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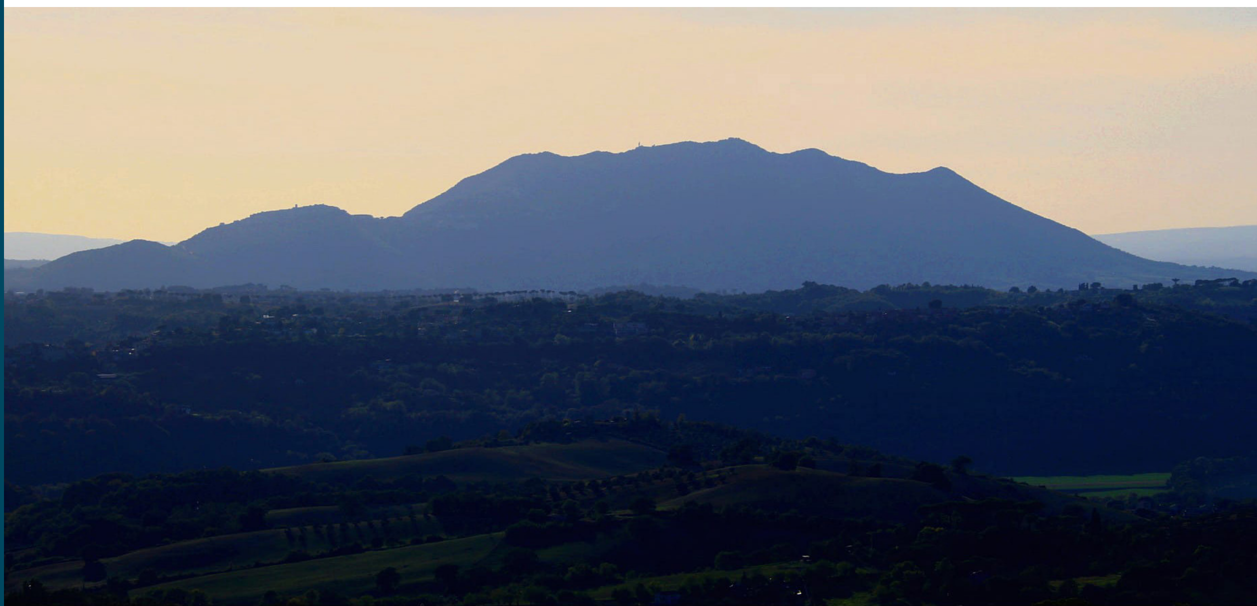

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Geological map of the Mt. Soratte ridge (Central Apennines, Latium, Italy)

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Cover
Above: Panoramic view of Mt. Soratte ridge from Poggio Mirteto (RI) (Photo courtesy of Monica Cantonetti).
Below: Panoramic view of Sant'Oreste village from the south. In the left background Mt. Soratte. On the right a portion of the Tiber valley is visible (Photo courtesy of Federico Artegiani).

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ABSTRACT

In this work we present the geological map of Mt. Soratte (Central Apennines, Latium, Italy), drawn up at a scale of 1:5,000, following the guidelines proposed by the CARG (Geological CARtography) project. The study area is characterised by a Meso-Cenozoic succession mainly dominated by pelagic deposits belonging to the Umbria-Marche-Sabina Basin, set up following the Early Jurassic extensional tectonics. A peculiarity of this area is the occurrence of neptunian dykes filled up by Middle Jurassic and Cretaceous units as well as epiescarpment deposits of Cenomanian/Turonian units overlying Lower Jurassic units, as a results of a Cretaceous extensional tectonics. A further note goes to the presence of hiatus in the succession, which lacks Cretaceous units as well as units subsequent to the upper Eocene until the Plio-Pleistocene. The current landscape of the Mt. Soratte area is the result of a complex morpho-tectonic evolution started from the Miocene compression, which structured the Apennine chain, followed by the extensional tectonics, leading to the formation of the Tiber Valley. This scenario has allowed the arrangement of wide volcaniclastic and continental clastic deposits in the entire area surrounding the Mt. Soratte relief.

Keywords: Mt. Soratte Ridge, Umbria-Marche-Sabina succession, Jurassic extensional phase, Cretaceous extensional phase, pelagic carbonate platform-basin systems.

INTRODUCTION AND GEOLOGICAL SETTING

The Mt. Soratte is an isolated relief within the Central Apennines, part of the "*Dorsale Tiberina*" (Chiocchini et al., 1975; Martinis, 1992), comprising several peaks, the highest of which reaches 691 m above sea level. It is situated approximately 40 km north of Rome, flanked by the Sabatino Graben to the west and the Tiber Valley to the east (Bortolani and Carugno, 1979) (Fig. 1).

The geological framework of Mt. Soratte consists of Meso-Cenozoic rocks belonging to the Umbria-Marche-Sabina sedimentary succession (Centamore et al., 1971; Farinacci et al., 1981; Galluzzo and Santantonio, 2002), which is mainly composed of carbonatic, marly, and siliceous lithologies (Fig. 2). This stratigraphic sequence resulted from extensional tectonics that occurred during the Early Jurassic (Hettangian–Sinemurian boundary), associated with the opening of the Western Tethys Ocean (Bertotti et al., 1993; Picotti and Cobianchi, 1996; Manatschal and Bernoulli, 1999; Santantonio and Carminati, 2011). In this setting, the Calcare Massiccio palaeoplatform (Calcare Massiccio A *sensu* Centamore et al., 1971; Chiocchini and Mancinelli, 1978) was dissected by extensional faulting, leading to the differentiation of two distinct palaeogeographic domains: the Laziale-Abruzzese Domain and the Umbria-Marche-Sabina Domain (Parotto and Praturlon, 1975; Salvini and Vittori, 1982; Passeri and Venturi, 2005). The extensional tectonics produced a complex submarine palaeotopography in the Umbria-Marche-Sabina Basin, characterised by a system of structural highs and lows, bounded by extensional faults (Farinacci, 1967, 1970; Colacicchi et al., 1970; Centamore et al., 1971; Santantonio, 1993, 1994; Galluzzo and Santantonio, 2002; Santantonio and Carminati, 2011; Fabbi and Santantonio, 2012; Cipriani and Bottini, 2019a).

In the Hettangian–early Sinemurian, once faulting ceased (Fabbi and Santantonio, 2012), the fault surfaces on the footwall blocks began to retreat due to submarine erosion and slope instability, evolving into palaeoescarpments that became sites for specific depositional environments. The same tectonic phase also led to the drowning of the Calcare Massiccio A palaeoplatform (*sensu* Schlager, 1981), changing the sedimentation patterns within the Umbria-Marche-Sabina Basin.

The drowning of the Calcare Massiccio A occurred in two forms: drowning unconformity or drowning succession (e.g., Marino and Santantonio, 2010). On structural highs carbonate sedimentation persisted until the early Pliensbachian (Morettini et al., 2002; Passeri and Venturi, 2005). The unit that record the progressive transition from a benthic sedimentation style to a pelagic one is referred as "drowning succession", and is represented by the "calcare massiccio B" member (*sensu* Petti et al., 2007; Calcare Massiccio B *sensu* Centamore et al., 1971), whereas in the structural lows, the drowning occurred at the Hettangian–Sinemurian boundary and is represented by the "calcare massiccio C" lithofacies (*sensu* Petti et al., 2007; Calcare Massiccio C *sensu* Centamore et al., 1971; Marino and Santantonio, 2010). Following the drowning event, the structural highs and lows, although both situated within a basinal context (i.e., in the Umbria-Marche-Sabina basin), displayed two distinct types of carbonate sedimentation. A Pelagic Carbonate Platform (PCP *sensu* Santantonio, 1993, 1994) with condensed pelagites developed on the structural highs, and a typical basinal pelagic succession in the structural lows. The latter presents substantial differences in terms of lithofacies between the proximal and distal areas of a structural high (f.a.B *sensu* Santantonio, 1993). Basin units, typically chert-rich, unconformably lying on the palaeosurfaces lead to the formation of spherules, crusts, and pore fillings on the surface of the already lithified and porous Calcare Massiccio (neritic limestones without chert) in contact with the basin units, through SiO_2-saturated fluids resulting from the dissolution of siliceous skeletal clasts (Santantonio et al., 1996). Additionally, the palaeoescarpments connecting the Pelagic Carbonate Platform and the basin, formed after the cessation of rifting-related fault activity, hosted stratigraphic contacts between basinal deposits and, as well as the structural high units, highly fossiliferous condensed deposits rich in both invertebrate and vertebrate macrofauna (Cecca and Santantonio, 1986; Cresta and Pallini, 1986; Cecca et al., 1987, 1990; Mariotti et al., 1978; Mariotti and Pignatti, 1993; Manni and Nicosia, 1994; Mariotti, 1994, 2003; Monari, 1994a, 1994b; Manni and Tinozzi, 2002; Gill et al., 2004; Citton et al., 2018, 2019; Romano et al., 2019) and breccias belonging to the structural high-type succession (f.a.C *sensu* Santantonio, 1993; Santantonio et al., 1996, 2024; Romano et al., 2019). On the structural highs, the sedimentary succession is represented by the "Bugarone Group" (*sensu* Cecca et al., 1990). Units belonging to this group are condensed counterparts of the basinal sedimentary succession, except for the siliceous member of the Calcari Diasprigni, which is represented by a hiatus of approximately 20 Ma on the structural highs interpreted by Bartolini and Cecca (1999) as the result of carbonate productivity crisis ranging from early Bajocian to late early Kimmeridgian. This configuration persisted until the Early Cretaceous (Berriasian–Valanginian boundary), when the Maiolica formation levelled out the palaeotopographic differences in the basin (Galluzzo and Santantonio, 2002; Bollati et al., 2012). The sedimentary sequence then remained uniform until the Miocene, with some exceptions. Evidence of Early and Late Cretaceous extensional tectonics has indeed been identified by various authors in Northern Italy (Castellarin, 1972; Centamore et al., 2009; Bertok et al., 2012; Picotti et al., 2019), Central Italy (Marchegiani et al., 1999; Centamore et al., 2007, 2009; Cipriani and Bottini, 2019b), and Southern Italy (Festa et al., 2018; Vitale et al., 2018; Vitale and Ciarcia, 2022; Tavani et al., 2023).

From the Tortonian onwards, the study area experienced a compressional regime associated with the formation of the Apennines started after the 38 Ma Alps-Apennines subduction flip (Carminati et al., 2012). As well as other tract of the central-northern Apennines, Mt. Soratte Ridge was structured by thin-skinned, NW-SE trending compressional tectonics induced by a W-directed subduction of the Adriatic lithosphere beneath the European Plate as a result of convergence between Africa and Europe (e.g., Malinverno and Ryan, 1986; Doglioni et al., 1991; Carminati et al. 2010; Curzi et al., 2020). During the build-up of the central-northern Apennine wedge the structural evolution has been controlled by the presence of Upper Triassic evaporites and dolostones (Anidridi di Burano fm.) which acted as a regional decollement level. Since the late Oligocene the western portion of the wedge starts to shorten eastward, scraping the sedimentary succession lying above the Adriatic plate (e.g., Cosentino et al., 2010). Subsequently, a new phase of extensional tectonics, active since the upper part of the Late Pliocene due to slab retreat and consequent opening of the Tyrrhenian back-arc basin (e.g. Doglioni et al., 1999; Scrocca et al., 2003; Faccenna et al., 2004; Cosentino et al., 2010), resulted in the development of NW–SE trending horst and graben structures (Ambrosetti

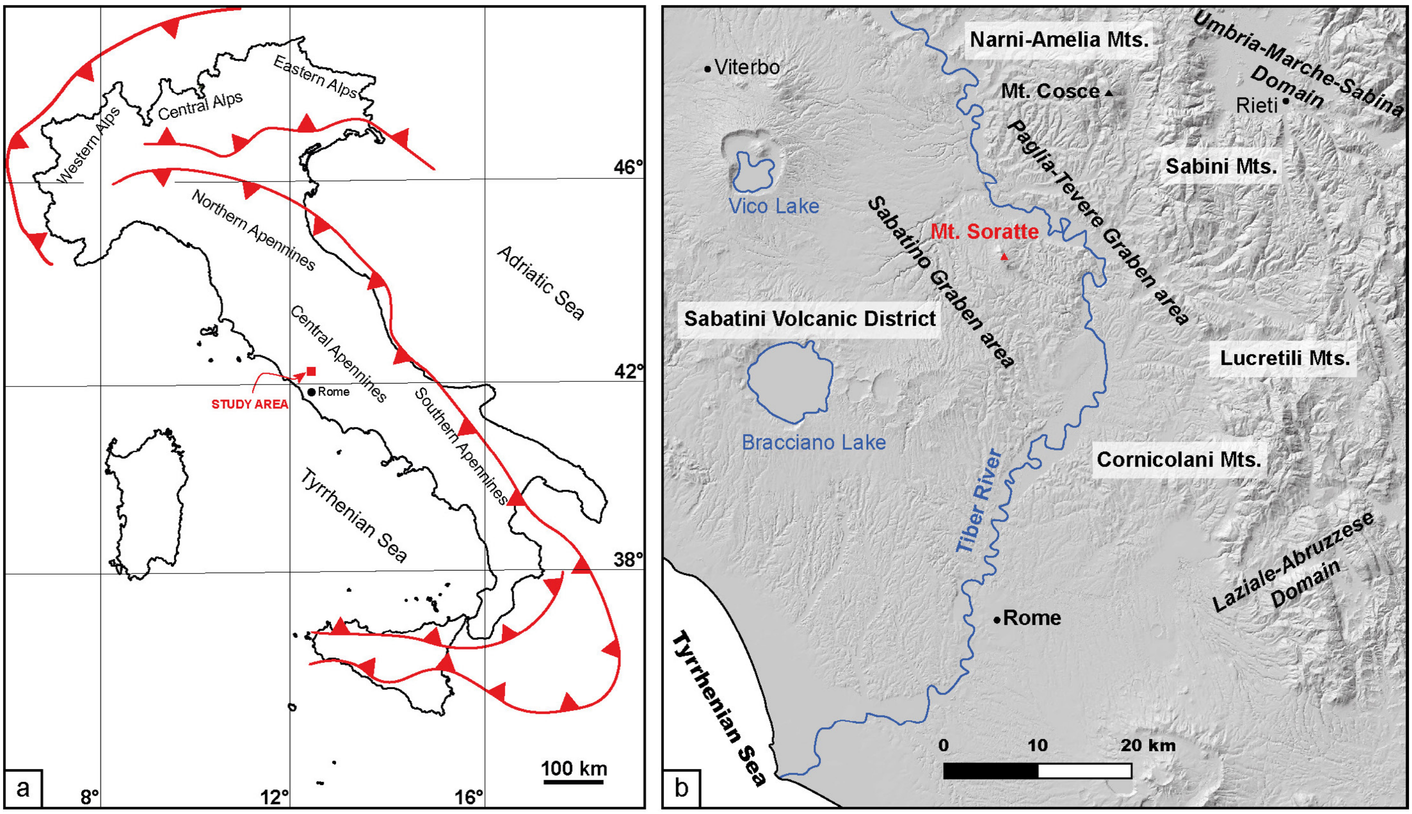


Fig. 1 - a) Simplified tectonic map of Italy (Main thrust fronts are represented by red lines; study area is highlighted by the red square). b) Regional overview of the surroundings of Mt. Soratte ridge (DEM from Tarquini et al., 2023).

et al. 1978), including the Paglia-Tevere Graben (Fig. 1b) to the east of Mt. Soratte (Mancini et al., 2004; Mancini and Cavinato, 2005; Sottili et al., 2010). Finally, the area was affected by volcanic activity from the Sabatini Volcanic District (Fig. 1b), part of the Quaternary Roman Province (Peccerillo, 2017), also related to the Tyrrhenian back-arc basin opening, from approximately 0.8 Ma to 90 ka (Sottili et al., 2010).

The aim of this project is to provide a new geological map of the Mt. Soratte area, which has been investigated in the last century by several authors (Clerici, 1929; Beneo, 1946, 1947a, 1947b; Manfredini and Motta, 1947; Benelli, 1958; Lupia Palmieri, 1966; Chiocchini et al., 1975; Toro, 1978; Bortolani and Carugno, 1979; Cavinato and Tozzi, 1986; Di Filippo et al., 1991; Martinis, 1992; Girotti and Mancini, 2003; Mancini et al., 2004; Mancini and Cavinato, 2005). However, a detailed map at a 1:5,000 scale has never been produced and published. A geological map is presented, accompanied by geological cross-sections, a diagram of stratigraphic relationships, and explanatory notes that describe the bio-lithostratigraphic characteristics of the units outcropping in the Monte Soratte area.

METHODS AND TECHNIQUES

The geological mapping of the Monte Soratte area was conducted at a 1:5,000 scale following the guidelines of the CARG Project ("Quaderni del Servizio Geologico d'Italia", Pasquaré et al., 1992; Galluzzo et al., 2009; Vita et al., 2022). The topographic basemap was the Carta Tecnica Regionale Numerica (CTRN v.2014) at a 1:5,000 scale from the Lazio Region (available online at: https://geoportale.regione.lazio.it/layers/ctr_5k_retiled:geonode:ctr_5k_retiled; Elements no. 356102 "Monte Ciola", no. 356141 "Stazione di S. Oreste", no. 356153 "Monte Maiano", no. 356154 "Sant'Oreste", no. 366113 "Monte Santo"). The contour interval of the CTRN is 5 metres. For the field mapping, a tablet (Samsung Galaxy Tab S7 FE) equipped with the open source QField application (version 3.28, available online https://qfield.org/) was used alongside traditional geological mapping techniques. The graphic layout was prepared using the symbol library of the CARG Project, which is freely accessible online (https://progetto-carg.isprambiente.it/quaderno15&oggettidigitali/), and the QGis software v. 3.36, also freely available online (https://www.qgis.org/) using the spatial reference system RDN2008 (EPSG: 6708/UTM 33N). For the geological cross-sections and other schematics, Adobe Illustrator 2021 software was utilised. The formation nomenclature refers to the official "*Catalogo delle Formazioni Geologiche Italiane*" (https://sgi.isprambiente.it/catalogo-formazioni-italiane/). Informal acronyms have been adopted when the geological units are not described within the official *Catalogo delle Formazioni Geologiche Italiane* and, also, Jacobacci et al. (1974), Centamore et al. (1975), and Petti et al. (2007) were consulted. To accurately characterise the depositional units, more than 50 thin sections were prepared. The description of microfacies and textures was based on the classifications by Dunham (1962) and Embry and Klovan (1971).

FIELD DATA

Lithostratigraphy

The litho-biostratigraphic features of the mapped units will be described below from older to younger. Abbreviations are the same as those contained in the geological map and used by the Italian Geological Survey (except for "Sant'Oreste breccia").

Palaeoplatform succession

Monte Cetona formation (*sensu* Ciarapica et al., 1986) (FZM): equivalent of the "calcari e marne a *Rhaetavicula contorta*", specifically in this area referring to the upper member RET2 (e.g., Barchi e Marroni, 2007), represents the oldest unit outcropping in the Monte Soratte Ridge. Lithologically the unit is represented by: i) dark grey, thick-bedded (up to 1 m) fetid and vacuolar dolostones and dolomitic limestones, locally laminated (Fig. 3a); ii) well-bedded (up to 10 cm) grey limestones and dolomitic limestones often laminated with the presence of ripple marks. No remains of macro- and microfossils have been noticed (Pl. 1a). The lower stratigraphic boundary of the unit is not exposed, while the upper stratigraphic boundary to Calcare Massiccio is exposed at geographic coordinates 42°14'31.14"N; 12°30'43.50"E. The transition to the overlying Calcare Massiccio is marked by a change from dark grey dolostones to whitish, grain-supported deposits. In the study area, the outcrops of this unit are very small. The thickness obtained from the geological sections appears to be around 50 m. At regional scale, the thickness of this unit is variable: Cipriani (2019) reported a thickness of 110 m in the central Narni-Amelia Ridge (locality Ponte Arverino near Poggio (TR), almost 20 Km northeastward with respect to the study area), as well as Passeri and Pialli (1973) for the Poggio area (Ponte Arverino section). In the Mt Civitello 1 well log (available online: https://www.videpi.com/deposito/pozzi/profili/pdf/monte_civitello_001.pdf), drilled by AGIP in 1988 near Pietralunga (PG), about 130 Km north from Mt. Soratte, the thickness of Monte Cetona formation is 150 m; at Monte Cetona (type-locality of the unit) the exposed thickness is also 110 m; at Mt. Malbe (Perugia) this unit is at least 80 m-thick from the bottom boundary (with the "Calcare Cavernoso") to

the outcropping surface (the top boundary is not exposed, Barchi e Marroni, 2007). The age is Rhaetian *p.p.*
Calcare Massiccio (MAS): massive to poorly-bedded (up to 1 m), white to hazelnut, limestones and locally dolomitic limestones (Fig. 3b). The most frequent textures are litho-bioclastic grainstones/rudstones, microbial bindstones, cementstones and mudstones. This formation is characterised by shallowing-upward asymmetric peritidal cycles. Reddish paleokarst levels are associated with stromatolitic, fenestral, oncolitic, peloidal and gastropod-rich facies (Pl. 1b, 1c). Well exposed supratidal facies, characterised by teepee structures, are observable near Santa Lucia (42°14'25.94"N; 12°30'23.42"E) (Fig. 3c). Fossils assemblage consists of gastropods, echinoderms, bivalves, brachiopods, benthic foraminifera (lituolids, valvulinids, *Trocholina* sp.), calcareous algae (*Palaeodasycladus mediterraneus*, Dasycladaceae), microproblematica (*Tubiphytes* sp., *Lithocodium aggregatum*, *Bacinella* sp., *Thaumatoporella parvovesiculifera*) and bacteria (Cyanophyceae, *Cayeuxia* sp.). Calcare Massiccio crops out widely along the entire Mt. Soratte Ridge, with excellent exposure along the southwest slope of Mt. Soratte. In the basinal succession the transition to the overlying unit ("calcare massiccio C lithofacies") is not exposed, whereas the boundary with the overlying unit in the PCP-top succession ("calcare massiccio B member" - MAS_1) is well exposed in the southern part of Monte Piccolo area. Locally, the Calcare Massiccio is laterally in contact with Jurassic and Upper Cretaceous deposits (e.g., southern slope of Sant'Oreste village - 42°13'54.24"N; 12°31'31.67"E and near Eremo S. Silvestro - 42°14'40.65"N; 12°30'11.18"E), whereby the unconformable boundary is marked by the occurrence of chert nodules and crusts. Silicified Calcare Massiccio crops out along a hiking trail at 42°14'18.90"N; 12°30'36.04"E. The total thickness of the Calcare Massiccio cannot be evaluated due to the lack of continuity between the lower and the upper boundaries. Information obtained from field surveys and those provided by geological cross-sections suggest a thickness of at least 450 m (Fig. 2). The age is ?Rhaetian *p.p.*/Hettangian–Sinemurian *p.p.*

Pelagic succession

This section will be divided following the depositional environments established after the Jurassic rifting stage: PCP and basinal successions.

Pelagic Carbonate Platform (PCP) succession

calcare massiccio B member (*sensu* Petti et al., 2007; see also Centamore et al., 1971) (MAS_1): upper member of the Calcare Massiccio (MAS). It is characterised by massive to well-bedded (up to 15 cm) (Fig. 4a) hazelnut to light brown limestones, with packstone to wackestone textures bearing coated grains; occasionally a bioclastic floatstone texture may be observed. Fossil assemblage consist of crinoids, brachiopods, bivalves, gastropods, calcareous green algae, siliceous and calcareous sponge spicules and benthic foraminifera (*Ophthalmidium martanum*, Valvulinidae, Trochamminidae, *Involutina* sp.) (Pl. 1d–f, 2a). The calcare massiccio B member crops out extensively in the southern area of Sant'Oreste. The largest outcrops are located along the slope facing the cemetery (42°13'52.69"N; 12°31'33.13"E) and on Monte Piccolo; smaller outcrops can also be observed at 42°13'51.73"N; 12°31'28.72"E. The lower stratigraphic boundary is well exposed at Monte Piccolo and it is marked by the vanishing of the peritidal sedimentological feature typical of the Calcare Massiccio which results in an upward decrease in the benthic content within the calcare massiccio B member. This formation often lies in angular unconformity along and at the base of Jurassic escarpments and within niches (off-platform unconformity-bounded drowning succession *sensu* Marino and Santantonio, 2010). The transition to the overlying "calcari nodulari dell'Infernaccio" is marked by the disappearance of the benthic content and the coated grains. The thickness is about 60 m. The age is Sinemurian *p.p.*–Pliensbachian *p.p.*
"calcari nodulari dell'Infernaccio" (IFC): massive to well-bedded (up to 15 cm) (Fig. 4b) hazelnut to light brown limestones with wackestone to packstone texture, rarely reddish grain-supported encrinites. Fossil assemblage consist of ammonites, belemnites, bivalves, siliceous and calcareous sponge spicules, gastropods, crinoids, radiolarian, and benthic foraminifera (*Ophthalmidium martanum*, *Involutina liassica*, nodosariids) (Pl. 2c). IFC crops out towards E, NW and NE of the Sant'Oreste village, immediately below Croce. The lower stratigraphic boundary is poorly exposed in the upper part of the eastern slope of Sant'Oreste, whereas the upper boundary does not crop out. The overlying unit ("calcari nodulari e marne verdi de l Ranchi") is missing, the contact with the overlaying "calcari nodulari a filaments di Fosso del Presale" is marked by an unconformity surface (see geological cross section A-A'). Due to these geometries, it was not possible to correctly estimate the thickness, which is around 15 - 20 m (Fig. 2). The age is Pliensbachian *p.p.*–Toarcian *p.p.*
"calcari nodulari a filaments di Fosso del Presale" (PLS): equivalent of the "Calcari Dolomitizzati Nocciola" (Centamore et al., 1971) and "Bugarone inferiore" (Cecca et al., 1990). Massive-bedded (up to 1 m) (Fig. 4c) brown to reddish-brown limestones with wackestone to packstone texture rich in thin-shelled bivalves (*Bositra buchii* and *Lentilla humilis*, Conti and Monari, 1992), with rare ammonites, gastropods, ostracods and benthic foraminifera

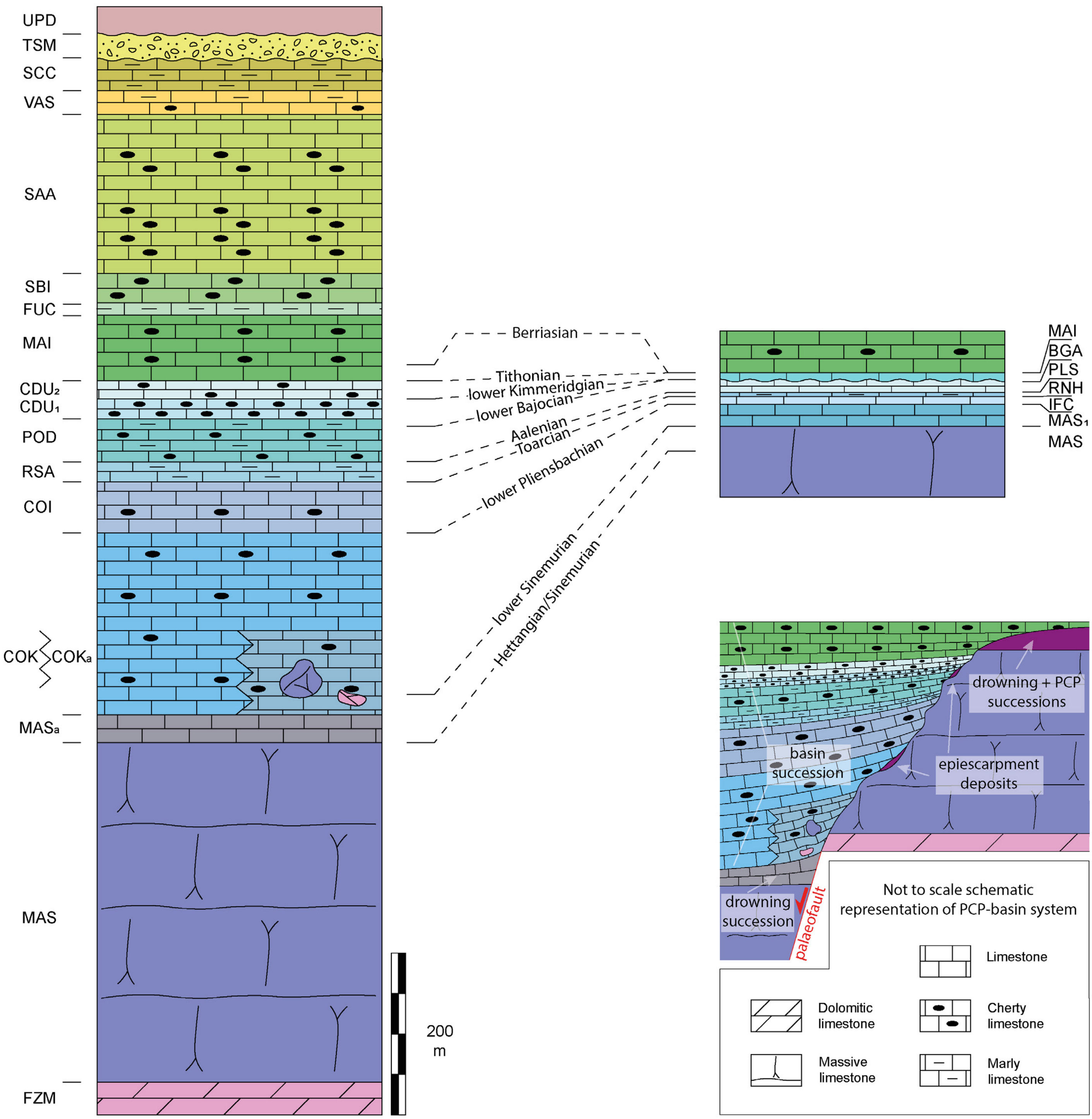


Fig. 2 - Schematic stratigraphic setting of the Umbria-Marche-Sabina Domain and relationship between basin succession and PCP-top succession (correlation lines are time lines); Legend of the acronyms: FZM - Monte Cetona formation; MAS - Calcare Massiccio; MAS_a – "calcare massiccio C" lithofacies; COK - "corniola detritica" (COKa - "olistoliths-rich lithofacies"); COI – Corniola; RSA – Rosso Ammonitico; POD – Calcari e Marne a Posidonia; CDU_1 – "selciferous" member of Calcari Diasprigni; CDU2 – "*calcari a Saccocoma e aptici*" member of Calcari Diasprigni; MAS_1 – "calcare massiccio B" member; IFC – calcari nodulari dell'infernaccio; RNH – calcari nodulari e marne verdi de l Ranchi; PLS – calcari nodulari a filaments di Fosso del Presale; BGA – calcari nodulari ad ammoniti ed aptici di Cava Bugarone; MAI – Maiolica; FUC – Marne a Fucoidi; SBI – Scaglia Bianca; SAA – Scaglia Rossa; VAS – scaglia variegata; SCC – Scaglia Cinerea; TSM – "Tenaglie-Fosso S. Martino unit"; UPD – "undifferentiated pyroclastic deposits".

(Pl. 2e). The "calcari nodulari a filaments di Fosso del Presale" crops out in the southern part of Sant'Oreste village. The overlying unit ("calcari nodulari ad ammoniti ed aptici di Cava Bugarone") is missing and the contact with the overlying Maiolica is marked by an unconformity surface. As well as the other PCP units, this one also rests in angular unconformity along Jurassic escarpments, and within neptunian dykes.

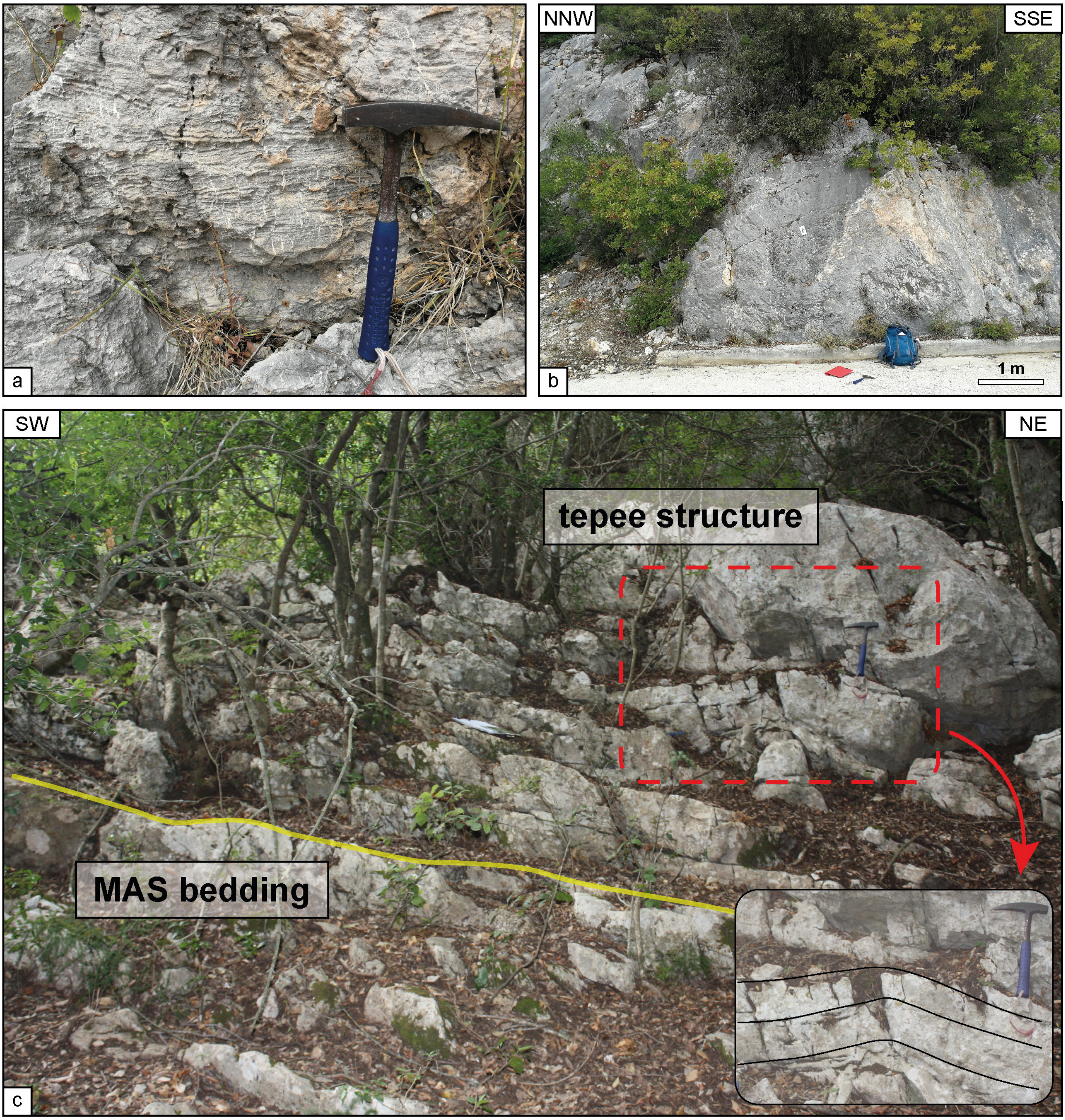
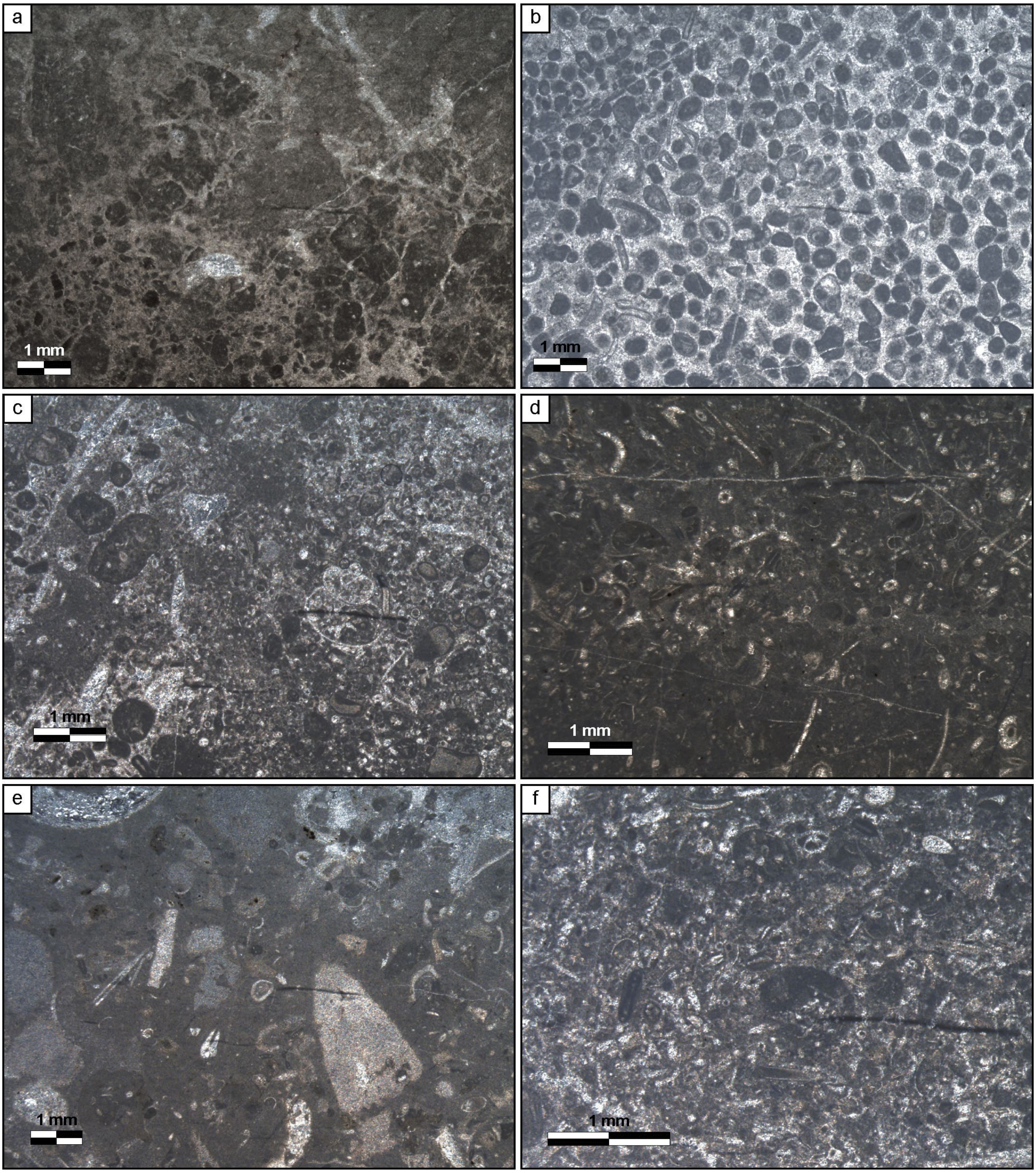


Fig. 3 - a) Laminated structures in FMZ. b) Massive beds of MAS southwest of Mt. Soratte. c) Bedding (yellow line) and teepee structures (highlighted by red dashed square) near Santa Lucia (hammer for scale).

Due to these geometries, it was not possible to correctly estimate the thickness, which is about 10-15 m. The age is Toarcian p.p–?Bajocian *p.p.*

Basinal succession

"corniola detritica" (COK): well-bedded (up to 15 cm) to thickly-bedded (up to 40 cm), light grey to hazelnut limestones (Fig. 5a). Packstone to grainstone texture is dominant, rarely wackestone intervals (Pl. 2b) with layers and nodules of grey chert occur (Fig. 5b). Fossiliferous content is represented by radiolarian, siliceous sponge spicules and rare ammonites as a background pelagic supply, whereas the resedimented intervals are rich in platform material such as ooids and fragments of: echinoderms, gastropods, bivalves, algae and corals. The lower portion



Pl. 1 - a) Monte Cetona formation. Microbrecciated dolomitic limestone with no faunas. b) Calcare Massiccio. Coated grains cementstone with intraclasts. c) Calcare Massiccio. Grainstone-cementstone with ooids, oncoids, intraclasts, gastropods. d - f) calcare massiccio B member. Wackestone-packstone with *Ophthalmidium martanum*, valvulinidae, lagenidae, ammonoids and echinoids fragments, sponge spicules.

of this unit is represented by a lithofacies ("olistoliths-rich lithofacies" – COKa) made up of metric scale olistoliths of FZM and MAS dispersed in a poorly-bedded (30-40 cm), hazelnut packstone to wackestone limestone. COKa crops out in the Croce area (42°14'15.04"N; 12°30'57.76"E) where in the E-SE part is intensely deformed, whereas in

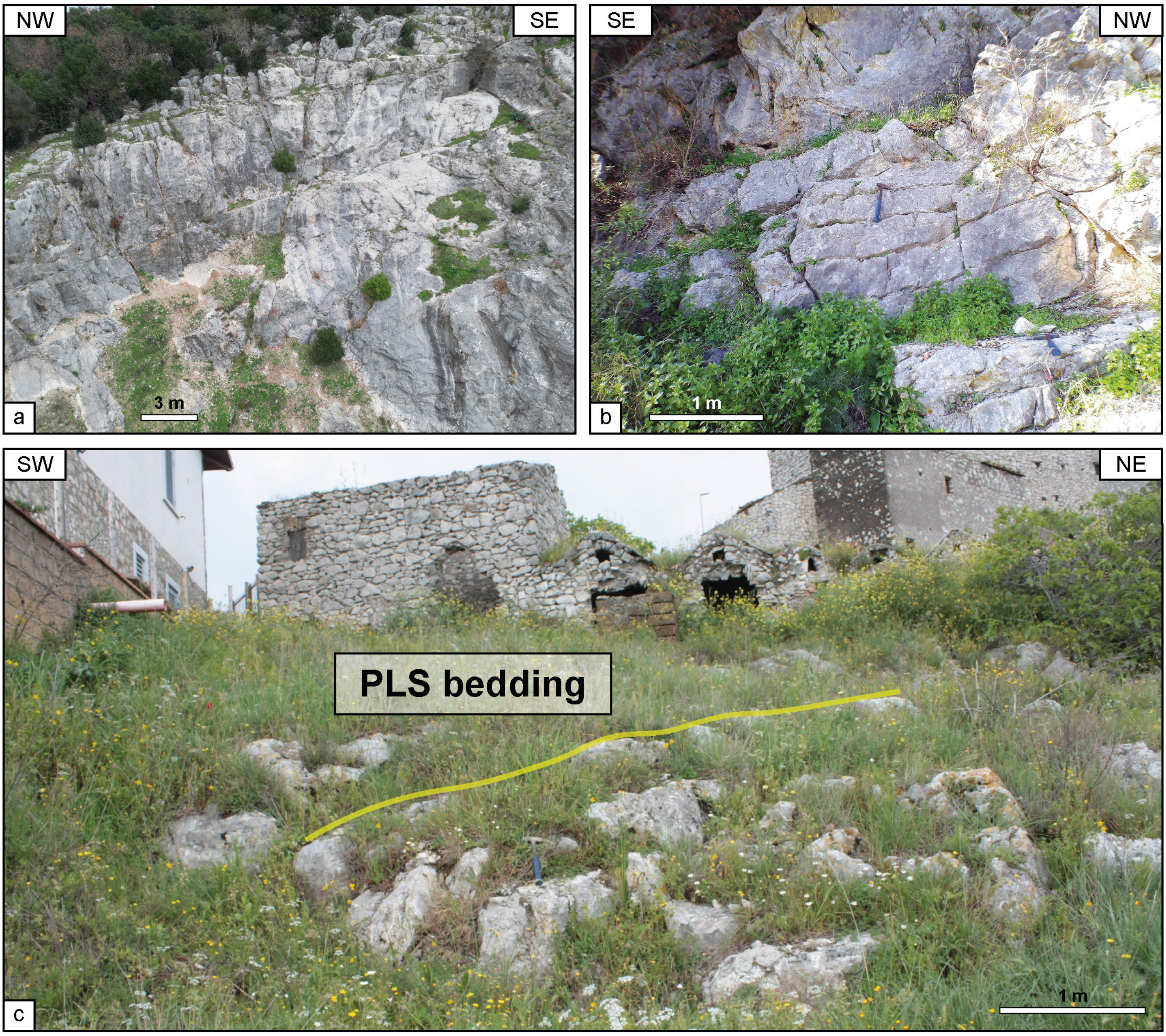


Fig. 4 - a) MAS$_1$ at the Mt. Piccolo quarry. b) Outcrop of IFC located south of the village of Sant'Oreste (hammer for scale). c) Outcrop of PLS located south of the village of Sant'Oreste (bedding in yellow line; hammer for scale).

the western part rests unconformably on MAS. COK widely crops out in the eastern part of Sant'Oreste village. Due to the unconformable contact of the lower boundary of this unit on the Calcare Massiccio and the absence of the upper boundary with the overlying units (Corniola and Rosso Ammonitico/Marne di Monte Serrone) it was not possible to estimate the total thickness of the formation; however the minimum thickness outcropping is about 100 m (Fig. 2). The age is Sinemurian *p.p.*-Pliensbachian *p.p.*

Calcari e Marne a Posidonia (POD): hazelnut limestones with wackestone texture. The fossil content is represented by thin-shelled bivalves *Bositra buchii* and *Lentilla humilis* (Conti and Monari, 1992) and radiolarians. This unit crops out as a metric-scale neptunian dyke along the southern slope of Sant'Oreste village (42°13'52.93"N; 12°31'29.43"E) (Fig. 2, 5c). The age is Toarcian *p.p.*–Bajocian *p.p.*

Maiolica (MAI): well-bedded (15 - 30 cm), locally massive, white to light grey limestones with mudstone texture and rare wackestone intervals, with white to grey chert occurring in nodules or lists. The fossil assemblage is characterised by the presence of radiolarians, calcisphaerulids and calpionellids (in the lower levels of the unit) (Pl. 3a). This unit crops out along the southern slope of Sant'Oreste village (42°13'56.97"N; 12°31'15.48"E) (massive facies, Fig. 6a) and (42°13'58.92"N; 12°31'24.79"E); furthermore, this unit can be found within neptunian dykes in MAS, MAS$_1$ (Fig. 6b), IFC and PLS (Pl. 2f). Both the lower and the upper

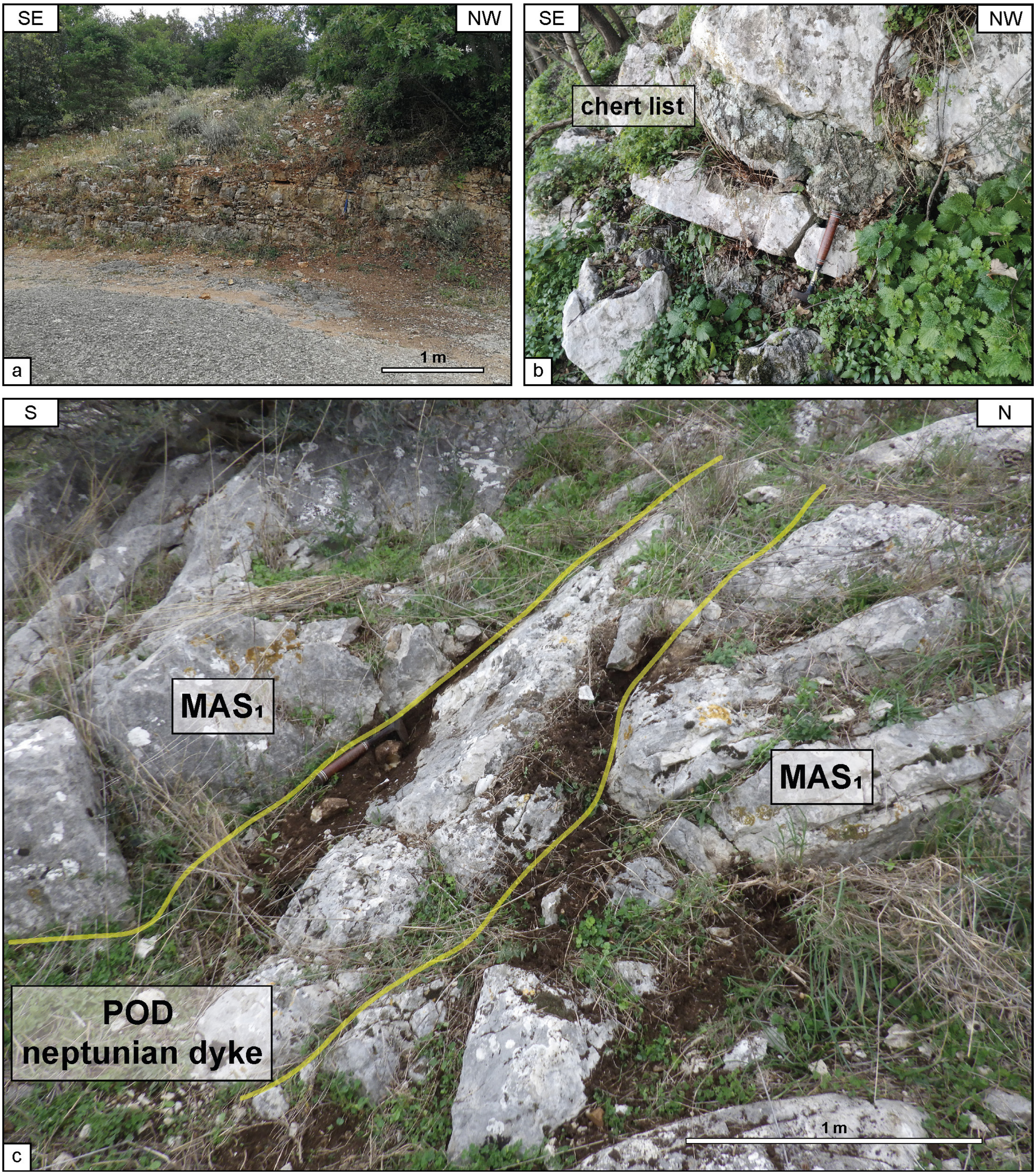
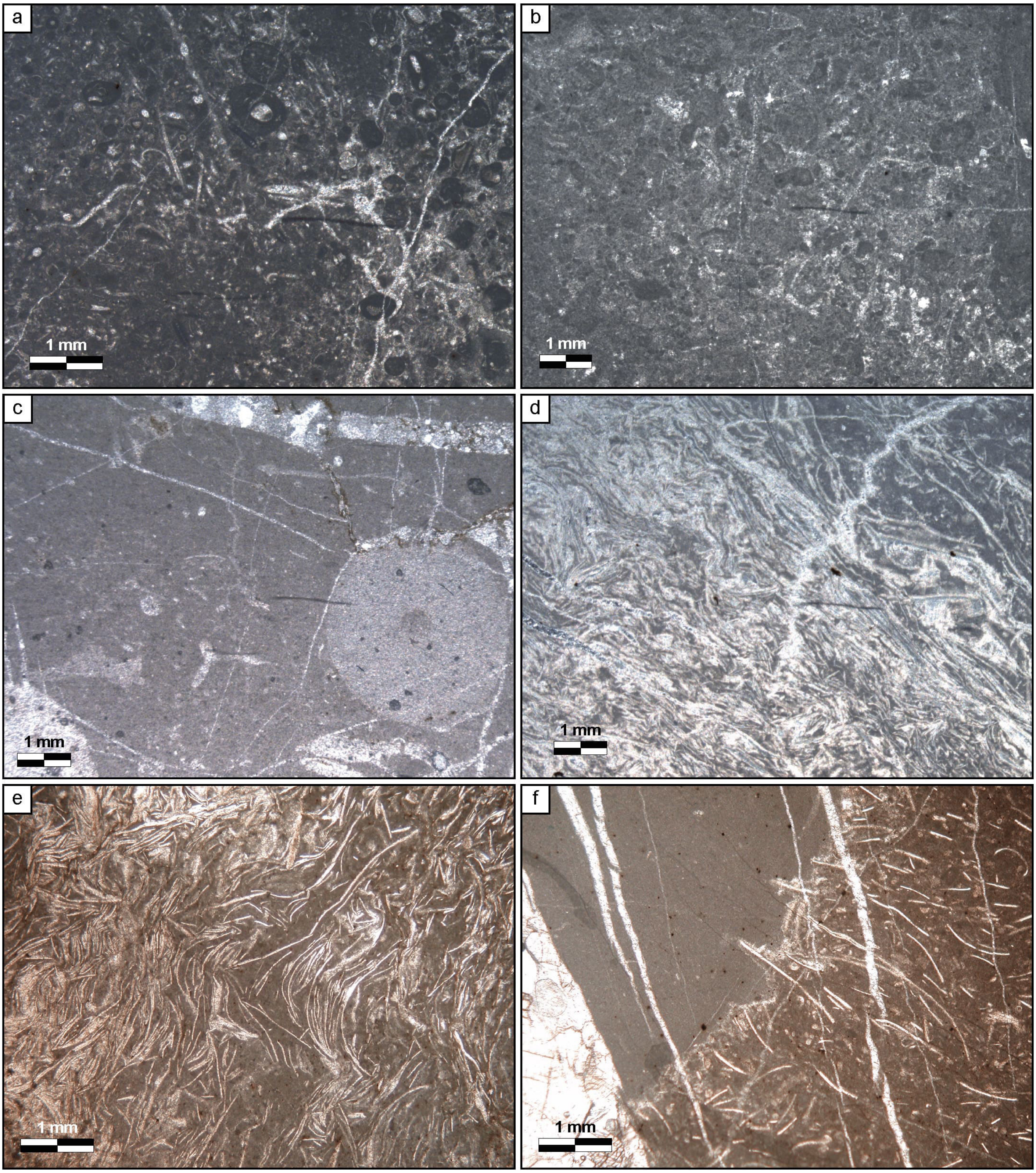


Fig. 5 - a) Well-stratified COK northwest of Croce. b) Chert list within COK outcropping south of Sant'Oreste (hammer for scale). c) Neptunian dyke (defined by yellow lines) of POD within MAS_1 on the southern slope of Sant'Oreste (hammer for scale).

boundaries of the unit are missing; in particular, the base of the Maiolica directly onlaps the Jurassic palaeoescarpments and the deposits perched along the scarp (Fig. 6c). The measured thickness is about 50 m. The age is Tithonian *p.p.*–Aptian inf. *p.p.*

"Sant'Oreste breccia" (BSO): A peculiar feature of this area is represented by a massive clastic deposit resting unconformably on MAS_1 and MAI (Fig. 7d), cropping out in a limited area along the southern slope of Sant'Oreste village (42°13'52.13"N; 12°31'23.92"E). This unit



Pl. 2 - a) calcare massiccio B member. Wackestone-packstone with *Ophthalmidium martanum*, *Tubiphytes* sp., valvulinidae, lagenidae, ammonoids and echinoids fragments, sponge spicules. b) “corniola detritica”. Wackestone with intraclasts. c) “calcari nodulari dell’Infernaccio”. Wackestone with sponge spicules, radiolarians and echinoid spine (trasversal section). d) Calcari e Marne a Posidonia. Wackestone-packstone with “Posidonia” (thin-shelled bivalves). e) “calcari nodulari a filaments di Fosso del Presale”. Wackestone with “Posidonia” (thin-shelled bivalves) and radiolarians. f) Neptunian dyke of Maiolica within “calcari nodulari a filaments di Fosso del Presale”.

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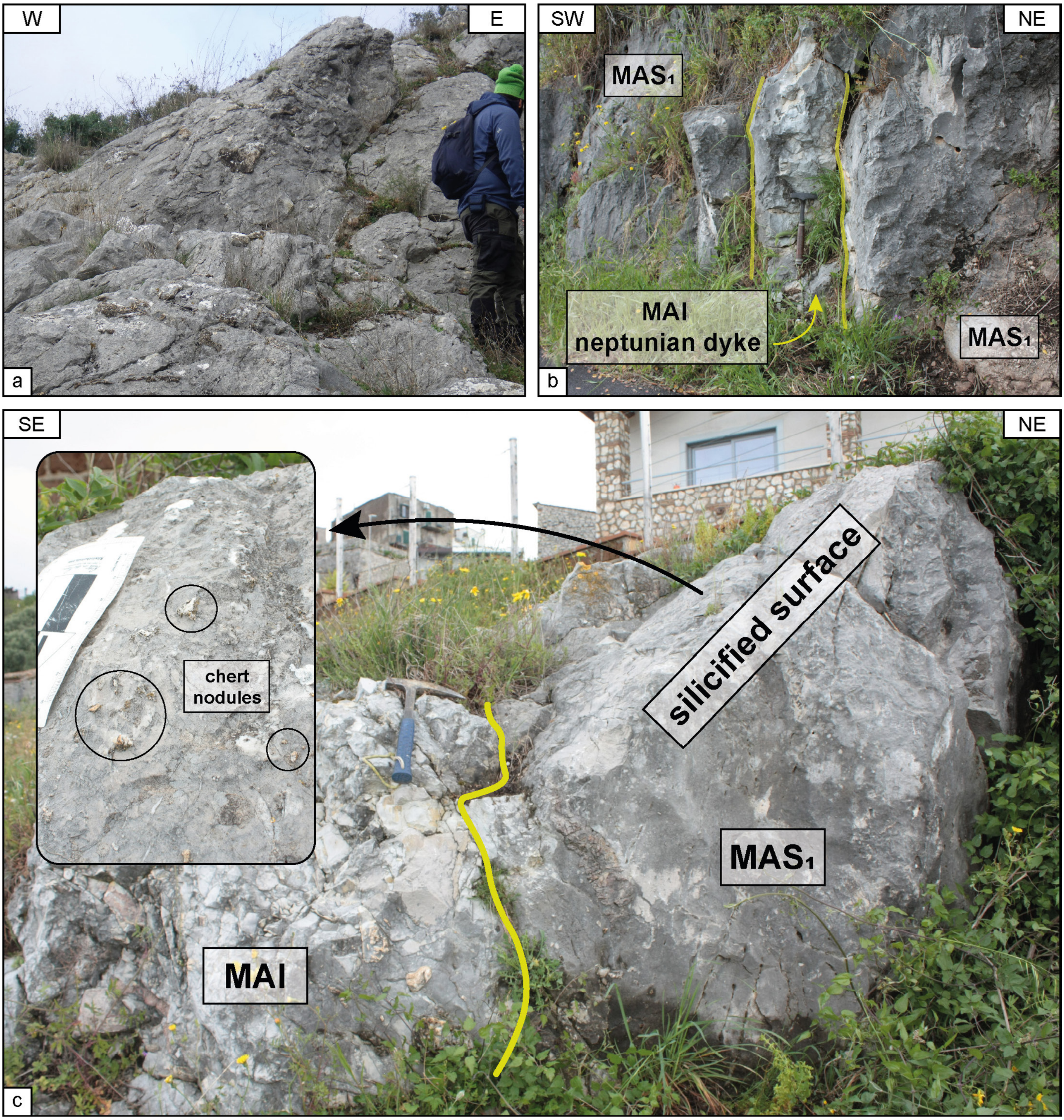
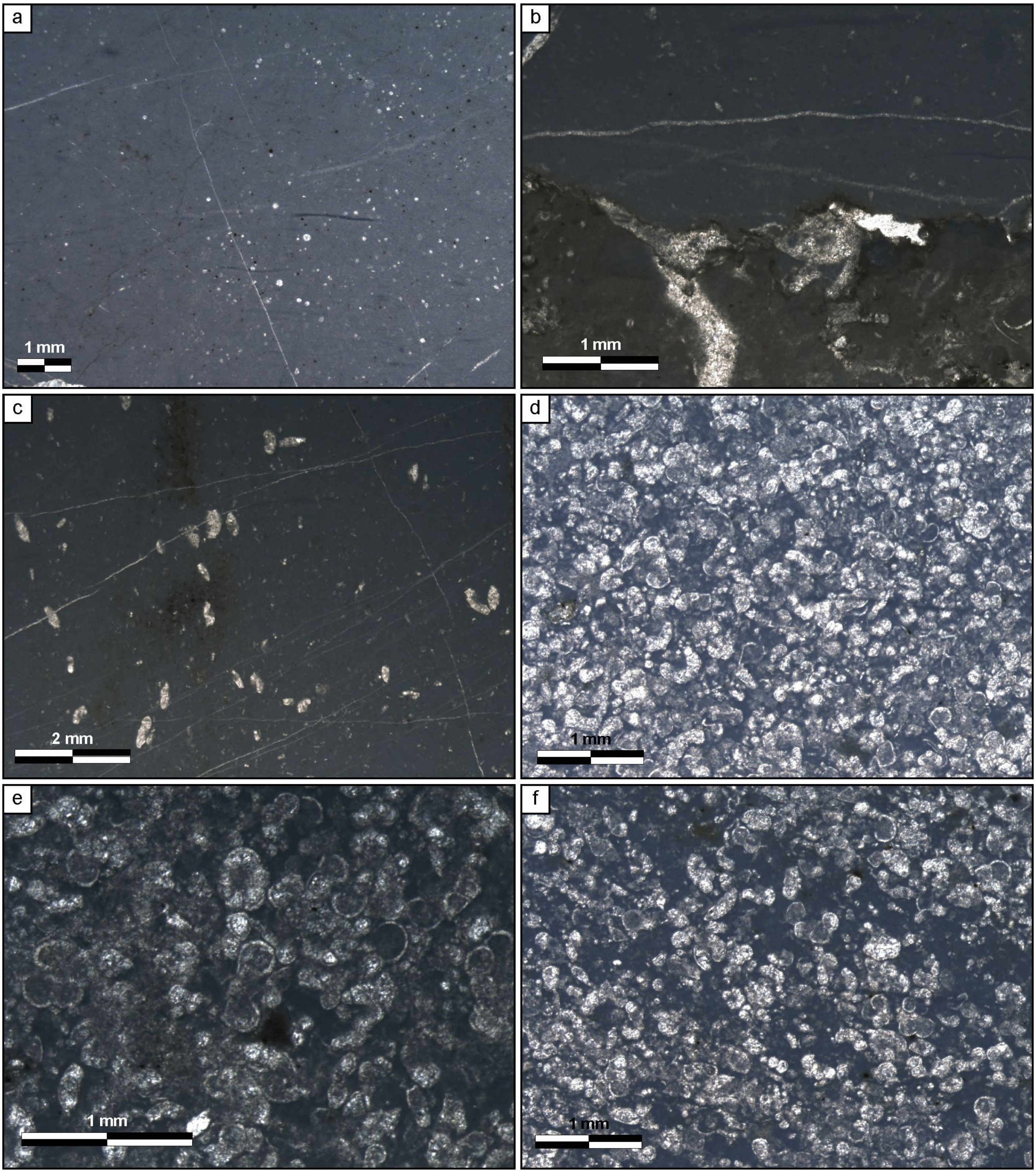


Fig. 6 - a) Massive beds of MAI southwest of Sant'Oreste village. b) Neptunian dyke (defined by yellow lines) of MAI within MAS_1 (hammer for scale). c) Unconformable stratigraphic contact (onlap; yellow line) between MAI and MAS_1. Silicified surface with chert nodules is highlighted (hammer for scale).

consists of polymictic breccias made of heterometric clasts belonging to the (i) Calcare Massiccio, (ii) "calcare massiccio B member", (iii) "calcari nodulari dell'Infernaccio", (iv) "calcari nodulari a *filaments* di Fosso del Presale" and (v) Maiolica (Fig. 7e,7f; Pl. 4d - e). The textures range from rudstone to floatstone with a pale green matrix and pebbly-mudstone of Scaglia Bianca-type lithofacies. The outcropping portion was measured at around 2-3 m. The age of the Sant'Oreste breccia was inferred around the Albian *p.p.*–Cenomanian *p.p.* due to the presence of rare planktonic foraminifera (*Thalmanninella* sp. and *Planomalina buxtorfi*) in the matrix (Tabs. 4f, 5a), coupled with the lack of clasts younger than the Early Cretaceous.



Pl. 3 - a) Maiolica. Mudstone with radiolarians. b) Sample with a clast of calcare massiccio B member (lower portion) and matrix of Scaglia Bianca (higher portion). c) Scaglia Rossa. Mudstone with globotruncanids and radiolarians. d-f) Scaglia Rossa. Wackestone with globotruncanids and *Helvetoglobotruncana helvetica*.

Scaglia Bianca (SBI): this unit was found exclusively along the southeastern slope of Sant'Oreste, and consists of neptunian dykes, sills and small outcrops unconformably resting on MAS_1 (Fig. 7a-c). Due to the limited extension of some outcrops, it was not possible to represent them all on the geological map. The unit is represented by white to hazelnut limestone with texture ranging from mudstones to wackestone rich in planktonic foraminifera (*Thalmanninella*

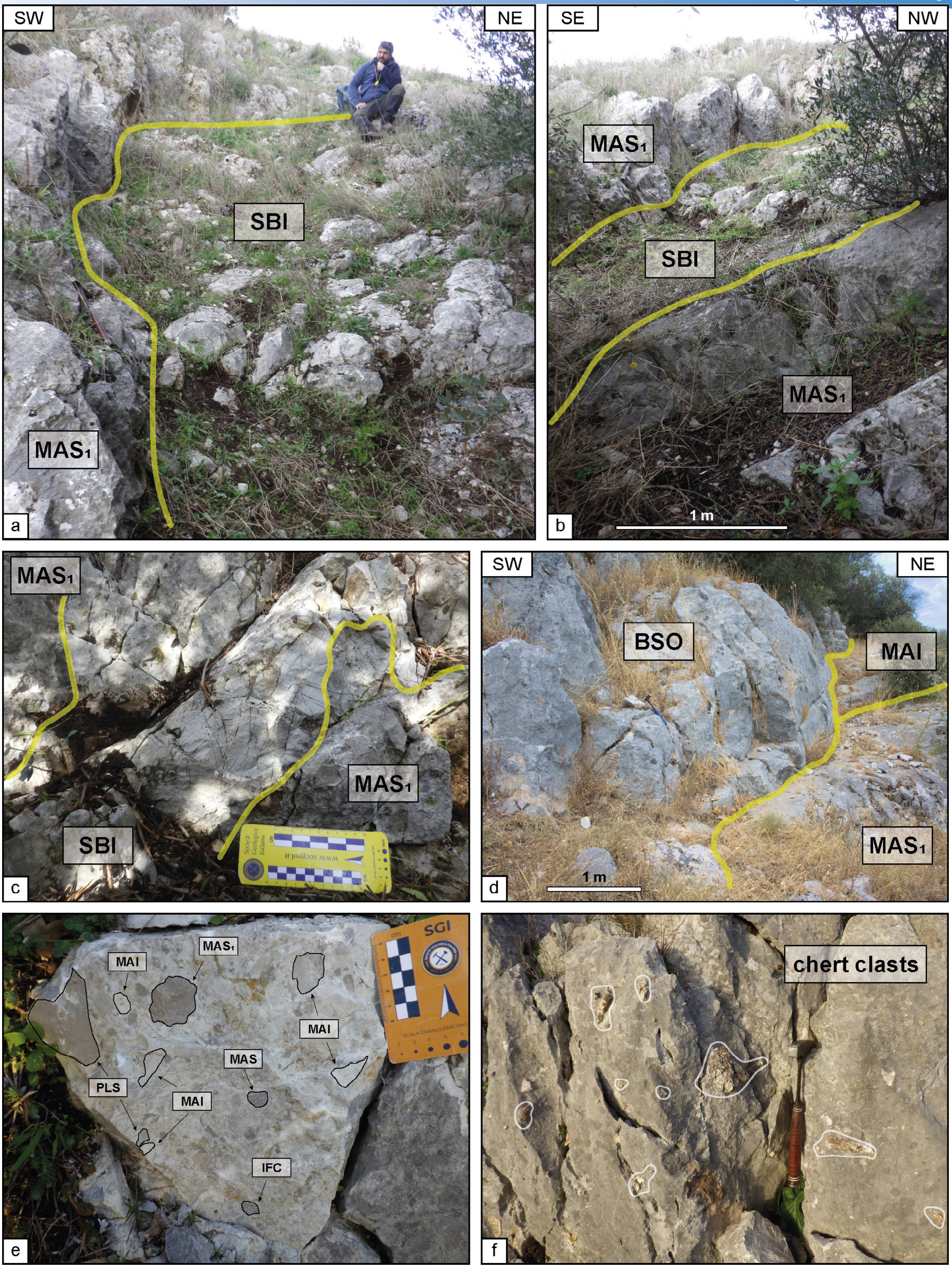
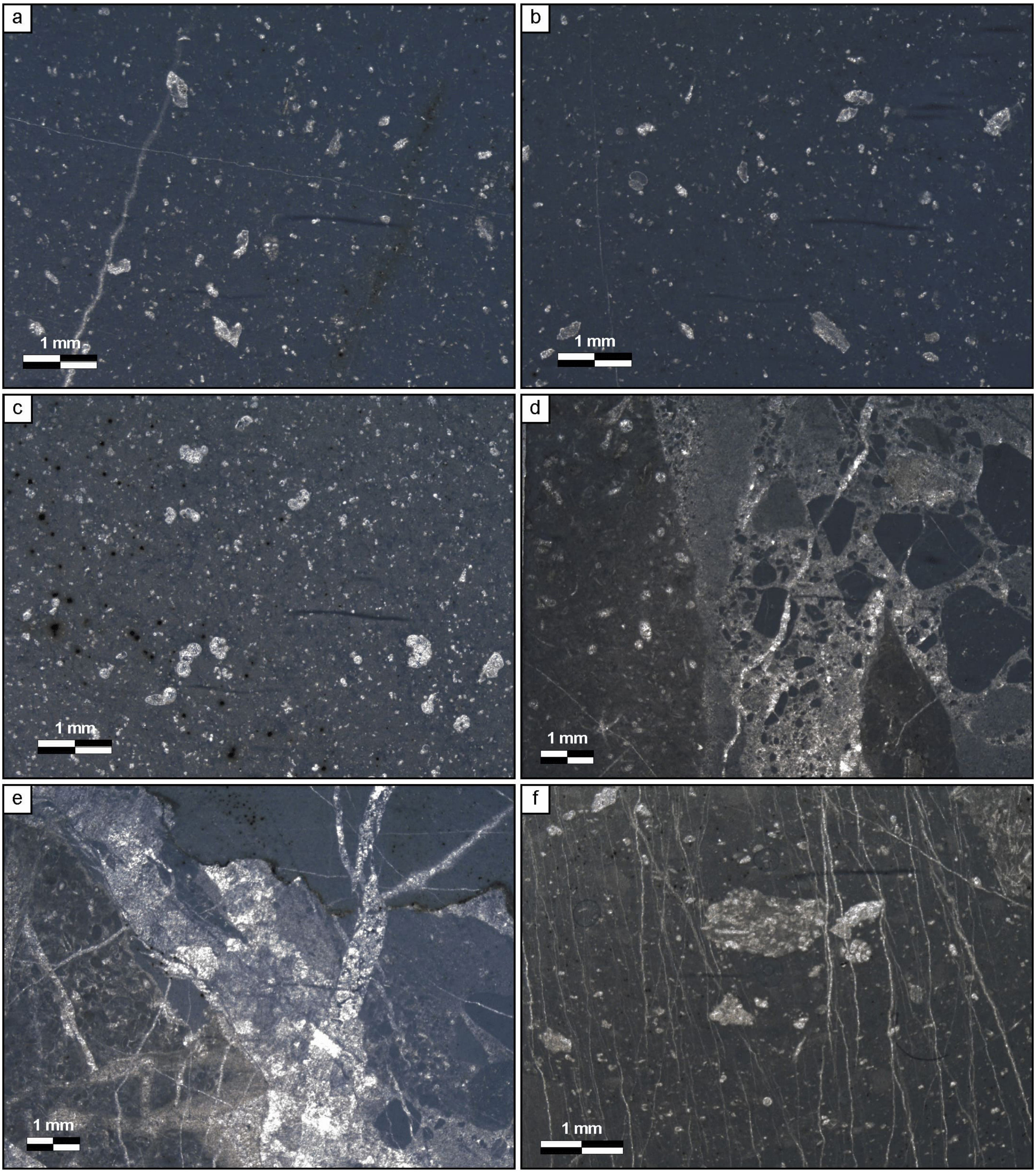


Fig. 7 - a) Epiescarpment deposit of SBI in an unconformable contact over MAS_1 (yellow line highlight the contact). b) Lateral view of the outcrop showed in Fig.7a; here both lateral and bottom surfaces are visible (yellow lines). c) Neptunian dyke (defined by yellow lines) of SBI within MAS_1 in the same outcrop of Fig.7a and Fig.7b. d) Unconformable stratigraphic contact (yellow lines) between BSO, MAI and MAS_1 south of Sant'Oreste village. e) Sample of BSO with various clasts belonging to older units (MAS, MAS_1, IFC, PLS, MAI) embedded in a Scaglia Bianca-type matrix. f) Heterometric chert clasts (highlighted in white) within BSO (hammer for scale).



Pl. 4 – a-c) Scaglia Rossa. Mudstone-wackestone with globotruncanids and radiolarians d-e) Sant'Oreste breccia. Sample of clastic deposit with clast of calcare massiccio B member with *Ophthalmidium martanum* and Maiolica in a Scaglia Bianca matrix. f) Sant'Oreste breccia. Particular of the matrix of the clastic deposit. Wackestone with *Thalmanninella* sp.

sp.) and radiolarians. Sharp-edged clasts (from a few mm to 1-2 cm) made up of MAS_1 were found dispersed in the micritic matrix (reported in the geological map). The outcropping thickness of this unit is in the order of tens of centimetres or less, depending on the accommodation space along the roughness of the palaeoescarpment. The age was calibrated according to the foraminiferal assemblage to a Cenomanian *p.p.*–early Turonian *p.p.*

Scaglia Rossa (SAA): well-bedded (up to 10 -15 cm) (Fig. 8a) pink to white limestones with reddish chert in nodules and non-frequent layers (Fig. 8b). The texture is composed of mudstones to wackestones rich in planktonic foraminifera (*Globotruncana linneiana*, *Globotruncana stuarti*, *Globotruncana arca*, *Globotruncana lapparenti*, *Helvetoglobotruncana helvetica* (Pl. 3d - f), *Morozovella* spp. and radiolarians (Pl. 3c, 4a - c). Those features are well shown in the north-eastern part of the map, in the locality "Il Casone". In the southeastern part of Sant'Oreste village (42°13'54.17"N; 12°31'29.07"E) the Scaglia Rossa unit crops out in confined patches unconformably lying on MAS_1, whereas the largest outcrop is bounded by two thrusts. Total thickness of the unit cannot be measured due to the unconformable nature of the contacts; however, the outcropping thickness can vary from a few decimetres to a few tens of meters. The age of SAA base in this area can be inferred around the Late Cretaceous (early Turonian) due to the presence of globotruncanids planktonic foraminifera; a Paleocene-Eocene age for the youngest/uppermost part of the unit is inferred by the occurrence of the genus *Morozovella*.

"scaglia variegata" (VAS): pink to white marly-limestones and marls. This unit can be observed at 42°14'9.93"N; 12°30'50.42"E and south of Croce area (42°14'15.04"N; 12°30'57.76"E) in outcrops belonging to a thrust zone (represented by a well-developed top-to-the NE S-C domain) (Fig. 9a). The micropaleontological content is rich in *Turborotalia* sp., *Globigerinatheka* spp. and radiolarians (Pl. 5b - c). The outcropping thickness was measured at around 3 - 4 m. The age of VAS is middle Eocene *p.p.*

Unconformity-Bounded Stratigraphic Units

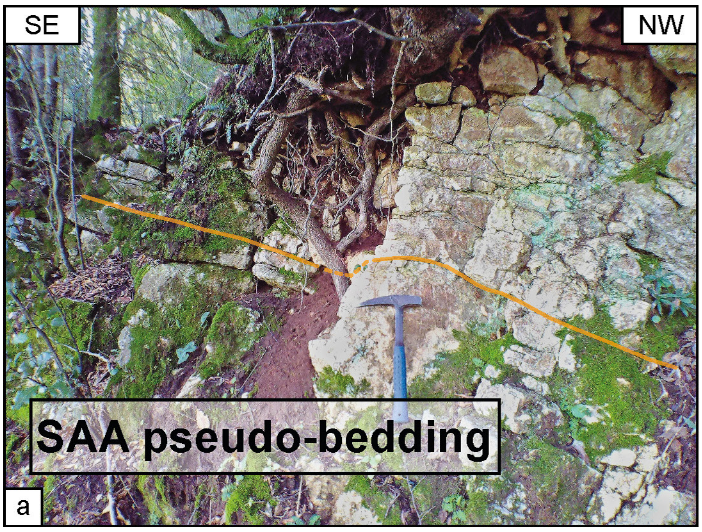
"Tenaglie-Fosso S. Martino unit" (TSM): this unit belongs to the "Tenaglie-Fosso S. Martino synthem" (Mancini et al., 2004) and can be divided into two laterally-heteropic lithofacies: "bioclastic calcarenites and cemented breccias" ("*calcareniti bioclastiche e brecce cementate*" *sensu* Mancini et al., 2004) and "sands, sandstones and bioclastic sands ("*sabbie, arenarie e sabbie bioclastiche*" *sensu* Mancini et al., 2004). In the study area only the "*bioclastic calcarenites and cemented breccias"* unit crops out in the southeastern part of Mt. Piccolo, where it is made of polymictic breccias and conglomerates dispersed in a well-cemented grey arenaceous and calcarenitic matrix (Fig. 9b, 9c). *Elphidium crispum* was found in the matrix (Pl. 5d-e). Total outcropping thickness is around 10 m. The age of TSM is Piacenzian *p.p.*–Gelasian *p.p.*

"undifferentiated pyroclastic deposits" (UPD): reddish to ochraceous pyroclastic flow unit made up of welded cineritic matrix (Fig. 10a), pumices (Fig. 10b), sparse lithic clasts and scoria. This unit widely crops out in southwestern part of the study area, where the thickness is around 50 m. The age, defined by literature, is around Pleistocene *p.p.*

Ubiquitary units: this section reports all the deposits not belonging to formal units, informal units or synthems, derived from the active erosive processes that are currently dismantling and shaping Mt. Soratte:

(a) slope deposits, made up of variable grain size of loose, and locally cemented, carbonate clasts blocks and ochraceous sands are widely present throughout the area, in particular along the western slope of Mt. Soratte. This unit can be found as infills of incisions in UPD or older slope deposits (Fig. 10c). Thickness is variable from a few to tens of meters. The age is Pleistocene *p.p.*

(b2) Eluvial-colluvial deposits, made of non-cemented brownish to reddish silts, clays and calcareous sands, are generally found in the topmost areas. Thickness is around few meters. The age is Holocene.



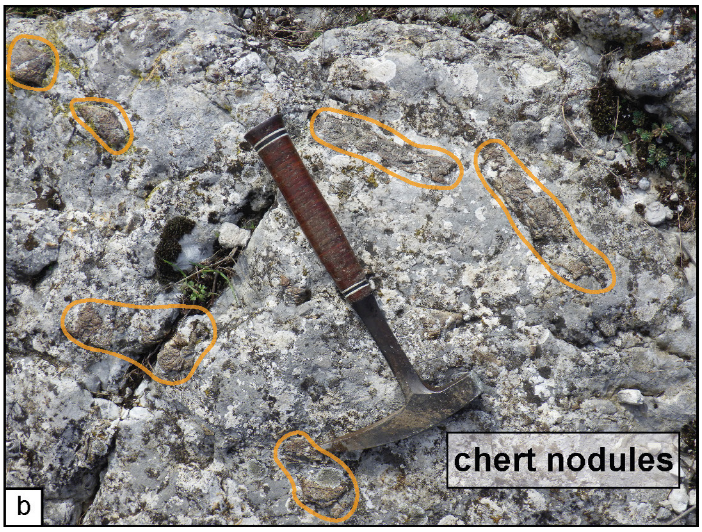


Fig. 8 - a) Pseudo-bedding of SAA (orange line; hammer for scale). b) Chert nodules within SAA (orange lines; hammer for scale).

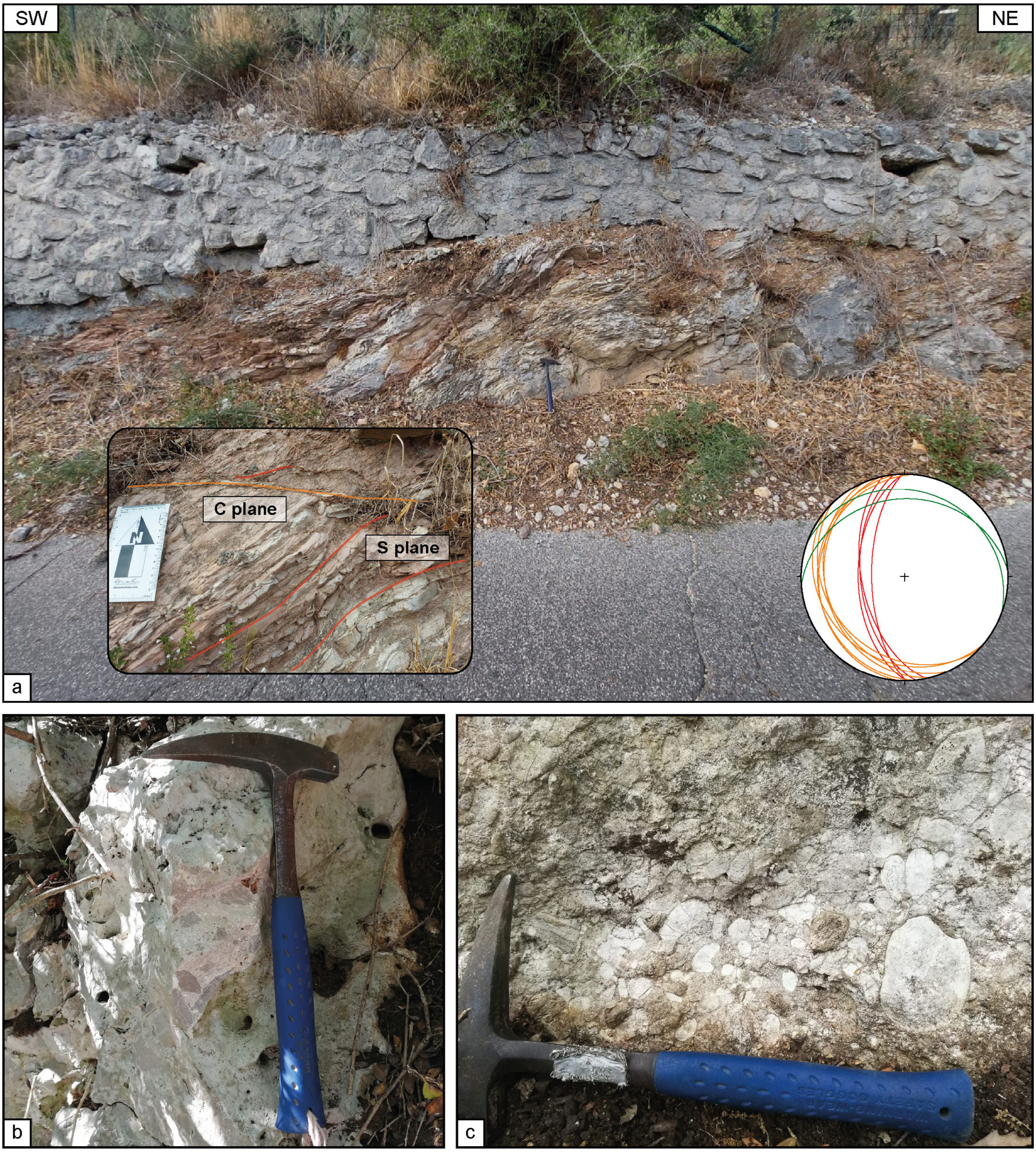
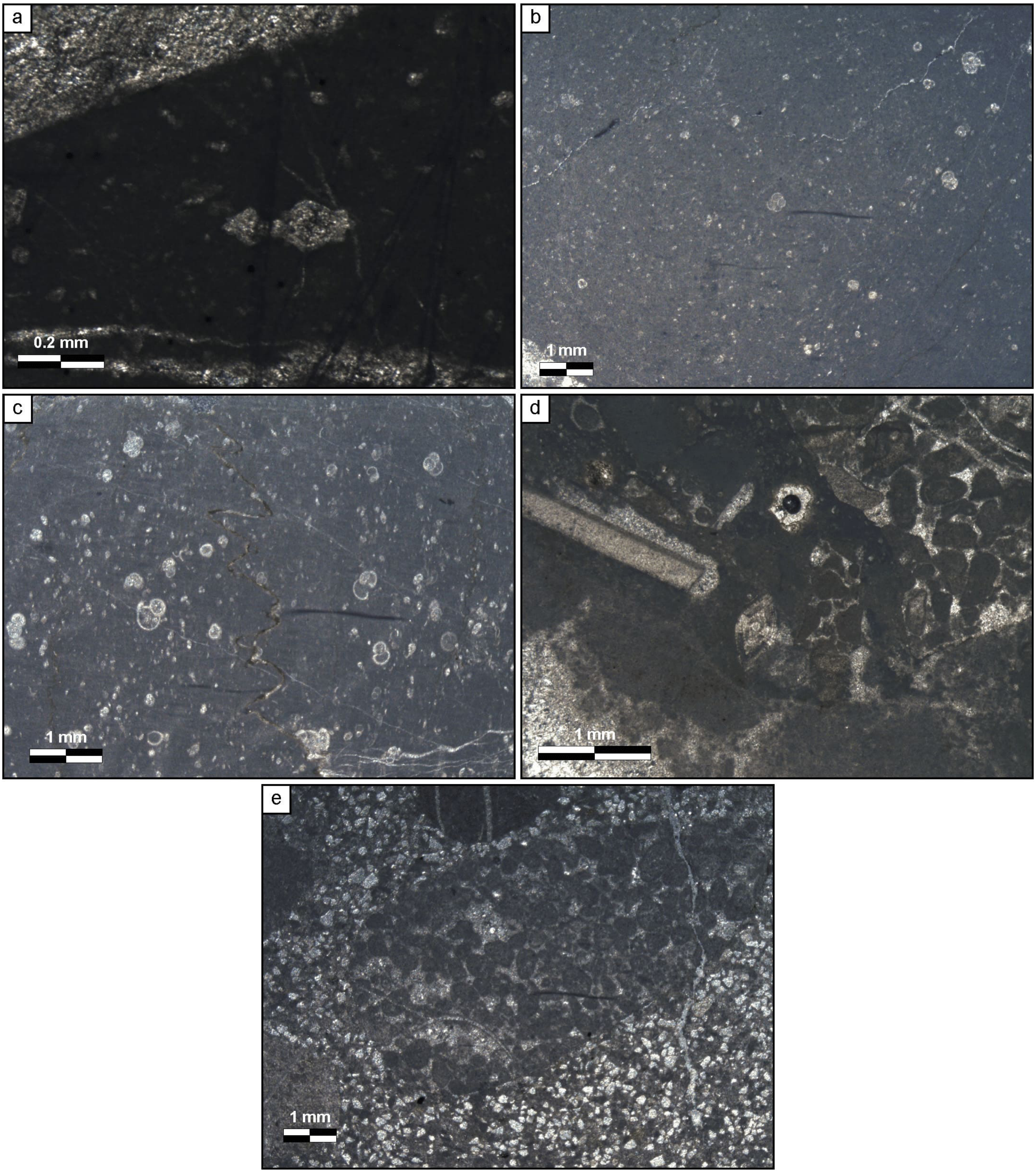


Fig. 9 - a) Outcrop of VAS at 42°14'9.93"N; 12°30'50.42"E (hammer for scale); S-C fabric is highlighted in the box together with the stereoplot relating to the S-C plane trends (the colours correspond to: orange for C planes, red for S planes and green for C' planes). b) Well-cemented breccias belonging to TSM, southeast of Mt. Piccolo (hammer for scale). c) Well-cemented conglomerates belonging to TSM, southeast of Mt. Piccolo (hammer for scale).



Pl. 5 - a) Sant'Oreste breccia. Particular of the matrix of the clastic deposit. Mudstone with *Planomalina buxtorfi*. b-c) "scaglia variegata". Mudstone with *Globigerinatheka* spp. and *Turborotalia* sp. d-e) Tenaglie-Fosso S. Martino unit. Cemented bioclastic breccia with *Elphidium crispum* in the matrix. Clasts of Calcare Massiccio.

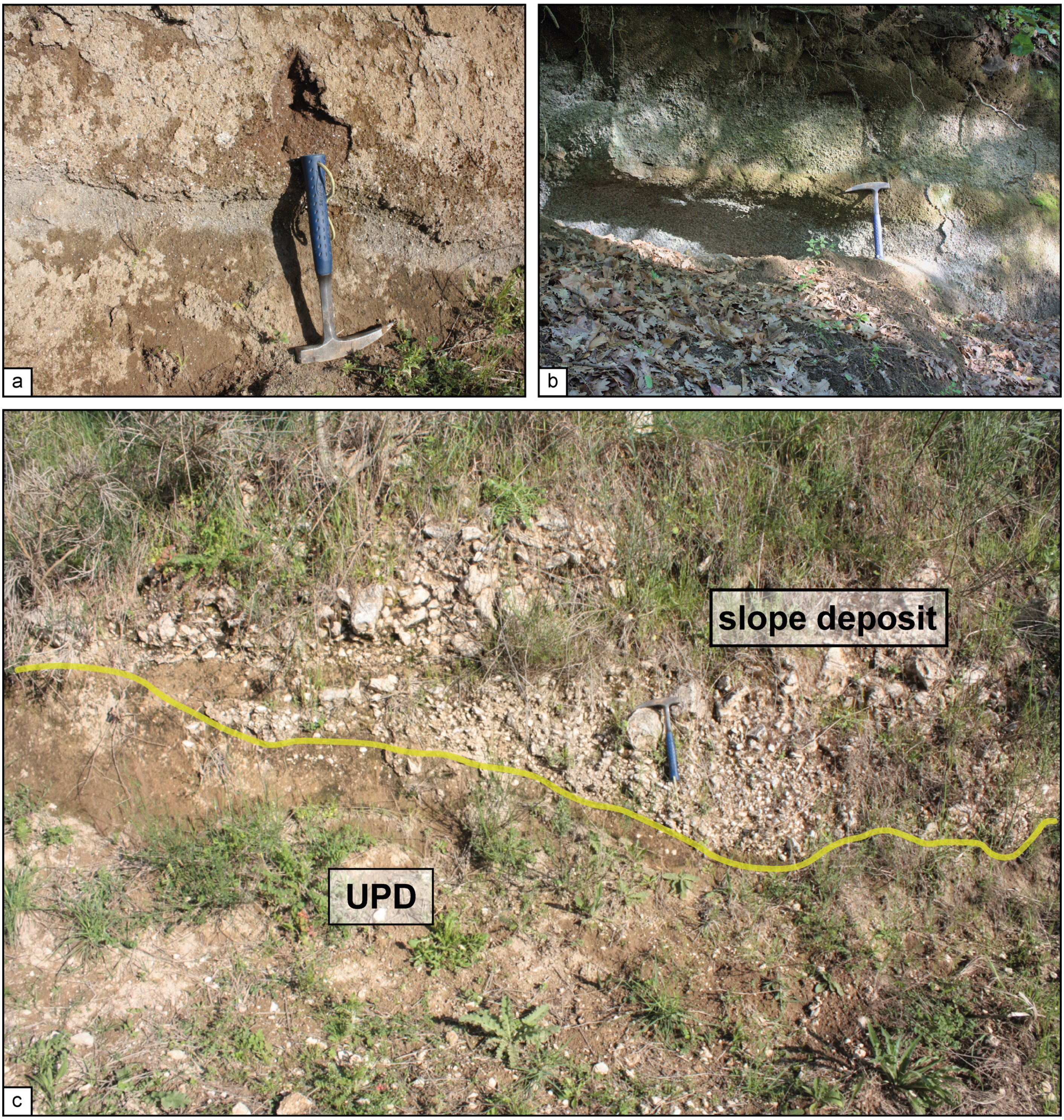


Fig. 10 - a) Outcrop of reddish tuff belonging to UPD along the western slope of Mt. Soratte (hammer for scale). b) Pumice intervals belonging to UPD outcropping along the northwest slope of Mt. Soratte (hammer for scale).. c) Slope deposit infills an incision in UPD (yellow line) along the western slope of Mt. Soratte (hammer for scale).

STRUCTURAL SETTING

The following sections will discuss the major tectonic phases that affected Mt. Soratte area from the oldest to the youngest: Early Jurassic extensional tectonics, Cretaceous extensional tectonics, Miocene compressional tectonics, and Plio-Pleistocene extensional tectonics.

Early Jurassic extensional tectonic phase

The oldest recognisable tectonic phase in the Mt. Soratte area is associated with Early Jurassic rifting related to the opening of the Western Tethys (Bertotti et al., 1993; Picotti and Cobianchi, 1996; Manatschal and Bernoulli, 1999; Santantonio and Carminati, 2011). The faults responsible for the rifting, which fragmented the MAS palaeoplatform, evolved into palaeoescarpments once their activity ceased. These palaeoescarpments have been observed at Mt. Soratte, although there is no evidence of the original palaeofaults. The palaeoescarpments were identified due to the distinctive post-diagenetic overprinting process known as silicification of the Calcare Massiccio (Fig. 6c) and by the onlap of basin units. The latter can be observed to the south of Sant'Oreste village between MAI and MAS_1, IFC and PLS (Fig. 11), as well as to the north of the village between COKa and MAS.

Cretaceous extensional tectonic phase

Several authors have contributed data from the Central Italy area concerning a previously undescribed tectonic phase dated to the Cretaceous (Marchegiani et al., 1999; Centamore et al., 2007, 2009; Fabbi et al., 2016, 2023; Cipriani and Bottini, 2019a, 2019b). In particular, Cipriani and Bottini (2019a, 2019b) identified an Early Cretaceous tectonic rejuvenation of an Early Jurassic margin at Monte Cosce, approximately 20 km northeast of Mt. Soratte (Fig. 1b), where the unit of "Mt. Cosce Breccia" (polygenic, chaotic, coarse-grained, pure carbonate breccia) provides evidence of active tectonics during the Early Cretaceous.

At Mt. Soratte, no direct evidence of Cretaceous palaeofaults has been found, but key outcrops and units can be explained by invoking the tectonic phase. Unconformable stratigraphic contacts can be indeed observed between SBI (Cenomanian *p.p.* - early Turonian *p.p.*) and MAS_1 (Sinemurian *p.p.*–Pliensbachian *p.p.*) (Fig. 7a, 12a) as well as SAA (Lower Turonian *p.p.* - Middle Eocene *p.p.*) and MAS_1, south of the village of Sant'Oreste. Also a neptunian dyke of SAA (Turonian) within MAS (?Rhaetian *p.p.*/Hettangian–Sinemurian *p.p.*) was found south of Eremo S. Silvestro (42°14'40.65"N; 12°30'11.18"E) (Fig. 12c). Additionally, the discovery of the unit named in this work "Sant'Oreste breccia" (BSO, dated to the Albian *p.p.*-Cenomanian *p.p.* based on the presence of planktonic foraminifera in the matrix) in unconformable stratigraphic contact with the MAI and MAS_1 provides further evidence of the exposure of a scarp during the Cretaceous.

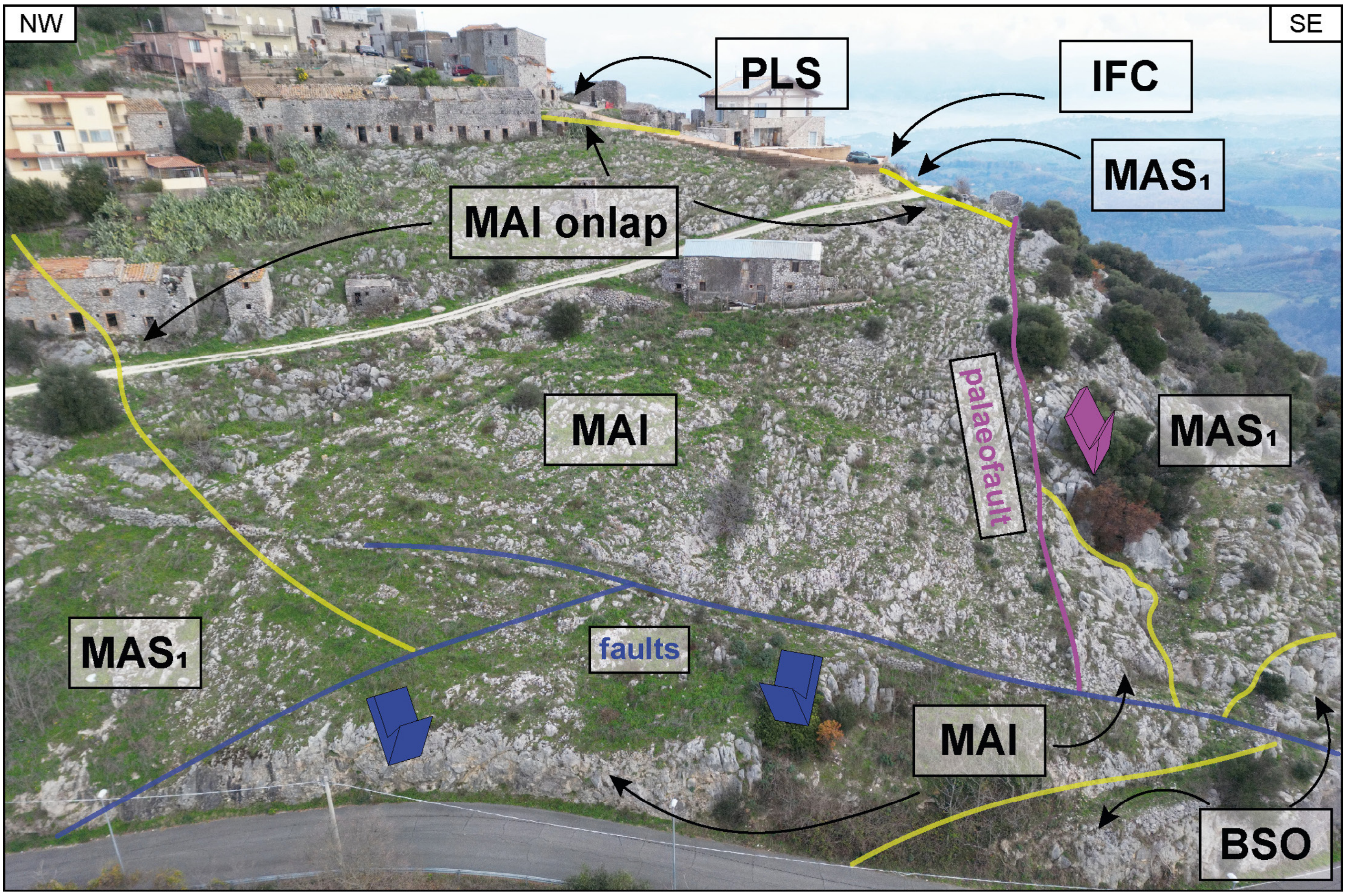


Fig. 11 - Panoramic view of the SW slope of Sant'Oreste village. On the right part of the image a palaeofault (purple line) displaces MAI, already in unconformable contact on the MAS_1 resting on the palaeoescarpment. In the upper part of the image MAI onlaps MAS_1, IFC and PLS resting on the top of the Jurassic structural high. In the left part of the image MAI onlaps MAS_1 resting on the palaeoescarpment. All yellow lines are unconformable stratigraphic contacts, blue lines are normal faults.

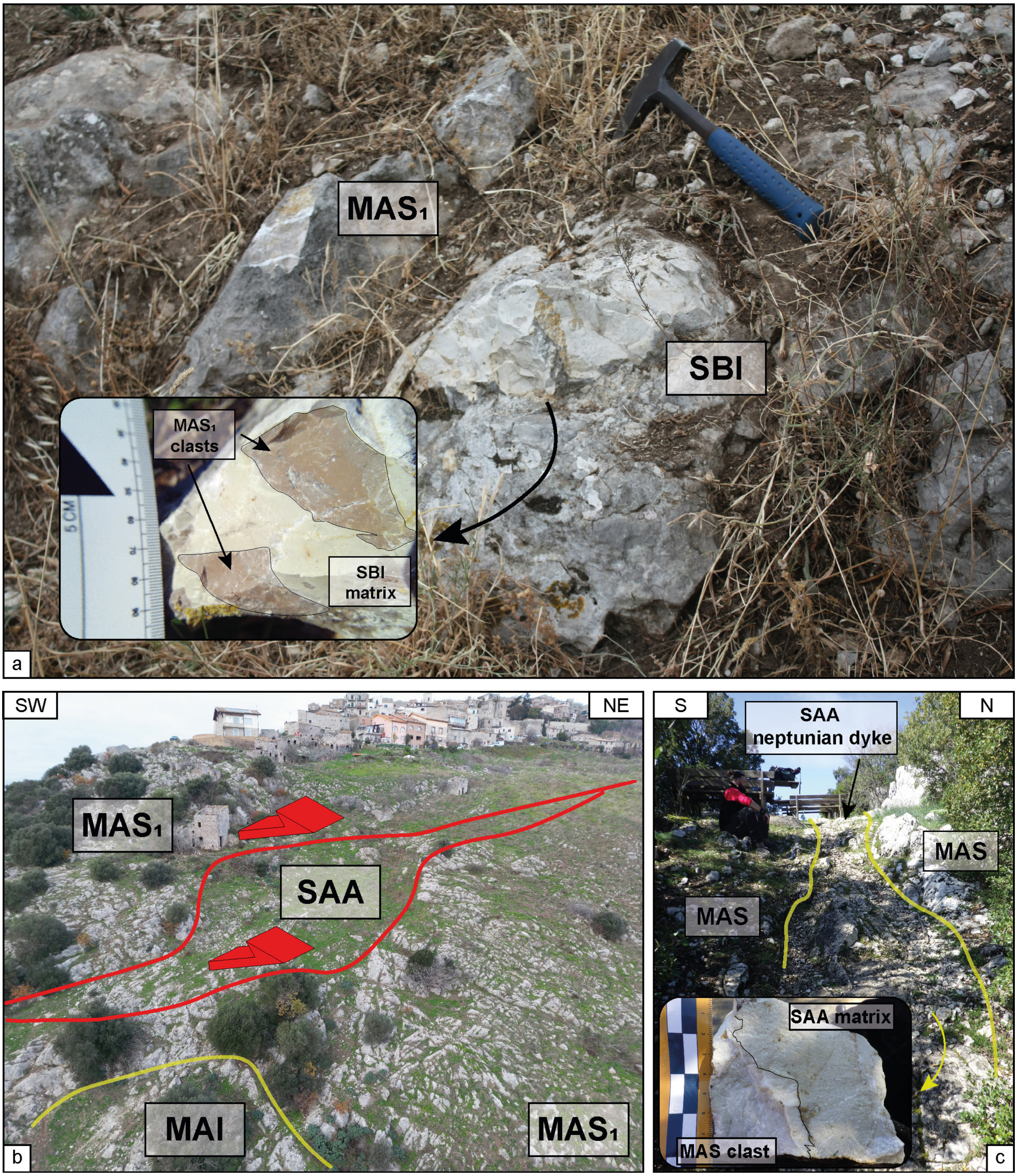


Fig. 12 - a) Unconformable stratigraphic contact between SBI and MAS_1 (hammer for scale); the box highlights the presence of MAS_1 clast embedded in SBI matrix. b) Panoramic view of the southern slope of the Sant'Oreste village showing the unconformable stratigraphic contact of MAI on MAS_1 (yellow line) and the geometric relationship between SAA and MAS_1 together with the presence of thrust planes (red lines). c) Neptunian dyke of SAA within MAS (defined by yellow lines); the box highlights a clast of MAS embedded in SAA matrix.

Miocene orogenic phase

Evidence of this tectonic phase is indicated by the presence of several small-scale thrusts and two main thrusts (from here onward identified as lower thrust and upper thrust). The upper-thrust zone was identified at 42°14’9.93”N; 12°30’50.42”E, where a SW-dipping plane inclined around 25° juxtaposed COKa (Sinemurian *p.p.*) on VAS (Lutetian–Priabonian *p.p.*). In the same area a splay juxtaposed VAS on IFC (Pliensbachian *p.p.*–Toarcian *p.p.*) (Fig. 13). The same plane was found south of Croce area (42°14’15.04”N; 12°30’57.76”E) (Fig. 14). The lower thrust is well exposed in the southeastern slope of Sant’Oreste village where MAS_1 is juxtaposed on SAA unconformably lying on a palaeoescarpments made of MAS_1 (Fig. 12b). The same plane was found also at the toe of the scarp north of Sant’Oreste village, where MAS overthrust COK, and southwestward of “Piano delle Pere” (42°14’30.65”N; 12°30’50.25”E) where the plane is intraformational in MAS (Fig. 15a, 15b).

Pliocene-Pleistocene extensional phase

Well-exposed NW-SE high-angle normal faults trend can be observed along the flanks of Mt. Soratte Ridge, in particular westward of “Piano delle Pere” and all along the southwest slope of the ridge (Fig. 16a). Many of these are intraformational in MAS and do not show conspicuous displacements but we can infer that the main faults are buried NE and SW of the ridge. In addition, a set of fault trending NE-SW was found to the north of Mt. Soratte, and between Mt. Piccolo and cemetery area (Fig. 16b), as well as less common set of faults trending NW-SE well visible in the Eremo S. Silvestro area (42°14’43.28”N; 12°30’9.78”E).

DISCUSSION AND CONCLUSIONS

This work has provided a new detailed geological map of the Mt. Soratte ridge.

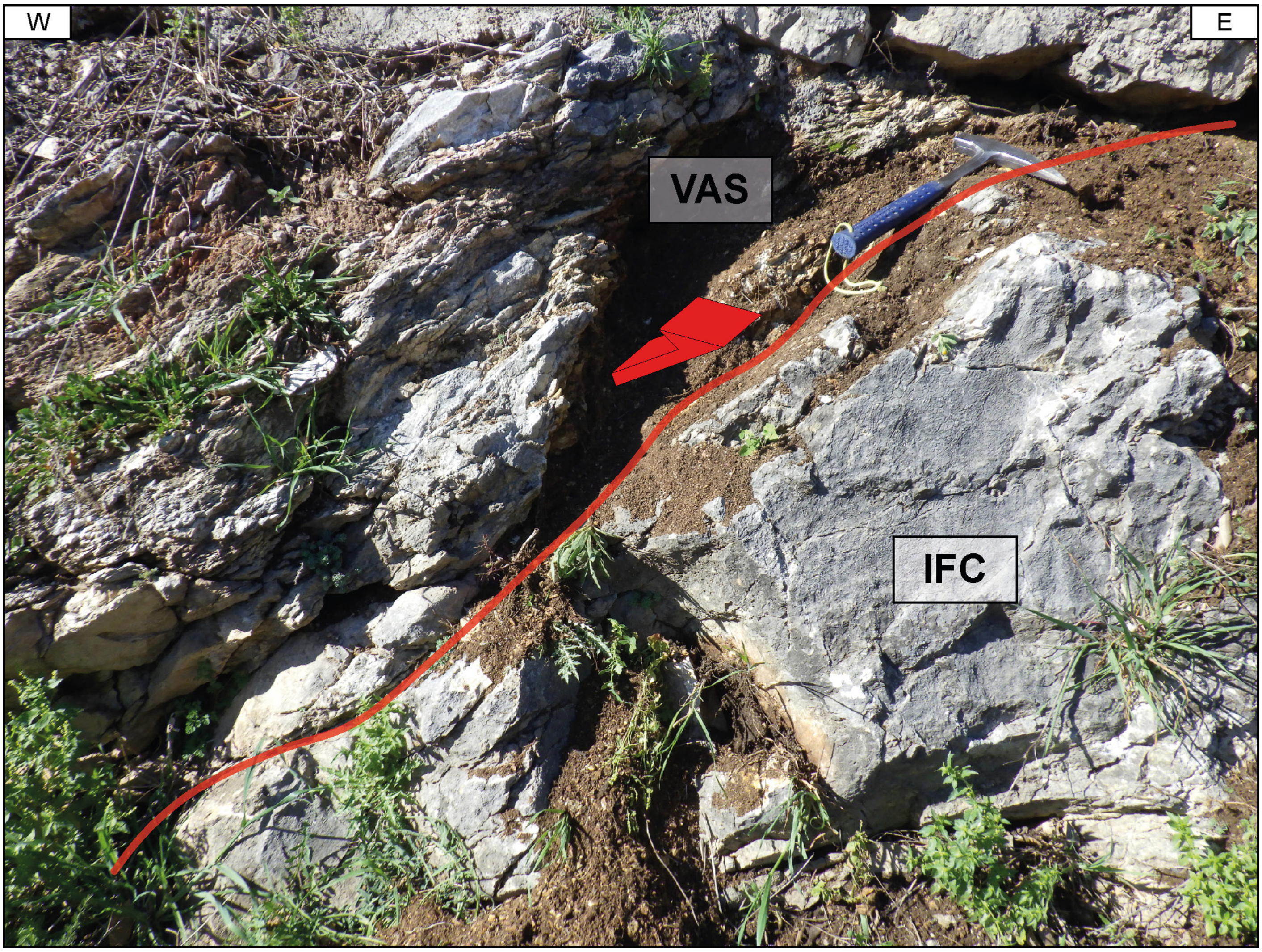


Fig. 13 - Outcrop of VAS in the hanging wall of the thrust fault (red line) juxtaposed over IFC at 42°14’9.93”N; 12°30’50.42”E (hammer for scale).

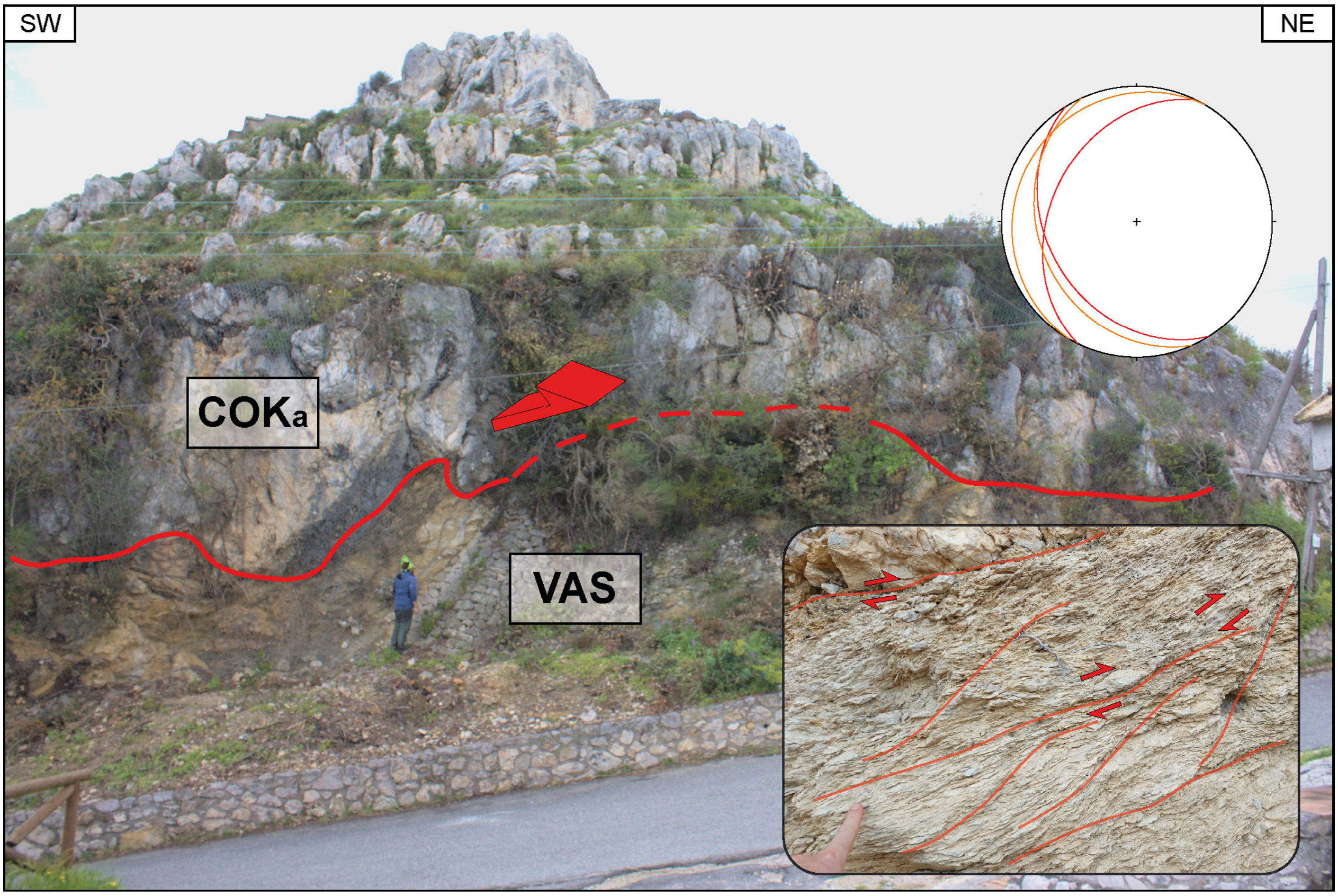


Fig. 14 - Outcrop of COKa in the hanging wall of the thrust fault (red line) juxtaposed over VAS south of Croce area; S-C fabric is highlighted in the box and the stereoplot relating to the S-C plane trends (the colours correspond to: orange for C planes, red for S planes).

From Sant'Oreste to the SE relief (Mt. Piccolo) a Jurassic structural high can be described (PCP *sensu* Santantonio, 1993, 1994). This part of the Mt. Soratte Ridge shows facies and geometric arrangements of the strata typical of a PCP-top succession. The slope in front of the cemetery and Mt. Piccolo shows discordant contacts within the MAS_1 strata. The presence of syn-sedimentary faults-controlled strata suggest dragging along active faults affecting the palaeoescarpments during the deposition of MAS_1. The sedimentary succession appears to be extremely lacunose at different stratigraphic levels.

The Jurassic basin succession lacks all the units except for COK and MAI, the latter showing a low outcropping thickness comparing with the typical one observed in areas far from the Jurassic structural highs. The presence of POD is limited to a few neptunian dykes (Fig. 5c; Pl. 2d) along the southern slope of Sant'Oreste village. The formation of these neptunian dykes is also notified by Cipriani et al. (2020) at the Sabina Plateau (25 Km NE from Mt. Soratte) together with the presence of overbank deposits along the Jurassic palaeoescarpment, the result of calciturbidites originating from the Apennine Platform during the Bajocian. Santantonio et al. (2024) refers at this feature as a product of a short-lived tectonic episode which also produced gravitative instabilities that affected the eastern margin of the Sabina Plateau with submarine collapses in the early Bajocian. Other evidence of this tectonic phase is reported in the sheet 348 "Antrodoco" of the Geological Map of Italy at 1:50,000 scale (Servizio Geologico d'Italia, 2023) and relative explanatory notes by Capotorti and Chiarini (2023) referring to the drowning of the Mt. Giano carbonate platform (50 Km NE from Mt. Soratte) driven by early Bajocian tectonic phase. In the Cretaceous, the Marne a Fucoidi (FUC) are missing. A hypothesis for the lack of these units can be traced back to the shape of the Jurassic structural high and its evolution over time. The COK crops out exclusively in the area northeast of the cemetery, passing abruptly with lateral contact to the MAS_1: a situation of this type could have occurred after the extensional tectonics producing a perched basin. In this scenario, an insufficient subsidence could not leave the necessary amount of accommodation space for the Jurassic basinal succession until MAI. A second hypothesis could be found in the thickness of the basinal succession,

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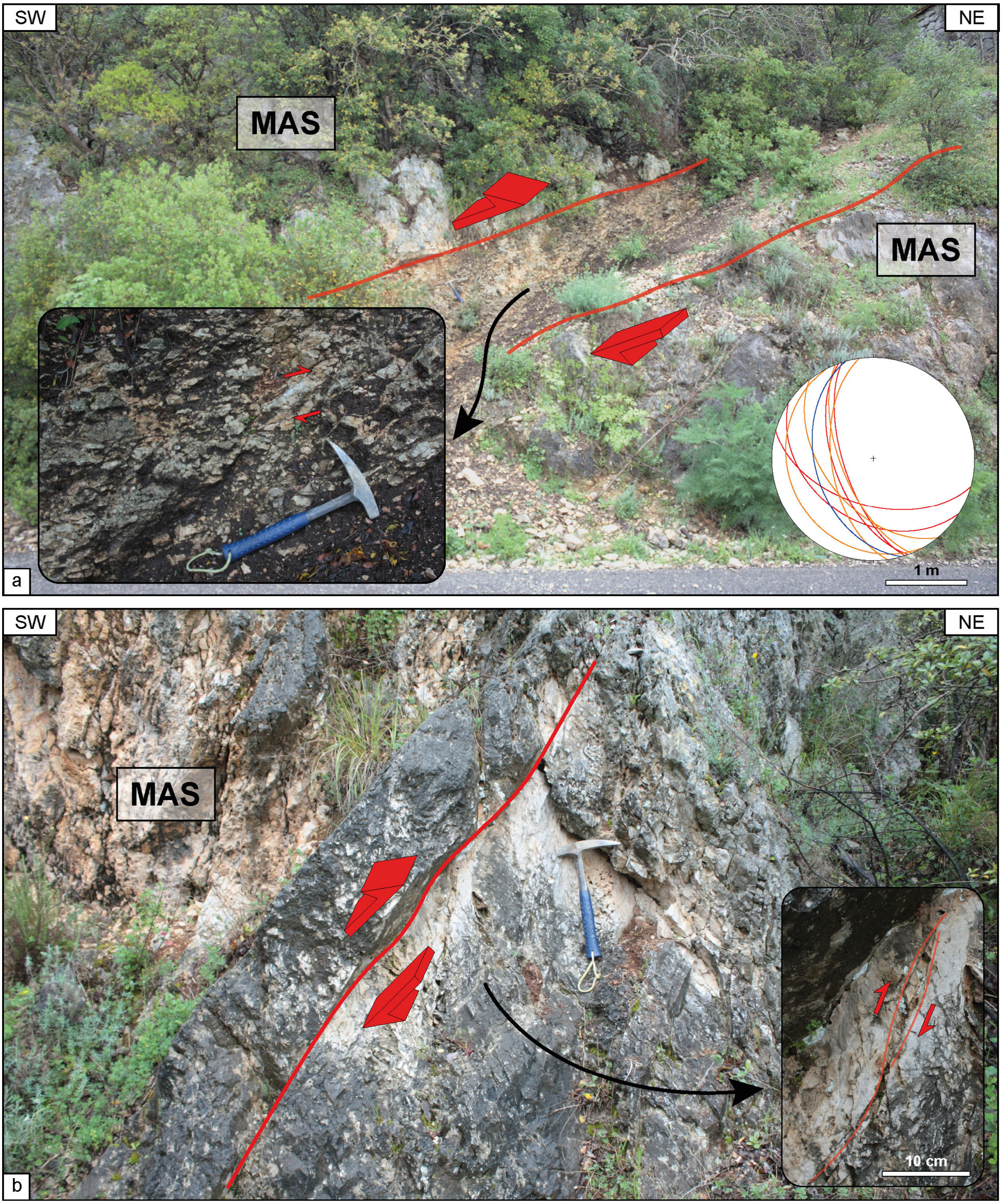

Fig. 15 - a) Outcrop of MAS with an intraformational thrust, northeast of Sant'Oreste; deformed clasts (sigmoids) are highlighted in the box together with the stereoplot relating to the S-C plane trends (the colours correspond to: orange for C planes, red for S planes and blue for thrust fault). b) Detail of the same outcrop shown in Fig. 15a; S-shaped fracture is highlighted in the box.

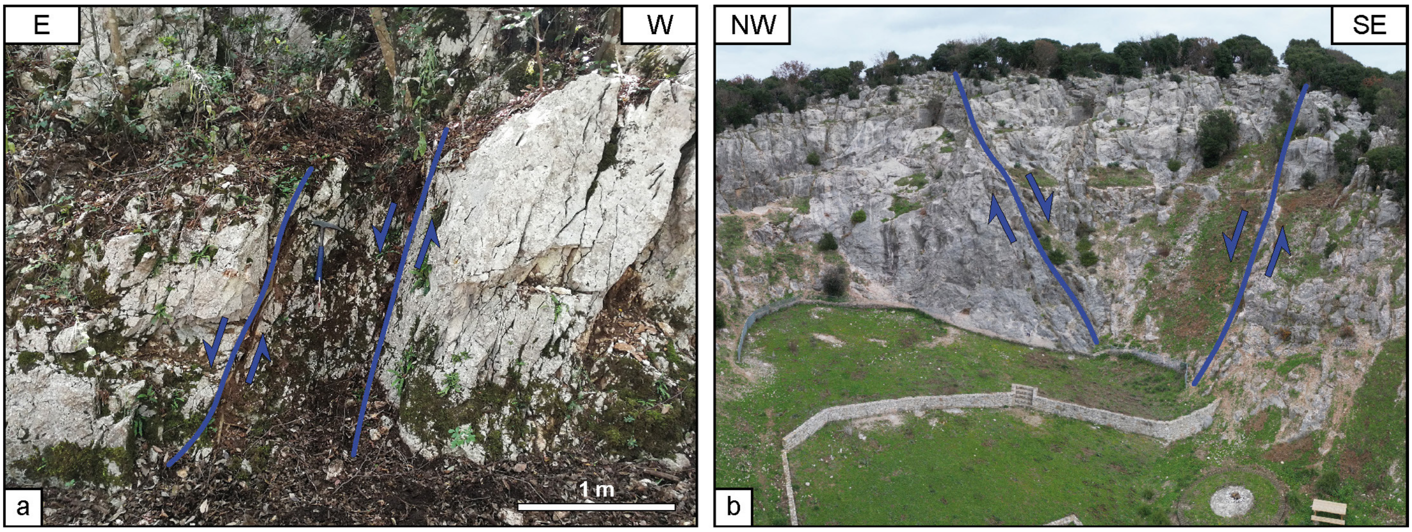

Fig. 16 - a) Normal faults westward of "Piano delle Pere" (blue lines; hammer for scale). b) Normal faults (blue lines) in the Mt. Piccolo quarry.

which in this portion of the basin could have been so thin as to have been eroded and resedimented in a different depocenter.

One of the peculiarities of this area is related to the occurrence of Upper Cretaceous - lower Palaeogene pelagic deposits (Scaglia Bianca Fm. - SBI and Scaglia Rossa Fm. - SAA) unconformably lying on Lower Jurassic pelagic deposits ("calcare Massiccio B member" - MAS_1 *sensu* Petti et al., 2007; see also Centamore et al., 1971). The extensional tectonics leading to the formation of the Umbria-Marche-Sabina domain began in the Early Jurassic and continued until the Early Cretaceous, forming a basin subsiding enough to accommodate a thick succession of pelagic sediments until its filling (Galluzzo and Santantonio, 2002; Bollati et al., 2012).

This trend has been repeatedly disturbed, as shown in the Mt. Cosce area (Cipriani and Bottini, 2019b), a few kilometres NW from Mt. Soratte, where a "middle" Barremian extensional phase was observed and in other portions of the central Apennines, e.g., sheet 348 "Antrodoco" of the Geological Map of Italy at 1:50,000 scale (Servizio Geologico d'Italia, 2023) and relative explanatory notes by Capotorti and Chiarini (2023). In the Mt. Soratte area, it is possible to highlight the presence of a Cretaceous extensional phase in three key areas:

I) Along the southeast slope of Sant'Oreste village, several neptunian dykes made up of Maiolica (MAI) have been found. Moreover, in the same area, a few metre-sized patches of Cenomanian Scaglia Bianca fm. are enclosed within "calcare Massiccio B member" (Fig. 7a,7b,7c). This outcrop is extremely circumscribed, showing both lateral and basal contacts of SBI on MAS_1. Furthermore, within SBI, there are angular clasts of MAS_1 (Pl. 3b). This condition is only possible if this latter unit was already lithified and was directly in contact with SBI during its deposition. Along the same slope, a contact between SAA and MAS_1 can also be observed. In this case, the contact surface appears to be mildly tectonised due to the presence of a thrust plane a few metres above. Even in this case, MAS_1 clasts are found dispersed in the SAA matrix, thus demonstrating an original unconformable stratigraphic contact, attesting to the displacement of the aforementioned thrust by a few metres.

II) Along the southern slope of Sant'Oreste village (42°13'52.13"N; 12°31'23.92"E), a sedimentary breccia was observed, consisting of heterometric clasts belonging to the structural high succession supported by a greenish micritic matrix containing planktonic foraminifera. This unit, named in this work "Sant'Oreste breccia" (BSO), represents the product of a gravitational collapse developed along the slope of the Cretaceous escarpment, arranged in angular unconformity on the MAI and MAS_1 units (Fig. 17). The presence of clasts no younger than the MAI, together with the biostratigraphic observations that have highlighted the presence of *Planomalina buxtorfi* and *Thalmanninella* spp. (Pl. 5a) in the matrix of the breccia yields an Albian *p.p.*-Cenomanian *p.p.* age.

III) Along the path that connects Madonna delle Grazie to the Eremo S. Silvestro (42°14'40.65"N; 12°30'11.18"E), a neptunian dyke of SAA was found, with a width varying from a few dozen centimetres to a metre, embedded in MAS. The filling consists of planktonic foraminiferal packstones among which specimens of the species *Helvetoglobotruncana helvetica* (Pl. 3 d–f) have been identified.

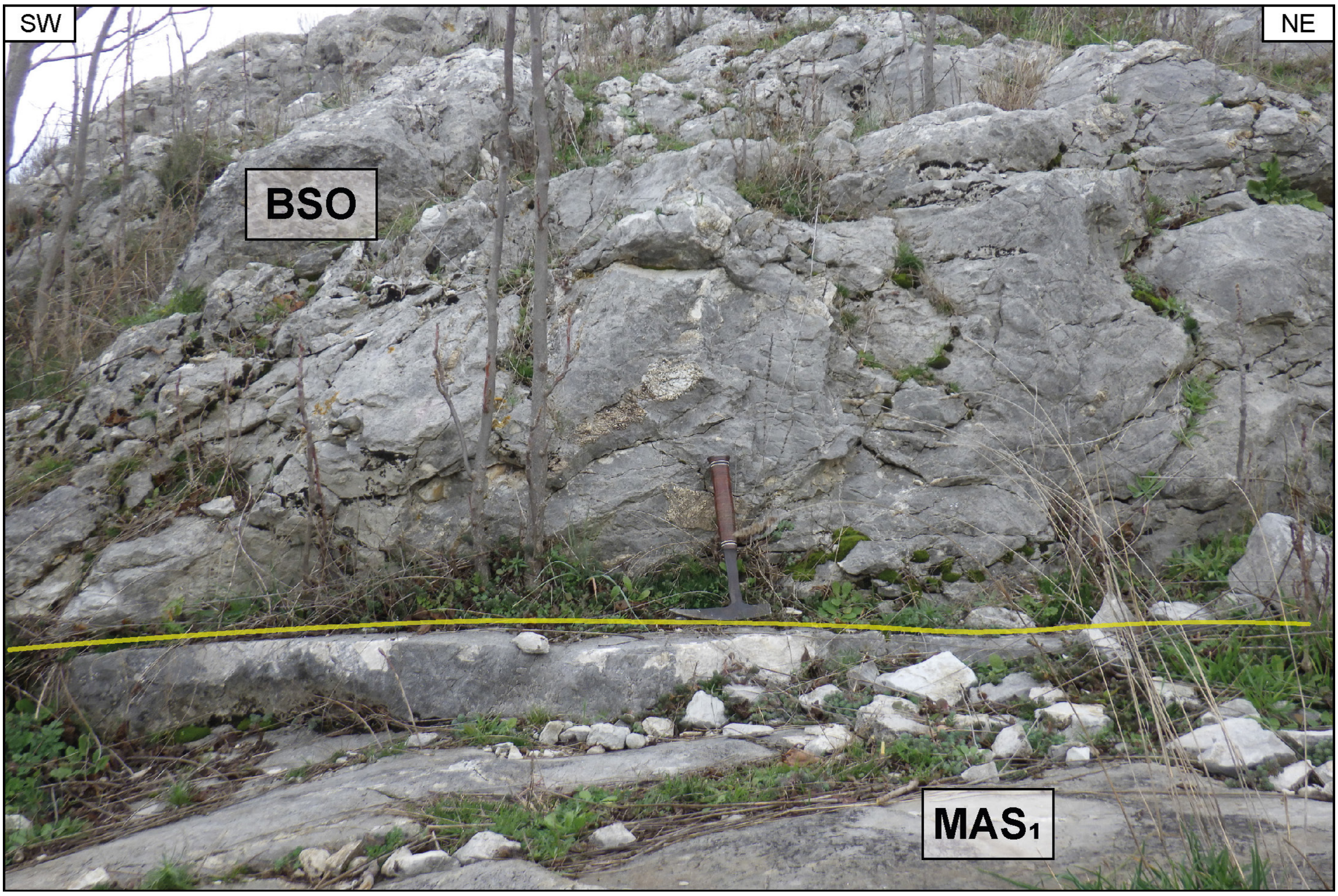

Fig. 17 - Stratigraphic unconformity (yellow line) on the Cretaceous palaeoescarpments between BSO and MAS_1 (hammer for scale).

The information collected about the relationship between BSO, SBI and SAA with the Jurassic units suggests how the Cretaceous extensional phase is mainly set up at the edges of the structural high of Mt. Soratte, following the trend of the Jurassic escarpments, which acted as zones of weakness for the establishment of the faults, opening fractures filled by syn-tectonic deposits in the surrounding areas. The retreat of the Cretaceous faults led to the formation of scarps developed on the remains of the Jurassic structural high of Sant'Oreste. The products of gravitational collapses, as observed from the BSO outcrop, could be deposited on the roughness of the palaeoescarpments and thus preserved.

In the Miocene, the Mt. Soratte area was involved in the structuring of the Apennine chain (Carminati et al., 2012), as evidenced by the presence of NE-verging thrusts stacked vertically to form a duplex geometry. The thrust trend involved the flanks of the Sant'Oreste Jurassic structural high, preserving the original onlap contacts between COK and the Monte Cetona formation (FZM) as well as only weakly deforming the primary contacts between SAA and MAS_1 along the southern flank of the village. Northwestward of Sant'Oreste village a thrust-zone occurred. Here VAS overlies IFC and, in turn, is overlien by COK. This younger-on-older arrangement could be explained invoking an unconformable stratigraphic contact of VAS along the rejuvenated palaeoescarpments as a result of the Cretaceous extensional tectonics (similarly to SBI and SAA).

The Plio-Pleistocene extensional phase follows a NW-SE trend widely observed along the eastern and western flanks of Mt. Soratte, isolating its structure within the Tiber plain. Although limited in extent, the presence of the "Tenaglie-Fosso S. Martino unit" (TSM) and in particular the "*calcareniti bioclastiche e brecce cementate*" lithofacies testifies to the presence of a deltaic/shelfal system laterally fed by debris falling from the relief of the Mt. Soratte Ridge. The ignimbrite deposits of the "undifferentiated pyroclastic deposits" (UPD) cover the majority of the areas around the relief of Mt. Soratte. It is quite common to observe the direct contact of UPD on Mesozoic carbonates, often associated with alteration phenomena of the surface of the latter due to the high temperatures reached by the pyroclastic material during its emplacement (Fig. 18).

The Mt. Soratte ridge represents an important element in the Umbria-Marche-Sabina domain, offering wide information about the evolution of the central Apennines.

Fig. 18 - Contact between UPD and Mesozoic carbonates. Altered carbonate clasts embedded in UPD is highlighted in the box.

The ridge preserves evidence of a Jurassic structural high affected by Cretaceous extensional tectonics that rejuvenated Jurassic palaeoescarpments, hosting unconformable contacts, neptunian dykes, and syn-tectonic breccias such as the Sant'Oreste breccia. All these features testify a complex multistage evolution of the structural high.

Miocene compression developed NE-verging thrusts and a duplex geometry that only mildly affected the earlier extensional architecture, allowing for the preservation of stratigraphic relationships, onlap geometries and unconformable contacts. Plio-Pleistocene normal faulting eventually isolated the ridge within the Tiber graben. The combination of detailed field mapping, stratigraphic analysis, and structural observations confirms Mt. Soratte as a well-preserved archive of Meso-Cenozoic evolution, where the interaction of tectonics and sedimentation is well recorded along the stratigraphic and structural framework. This study also highlights the value of high-resolution geological mapping (1:5,000 scale) for reconstructing complex geological histories in morphologically and structurally articulated regions.

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