Geological Field Trips and Maps

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Stratigraphy and tectonic evolution of a portion of the Simbruini-Ernici Mountains (Central Apennines - Italy): review and new data from detailed geological mapping

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Cover page Figure:
Above: Panoramic view from Mt. Cappello of the steeply dipping Cretaceous to Miocene stratigraphic succession between Mt. Fragara, Mt. del Passeggio, and Pizzo Deta (on the extreme left). In the lower part, the Brecciaro valley is visible (Photo courtesy of S. Fabbi).
Below: Panoramic view of the high Cosa River valley and of the ridge which runs from Mt. Vermicano, Mt. Pozzotello, Mt. Fanfilli, and La Monna (from left to right), where the Middle Jurassic to Lower Cretaceous stratigraphic succession is spectacularly exposed (Photo courtesy of A. Cipriani).

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ABSTRACT

We describe a portion of the Simbruini-Ernici Mountains, that is going to be included in the Sheet 377 "Trasacco" of the Geological Map of Italy at 1:50,000 scale. The study area is characterized by peculiar tectono-stratigraphic features, such as the occurrence of a narrow pelagic intra-platform basin linked to the E-Jurassic rifting of W-Tethys, filled by the progradation of the carbonate platform margins. During the rest of the Mesozoic, and in the Miocene, this portion of the Apennine platform persisted in a carbonate platform setting. Early Cretaceous synsedimentary tectonics is recorded by the Berriasian-Aptian units. Cenomanian to Campanian rudist-dominated associations developed in inner platform settings. After the "Palaeogene hiatus", carbonate sedimentation was resumed in the Early Miocene but ended in the Tortonian when chain building started. Throughout the Messinian and Pliocene wedge-top basins formed, filled by thick clastic polygenic deposits. Since the Late Pliocene, the uplift of the chain caused subaerial exposure and erosion. This phase is responsible of the deposition of Quaternary clastics, which have been organised for the first time as stratigraphic units. The wide array of continental deposits of the study area records several erosional/depositional cycles, controlled by the combined tectonics and climatic oscillations.

Keywords: CARG Project, Tectonics, Stratigraphy, Wedge-top basins, Geological Mapping.

INTRODUCTION

The Simbruini-Ernici Mountains are located in the Central Apennines across the Latium-Abruzzi border. The geology of the area has been studied since the 19th century (Fabbi et al., 2018; Fabbi, 2020) and three sheets of the Geological Map of Italy at 1:50,000 scale, which cover the northwest sector, have been already published by ISPRA (sheets 367 "Tagliacozzo", 376 "Subiaco" and 389 "Anagni" - Servizio Geologico d'Italia, 1975, 1998, 2005a). Nevertheless, those maps were made before the beginning of the CARG Project, so they only partially meet the updated Geological Survey of Italy (ISPRA) guidelines for maps at 1:50,000 scale. In addition, the stratigraphic subdivisions shown into these three maps, as well as the other geological maps published through the area (Devoto, 1970; Fabbi, 2016, 2018; Cavinato et al., 1990, 2012), are poorly detailed (especially for the Mesozoic carbonates) and quite different from each other, which hampers reconstructing a common stratigraphic evolution.

In this paper, we present original stratigraphic data, a tectonic interpretation and a new geological map of a portion of the Simbruini-Ernici Ridge, which follow-on from fieldwork made in the frame of the CARG Project, with particular focus on a portion of the Geological Sheet 377 "Trasacco'' of the Geological Map of Italy at 1:50,000 scale. The geological surveying was financed by the Latium Region, and so, only the Latium territory of sheet n. 377 is here presented. Although the study area has a limited extension (~70 km^2), most of the Mesozoic-Cenozoic stratigraphic succession of the Apennine Carbonate Platform is exposed, missing only Triassic and lowermost Jurassic units (see Main Map). This gave us the chance to establish a reference stratigraphy for the area, aiming to improve the stratigraphic settings of the old, published maps and to display the base for future studies in the area. This represents the first attempt to apply a modern stratigraphic scheme for the Simbruini-Ernici Mountains that meets the CARG Project standards, mirroring the most updated sheets of the Central Apennines.

For the study area, the first geological cartography dates back to the sheet 151 "Alatri" (R. Ufficio Geologico, 1939) and relative explanatory notes by Beneo (1939, 1943), and the subsequent sheet 152 "Sora" (Servizio Geologico d'Italia, 1968) with the relative explanatory notes by Praturlon (1968) of the Geological Map of Italy 1:100,000. In addition, parts of the study area were represented in the maps made by Devoto and Parotto (1967), Devoto (1970) and in the synthetic overview map by Cavinato et al. (2012). We aim at introducing and describing an updated list of Mesozoic-Cenozoic lithostratigraphic units, as well as some Pliocene-Quaternary continental deposits that are here for the first time characterised as stratigraphic units. These would hopefully represent the base-reference for the following geological maps dealing with the Simbruini-Ernici Ridge and more widely the Central Apennines.

Methods and techniques

Field mapping was performed at 1:10,000 scale, as recommended by the guidelines of the CARG Project (Pasquaré et al., 1992; Galluzzo et al., 2009; Vita et al., 2022). In the field, a bio-lithostratigraphic approach based on the identification of the diagnostic lithofacies and facies associations, as well as of the main fossils, was performed. The nomenclature established for the Jurassic-Miocene interval is taken, with some changes, from the sheets 368 "Avezzano" and 378 "Scanno" of the Geological Map of Italy at 1:50,000 scale (Servizio Geologico d'Italia, 2005b, 2010a, and relative explanatory notes by Centamore et al. (2006) and Miccadei et al. (2010), whereas the Pliocene-Quaternary syn- and post-orogenic deposits are described for the first time. The lithostratigraphic nomenclature is, however, based on non-standardised units, mostly of formational rank. These units are reported along with the acronyms used on the main map, in order to make their reading easier.

Carbonate microfacies and biostratigraphic analyses were performed using about 350 thin sections over 300 collected hand samples. The classification follows Dunham (1962) and Embry and Klovan (1971). The biostratigraphy

of marine units is based on different groups of microfossils (mostly calcareous algae and benthic foraminifera). Macrofossil-rich horizons (gastropods, bivalves, hydrozoans, brachiopods and echinoderms, among others) were also considered. Key references for biostratigraphy of the Mesozoic shallow-water carbonate successions, as well as useful informal bio-chronostratigraphic schemes, were used (Carras et al., 2006; Chiocchini et al., 2012, 2019).
Fieldwork was performed using the classical methodologies of geological mapping, combined with digital devices equipped with FieldMove Clino (https://www.petex.com/products/move-suite/digital-field-mapping/). The digitalisation of field data was performed using Qgis v. 3.20 (http://qgis.osgeo.org). Geometric features used for the map are from the symbols library of the CARG Project, freely available online at https://progetto-carg.isprambiente.it/quaderno15andoggettidigitali/ (see also Falcetti and Radeff, 2022). The editorial handling of the main map was performed using the software Adobe Illustrator CC2018.

GEOLOGICAL SETTING

The Central Apennines mostly consist of NW-SE oriented carbonate ridges made up of Mesozoic-Cenozoic rocks, with interposed valleys filled by siliciclastic deposits, as well as Quaternary intermontane basins with continental (mainly fluvial-lacustrine) and volcanoclastic deposits (Fig. 1).
The geological history of the study area reflects, at least until the Late Miocene, the evolution of the Latium-Abruzzi carbonate platform, which developed since the Triassic on the southern margin of Tethys Ocean (Laubscher and Bernoulli, 1977; Accordi and Carbone, 1988; Damiani et al., 1991a; Bosellini, 2004; Cosentino et al., 2010).
Tethys Jurassic carbonate platforms reached their maximum extension during the Hettangian (Channel et al., 1979; Bosellini, 2004), before being dismembered by rift-related extensional tectonics (Bernoulli et al., 1990; Santantonio and Carminati, 2011). In Central Italy, this tectonic phase drove the development of two different palaeogeographic domains: i) a wide shallow-water carbonate platform (Latium-Abruzzi carbonate platform or Apennine Carbonate Platform *sensu* Mostardini and Merlini, 1986), southeastward of the "*Ancona-Anzio line*" *auctt.* (Parotto and Praturlon, 1975; Castellarin et al., 1978), and ii) a pelagic basin (i.e., Umbria-Marche-Sabina Basin) northwestward of the "*Ancona-Anzio line*" *auctt.* (Centamore et al., 1971; Galluzzo and Santantonio, 2002; Santantonio and Carminati, 2011). In the Latium-Abruzzi Domain, high sedimentation rates produced the accumulation of a very thick (thousands of metres) succession of "Bahamian type" neritic carbonates (D'Argenio, 1974; Parotto and Praturlon, 1975, 2004; Accordi and Carbone, 1988; Damiani et al., 1991a; Centamore et al., 2007; Chiocchini et al., 2008; Romano et al., 2019). Shallow-water conditions persisted at least until the Campanian or the Maastrichtian, occasionally interrupted by subaerial exposures (Praturlon, 1968; D'Argenio, 1974; Accordi and Carbone, 1988; D'Argenio and Mindszenty, 1991). Commonly, the Upper Cretaceous succession is directly overlain by Miocene carbonates through a sharp paraconformity or a low-angle angular unconformity (Damiani et al., 1990, 1991a; Civitelli and Brandano, 2005). The origin of such unconformity, so-called the "Palaeogene hiatus", is still object of scientific debate: most authors have interpreted it as a result of a prolonged subaerial exposure of the platform top (Devoto, 1967a; Parotto and Praturlon, 1975; Damiani et al., 1990, 1991a) probably due to a crustal bulging (Sabbatino et al., 2021). An alternative hypothesis considers the platform top constantly placed within the waves base level, where depositional (highstand) and erosional (lowstand) phases would alternate in response to sea-level oscillation ("shaved platform"), thus winnowing almost the entire thickness of sediments deposited during the Palaeogene (Brandano, 2017). The Early to Middle Miocene succession is characterised by a heterozoan benthic association and interpreted to be deposited into a gently dipping carbonate ramp (Civitelli and Brandano, 2005).
The Mesozoic-Cenozoic carbonates were deformed by the northeastward migration of the Apennine accretionary wedge, driven by the W-subducting Adriatic lithosphere (Doglioni et al., 1996, 1999; Tavani et al., 2023a). The slab hinge retreat produced a fast eastward migration of the fold-and-thrust belt, triggering the opening of the Provençal and later Tyrrhenian back-arc basins (Bally et al., 1986; Boccaletti et al., 1990; Patacca et al., 1991; Gueguen et al., 1998; Carminati and Doglioni, 2012). The Apennine chain is interpreted as the result of thin-skinned tectonics (Doglioni, 1991; Doglioni et al., 1999), being characterised by low structural relief and deformation of the sole sedimentary cover (Bally et al., 1986; Royden et al., 1987; Patacca et al., 1991, 1992; Doglioni et al., 1999; Carminati et al., 2012). Orogenic deformation started during the Late Miocene. This caused the demise of the Miocene carbonate factory and the subsequent onset of terrigenous sedimentation (hemipelagic and later turbiditic). Hemipelagic deposits mark the definitive drowning of the carbonate ramp, whereas turbidites testify for the onset of the foredeep sedimentation (Patacca et al., 1992; Milli and Moscatelli, 2000; Bigi et al., 2003; Carminati et al., 2007). The Quaternary evolution of the Central Apennines was controlled by extensional tectonics that, starting from the Early Pleistocene (Galadini, 1999), produced the lowering of the chain towards SW with even considerable throws along NW-SE oriented faults (Roberts and Michetti, 2004).

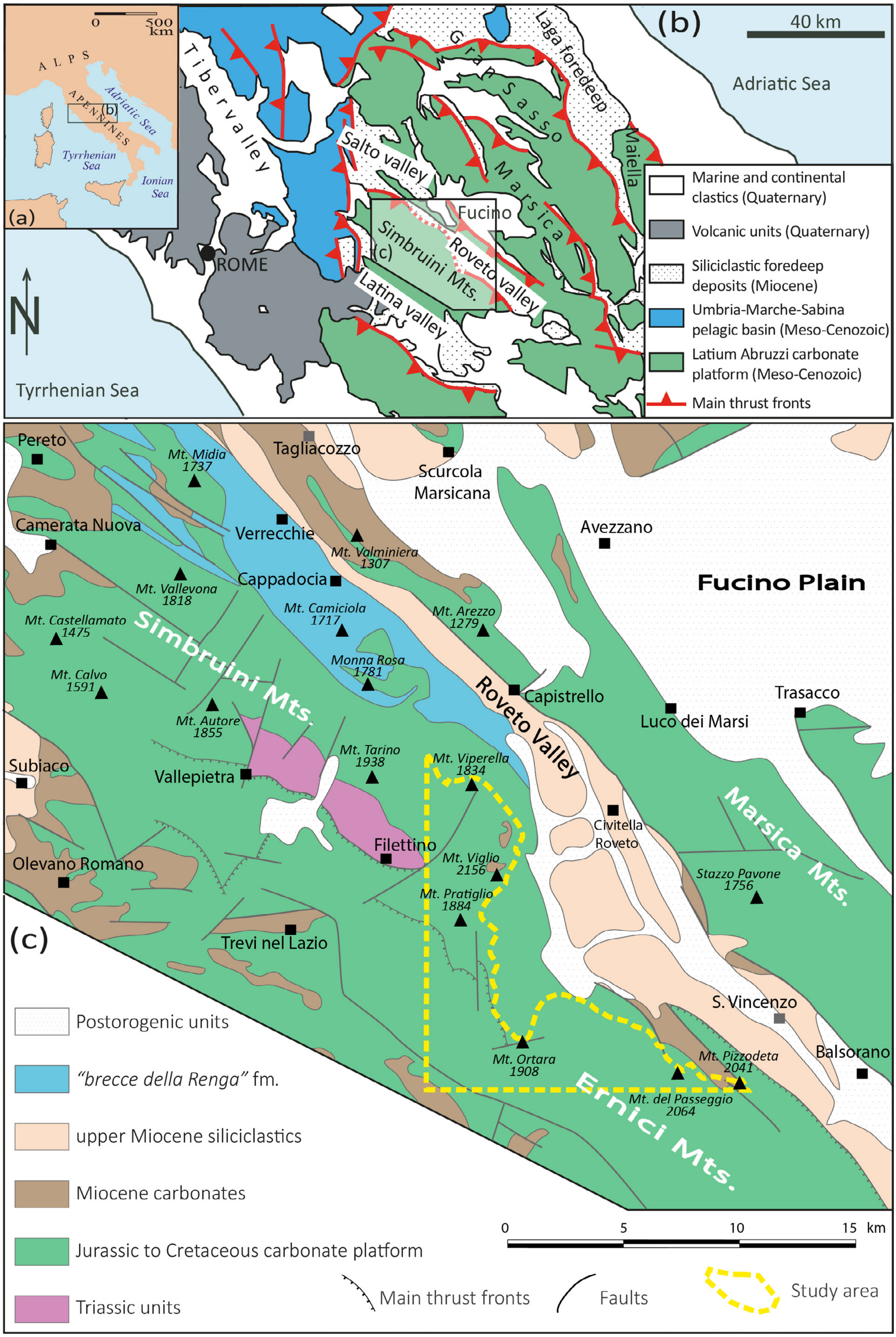

Fig. 1 - Geographic and geological setting of the study area (modified from Fabbi, 2018)

Most of the Apennine chain is nowadays controlled by an extensional regime, whereas compression is limited to the frontal zone (Carminati and Doglioni, 2012).

Geology of the Simbruini-Ernici Mountains

The geological evolution of the Simbruini-Ernici Mountains reflects that of the Latium-Abruzzi carbonate platform, with few exceptions. In the Late Triassic – Early Jurassic, a basin hosting pelagic sedimentation was interposed between shallow-water areas (Filettino basin – Ciarapica and Passeri, 2002). This basin was then filled by a prograding carbonate platform margin during the latest Toarcian-Aalenian (Damiani, 1975; Damiani et al., 1991b; Cirilli, 1991, 1993), when the shallow-water carbonate sedimentation was resumed and continued up to the latest Cretaceous (Damiani et al., 1990, 1991a; Cosentino et al., 2010; Fabbi et al., 2020). The Miocene carbonates (Aquitanian/Burdigalian to Tortonian in age – Civitelli and Brandano, 2005) directly rest on the latest Cretaceous carbonates through the "Palaeogene hiatus" that represents about ~40 Myr of depositional gap. Late Miocene orogenic compression was predated by an extensional phase, which produced the dismantling of large volumes of Mesozoic-Cenozoic carbonates, producing the "*brecce della Renga*" unit (Carminati et al., 2014; Fabbi and Rossi, 2014; Fabbi et al., 2014). Deltaic or shallow-marine deposits reveal that, during the late Messinian and the Early Pliocene, the area experienced uplift and emersion (Devoto, 1967a; Cipollari and Cosentino, 1999; Cosentino and Cipollari, 2012; Fabbi and Santantonio, 2019).

Remarkably, pieces of evidence of Pleistocene glacial phases are commonly found along the slopes of Mt. Viglio, Mt. Crepacuore, Mt. Ortara, Mt. Pozzotello, Mt. Prato, Mt. Ginepro, Mt. del Passeggio and Pizzo Deta, where superb glacial cirques occur (Damiani and Pannuzi, 1976, 1979, 1990; Jaurand, 1995). Glacial valleys also occur at Campo Staffi, Valle della Moscosa, Valle del Pozzotello, Pratiglio di Sant'Onofrio, Campocatino, with some well-preserved moraines and erratic boulders (Damiani and Pannuzi, 1976, 1979, 1990; Jaurand, 1995), see Fig. 2 for the exact location of localities quoted in the text.

STRATIGRAPHY

The stratigraphic succession is subdivided as follows:

I – *Mesozoic-Cenozoic carbonate succession:* carbonate units referable to different depositional environments of the Mesozoic-Cenozoic shallow-water carbonate platform, slope-basin and carbonate ramp;

II- *Neogene clastic succession*: consisting of clastic units related to Miocene pre-thrusting syn-sedimentary tectonics followed by deposition in thrust-top basins;

III- *Pliocene-Quaternary continental deposits*: clastic deposits and debris covers, linked to the subaerial erosion of the chain, and to depositional settings influenced by Quaternary climatic oscillations.

Mesozoic-Cenozoic carbonate succession

Although the Latium-Abruzzi (or Apennine) carbonate platform was intensively studied along more than a century, there are just very few stratigraphic units that could be considered as formally defined. Most of the "formations" described in this section have been widely used in the regional cartography, but they should be considered as informal. The only exception is represented by the Corniola, which has been ratified by the Italian Commission of Stratigraphy as an historical formation (Petti et al., 2007).

Corniola (COI – Pliensbachian *p.p.*-Toarcian *p.p.*)

This is the oldest stratigraphic unit cropping out in the study area and is well exposed along the Filettino-Campo Staffi Road (Val Granara) and in the neighbours of Mt. La Forchetta-La Monna (Fig. 2). The COI is a grey/hazel mudstone/wackestone, sometimes dolomitised, organised in 10-40 cm thick beds with thin marly interbeds (Fig. 3a, 3c). Marly limestone intervals are nodular (Fig. 3b). Turbiditic oolitic/peloidal wackestones to grainstones are interbedded within the pelagic mudstones and become more frequent in the upper portion (Fig. 3d). Chert nodules occur in the southernmost outcrops. Burrows are common and fossils consist of radiolarians, sponge spicules, brachiopods and rare ammonites. Damiani et al. (1981) describe Carixian (lower Pliensbachian) ammonites from comparable pelagic deposits near Filettino. Carbone and Sirna (1980) and Damiani et al. (1998) report lower Toarcian ammonites from Valle Granara (Tab. 1). The base of the unit is not exposed in the study area, whereas the upper boundary is marked by the gradual decrease of grey wackestones and the concomitant increase of resedimented oolitic packstones-grainstones, typical of the overlying "*unità oolitica*" (Fig. 4a). The depositional environment is referable to a pelagic basin bounded by carbonate platform margin, as highlighted by oolites transported from a shallow-water setting. The thickness is not determinable in the field, but it exceeds 200 m. This unit corresponds to the upper portion of "*unità Sant'Antonio*" and to the entire the "*unità Vadatino*" described by Damiani (1975) and Damiani et al. (1991a, b).

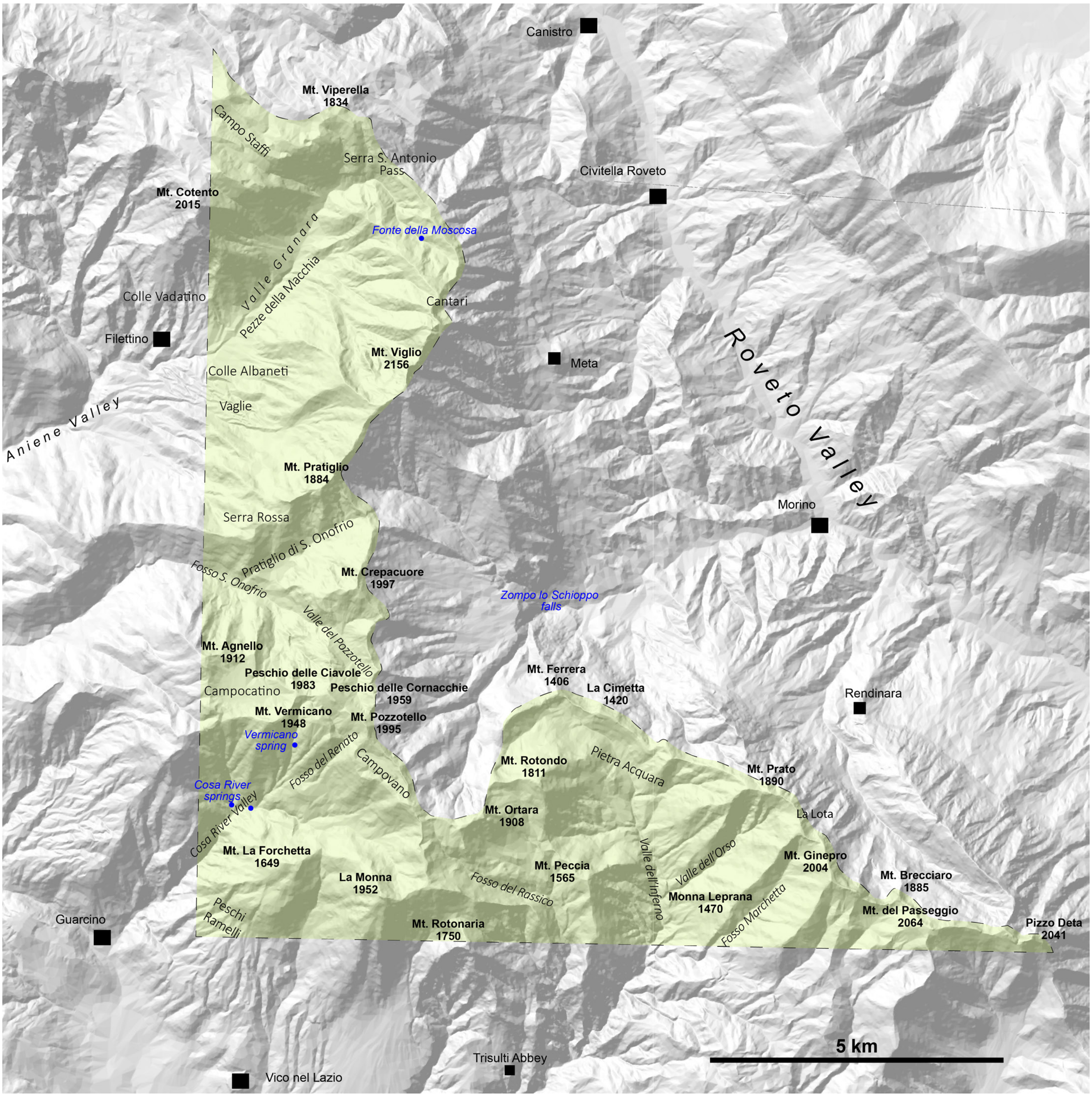

Fig. 2 - Location map of the localities cited in the text. Basemap: 10 m - resolution DEM of Italy (Tarquini et al., 2007).

"unità oolitica" ("oolitic unit") (**UOO** – Toarcian *p.p.*-Aalenian *p.p.*)

This unit crops out along the Filettino-Campo Staffi Road (Valle Granara) and in the neighbours of Mt. La Forchetta-La Monna (Figs. 2, 4a-c). It has been widely recognised and used in several official geological maps at 1:50,000 scale of Central Apennines (see sheets n. 348 "Antrodoco", 358 "Pescorocchiano", 360 "Torre de' Passeri", 369 "Sulmona", 378 "Scanno" and 402 "Ceccano" – Servizio Geologico d'Italia, 2005b, 2005c, 2005d, 2010a, 2010b, 2011, 2022). It is made up of oolitic grainstones and packstones, organised in dm- to m-thick beds, with subordinate oolitic/bioclastic packstones to rudstones (Fig. 4c). Lenticular beds are common, as well as other sedimentary structures (plane-parallel and cross lamination/stratification – Fig. 4b). The fossil content (Tab. 1) consists of *Thaumatoporella parvovesiculifera,* cyanobacterial aggregations, crustaceans coprolites, and an oligotypic benthic foraminifera assemblage. The upper boundary is marked by red palaeosols and ferruginous crusts. Channelised bodies overlying pelagic deposits (COI) and tractive sedimentary structures suggest

Table 1

Unit	Benthic forams	Calcareous algae	Other microfossils	Macrofossils
CBZ	*Amphistegina* sp., *Cibicides* sp., *Elphidium* sp., *Heterostegina* sp., *Miogypsina globulina*, *Neorotalia* sp., *Operculina* sp.			Ostreid bivalves, echinoderms, bryozoans, abundant red algae fragments
RDT	*Accordiella conica*, *Aeolisaccus kotori*, *Cuneolina* sp., *Dicyclina schlumbergeri* (Fig. 13d-e), *Keramosphaerina tergestina*, *Moncharmontia apenninica*, *Murgeina apula*, *Neorotalia? cretacea*, *Nezzazatinella picardi*, *Nummoloculina* cf. *irregularis*, *Pilatorotalia pignattii*, *Pseudocyclammina sphaeroidea*, *Reticulinella fleuryi*, *Reticulinella kaeveri*, *Rotalispira maxima* (Fig. 13e), *Rotalispira scarsellai*, *Rotorbinella lepina* (Fig. 13d), *Scandonea mediterranea*, *Scandonea samnitica*, *Siphodinarella costata*, *Spiroplectammina multicamerata*, smaller nezzazzatids, discorbids and miliolids	*Heteroporella lepina*, *Sgrossoella parthenopeia*	*Thaumatoporella parvovesiculifera*	Gastropods, locally abundant echinoids, rudists: *Biradiolites* spp., *Durania* spp., *Gorjanovicia* spp., *Hippurites* spp., *Plagioptychus* sp., *Pseudopolyconites* sp., *Radiolites* spp., *Sauvagesia* spp., *Vaccinites* spp.
IBX	*Biconcava bentori*, *Biplanata peneropliformis*, *Chrysalidina gradata*, *Cisalveolina fraasi* (Fig. 11f), *Cisalveolina lehneri* (Fig. 11e), *Coscinoconus* sp. (Fig. 11f), *Cuneolina* sp. (Fig. 11d), *Merlingina cretacea*, *Nezzazata isabellae*, *Nezzazata simplex*, *Ovalveolina maccagnoae*, *Pararotalia* sp., *Pseudorhapydionina dubia*, *Pseudorhapydionina laurinensis*, *Pseudorhipidionina murgiana*, *Rajkanella hottingerinaformis*, *Rotorbinella mesogeensis*, *Sellialveolina viallii* (Fig. 11c), *Sigmomassilina ottadunensis*, *Vandenbroeckia causae*			*Chondrodonta joannae*, caprinid rudists
CIR	*Akcaya capitata* (Fig. 9f), *Akcaya minuta*, *Archaealveolina reicheli* (Fig. 9d), *Coskinolinoides fleuryi*, *Cribellopsis* sp. (Fig. 9f), *Dictyoconus* cf. *algerianus*, *Fissumella motolae*, *Mesorbitolina* cf. *texana*, *Neoiraqia insolita*, *Nezzazata isabellae*, *Praechrysalidina infracretacea* (Fig. 9e), *Simplorbitolina aquitanica*, *Valdanchella dercourti*	*Garwoodia fluegeli*, *Salpingoporella* sp.		Requieniid rudists, gastropods
CMS	*Mesorbitolina parva*, *Mesorbitolina texana*, *Palorbitolina lenticularis*, *Praechrysalidina infracretacea*	*Salpingoporella dinarica (Fig. 8d)*	Charophyta oogonids	
CCG	*Akcaya minuta*, *Campanellula capuensis*, *Praechrysalidina infracretacea*, miliolidae and textularidae	*Clypeina* sp., *Otternstella lemmensis*, *Permocalculus* sp., *Piriferella spinosa*, *Salpingoporella annulata*, *Salpingoporella biokovensis*, *Salpingoporella polygonalis*	*Favreina salevensis*, "*Rivularia*" sp., ostracods	*Chondrodonta glabra*, requieniid rudists
CCM	*Conicokurnubia orbitamminiformis*, *Farinacciella ramalhoi*, *Kurnubia palastiniensis*, *Kurnubia wellingsi*, *Pseudocyclammina* sp., *Redmondoides lugeoni*, *Trocholina* sp., miliolidae, valvulinidae	*Aloisalthella sulcata* (ex *Clypeina jurassica*), *Apinella* sp., *Campbelliella striata* (Fig. 6g), *Heteroporella anici*, *Megaporella boulangeri*, *Rajkaella bartheli*, *Salpingoporella annulata*, *Salpingoporella grudii*,	*Cladocoropsis mirabilis* (Fig. 6f), *Favreina salevensis*, carophyta oogonids	Bivalve and gastropod remains
UCD	*Bosniella bassoulleti*, *Everticyclammina* sp., *Kilianina blanchetiformis*, *Kurnubia palastiniensis*, *Kurnubia wellingsi*, *Paleopfenderina salernitana*, *Paleopfenderina trochoidea*, *Paravalvulina* sp., *Pfenderella arabica*, *Praekurnubia crusei*, *Protopeneroplis striata*, *Redmondoides lugeoni*, *Siphovalvulina beydouni*, *Siphovalvulina variabilis*, *Trocholina* sp., miliolidae	*Cylindroporella arabica*, *Salpingoporella annulata*, *Salpingoporella sellii*, *Selliporella donzellii*, *Selliporella* sp.	*Cayeuxia* sp., "*Rivularia*" *piae*	Gastropods, rare bivalves, brachiopods
CLT	*Siphovalvulina* sp., *Trochammina* sp.	*Gutnicella* sp.	*Cayeuxia* sp., ostracods	Gastropods, terrestrial plant remains.
UOO	*Ammobaculites* sp., *Bosniella* sp., *Pseudocyclammina liassica*, *Siphovalvulina colomi*	*Thaumatoporella parvovesiculifera*	*Favreina* sp., "*Rivularia*" *piae*	
COI			Radiolarians, sponge spicules	Brachiopods, Ammonites: *Hildaites* gr. *serpentinus*, *Harpoceras* gr. *mediterraneum*

Fig. 3 - a-b) field and c-d) microfacies views of *Corniola*; a) thin beds of pelagites displaying also erosional truncations related to soft sediment deformation structures. Southern slope of Mt. La Forchetta; b) detail of the protonodular facies; c) mudstone with disarticulated ostracod valvae and recrystallised finer bioclasts; d) oolitic and bioclastic wackestone. Oolites show concentric-radial fabric and are associated with sponge spicules.

deposition on a slope adjacent to the carbonate platform, prograding into (and evening out) a deeper basin. The maximum thickness is about 80 m.

"calcari maculati di Vallepietra" ("Vallepietra spotted limestone") (**CLT** – Aalenian *p.p.*) (cf. "*Calcari Maculati*" by *Bergomi, 1974*)

Deposits referred to the CLT crop out at Filettino and in the neighbours of Mt. La Forchetta-La Monna (Figs. 2, 4d-f) and are represented by whitish-hazelnut limestone and marly limestone organised in 30-40 cm-thick beds (Fig. 4d), characterised by greenish, red or violet spots, along with green or purple vadose calcisiltitic layers and ferruginous crusts with nodules (Fig. 4e). These peculiar features indicate pedogenesis and palaeosols development. The main microfacies are represented by bio-lithoclastic mudstones and wackestones, with localised interbeds of bioclastic/oolitic packstone to rudstone (Fig. 4f). Fossiliferous content (Tab. 1) consists of an oligotypic fauna with smaller benthic foraminifera, algal nodules, gastropods and ostracods. Damiani et al. (1998) report the occurrence of terrestrial plant remains. The upper boundary is marked by the disappearance of palaeosols and by the onset of whitish cyclothemic beds. The depositional environment is referable to a low-energy lagoon affected by frequent subaerial exposures, in arid or semi-arid conditions. The maximum thickness is about 80 m.

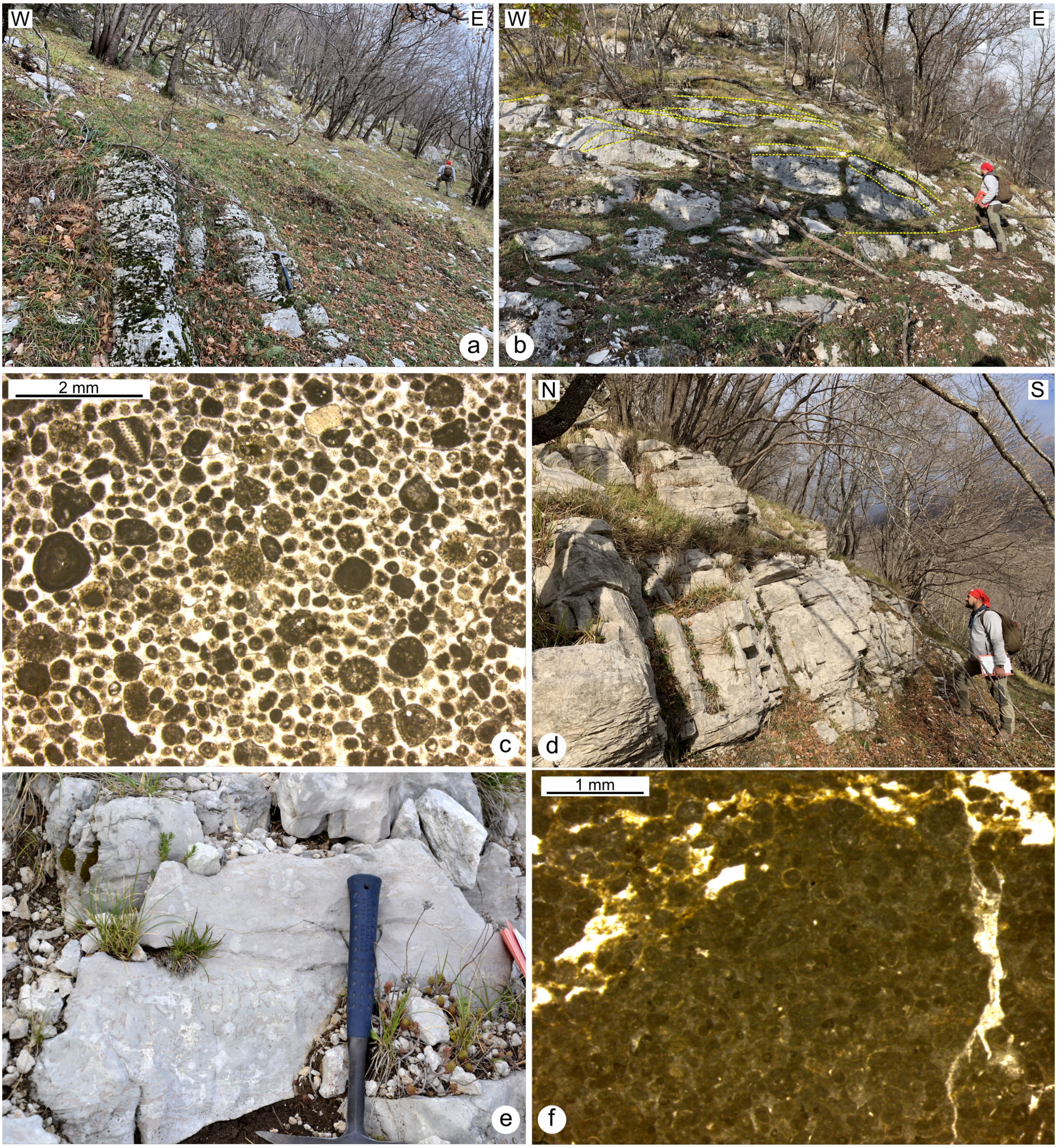

Fig. 4 - a) transitional passage from the thinly-bedded pelagites of *Corniola* (lower part of the picture) to the thicker deposits of *"unità oolitica"*; b) lensoidal and clinobedded facies of *"unità oolitica"*; c) oolitic grainstone with few fragments of dasycladacean green algae; d) well-bedded limestones of *"calcari maculati di Vallepietra"*; e) characteristic polychrome emersive facies of *"calcari maculati di Vallepietra"*; f) lithoclastic rudstone made of clasts bearing oolitic/peloidal packstone textures. The clasts are bounded by a calcisiltitic matrix.

"unità calcareo-dolomitica" ("calcareous-dolomitic unit") (**UCD** – Bajocian-Callovian *p.p.*)

This unit extensively crops out in the study area and the best exposures are located at Valle Granara, Pratiglio di S. Onofrio and along the slopes of Mt. La Forchetta-La Monna-Mt. Rotonaria (Figs. 2, 5a). It is made up of limestones and subordinate limestone/dolostone alternations. Limestones are typically organised in dm- to m-thick beds driven by peritidal cyclicity, consisting of alternations of white fenestral wackestones (Fig. 5d), hazel intraclastic packstones and white or grey oolitic grainstones; locally, rudstones bearing oncoids and algal nodules up to 5 cm in diameter occur (Fig. 5d-e). Along the southern slopes of La Monna, a decametric paleosols-bearing interval occurs. Dolomitisation usually affects former peritidal limestones. Dolomitic breccias are also present, bearing calcareous relics and isolated whole specimens of dasycladacean algae (*Selliporella* sp. – Fig. 5b). In the upper portion, plurimetric alternations of limestones and saccharoidal dolostones occur. At the top of the unit, a characteristic horizon bearing a rich brachiopod fauna (Fig. 5c) and calcareous algae occurs (see also Devoto and Parotto, 1967, and Damiani et al., 1998). The fossiliferous content (Tab. 1) is made up of cyanobacterial aggregates (Fig. 5e) and dasycladacean algae, benthic foraminifera, whole and fragmented gastropods, rare bivalves and brachiopods as well. The upper boundary is marked by i) the abrupt decrease of saccharoidal dolostones, ii) the appearance of well bedded hazelnut limestones, and iii) the common occurrence of *Cladocoropsis mirabilis* and *Aloisalthella sulcata*. The depositional environment is referable to an inner platform displaying a complex pattern of sub-environments ranging from subtidal to supratidal and characterised by lagoons, tidal flats, channels, and carbonate sand shoals. The observed thickness ranges between 600 and 700 metres.

***"calcari con* Cladocoropsis *e* Clypeina"** ("*Cladocoropsis* and *Clypeina* limestones") (**CCM** – Callovian *p.p.*-Berriasian *p.p.*)

This unit is widespread in the study area, and the best exposures are placed along the slopes of Mt. Crepacuore (Fig. 6a), along the Cosa River valley, between Mt. Ortara and Mt. Rotondo, and at Mt. Peccia (Fig. 2). The unit is made up of hazelnut and white to greyish limestones and dolomitic limestones, organised in pluridecimetric beds. Characteristic is the abundance of *Cladocoropsis mirabilis*, often very large in size (Fig. 6b), in the lower-middle part of the unit. Locally, laminated dm-thick arenitic horizons with quartz granules occur in the lowermost portion of the formation as well (Fig. 6c). Such quartz-bearing horizons are found associated to dasycladacean algae (*Aloisalthella sulcata, ex Clypeina jurassica*) (Fig. 6d). The fossiliferous content (Tab. 1) consists of *Cladocoropsis mirabilis* (Fig. 6f), *Aloisalthella sulcata* and further dasycladacean algae, crustacean coprolites, benthic foraminifera and carophyta oogons. Few bivalves and gastropods remains occur as well. The upper boundary is marked by the disappearance of *Campbelliella striata* and is characterised by a thick stack of saccharoidal dolostones. The depositional environment is referable to an inner carbonate platform, with a wide tidal flat and lagoon settings. The maximum thickness is about 650 metres.

"calcari ciclotemici a gasteropodi" ("cyclothemic limestone with gastropods") (**CCG** – Berriasian *p.p.*-lower Aptian *p.p.*)

This unit is widespread in the study area, with good outcrops along the Filettino-Campo Staffi Road, on the western slopes of Mt. Viglio, along the forest road reaching the Cosa River springs (about 1 km south of Campocatino), and in the Valle dell'Inferno-Pietra Acquara area (Figs. 2, 7a-b). The lower portion is represented by a **dolomitic lithofacies** (**CCG_a** – cf. "*membro dolomitico*" CCG_1 in Centamore and Dramis, 2010; "*dolomie di fosso Fioio*" in Compagnoni et al., 2005; Fabbi, 2018). CCG_a is made up of saccharoidal, brown to dark grey dolostones in massive beds (where appreciable), with subordinate m-scale interbeds of limestones and dolomitic limestones (Fig. 7c). Intense dolomitisation has largely obliterated the original sedimentological characters and sedimentary structures. This lithofacies is laterally discontinuous and displays clear thickness variations. A Triassic age was erroneously attributed to the same deposits cropping out in the Valle dell'Inferno by Beneo (1939, 1943). Where this lithofacies is missing, the CCG is made of limestones, and alternating limestone and dolostone with bed thickness ranging from decametric to metric (see Fig. 7a-b). Main microfacies are hazel/whitish wackestones with calcareous algae and rare gastropods; subordinate are whitish peloidal/bioclastic grainstones and packstones, as well as laminated microbial limestones with birdseyes and *fenestrae*; oolitic horizons rarely occur. The topmost 30 m of the unit is characterised by floatstones with ostreids (mostly displaced and iso-oriented valves of *Chondrodonta glabra* – Fig. 7d) and requieniids, with interbedded mudstones-wackestones rich in benthic foraminifera, algae and ostracods. Fossils are represented by gastropods, calcareous algae (Fig. 7e-f), benthic foraminifera, crustacean coprolites and cyanobacteria aggregates. The passage to the overlying CMS is sharp and marked by the occurrence of greenish marls and calcareous pebbles. The depositional environment is referable to an inner carbonate platform subject to peritidal cyclicality, with supratidal to subtidal sub-environments. The thickness of the unit ranges between 250 and 600 meters.

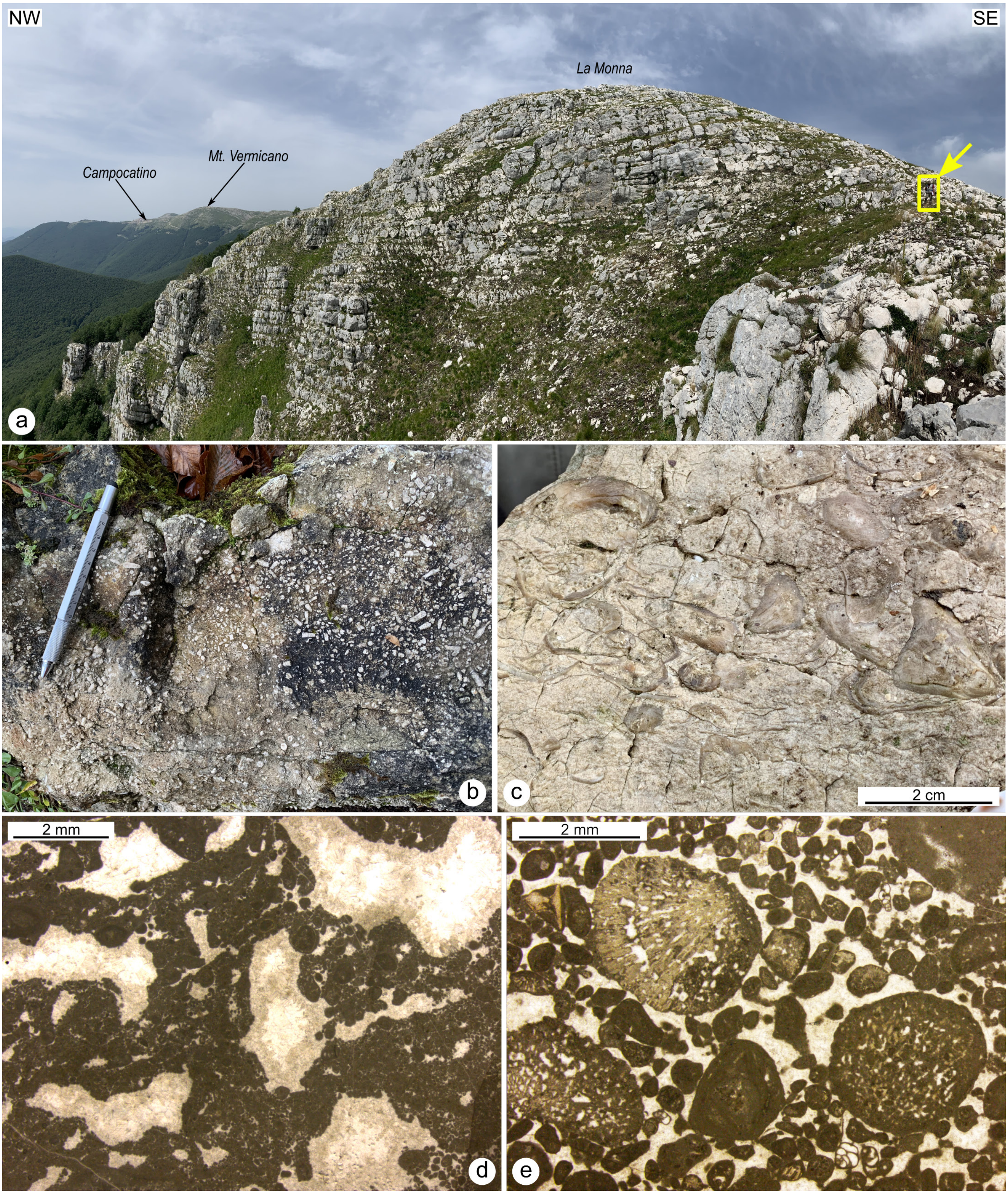

Fig. 5 - a-c) field and d-e) microscopic view of "*unità calcareo-dolomitica*"; a) panoramic view of the southern slope of La Monna, where hundreds of metres of limestones and dolostones referable to "*unità calcareo-dolomitica*" crop out. Note the massively to well-bedded stratal organisation. Arrow indicates geologist for scale; b) detail of the dolostones consisting of dolomitic breccias with calcareous relics, mainly intraclasts of the limestone "protolith" and isolated whole specimens of dasycladacean algae; c) brachiopod-rich deposits found at the top of "*unità calcareo-dolomitica*"; d) fenestral wackestone-packstone with oolites and peloids; e) bioclastic oncoidal rudstone with large rounded rivulacean-type cyanobacteria '*Rivularia*' and few siphovalvulinids foraminifera.

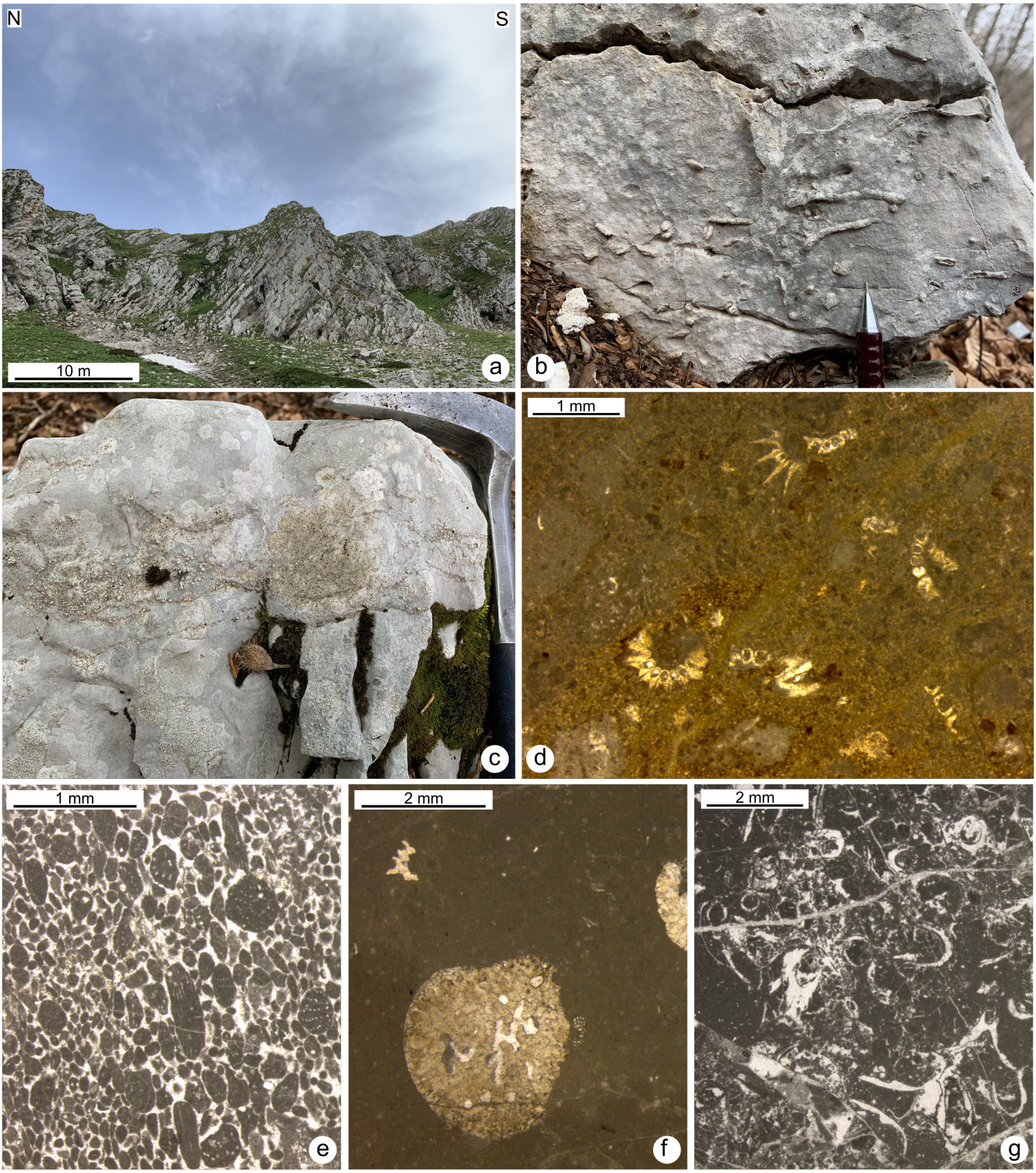

Fig. 6 - a-c) field and d-g) microscopic view of "*calcari con* Cladocoropsis *e* Clypeina"; a) exposure of the well-bedded limestones along the western slopes of Mt. Crepacuore; b) specimens of *Cladocoropsis mirabilis* in selective erosion, exposed along the Cosa River valley; c) arenitic horizons with randomly-arranged quartz granules,cropping out along the north-western slopes of Mt. Peccia; d) wackestone with abundant *Aloisalthella sulcata (ex Clypeina jurassica)*; e) grainstone composed of moderately sorted fragments of *Favreina salevensis*; f) *Cladocoropsis mirabilis*-bearing floatstone, with specimens dispersed in a bioclastic wackestone matrix with *Kurnubia*; g) bio-peloidal packstone with abundant *Campbelliella striata*.

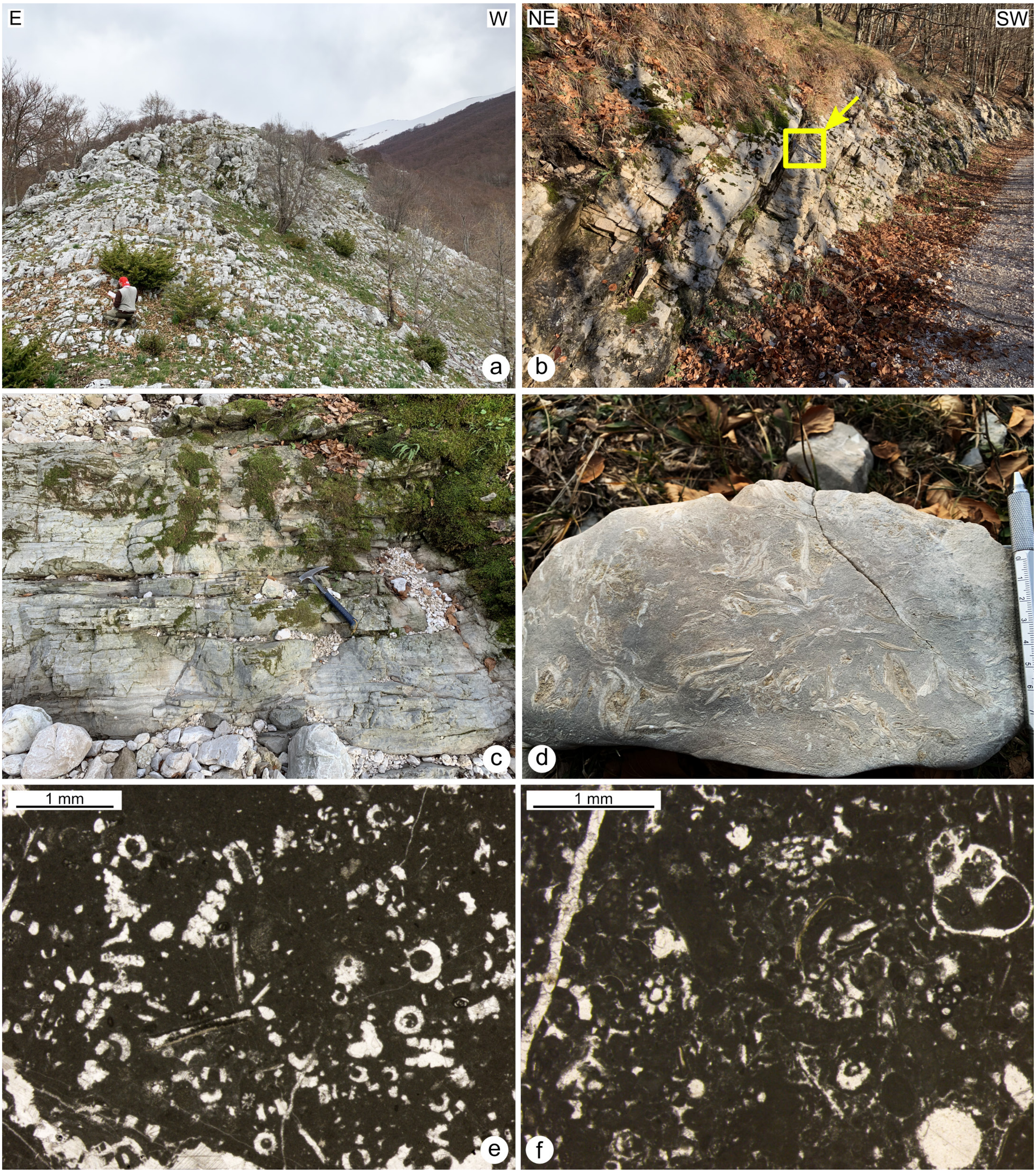

Fig. 7 - a-d) field and e-f) microscopic view of "*calcari ciclotemici a gasteropodi*"; a) well-bedded limestones and subordinate dolostone cropping out on the southern slopes of Monna Leprana; b) alternations of limestones and dolostones in asymmetric peritidal cycles, exposed along the forest road reaching the Cosa River springs. Squared hammer for scale; c) thin alternation of dark and light grey dolostones referable to the "dolomitic lithofacies" CCG_a cropping out at Valle dell'Inferno; d) floatstones with displaced valves of ostreids (mainly *Chondrodonta glabra*); e) wackestone with very abundant *Salpingoporella annulata* and few miliolid benthic foraminifera; f) wackestone with green algae (*Salpingoporella* sp.) and gastropods.

"calcari e marne a* Salpinogoporella dinarica *e carophyta" ("*Salpingoporella dinarica* and carophyta limestones and marls") *(***CMS** – lower Aptian *p.p.)*

This unit crops out scattered within the study area. Good exposures are between Serra S. Antonio Pass and Campo Staffi, on the western slopes of Mt. Viglio Fig. 8a), at Vermicano spring (about 1 km southeast of Campocatino), at Pietra Acquara and in Valle dell'Inferno-Monna Leprana area (Fig. 2). This formation consists of greenish marls and shaly marls, interbedded with hazel micritic limestones. Conglomerates and breccias made of heterometric pebbles sourced from the local carbonate succession occur at different stratigraphic intervals (Fig. 8b). Such clastic deposits show some typical debris-flow features, also associated with slumpings (Fig. 8c). Locally, marly lithologies pass laterally to wackestones and grainstones with abundant calcareous algae (*Salpingoporella dinarica*) and orbitolinid benthic foraminifera (Fig. 8d-e). The palaeontological content (Tab. 1) consists of benthic foraminifera, charophyte oogonids and dasycladacean algae (Fig. 8f). The upper boundary of the unit is sharp and by is marked by the disappearance of marly-clayey horizons and the onset of peritidal, coarse-grained facies with abundant benthic foraminifers. The depositional environment is referable to a carbonate platform, with restricted circulation in a lagoonal settings with lacustrine-palustrine environments. The thickness of the unit is variable and ranges from 10 to 40 metres.

"calcari ciclotemici a requienie" ("cyclotemic limestone with requienids") (**CIR** – upper Aptian–Albian)

This unit is widespread within the study area; best exposures are at Campo Staffi, on the southwestern slopes of Mt. Viglio, near Campocatino, at Pietra Acquara, and in the area comprised between Monna Leprana and Mt. del Passeggio (Figs. 2, 8a, 9a). CIR consists of hazel/whitish limestones and dolomitic limestones, organised in beds ranging from 5 to 80 cm. The lower portion is composed of peritidal cycles with fenestral and microbial facies, palaeosols and oxidised surfaces, along with thin beds of dolostones (Fig. 9b), suggesting inter-supratidal conditions. Bioclastic mudstones/wackestones, grainstones with abundant benthic foraminifera and subordinate requienid floatstones with bioclastic matrix represent the main textures (Fig. 9c-f). The micropalaeontological content (Tab. 1) essentially includes benthic foraminifers. Macrofossils assemblage includes requienid rudists and gastropods. The upper boundary is marked by well-developed palaeosols. The depositional environment can be referred to an inner carbonate platform setting controlled by frequent relative sea-level fluctuations. The thickness ranges between 200 and 250 metres.

"calcari intrabauxitici" ("intrabauxitic limestone") (**IBX** – *Cenomanian)*

This unit is extensively exposed in the study area. The best outcrops are at Campo Staffi, along the slopes of Mt. Viglio, between Campocatino and Campovano, at Mt. Ferrera and in the area between Pietra Acquara and Mt. del Passeggio (Figs. 2, 10 and 11). It consists of well-bedded (10-100 cm) limestones and dolomitic limestones, with subordinate marly limestones and conglomerates (Fig. 10a-c). Reddish horizons, oxidised breccias and palaeokarst are common. These features mark relatively prolonged subaerial exposure. Locally, discontinuous pockets of bauxite deposits occur (Figs. 10c and 11a). Bioclastic wackestone-packstone textures are extremely rich in benthic foraminifers, together with subordinate peloidal/algal mudstones and wackestones. The upper part of the unit is characterised by a caprinid rudists rudstone/floatstone forming low-relief mounds (Fig. 10d), associated with *Cisalveolina fraasi*-rich horizons. Locally, the topmost portion of the unit can also be represented by a floatstone bed rich in *Chondrodonta joannae* (Fig. 10e). The most representative microfossils essentially include benthic foraminifera (Tab. 1). The boundary with the overlying RDT is marked by an up to 2m-thick, polygenic conglomerate with black pebbles and a greenish marly matrix followed by peritidal, mainly microbialite-dominated, white limestones (Fig. 11a, b). The depositional environment is interpreted as an inner carbonate platform characterised by spotted prolonged emersion phases. The maximum thickness is about 200 metres.

"calcari a radiolitidi" ("radiolitid limestone") (**RDT** – Turonian–Campanian *p.p.*)

This unit is widespread throughout the mapped area, with the best exposures at Mt. Viglio-Serra S. Antonio Pass, Mt. Agnello-Mt. Pozzotello, Pietra Acquara-Mt Ginepro and Pizzo Deta (Figs. 2, 11, 12). The lowermost 30-40 metres of the unit are characterised by white-yellowish micritic facies arranged in peritidal cycles (30-60 cm thick – Fig. 12a) and bearing a scarce, oligotypic, benthic fauna dominated by the micro-problematicum *Thaumatoporella parvovesiculifera*. Horizons with cryptoalgal laminations, *fenestrae* and palaeokarst are frequent, as well as dolomitised levels. Upwards, the unit is made up of litho-bioclastic packstone/floatstone to grainstone/rudstone textures dominated by rudist fragments (Fig. 12b-d). Rudist shells form local in-life position bouquets and clusters (Cestari et al., 1992; Fabbi et al, 2020) (Fig. 12c). These lithotypes are associated with hazel colour wackestone beds, with abundant benthic microfauna. Macrofossil content (Tab. 1) consists of fragments or whole individuals

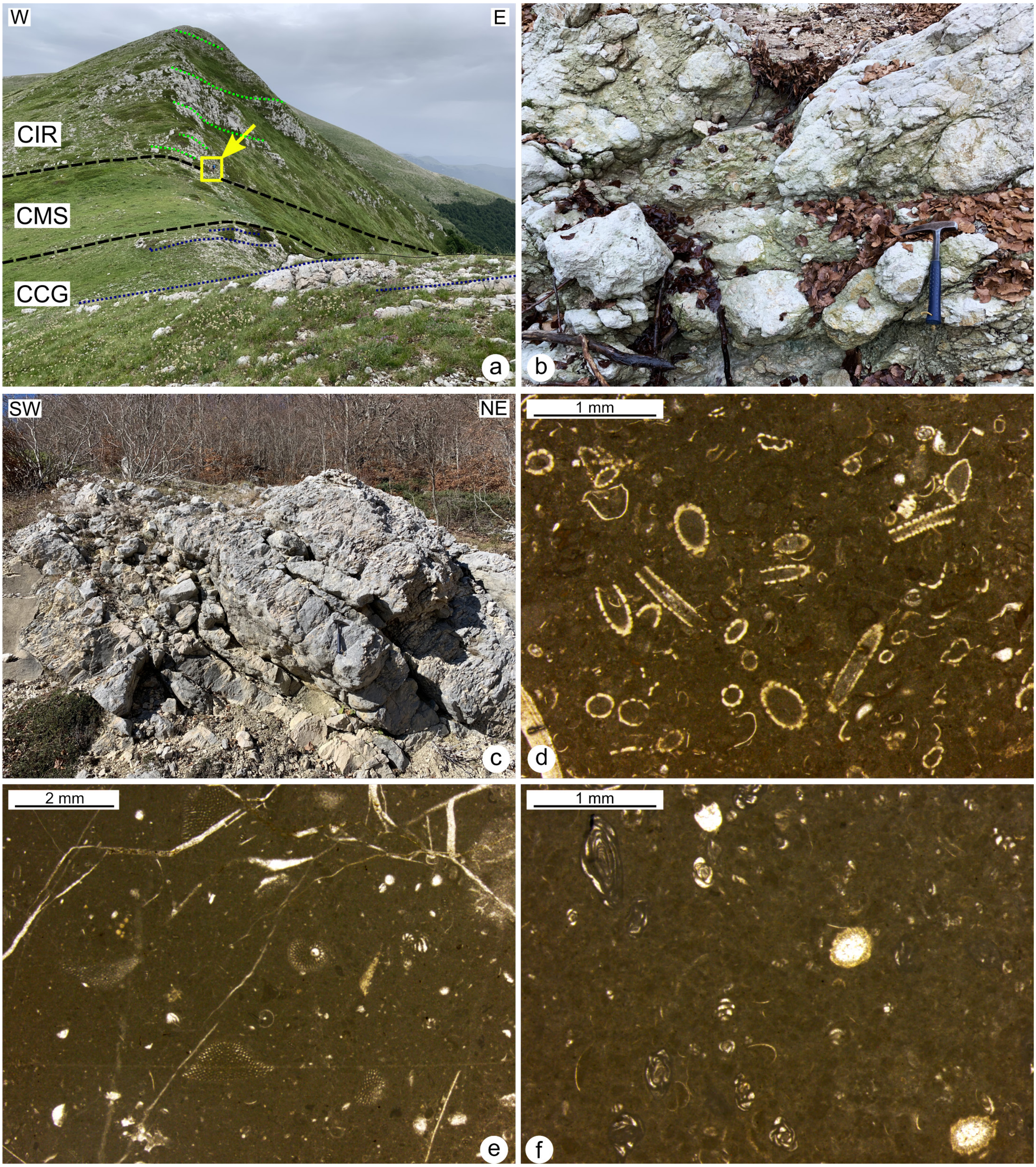

Fig. 8 - a-c) field and d-f) microscopic view of "*calcari e marne a* Salpinogoporella dinarica *e carophyta*"; a) panoramic view of the southern slope of Mt. Viglio, where the stratigraphic boundaries between "*calcari ciclotemici a gasteropodi*" (CCG), *"calcari e marne a* Salpinogoporella dinarica *e carophyta"* (CMS) and "*calcari ciclotemici a requienie"* (CIR) are well exposed. Arrow indicates geologist for scale; b) lithoclastic facies bearing heterometric clasts of limestones dispersed in a greenish marly matrix. Exposure of Monna Leprana; c) intercalation of clastic deposits, made of chaotically arranged pebbles to boulders and associated with incipient soft-sediment deformations, in an alternation of thick beds of limestones and thin layers of green-grey marls; d) wackestone with abundant *Salpingoporella dinarica* along with few ostracod valves; e) wackestone with *Palorbitolina* sp. and few other benthic foraminifera; f) wackestone with ostracod valves, miliolid foraminifera along with sparse charophyte oogonids.

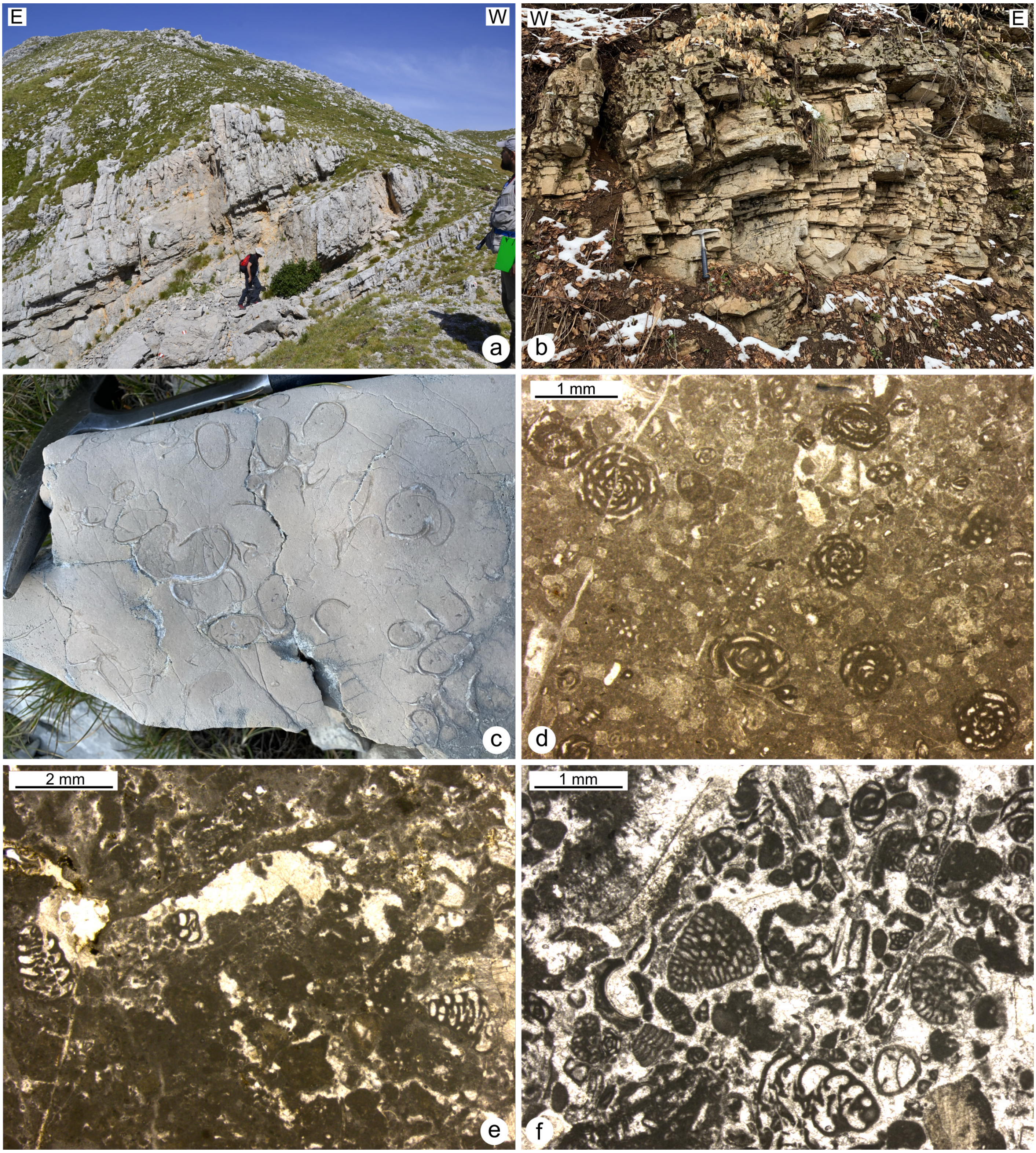

Fig. 9 - a-c) field and d-f) microscopic view of "*calcari ciclotemici a requienie*"; a) well to thickly-bedded limestones and, subordinate, dolomitc limestones, cropping out at Mt. Brecciaro; b) thin beds of dolostones and lime dolostones exposed along the road Filettino-Campo Staffi; c) specimens of requienids dispersed in a fine hazelnut matrix; d) partly dolomitised wackestone with abundant *Archaealveolina reicheli* along with miliolids and few ostracod valves; e) wackestone-packstone with *Praechrysalidina infracretacea* and indeterminate bioclasts; f) foraminiferal packstone-grainstone with *Cribellopsis* sp., *Praechrysalidina* sp. and *Akcaya* sp.

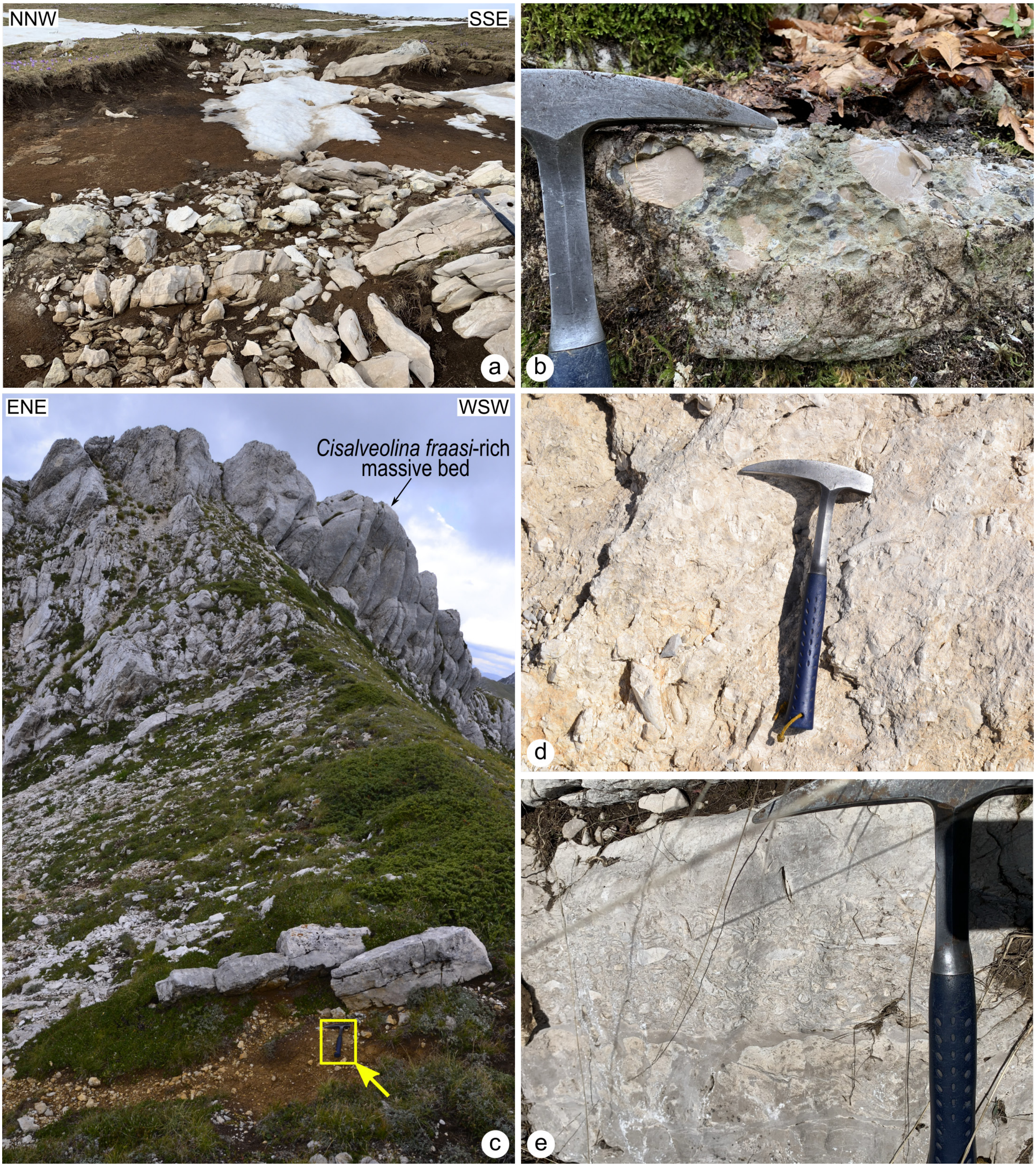

Fig. 10 - a-e) field characters of *"calcari intrabauxitici"*; a) beds of limestones showing asymmetric peritidal cycles, the top of which coincide with reddened layers. Few decimetres of bauxitic deposits are intercalated in the limestone at Mt. Ginepro; b) conglomeratic facies bearing heterometric and sub-angular clasts of limestones and black pebbles, the whole dispersed in a greenish marly matrix, cropping out at Pietra Acquara; c) bauxitic level overlain by well to massively bedded limestones. The highest massive bed in the picture coincides with *Cisalveolina fraasi*-rich deposits exposed along the eastern crest of Mt. del Passeggio; squared hammer for a scale; d) caprinid rudstone/floatstone, exposed along the sky slopes of Campocatino, at Mt. Agnello; e) rudists and ostreids (?*Chondrodonta* sp.) biostrome overlying emersion facies at Mt. Ginepro.

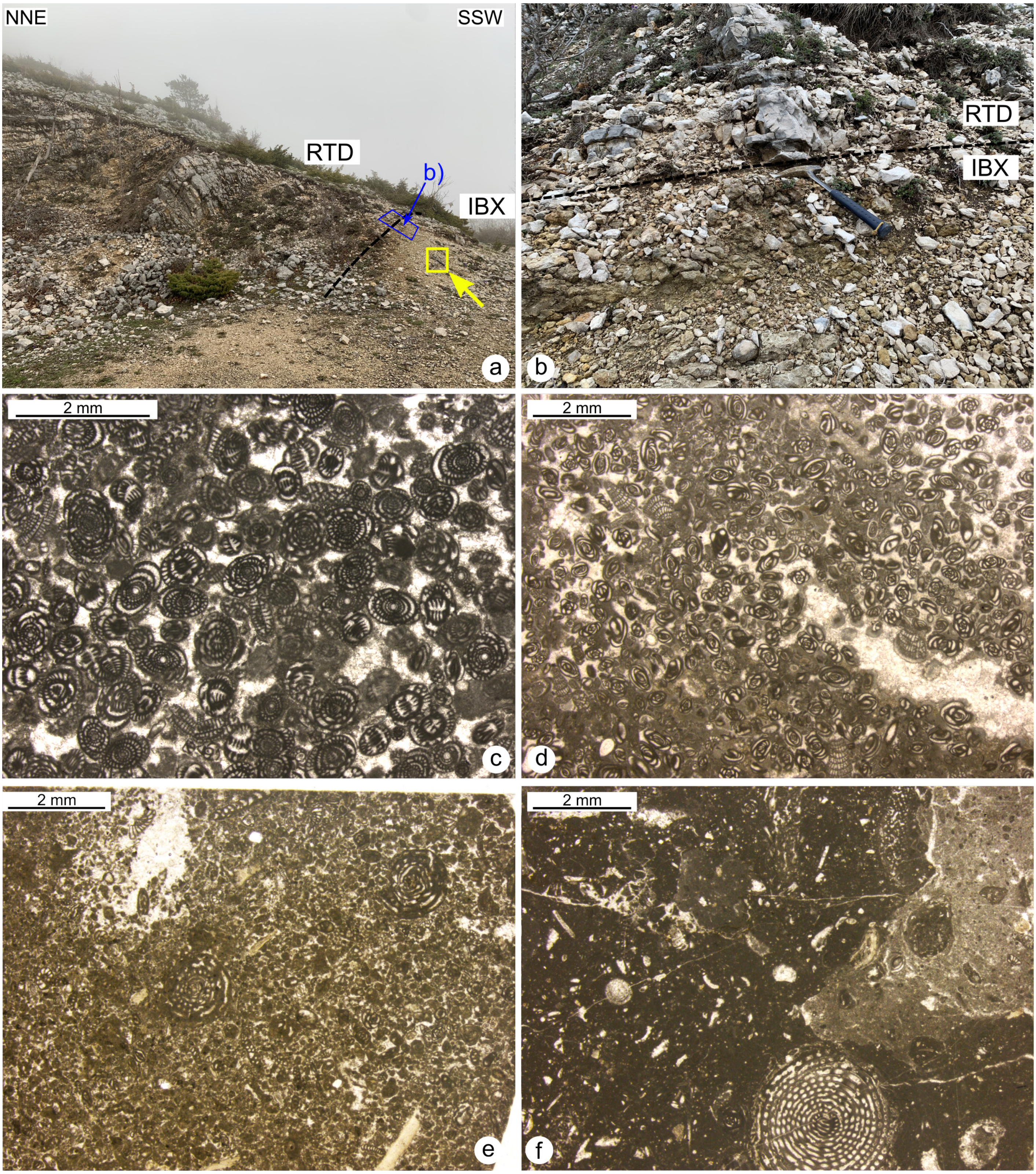

Fig. 11 - a-b) field and c-f) microscopic view of *"calcari intrabauxitici"*; a-b) field aspect of the stratigraphic boundary between *"calcari intrabauxitici"* (IBX) and *"calcari a radiolitidi"* (RDT). The passage is marked by the occurrence of polygenic conglomerates with greenish marly matrix, suddenly overlain by peritidal white limestones. Locality: Roditora, western slopes of Mt. Prato; c) foraminiferal packstone-grainstone with abundant *Sellialveolina viallii* and *Cuneolina* sp.; d) foraminiferal packstone-grainstone rich in small miliolids and *Cuneolina* sp.; e) *Cisalveolina leheneri* packstone, with peloids and small benthic foraminifera, among which nezzazatids; f) bioclastic and foraminiferal packstone-wackestone with *Cisalveolina fraasi* and *Coscinoconus* sp.

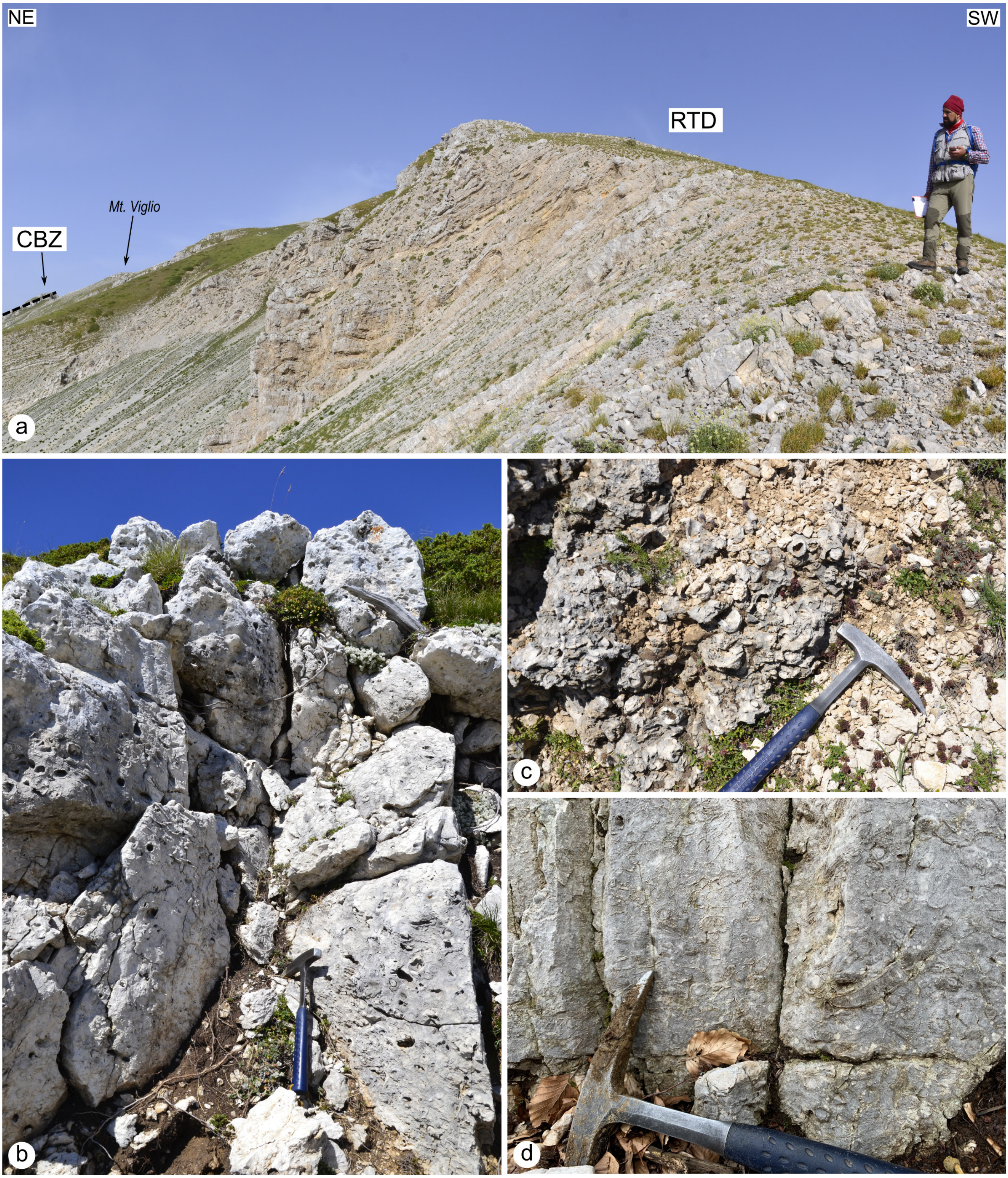

Fig. 12 - a-d) field characters of "*calcari a radiolitidi*"; a) panoramic view of the southern slopes of Mt. Viglio, where the well to thickly bedded limestones of the lower part of "*calcari a radiolitidi*" (RDT) crop out. The boundary with the overlying "*calcari a briozoi e litotamni*" (CBZ) is reported; b-d) rudist-rich biostromes and bouquets cropping out at Mt. Agnello (b-c) and Roditora (d).

of rudists, gastropods, and locally abundant echinoids and hydrozoans. Among microfossils (Tab. 1), benthic foraminifera are very abundant, as well as calcareous algae and *Thaumatoporella parvovesiculifera*. The upper boundary is represented by a sharp contact with CBZ (Fig. 13a), by means of the well-known "Palaeogene hiatus" (Crema, 1921; Parotto and Praturlon, 1975). Such unconformity truncates the RDT at different stratigraphic levels. The depositional environment is referable to an inner carbonate platform characterised by bioclastic sand bars, tidal flats and channels. The thickness is variable, up to 700 m.

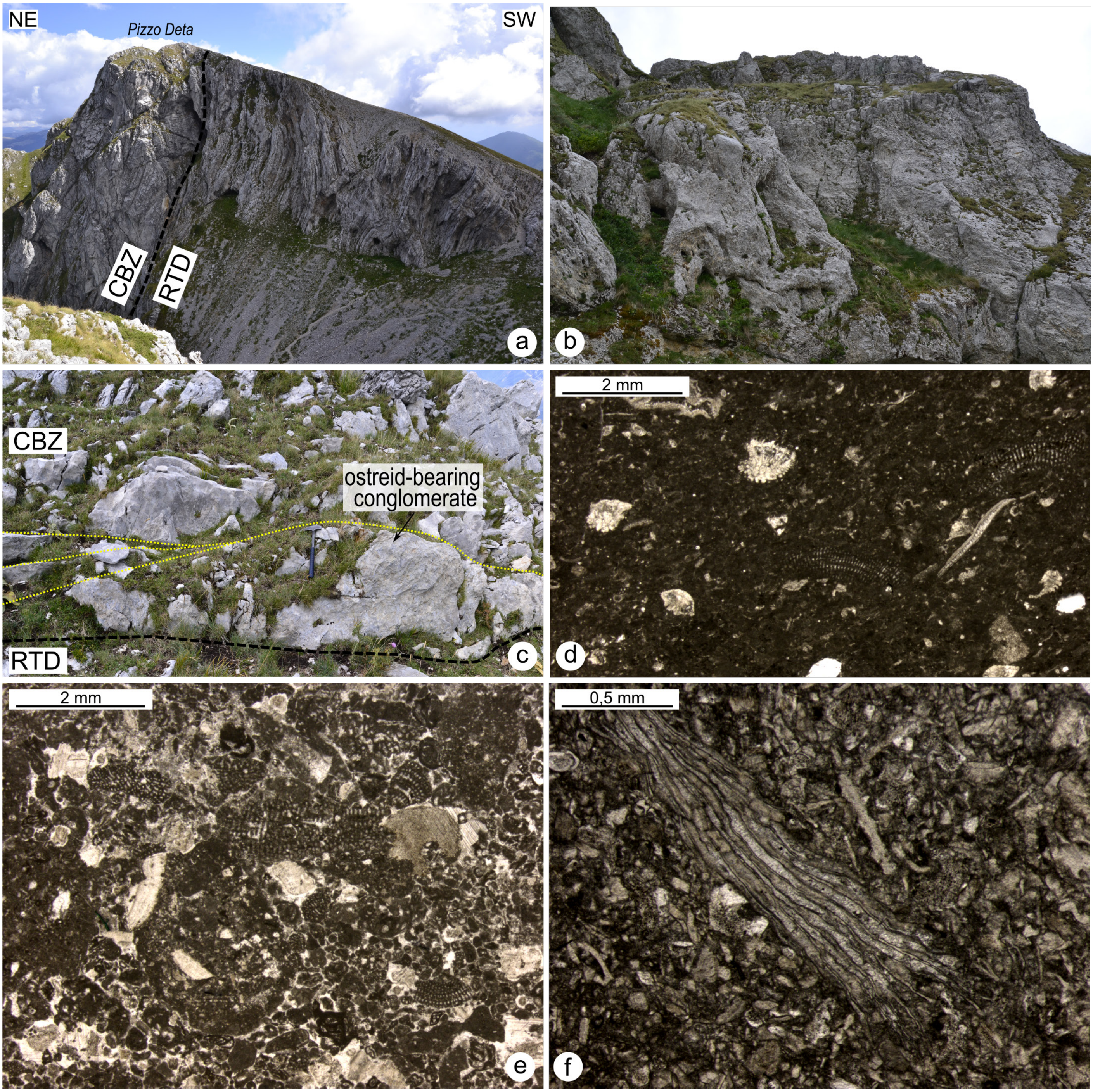

Fig. 13 - a) panoramic of the west-facing slopes of Pizzo Deta, where the stratigraphic boundary between "*calcari a radiolitidi*" (RDT) and "*calcari a briozoi e litotamni*" (CBZ) is spectacularly exposed; b) field view of the massively bedded limestones of "*calcari a briozoi e litotamni*", exposed at Mt. Viglio; c) litho-bioclastic conglomerates at the base of "*calcari a briozoi e litotamni*" exposed on the southern slopes of Pizzo Deta. Note the mound-shaped geometry of the ostreid build-ups; d-e) microfacies of the RTD; d) foraminiferal wackestone (calcimicrobial facies) with rotaliids (*Rotalispira maxima, Rotorbinella lepina*) *Rotorbinella* sp. and *Dicyclina* sp.; e) bioclastic packstone with abundant *Dicyclina* sp. and echinoderm fragments; f) bioclastic packstone of CBZ, with a large bryozoan fragment.

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"calcari a briozoi e litotamni" ("bryozoan and *Lithothamnion* limestone") (**CBZ** - ?Aquitanian-?Serravallian)

The younger outcropping carbonate unit is exposed in small portions of the mapped area (crest of the Cantari-Mt. Viglio, neighbours of Pietra Acquara, Pizzo Deta – Figs. 2, 13). CBZ consists of massively bedded limestones, white or greenish in colour (Fig. 13a). Bioclastic grainstones and packstones, and subordinate bryozoan floatstones, are the main textures (Fig. 13f). Bioclasts are represented by benthic foraminifera (Tab. 1) and bryozoan fragments, as well as fragments of bivalves, echinoderms and red algae. Occasionally, rare planktonic foraminifera may occur. At Pizzo Deta, the base of CBZ coincides with patches of polygenic conglomerates, up to 1 m in thickness, bearing well-sorted and rounded lithoclasts of carbonate units lacking within the local succession (Fig. 13c). These conglomerates are associated with a few decimetres of lensoid ostreid build-ups; bivalves are, in some cases, in life position. The top of the unit is not exposed in the study area, as the CBZ is cut by an erosional surface, covered by clastic units (RNG, PTY). The depositional environment can be referred to as a gently dipping carbonate ramp. Thickness cannot be determined but exceeds 50 metres.

Neogene clastic succession

During the development of the Apennine orogeny, clastic units were produced by the dismantling of tectonically exhumed older units, in different contexts.

"brecce della Renga" ("Renga breccias") (**RNG** – lower Tortonian–lower Messinian)

This unit occurs in two small outcrops in the neighbouring area of Mt. Prato-Mt. Ginepro (Fig. 14). In the study area, RNG consists of heterometric breccias composed of angular carbonate clasts ripped off from the Mesozoic-Cenozoic local succession, clasts size ranges from sand to boulder (Fig. 14b). The breccia is well cemented, organised in metric massive beds, with subordinate laminated arenites. The breccia was produced through the dismantling of pre-orogenic fault escarpments (Compagnoni et al., 2005; Fabbi and Rossi, 2014), by rock-fall or grain flow processes.

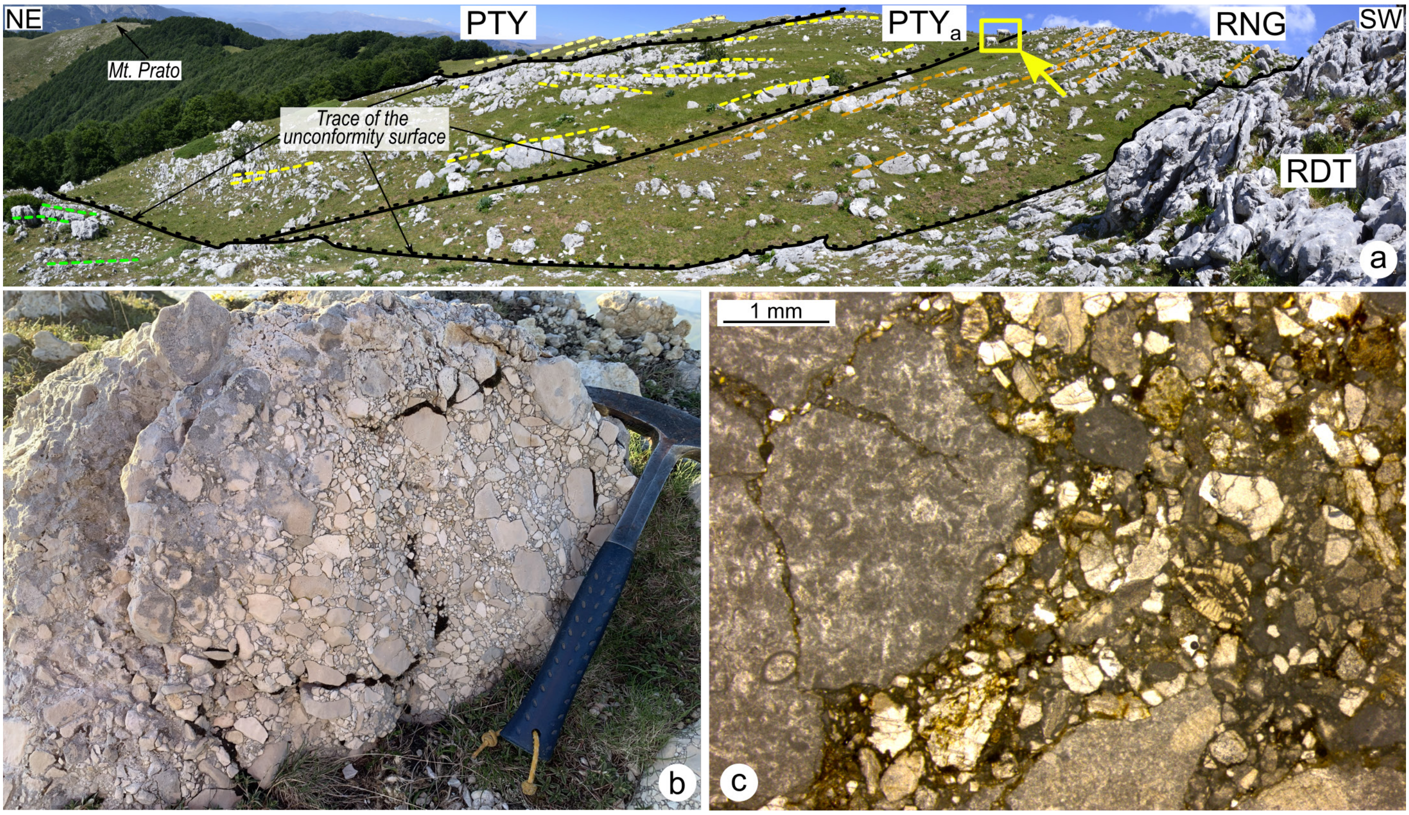

Fig. 14 - a-b) field and c) microscopic view of "*brecce della Renga*"; a) panoramic view of La Lota-Mt. Prato crest and slopes, where the unconformable relationships between "*calcari a radiolitidi*" (RDT) and "*brecce della Renga*" (RNG) are clear. Furthermore, both the units are overlain by the *"conglomerati di Monte Prato"* (PTY) and its carbonate-clastic lithofacies (PTY_a) *via* an erosional surface. Note the pinch-out geometry towards NE of RNG. Arrow indicates cows for scale; b) lithoclastic breccia dominated by polygenic, sub-angular and poorly sorted carbonate pebbles. The matrix is represented by fine-grained (sand size) carbonate particles, subordinately silts and clays, whereas the cement is calcitic; c) unsorted lithoclastic rudstone; note the foraminifer *Elphidium* sp. within the finer fraction.

RNG lays on the Cretaceous to Miocene carbonates through an erosional surface (Fig. 14a), whereas the upper boundary is represented by a further erosional surface, unconformably covered by the PTY and/or continental Quaternary deposits. The reported age (see above) derives from literature data (Fabbi and Rossi, 2014). The total observed thickness is about 30 m. In its type-locality, few km northwest of the study area, RNG is up to 400 m thick and displays a wide array of sedimentological and stratigraphic features (Devoto, 1967b; Compagnoni et al., 2005; Fabbi et al., 2014; Fabbi and Rossi, 2014).

"conglomerati di Monte Prato" ("Mt. Prato conglomerates") (PTY – upper Messinian–?Zanclean)

This peculiar unit corresponds to the "*puddinghe poligeniche con clasti estranei alla serie locale*" described by Devoto (1967; 1970) and to the "*puddinghe poligeniche del versante destro della Valle Roveto*" by Cavinato et al. (2012). It crops out along the slopes of Mt. Prato and in the Fonte della Moscosa-Serra S. Antonio area (northern slopes of Mt. Viglio) (Figs. 2, 14a , 15). PTY unconformably covers several units of the pre-orogenic succession (Figs. 14a, 15a) and consists of heterometric conglomerates (with clasts ranging from sand to cobble in size) and interbedded hybrid arenites (Fig. 15b-d). The clasts are sub-angular to rounded, generally well-sorted and locally imbricated, mostly made up of carbonates and sandstones sourced from the local succession. Noteworthy, subordinate exotic clasts most likely sourced from distant domains (with some affinities with the "Tuscan" succession, although the actual provenance area is unknown), such as "*pietra paesina*", radiolarian chert, pelagic carbonates, metamorphic (gneiss) and igneous (granitoids and rhyolitic) rocks, occur. The matrix is a yellowish hybrid sandstone. The conglomerates are generally well cemented and organised in tabular and lenticular bodies, whose thickness ranges from 50 to 200 centimetres. Crossed laminations/stratification and foresets are the most common sedimentary structures observed throughout (Fig. 15c-d). In PTY, a "**carbonate-clastic lithofacies**" (**PTY_a**) was recognised and mapped at Mt. Prato (Fig. 14a), consisting of unsorted heterometric breccias made up of angular clasts sourced by the local Cretaceous-Miocene carbonate units (Fig. 15f). PTY_a form clinobeds more than 1 m-thick produced by rock-fall and debris-flow processes and likely fed by a steep rugged topography affected by intense erosional processes. At Serra S. Antonio, clayey-silty and arenitic intervals are interspersed in the rudites of PTY. Such deposits were grouped in a second lithofacies ("**pelitic lithofacies**" – **PTY_b**), which contains freshwater gastropods, ostracods and plant remains. The upper boundary of PTY is placed at the unconformity with the continental Quaternary deposits.

The depositional system of PTY is referable to a complex array of coastal, fluvial-deltaic or marshy environments. The late Messinian–?Zanclean age is derived from the literature (Cipollari and Cosentino, 1999; Cosentino and Cipollari, 2012). The total thickness ranges from a few tens of metres to more than 350 metres.

Pliocene-Quaternary continental deposits

The Pliocene-Quaternary continental deposits lay above unconformity surfaces, and are grouped into *unconformity-bounded stratigraphic units* (UBSUs); when possible, they are referred to previously defined UBSUs.
A first subdivision is made based on the hydrographic basin to which each unit could be referred, i.e. Tiber/Aniene and Liri/Sacco rivers basins.

Tiber and Aniene Basin

Two synthems characterise the Tiber/Aniene basin: the *sintema della Val Granara* and the *sintema Fiume Tevere*.

"sintema della Val Granara" ("Val Granara synthem") (**VGR** - ?Lower-?Middle Pleistocene)

This synthem characterises the Val Granara area, upslope of Filettino village (Fig. 2). The deposits belonging to VGR are bounded at the base by an erosional surface carved in the Mesozoic carbonates. Within the VGR, two subsynthems were identified: I) the "***subsintema di Vaglie***" ("Vaglie subsynthem") (**VGR_1**) characterises the left slopes of the Val Granara, southeast of Colle Albaneti between 1125 and 1550 m a.s.l. (Fig. 2). It consists of calcareous breccias, often oxidised, organised in 25 to 100 cm-thick lensoid or tabular beds (Fig. 16a, b). Clasts derive from the dismantling of the pre-orogenic carbonate substrate of Val Granara left slopes. Clasts size ranges from millimetres to decimetres (sand to cobble), with scarce to abundant sandy-silty matrix; the cement is carbonatic (Fig. 16b). Due to its intense cementation and to the prevailing carbonate composition, VGR_1 is pervasively karstified (Fig. 16a). Clasts are sometimes imbricated, generally angular or sub-angular, often showing sharp edges. The deposit is faintly graded and referable to debris-flow or grain-flow processes in the context of ancient alluvial fans. VGR_1 forms hanging terraces. The basal unconformity corresponds to the palaeo-Aniene erosional surface, whereas the upper boundary corresponds to the present-day topography. Based on geomorphometric methods, Delchiaro et al. (2021) referred these deposits to the Lower Pleistocene (between 1,85±0,4 and 0,76±0,2 Ma). Maximum thickness exceeds 100 metres. II) The "***subsintema di Pezze della Macchia***" ("Pezze della Macchia subsynthem") (**VGR_2**) characterises the bottom of the Val Granara, throughout a SW-NE elongated belt.

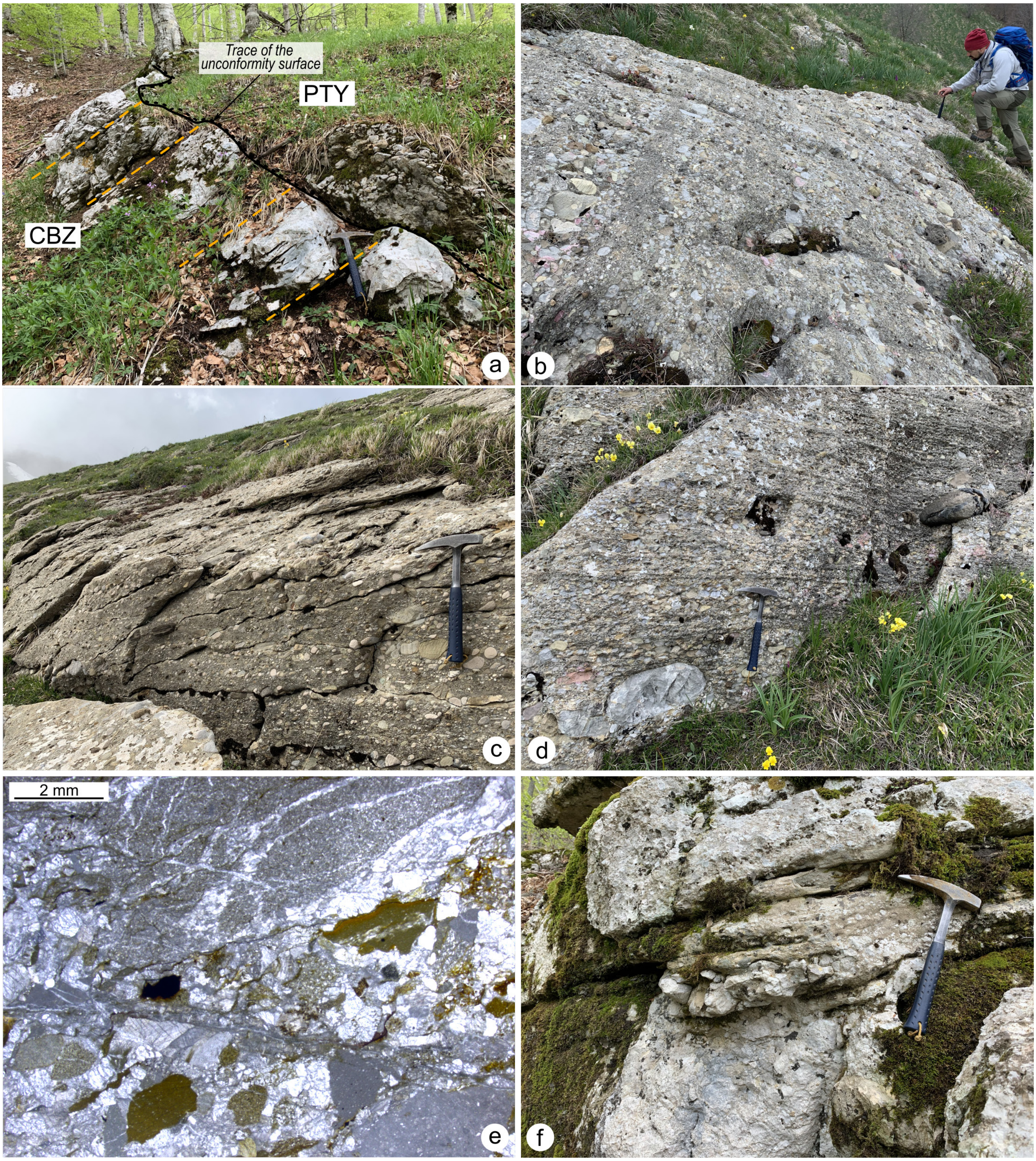

Fig. 15 - a-d, f) field and e) microscopic view of "*conglomerati di Monte Prato*"; a) unconformity between "*calcari a briozoi e litotamni*" (CBZ) and "*conglomerati di Monte Prato*" (PTY) cropping out at Pietra Acquara; b-d) typical features of the "*conglomerati di Monte Prato*", spectacularly exposed at Prato Rosso and and Mt. Prato. Note the clinostratification of bar foresets in c); e) thin section of the "*conglomerati di Monte Prato*", displaying a lithoclastic rudstone texture. Clasts are polygenic and heterometric, and dominated by quartz grains; f) detail of clinobedded breccias referred to the "carbonate-clastic lithofacies" (PTY_a) interposed between the Mesozoic substrate and the onlapping "*conglomerati di Monte Prato*" cropping out on the southern slopes of Mt. Prato.

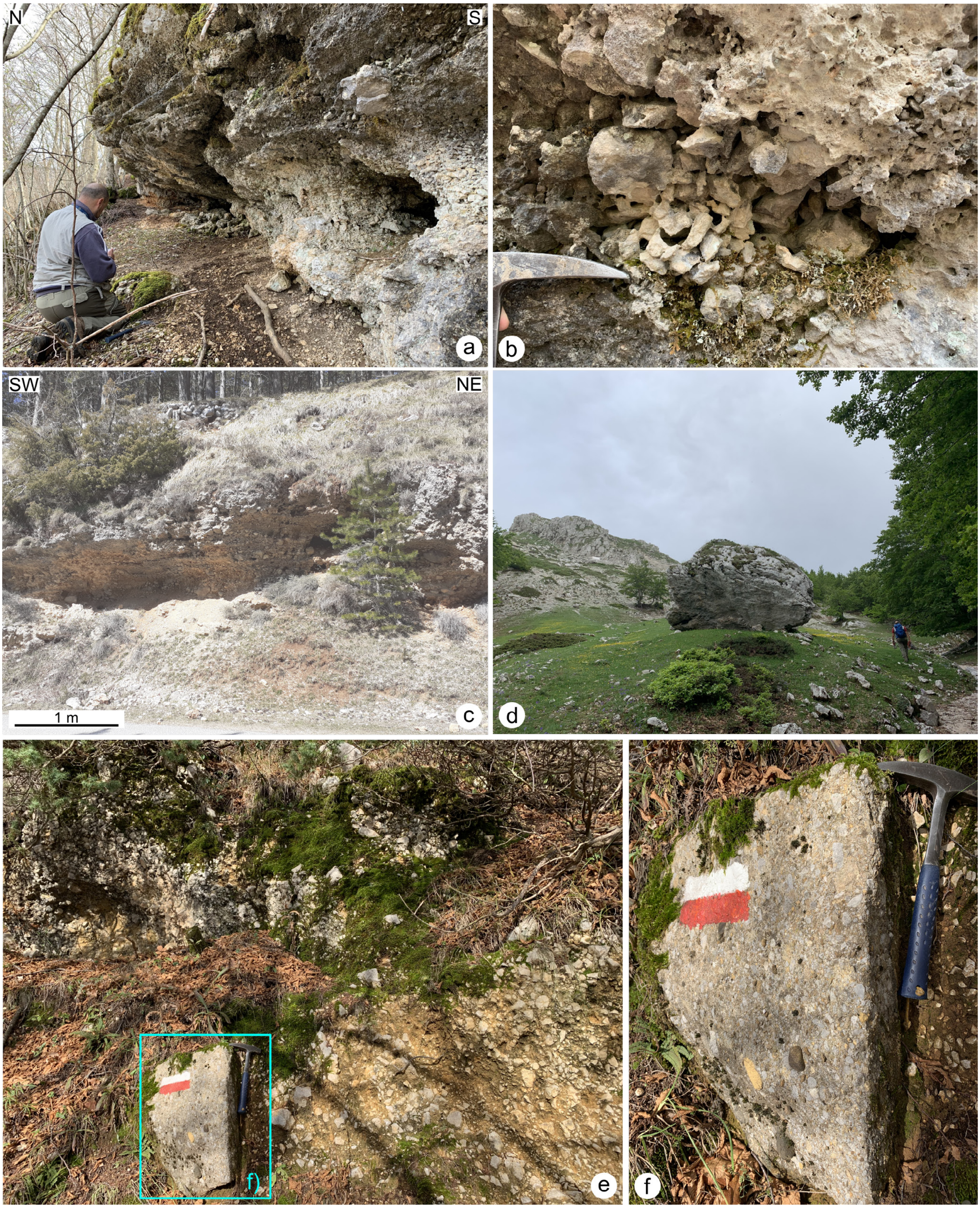

Fig. 16 - a-d) field pictures of the clastic continental deposits referred to the Val Granara and Tiber River synthems whereas e-f) represent the clastic deposits of the *"sintema di Guarcino"*. a) Cm to dm-thick lensoid or tabular beds of calcareous breccias referred to the "*subsintema di Vaglie*", cropping out at Fosso della Rendinara (western slopes of Mt. Viglio); b) detail of the heterometric and sub-angular to angular clasts. Note the dissolution of the carbonate cement bounding the clasts; c) field aspect of the polygenic breccias assigned to "*subsintema di Pezze della Macchia*" and exposed along the road connecting Filettino to Campo Staffi. Note the karst features affecting the clastic deposits; d) plurimetric erratic boulder made of Mesozoic carbonates and related to glacial transport along the Valle del Pozzotello; e) polygenic breccias made of heterometric blocks dispersed in a yellowish sandy matrix, referred to the *"sintema di Guarcino"*; f) enlargement of e) where a detail of the boulder made of "*conglomerati di Monte Prato*" is provided.

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The unit consists of polygenic breccias mainly composed of calcareous clasts coming from the dismembering of the Mesozoic succession outcropping along the Val Granara (Fig. 16c). Differently from VGR_1, VGR_2 bears clasts of the PTY, possibly sourced from the Serra S. Antonio and Fonte della Moscosa outcrops. The breccia is organised in tabular to lensoid layers, with a thickness ranging between 25 centimetres and more than 1 metre. Clasts are from sand to boulder in size, sub-angular to rounded and well sorted. Clasts may occur imbricated and associated with a reddish sand-silt matrix. The whole deposit, usually well lithified by carbonate cement, is commonly carved by karst processes (Fig. 16c). Its deposition can be referred to an alluvial system comparable with (but deeply incised by) the recent one. The basal unconformity is represented by an erosional surface affecting the Mesozoic bedrock whereas the upper boundary is placed at the present-day topography. Based on geomorphometric methods, Delchiaro et al. (2021) referred these deposits to the Middle Pleistocene (post-0,76±0,2 Ma). The thickness exceeds 50 m.

"sintema Fiume Tevere" ("Tiber River synthem") (**SFT** – Upper Pleistocene *p.p.*-Holocene)

This synthem develops above the erosional surface of the last glacial lowstand and includes all the deposits related to the Tiber River basin. It includes the "***subsintema dei Monti Simbruini***" ("Simbruini Mts. subsynthem") (**SFT_1**), which is here introduced and described for the first time. SFT_1 groups all the deposits linked to the glacial systems developed in the Aniene River basin during the last glacial phase (e.g., Jaurand, 1995). The most important deposits related to this subsynthem are represented by disorganised till deposits composed of highly heterometric carbonate and siliciclastic clasts (size ranging from clay to large boulder), referable to moraine systems (**SFT_{1c1}**), with a thickness exceeding 30-40 metres. Locally, matrix-free stacks of plurimetric erratic boulders, most likely linked to glacial transport (**SFT_{1c3}**), occur (Fig. 16d). At Fonte della Moscosa and Pratiglio di Sant'Onofrio, upstream of the moraines, flat morphologies indicate the occurrence of old marsh systems related to sedimentation in small moraine-barrage basins (**SFT_{1e3}**). SFT_1 includes also ancient cemented breccias composed of angular carbonate clasts occurring as scattered outcrops along the mountain slopes, subsequently incised during the Holocene erosive phase (**SFT_{1a3}**). The age of the unit is referred to the Late Pleistocene *p.p.*

Liri and Sacco Basin

Two synthems characterise the Liri/Sacco Basin: the *sintema di Guarcino* and the *sintema di Isoletta*.

"sintema di Guarcino" ("Guarcino synthem") (**GUR** - ?Upper Pliocene)

This synthem characterises the SW corner of the study area (Peschi Ramelli locality), forming a plateau between 900 and 1130 m a.s.l. It consists of polygenic breccias and conglomerates, locally very well cemented, made up of heterometric clasts coming from the erosion of the local Mesozoic-Cenozoic stratigraphic succession (Fig. 16e). Besides carbonate clasts, the unit also bears siliciclastic clasts and PTY boulders (Fig. 16f). Clasts are generally sub-rounded to rounded. The sandy and sandy-silty matrix is generally yellowish. Clastic bodies are characterised by tabular and lenticular geometries, erosional truncations and local sedimentary structures (clinostratification and cross-stratification). The base of GUR is represented by an erosional surface carved on the Mesozoic carbonates; the conglomerates rest above the Upper Cretaceous RDT and the Middle Jurassic UCD at the hanging wall and the footwall of the Guarcino fault, respectively. The unit shows evidence of displacement related to the fault activity. The upper boundary is represented by the present-day surface. The maximum thickness reaches ~100 m. At Collepardo, about 5 km southeast of Peschi Ramelli, lower Villafranchian vertebrate remains (*Agriotherium* sp.; Bellucci et al., 2019) were found within deposits referable to GUR, providing a Late Pliocene age for this unit.

"sintema di Isoletta" ("Isoletta synthem") (**ISL** – Upper Pleistocene *p.p.*-Holocene)

This synthem develops above the erosional surface related to the last glacial lowstand and includes all the deposits of the Liri River basin. It includes the **"*subsintema dei Monti Ernici*"** ("Ernici Mts. subsynthem") (**ISL_1**), here introduced for the first time. ISL_1 groups all the deposits referable to the Sacco River basin and sedimented during the last glacial phase, occurring in the Cosa River valley and at Valle dell'Inferno. The unit includes mixed deposits composed of disorganised heterometric (also plurimetric boulders) angular carbonate clasts with brown sandy-silty matrix, which deposition could be linked to the reworking of glacial deposits by means of debris-flow, alluvial transport, and avalanche processes (**ISL_{1i}**). ISL_1 includes cemented breccias made by angular carbonate clasts, occurring as scattered outcrops along the mountain slopes and incised during the Holocene erosive phase (**ISL_{1a3}**). The maximum thickness of ISL_1 reaches 30 m and is Late Pleistocene in age.

Ubiquitary deposits

All the deposits produced by the active erosional and depositional processes connected to the recent landscape evolution are not synthems but grouped under this informal category. Slope deposits, consisting of loose, mostly carbonate clasts of variable size, are widespread. Thickness ranges from a few metres to more than 50 metres (**a**). Landslide deposits are also common. They are made up of disorganised and chaotic limestone clasts with sizes ranging from sand to megablock. The thickness ranges from a few metres up to more than 50 metres (**a_1**). Rock debris composed of coarse heterometric clasts accumulates along the mountain slopes, occurring as huge stacks at the toe of the steeper slopes. Thickness is up to a few tens of metres (**a_3**). The alluvial deposits occurring within the main stream basins are composed of unsorted gravels; clasts show a variable degree of roundness. The estimated thickness is a few metres (**b**). Eluvial-colluvial deposits composed of silts, clays and calcareous sands are generally located in the most prominent areas as well as into glacial-karst depressions. Along the karstic landscape, the finer fraction forms the typical "*terre rosse*" (e.g., Campocatino and Campovano karst depressions), while colluvial deposits generally have a brown matrix. The thickness ranges from 2 to 10 metres (**b_2**). Finally, debris-flow deposits, consisting of heterometric and chaotic accumulations of carbonate clasts, occur at the toe of gullies cutting through the main slopes in high mountain areas (e.g., Fosso del Renato, in the Cosa River valley – **b_4**).

STRUCTURAL SETTING

In the following sections, the main tectonic phases recognised throughout the study area are summarised into pre-orogenic, orogenic and post-orogenic tectonics.

Pre-orogenic tectonics

Direct and/or indirect evidence of syn-sedimentary tectonics controlling the deposition of the pre-orogenic units are here briefly summarized. The direct ones are represented by syn-sedimentary fault planes, whereas the indirect ones are inferred on stratigraphic data, mostly consisting of abrupt variations in facies and thickness of the syn- and post-tectonic deposits, the occurrence of mass-transport deposits, depositional hiatuses and unconformities. The most important phases observed in the study area are:

1) The Rhaetian-Sinemurian extensional phase, related to the Tethys Ocean rifting (e.g., Santantonio and Carminati, 2011). The main indirect evidence lies in the existence of an intraplatform pelagic basin, testified by the occurrence of COI at Filettino and La Monna (Fig. 2). No Early Jurassic faults or fault-related escarpments were found in the study area, and the stratigraphic relationships with the pre-normal faulting bedrock and coeval shallow-marine deposits exposed at Vallepietra and Collepardo (Cirilli, 1991; Damiani et al., 1991b, 1998; Cavinato et al., 2012) cannot be precisely constrained.
2) A latest Jurassic-Early Cretaceous extensional phase. Indirect evidence are seen through the wide variation in thickness of the CCM, and in particular of the CCG (from 250 m in the Mt. Viglio area to more than 600 m in the Mt. Rotonaria-Mt. Rotondo sector), but direct field constraints of such tectonic phase are obscured by poor outcrop conditions (see paleofaults in cross-section C-C' on the Main Map).
3) An early Aptian tectonic phase. Direct evidence is outlined by synsedimentary normal faults, with metric to decametric displacements, sealed by the marly deposits of CMS (Fig. 17a). The syn-depositional activity of these faults is consistent with the thickness variation of CMS (from 10 to 40 m in the Mt. Vermicano-Fosso del Renato area), and the occurrence of mass-transport deposits into the CMS, such as debrites and slumps.
4) Latest Cretaceous-Paleogene tectonics. The main indirect evidence is represented by the unconformable contact of the Miocene carbonate ramp deposits (CBZ) on a substrate made of Upper Cretaceous rocks of different age. This feature is regionally referred to the formation of rotated fault blocks with differential subsidence (e.g., Centamore et al., 2002; Cosentino et al., 2010).
5) A Late Miocene extensional phase. This is particularly noticeable in the Simbruini-Ernici Ridge, where the *"brecce della Renga"* (RNG) extensively crop out. In the study area the RNG rests through an erosional surface and in angular unconformity, on different Cretaceous and Miocene units (Fig. 17b). Furthermore, the synsedimentary faults mapped at Mt. Viglio responsible of the tectonic contact of Miocene ramp carbonates on Upper Cretaceous rudist-bearing facies, are interpreted as Late Miocene faults rotated by orogenic deformations and, locally, reactivated producing younger-on-older relationships (see also Cavinato et al., 1993 – Fig. 17c).

Orogenic Tectonics

Contractional structures linked with the building of the Apennines fold and thrust belt, such as reverse faults, and folds, are common (Fig. 18). The presence of younger-on-older relationships reflects the control exerted by pre-orogenic tectonics or by the development of out-of-sequence thrusts (e.g., Carminati et al., 2014). Three main tectonic units were identified in the study area (Fig. 19).

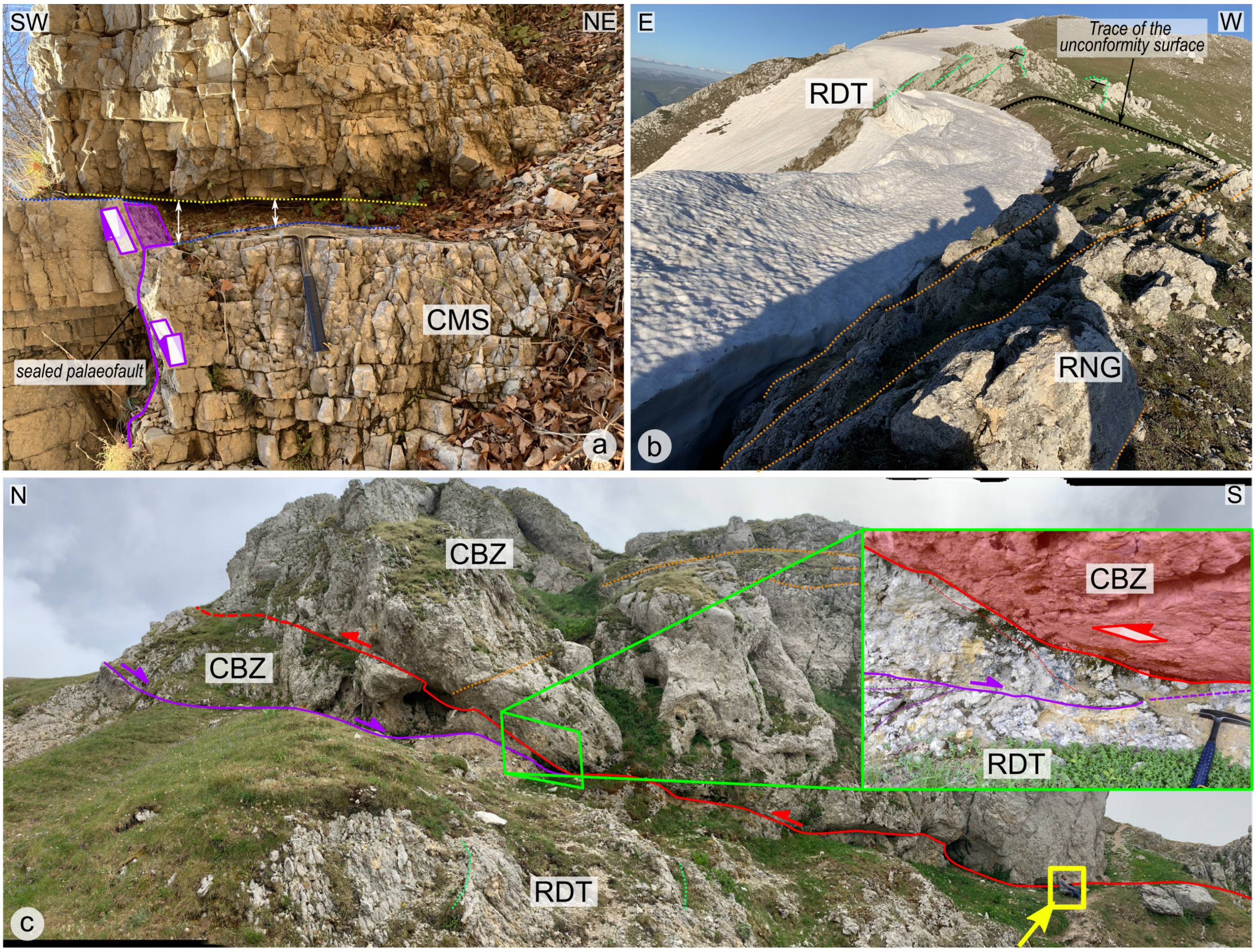

Fig. 17 - Field direct and indirect evidence of pre-orogenic synsedimentary tectonics; a) small scale synsedimentary normal fault affecting the Aptian deposits of "*calcari e marne a carophyta e* Salpinogoporella dinarica*"* (CMS). The fault is sealed by greenish marls showing thickness variations between the footwall and the hanging wall blocks. Locality: Fosso del Renato; b) indirect evidence of the Miocene synsedimentary normal faulting, represented by the high angle unconformity between the Cretaceous "*calcari a radiolitidi*" (RDT) and the Messinian "*brecce della Renga"* (RNG). Locality: northern slopes of Mt. Ginepro; c) Miocene rotated normal fault downthrowing the carbonate ramp deposits of "*calcari a briozoi e litotamni*" (CBZ) at the hanging wall on the "*calcari a radiolitidi*" (RDT) at the footwall. This tectonic structure is mostly overprinted by orogenic deformations, producing "younger-on-older" relationships. Howerer, locally extensional kinematic features are preserved, as shown in the inset. Locality: western slopes of Mt. Viglio. Arrow indicates geologist for scale.

1. Campo Staffi unit

It includes all the outcrops located to the north and at the hanging wall of the "Val Granara line" representing an important NE-SW-trending and NW-dipping fault buried by the Quaternary deposits. Its geometry, inferred on geometric and stratigraphic evidence, seems to have both compressional and dextral (oblique-slip) kinematics, producing a salient of the northern sector of the Simbruini Mts. with respect to the southern footwall block. A small imbricate fan composed of low-displacement and low-angle thrusts is associated to the main fault, and dismembers its hanging wall anticline as it can be observable along the road connecting Serra S. Antonio Pass to Campo Staffi (Fig. 2 for location).

2. Mt. Ortara-Mt. Pratiglio unit

It is the highest structural unit in the study area. It is bounded at the base by a complex compressional structure known in the literature as the "Vallepietra-Filettino-Mt. Ortara line" (VFL) (Devoto and Parotto, 1967; Carminati et al., 2014), which generates younger-on-older relationships between the hanging wall and the footwall blocks.
The nature of the "Vallepietra-Filettino-Mt. Ortara line" was long debated. Devoto and Parotto (1967) defined it as a younger-on-older thrust. Damiani et al. (1998) described it as an extensional structure reactivated during the chain building. Sani et al. (2004) agreed with Devoto and Parotto (1967) and proposed the out-of-sequence activation of

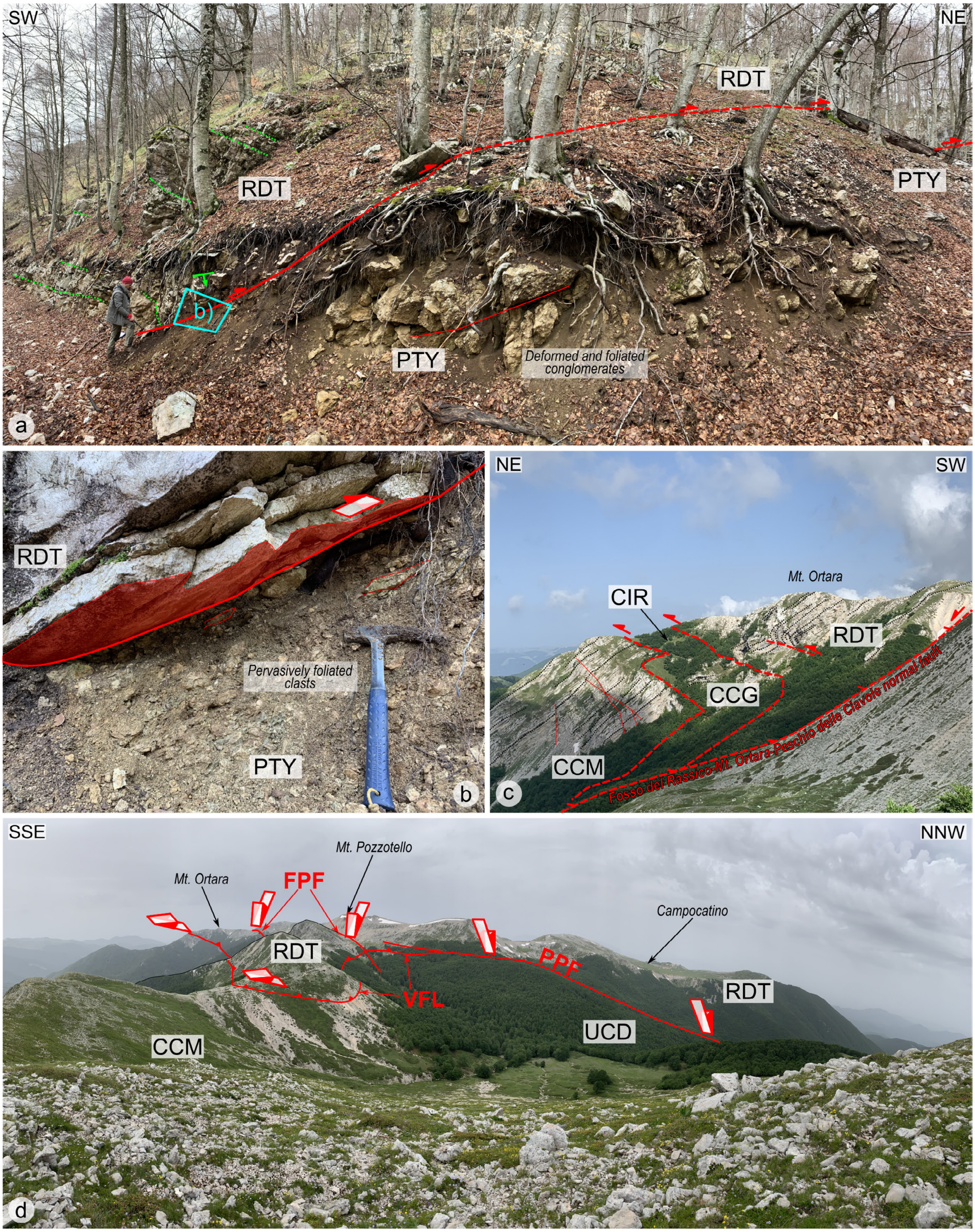

Fig. 18 - Main field evidence of orogenic deformations; a-b) out-of-sequence thrust juxtaposing the Cretaceous limestones of "*calcari a radiolitidi*" (RDT) on the wedge-top deposits of "*conglomerati di Monte Prato*" (PTY). Locality: Valle dell'Orso; b) a detail of the Valle dell'Orso principal slip surface. The clastic facies at the footwall show pervasive foliation and deformation of the particles; c) panoramic view of Mt. Ortara taken from the North-West, where the structural relationships described in the text are highlighted; d) line drawing on a panoramic view of the Campocatino-Mt. Ortara sector taken from the southern slopes of Mt. Crepacuore. The out-of-sequence "Vallepietra-Filettino-Mt. Ortara line" (VFL) is reported, displaced by the post-orogenic *Fosso del Rassico-Mt. Ortara-Peschio delle Cornacchie* (FPF; NE-dipping) and *Pratiglio di S. Onofrio-Peschio delle Ciavole* (PPF; SW-dipping) normal faults.

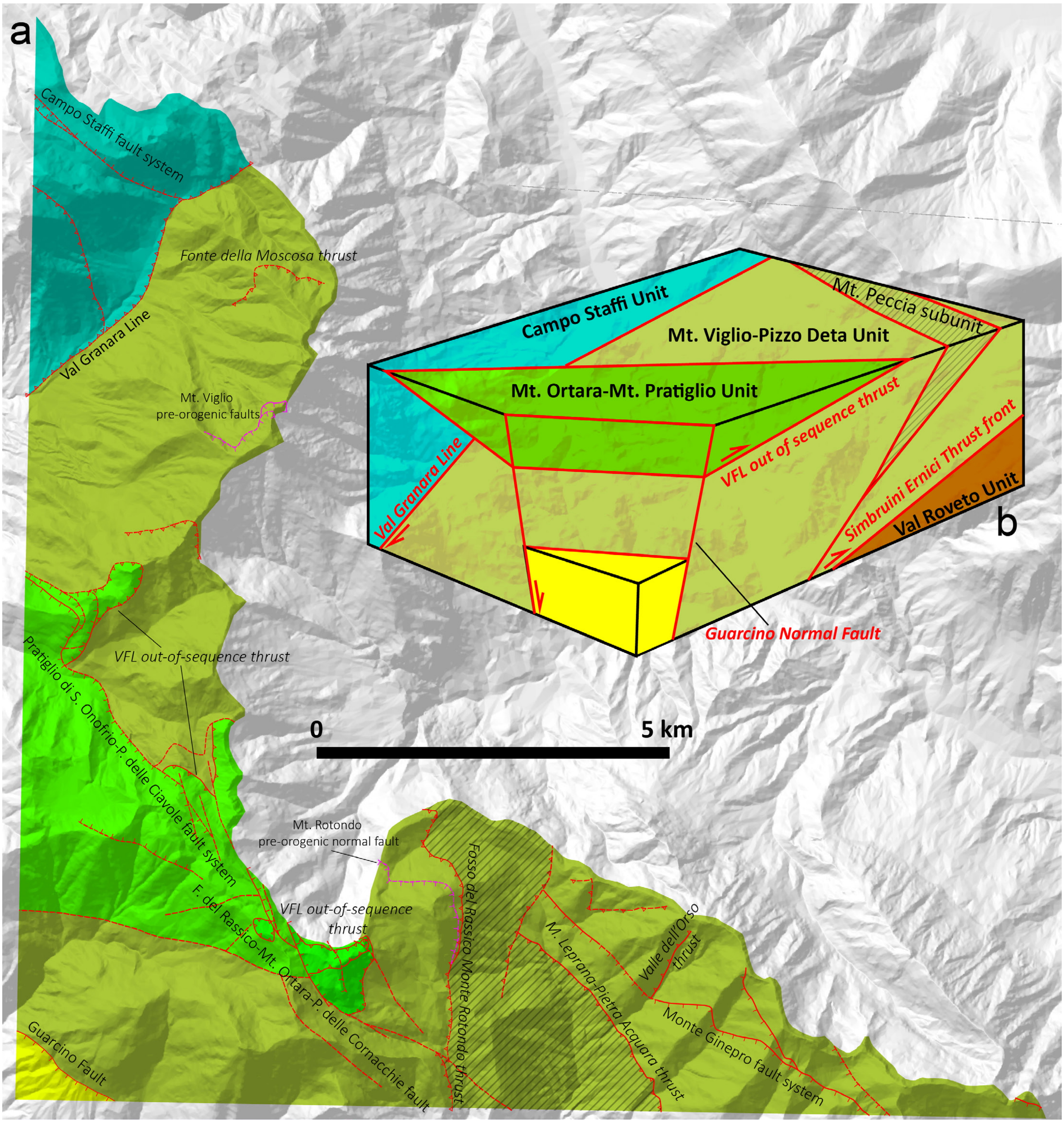

Fig. 19 - a) Sketch map representing the main tectonic units discussed in the text; b) idealised block-diagram representing the relationships between the tectonic units. . Basemap: 10 m - resolution DEM of Italy (Tarquini et al., 2007)

the thrust, as also confirmed by Cavinato et al. (1993) and Carminati et al. (2014). Finally, Calamita et al. (2008) considered it a Miocene pre-orogenic normal fault, inactive during the chain building.

Field characters, such as NE-verging hanging wall anticline, footwall syncline with overturned flank and chevron folds (Fig. 18c-d), suggest that this tectonic structure could be a thrust dissecting an already deformed succession. At Mt. Ortara, the VFL is characterised by 2 splays: at the hanging wall of the upper splay, Campanian deposits occur (Fig. 18c), overthrusting, through a sub-horizontal plane, very deformed Jurassic to Lower Cretaceous units (CCM to CIR), that in turn overthrust a footwall block made of Middle-Upper Jurassic rocks (UCD-CCM). To build such a complex structure, two or more pre-orogenic normal faults, dissecting the substrate before thrusting, are needed.

A similar situation was observed at Serra Rossa (Mt. Pratiglio-Pratiglio di S. Onofrio area – cross section C-C' in the Main Map). Here, two splays of the VFL occur, that produce the juxtaposition of Cenomanian-Campanian deposits (IBX and RDT) on Lower Cretaceous facies (CCG and CMS/CIR), with thrusts that were later displaced by extensional post-orogenic faults.

3. Mt. Viglio-Pizzo Deta unit

This is the widest tectonic unit of the study area, bounded upwards by the "Valle Granara line", by the VFL out-of-sequence thrust and by the Guarcino normal fault. It is bounded at its base by a thrust system exposed in the Val Roveto, out of the study area (e.g., Cavinato et al., 2012). Overall, this tectonic unit consists of a N/NE-dipping monocline made up of the whole Mesozoic-Cenozoic succession, internally deformed and dissected by secondary faults. One of these faults is the Fosso del Rassico-M. Rotondo thrust, a SSW-dipping low-angle thrust that causes the juxtaposition of Middle Jurassic carbonates (UCD/CCM boundary) on Lower Cretaceous ones (CCM/CCG boundary). This fault is accompanied by a hm-scale footwall syncline with an overturned western flank (see the geological cross section E-E' on the Main Map). The footwall of the Fosso del Rassico-Mt. Rotondo thrust is, in turn, dissected by the Monna Leprana-Pietra Acquara reverse fault, which in its southern portion has an NW-SE strike, but near the Pietra Acquara hut, it rotates of about 80° acquiring a NE-SW trend. Such a sudden trend variation suggests the development of a right lateral ramp that produces a salient in the northern sectors (La Cimetta-Mt. Ferrera). Therefore, in the area between Fosso del Rassico-Mt. Rotondo and Monna Leprana-Pietra Acquara thrusts, a tectonic sub-unit (so-called Mt. Peccia sub-unit) can be distinguished, represented by an extremely deformed uppermost Jurassic-Lower Cretaceous succession displaying decametric chevron folds.
Evidence of out-of-sequence compressional tectonics is seen on the western slopes of Mt. Prato-Mt. Ginepro and, in particular, at Fosso Marchetta-Valle dell'Orso, Pietra Acquara, and at Fonte della Moscosa (Fig. 2). Here, SW-dipping thrusts produce the overlap of Mesozoic-Cenozoic carbonates onto the uppermost Miocene-?Pliocene clastic deposits of PTY (Fig. 18a, b).

Post-orogenic tectonics

The Simbruini-Ernici Ridge shows relevant evidence of latest Pliocene-Quaternary extensional faults, that dissected the orogenic belt, shaping the current morphology, with ridges corresponding to the footwalls and valleys to the hanging walls of major normal faults.

The extensional faults characterising the study area have roughly NW-SE strikes and SW dips ranging between 50° and 70°; subordinate NE-SW oriented normal to strike-slip faults also occur.
In the following section the main extensional features are summarised (Fig. 20).

1. Guarcino fault

The Guarcino fault is a major fault, bordering the Ernici ridge in its southwestern side (from Trevi nel Lazio to Sora moving southeastward – see also Cavinato et al., 1990, 1991). The fault crops out at Peschi Ramelli, with the main plane dipping 45-50° towards SW and grooves suggesting a dip-slip kinematics (Fig. 20a). Fault rocks are represented by cataclasites with high matrix content. The Guarcino fault is marked by an important topographic rupture, related to its wide throw juxtaposing the RDT (Upper Cretaceous) on COI (Lower Jurassic), and to the rheological contrast between the limestones at its footwall, and the local presence of Pliocene conglomerates (GUR) at the hanging wall.

2. Fosso del Rassico-Mt. Ortara-Peschio delle Cornacchie fault system

This consists of a set of faults trending from NNW-SSE to WNW-ESE and dipping towards NE by 60° on average (Fig. 20b). This normal fault system displaces about a hundred metres of the younger-on-older VFL, juxtaposing the Upper Cretaceous RDT (at the hanging wall of the higher splay) on the Upper Jurassic CCM (at the footwall of the thrust). The fault system mostly controls the orientation of the Fosso del Rassico stream and gradually decreases its displacement moving towards both NW and SE.

3. Pratiglio di S. Onofrio-Peschio delle Ciavole fault system

A NW-SE striking and W-SW dipping set of normal faults can be observed through the area between Peschio delle Ciavole and Pratiglio di S. Onofrio (Fig. 2). This fault system displaces of a few hundred metres the hanging wall of the VFL on Middle-Upper Jurassic deposits (UCD). A spectacular exposure of these faults can be found at Fosso S. Onofrio, where a wide cataclastic band is associated to a W-dipping slip surface, showing dip-slip kinematics (Fig. 20c).

4. Mt. Ginepro fault system

The topographically highest portion of the Ernici Mts. is displaced by a SW-dipping fault system, which causes a repetition of the strongly deformed Upper Cretaceous succession. In particular, at Fosso Marchetta (Fig. 2) a main 45° S-dipping fault plane downthrows the hanging

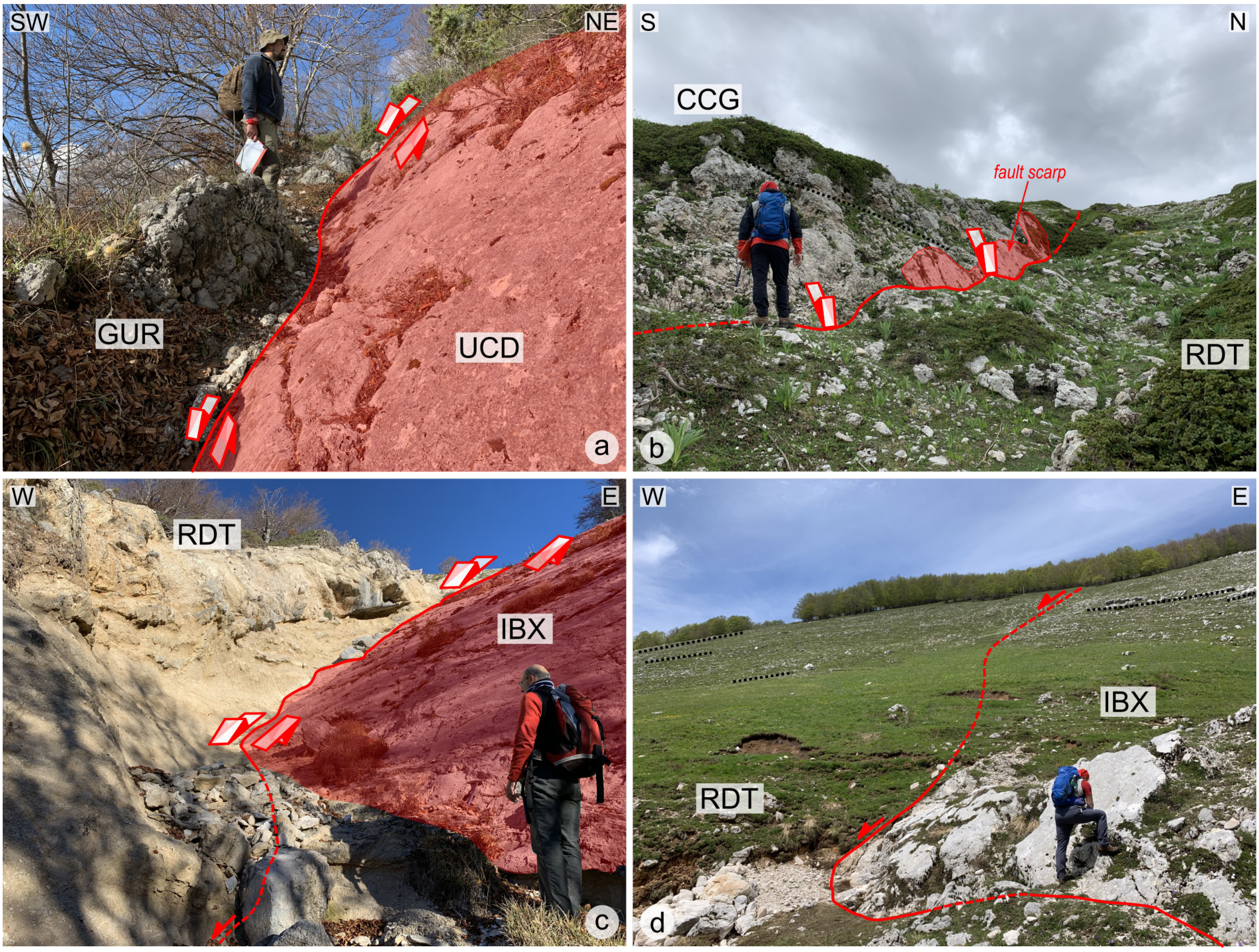

Fig. 20 - Field view of the main normal faults mapped in the study area; a) *Guarcino fault*; b) *Fosso del Rassico-Mt. Ortara-Peschio delle Cornacchie fault* exposed at Iubero dell'Ortara; c) spectacular exposure of the *Pratiglio di S. Onofrio-Peschio delle Ciavole fault system* at Pratiglio di S. Onofrio; d) the Fosso Marchetta outcrop of the *Mt. Ginepro fault system*. Legend: UCD = *"unità calcareo-dolomitica"*; GUR = *"sintema di Guarcino"*; CCG = *"calcari ciclotemici a gasteropodi";* IBX = *"calcari intrabauxitici"*; RDT = *"calcari a radiolitidi"*.

wall of the Fosso Marchetta-Valle dell'Orso out of sequence thrust, which is exposed at the footwall of the same normal fault (Fig. 20d). Such a structure, which seems to produce limited throws (few tens of metres), is associated with a N215° dipping main fault and can be followed on the field for more than 2 km between La Lota and Mt. del Passeggio (Fig. 2).

5. Campo Staffi fault system

This fault system of the Campo Staffi-Val Granara area consists of NE-dipping structures with limited throw, to which are associated antithetic, SW-dipping minor faults. Rare slip surfaces were identified in the field, as these tectonic elements appear generally as large fractured zones. Consequently, these normal faults were principally reconstructed on a stratigraphic basis. Extensional elements cut and displace the imbricate fan of thrusts and folds at the hanging wall of the "Val Granara line".

DISCUSSION AND CONCLUSIONS

The present work has allowed to define the geology of a sector of the central Apennines chain that will be included by ISPRA into the Sheet 377 "Trasacco" of the Geological Map of Italy at 1:50,000 scale.

A remarkable peculiarity the area is related to the occurrence of the Lower Jurassic pelagic deposits of COI, enclosed within a carbonate platform domain. The Latium-Abruzzi Carbonate Platform persisted in shallow-water at least throughout the Jurassic and the Cretaceous surrounded by deeper pelagic basins (Umbria-Marche-Sabina Basin, Mt.

Genzana Basin – Parotto and Praturlon, 1975; Damiani et al., 1991a, b). Relatively narrow intra-platform basins were most likely the remnants of ephemeral pelagic corridors, soon after filled by prograding carbonate platform margins (e.g., Fucino-Sulmona-Pescara valley, Marsican intra-platform basin – Colacicchi, 1964; Centamore et al., 2006, 2009). Due to the common stratigraphic features with these Mesozoic intraplatform basins present elsewhere in the Apennines, we infer the same for the Filettino and La Monna outcrops, here defined as "Filettino-La Monna Basin". The occurrence of breccias and megabreccias of lowermost Jurassic clasts within the pelagic deposits support for the dismantling of a submarine fault scarps. The Sinemurian-Toarcian Filettino-La Monna Basin was laterally confined by shallow-water areas of the "*Calcari a Palaeodasycladus*" cropping out elsewhere (e.g., Vallepietra to the NW, Mt. Rotonaria to the SE - Devoto, 1970; Damiani et al., 1991a, b, 1998). These are capped by a few metres of the Toarcian UOO, representing ooidal shoals of carbonate platform-margins setting. Those were most likely the source of resedimented ooids as carbonate turbidites found within the COI, evolving upwards to oolitic sand bodies, interpreted as prograding platform margins. This progradation evened out the Filettino-La Monna Basin during the Toarcian. A comparable basin-margin evolution is recorded by Middle-Upper Jurassic pelagic-to-shallow water deposits at the northern edge of the Latium-Abruzzi platform (Capotorti and Muraro, 2021).

From the late Toarcian up to the latest Cretaceous, and again in the Miocene, the area persisted under shallow marine conditions, mostly into an inner platform setting. Supratidal and subaerial conditions are recorded by the "*calcari maculati di Vallepietra*" (CLT) during the latest Toarcian-Aalenian, which is widespread in the whole study area and that directly overlies both Sinemurian rift-inherited morpho-structural highs and lows. Due to its field and facies peculiarity, as well as its palaeoenvironmental significance, we have separated CLT from the following UCD in order to propose it as a new potential formation, whose formalisation, however, is beyond the aim of the present contribution.

Peritidal conditions persisted through the rest of the Jurassic and the Early Cretaceous with high-energy peloidal, oolitic and oncolitic grainstones/rudstones associated with massive dolostones.

In the Early Cretaceous, synsedimentary tectonics complicated the physiography of the carbonate platform. This is marked by facies and thickness variation of the Berriasian-Barremian CCG, and by the occurrence of faults and syn-tectonic deposits in the Aptian CMS. Evidence of normal faulting in the late Early Cretaceous is widespread in the peri-Mediterranean area, affecting both carbonate platform (Graziano, 2000, 2001; Centamore et al., 2007, 2009; Santantonio et al., 2013; Picotti et al., 2019; Tavani et al., 2023b) and pelagic domains (Castellarin, 1972; Bertok et al., 2012; Cipriani, 2016; Fabbi et al., 2016; Cipriani and Bottini, 2019a, 2019b). Comparable evidence were produced by the interplay of synsedimentary tectonics and oceanographic changes during the earliest Late Cretaceous (D'Argenio and Mindszenty, 1995; Vlahović et al., 2005; Vitale and Ciarcia, 2021). Tensional deformations in carbonate platform produced i) less-subsident horst-blocks on which thinner palaeokarst- and bauxite-rich successions accumulated; and ii) structural lows with thicker shallow-marine successions. During the Cenomanian, local conditions favoured the development of rudist biostromes, especially in the inner part of the carbonate platform (e.g., Campocatino area), whereas bauxites, or emersion-related facies, formed in supratidal, presumable horst-block, settings.

In the early Aptian and Cenomanian-Turonian, important palaeoecological perturbations, linked to palaeoceanographic changes affecting the carbonate cycle (Steuber et al., 2023), produced a large-scale reassessment of the depositional environments. Shift in oceanic chemistry (mainly observed by C- and O- stratigraphic isotope curves) coincident with changes in trophic resources and sea-water acidification (i.e., Parente et al., 2008) were testified by the proliferation and, subsequent, demise of taxa like the bivalves *Chondrodonta* in the sedimentary record. These can be related to the effects of the oceanic anoxic events of the early Aptian ("Selli Event'" or OAE1a – Erba, 1994; Graziano et al., 2013) and Cenomanian-Turonian (OAE2, represented by the basinal "Bonarelli Level" – Jenkyns, 2010; Bottini and Erba, 2018), respectively pre-dated by the flowering of *C. glabra* and *C. joannae* (Posenato et al., 2018, 2020; Del Viscio et al., 2021). *Chondrodonta* accumulations are therefore proved as a useful field tool for identifying and mapping OAEs-related stratigraphic boundaries (CCG/CMS and IBX/RDT).

The onset of the OAE2 also produced an abrupt drop in diversity of the rich Cenomanian foraminiferal assemblage, which becomes replaced by a microbial-dominated carbonate factory, characterised by oligotypic fauna with no or few larger benthic foraminifera (see e.g., Arriaga et al., 2016), *Thaumatoporella parvovesiculifera* and peloidal bindstones. According to Trecalli et al. (2012), these features can be linked to the restoration of alkalinity after a stress on the carbonate platform, coinciding with abiotic precipitation. During the late Turonian-Campanian time span, the study area was characterised by a rudist-dominated foramol association, typical of an inner platform setting (Carannante et al., 1999; Simone et al., 2003). These are classically composed of alternations of fine-grained foraminiferal wackestones-packstones and oligotypic rudist floatstones.

The Mesozoic-Cenozoic carbonate succession was dismembered during the Late Miocene extensional phase, as testified by the *“brecce della Renga”* in the Simbruini-Ernici Ridge and by the synsedimentary faults mapped at Mt. Viglio. The clastic deposits are the product of the gravity-driven backstepping of steep submarine palaeoescarpments generated by faults that exposed the Mesozoic and Cenozoic carbonates at the footwall blocks (Fabbi and Rossi, 2014; Fabbi et al., 2014).

Since the Messinian, the study area was involved in the orogenic deformations, producing in-sequence and out-of-sequence thrusts. Throughout the Messinian and Early Pliocene, wedge-top basins were characterised by fluvial-deltaic-marshy environments. This is confirmed by the occurrence of thick clastic polygenic deposits of the PTY and coralgal facies found outside the study area (Fabbi and Santantonio, 2019). Such deposits were subsequently involved and deformed by out-of-sequence thrusting.

Since the Late Pliocene, the uplift of the chain caused subaerial exposure and ongoing erosion, which drove the present-day thick successions of Quaternary clastic rocks. The wide array of continental deposits today observable into the study area records several erosional/depositional cycles, controlled by the combined effect of tectonics and climatic oscillations. Particularly important is the effect of Pliocene-Quaternary extensional faults, such as the Guarcino fault which borders the Ernici ridge south-westwards with a mean throw exceeding 1 km.

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