry, contributed to frame the time of deposition of the SPs between about 2.6 and 2.4 Ma. The palynological investigations, in the silty-clay interlayers of the SPs (Fig. 3.5), identified the first evidence of cyclical expansion of herbaceous vegetation including steppe taxa (dominated by *Artemisia*), after the Late Pliocene phase (late Piacenzian), dominated by vegetation characteristic of a humid, subtropical-warm temperate climate, during a large part of the sedimentation of the underlying deposits of the Castelnuovo dei Sabbioni Synthem (Albianelli et al., 1995; Bertini, 2010, 2013). The presence of evident climatic fluctuations both in the values of temperatures and humidity was also detected through sedimentological investigations, in a nearby quarry (currently not visible). In particular, Ghinassi et al. (2004) recognised, in the SPs deposits, sedimentary cycles, 2 to 6 m thick, characterised by sequences of the "wetting – drying – wetting" type. Each cycle, whose duration has been estimated at around 40 kyr, is delimited, at the base and at the top, by more or less thick layers of iron mineral encrustations which would represent periods characterised by a reduced accumulation of aeolian sands caused by the rising of the aquifer.

STOP 3.4 - The Accademia Valdarnese del Poggio and the Palaeontological Museum, Montevarchi

Coordinates: Lat. 43° 31' 27.56''N, Long. 11° 34' 01.69''E

TO OBSERVE:

- Exhibition rooms at the Palaeontological Museum.
- *Biblioteca Poggiana.*

TO DISCUSS:

- The role of terrestrial biotic proxies for the stratigraphical and environmental reconstructions.

LUNCH BREAK IN THE CLOISTER

The Accademia del Poggio (AdP), named in honour of Poggio Bracciolini, was founded in 1805 in Figline Valdarno; its earliest activities concentrated around the first fossil collection and a library. Between 1818 and 1819 it was moved in the former convent of San Lodovico in Montevarchi, where the Palaeontological Museum and *Biblioteca Poggiana* was instituted. Since 1835 AdP publishes the *Memorie Valdarnesi*. It was erected in a legal institution with Regio Decreto of 01.02.1874. A series of monographs on the territory and on literary works started to be published since 1980. George Cuvier and Alessandro Manzoni are among the most eminent national and international members. Today the AdP focuses its activity on a range of scientific topics especially concerning geology and palaeontology, history and local traditions as well as the protection and enhancement of the palaeontological, archaeological, historical, natural and artistic heritage of the Upper Valdarno. It carries out numerous initiatives (archival, education, research) in collaboration with the University of Siena and Florence and with different associations. In 2005 the *Audioteca Poggiana* was instituted; it preserves over ten thousand vinyl records. The AdP was recognised by the *Regione Toscana* as an institution of cultural relevance in 2012. At the end of 2014, the Academy will finally reopen to the public after having been closed for six years for the restoration of many of the fossils of its collection and of its building. The Museum will include two new

https://doi.org/10.3301/GFT.2023.06

sections: the Archaeological collection "Tracchi" and the restored fossils. During our visit we will have the chance to see the new structures and the new installation for fossil remains.

STOP 3.5 - Le «balze», Castelfranco di Sopra

Coordinates: Lat. 43° 36' 53.9''N, Long. 11° 33'18.81''E

TO OBSERVE:

- Distal deposits of alluvial fan (Montevarchi Synthem and Ciuffenna T. Synthem).
- The typical morphology of the "Balze".

TO DISCUSS:

- Tectonics and sedimentation.
- Chronological framework.
- Erosion phenomena.

The splendid exposures on the almost vertical walls of the "Balze", along the Acqua Zolfina gorge, offer a broad overview of the deposits of alluvial fans bordering the NE edge of the basin (Pratomagno ridge) (Fig. 3.12)

The outcropping sediments are mostly referable to the upper portion of the Montevarchi Synthem (Lower Pleistocene) (Fig. 3.12). It consists of 30-40 m of sands, in tabular layers, containing isolated gravel-sandy layers with silty layers interbedded (*sabbie di Borro Cave*), deposited in the distal portion of the alluvial fan. The sandy layers are thick up to over 1 m, with a flat base and little erosion. Sands are typically graded, structureless at the base, and with groove cast and ripple at the top. The upper part of the strata is often draped by silty, massive, up to 50 cm thick, intensely bioturbated and pedogenised sediments. The sedimentary characteristics of these sands and silts

Fig. 3.12 – The *Balze* (Castelfranco di Sopra): spectacular view of the transversal alluvial fan deposits of the Montevarchi Synthem and the overlying Ciuffenna T. Synthem, deeply engraved by erosion. (Drone photo by M. Civitelli 2014-https://commons.wikimedia.org/wiki/File:BALZE_DEL_VALDARNO_1.jpg)

suggest their deposition by unconfined flows, which rapidly deposited their sediment load on the distal surface of the fan. The gravel-sandy layers, which are found interspersed in the sands, show a tabular or elongated lentiform geometry, with a flat or concave erosive base. These layers are 20 cm to over 1 m thick, sometimes they are amalgamated, and have a width that can exceed 10 m. They commonly consist of structureless gravels and sands that pass upwards in plane-parallel to trough cross-stratification. The pebbles, mainly made up of sandstone, are generally tiled. They were associated with deposits of shallow fluvial channels reaching the distal part of the alluvial fan. The alluvial fan deposits of the Montevarchi Synthem are delimited on the top by an unconformity surface highlighted by a slight unconformity, and by an erosive surface of basinal extension. The coarse deposits of alluvial fan of the overlying T. Ciuffenna Synthem (Lower and Middle Pleistocene) lean on it, consisting of channelled pebbles, frequently amalgamated, with interspersed lenses of sand and pedogenised silt (*ciottolami di Loro Ciuffenna*). The latter passes, upwards, to mainly sandy sediments, with lentiform levels of gravel interspersed (*sabbie del Tasso*). In these deposits at least three second order depositional cycles have been recognised, separated by palaeosols and erosive surfaces (Magi, 1989).

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Manuscript received 28 October 2022; accepted 04 July 2023; published online 30 August 2023;
editorial responsibility and handling by M. Della Seta