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Geoconservation in Sicily (Italy): the example of Isola delle Femmine (Palermo)

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Geoconservation in Sicily (Italy): the example of Isola delle Femmine (Palermo)

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Abstract

The Regional Administration of Sicily recently erected Isola delle Femmine - a small island of the Tyrrhenian Sea, close to Palermo - as a geosite. A detailed geological survey has been carried out in order to define the most important geological features of the island together with the development of a new geological map based on topographic data and a digital model at 1:2.000 scale specially processed. Finally, a geological pathway through the island has been traced and illustrated. The geological substrate of Isola delle Femmine consists of a Mesozoic carbonate succession belonging to the Panormide Carbonate Platform. Two lithostratigraphic units have been differentiated. The lowest consists of dolomitic limestones cropping out in the intermediate and northern part of the island. Despite the absence of biostratigraphic constrains, analogies with comparable deposits from the Palermo Mountains suggested to ascribe this unit to the Upper Triassic. The overlying unit consists of well-bedded rudist and stromatolitic limestones organized in peritidal cycles. The macro-and micro-facies analysis of these Cretaceous limestones allow to attribute this unit to the Lower Cretaceous (i.e. Aptian). Patches of upper Pleistocene skeletal calcarenites rich in benthic foraminifers and calcareous algae, overlap the Mesozoic units. Spectacular speleothems such as stalagmites, raggiate calcite and mammillary calcite suggest a relative long-lasting exposure of the Mesozoic carbonate substrate to groundwater. This is not surprising since glacio-eustatic oscillations caused sea-level falls up to 125 m during the Pleistocene thus exposing and linking to the mainland (Sicily) Isola delle Femmine and the surrounding area.

Keywords: geosites, geological map, carbonates, speleothems, Cretaceous, Sicily.

Introduction

In Italy, the management of the geological heritage is entrusted to ISPRA (Institute for Environmental Protection). However, several Italian regional administrations developed proper databases concerning the geosites. Since the early nineties of the past century, the Regional Administration of Sicily set as an objective to identify the geological sites of greater value and scientific interest in its territory. Consequently, a Regional Law (L.R. n. 25, 11 April 2012) formalized the "Rules for the recognition, cataloguing and protection of geosites in Sicily" to promote the establishment and management of geosites. The Regional Department for Land and Environment (ARTA Sicilia) has been charged with establishing a Regional Catalogue of Sicilian Geosites, based on the criteria and guidelines for the management and protection of geosites. The data analysis and definition of a single geosite are under the supervision of a Regional Committee on Geosites formed by delegates from the University, the Regional Administration and the Regional Order of Geologists.

As first effect of the Regional Law n. 25/2012, about 80 natural reserves have been erected also as geosites on the base of geological peculiarities already described as natural reserves at the time of their institution. However, in some cases, these geosites lack careful and updated descriptions of the geological peculiarities present in their area.

Taking into account the above considerations, the present contribution aims to describe and highlight the geological aspects of one of the natural reserves erected as a geosite, namely Isola delle Femmine (IdF hereafter), a small island located along the Tyrrhenian coast of Sicily, not so far from Palermo.

Methods

A first step for the description of the geosite has been the achievement of a detailed geological map of Isola delle Femmine. The map was based on an original 1:2,000 topographic map, and a Digital Elevation Model processed thanks to a Trimble R10 GPS instrumentation.

The geological mapping has been integrated by the analysis of bed attitude and the sampling of about 30 selected sites to define lithology and distribution of the outcropping rock successions.

The carbonate facies analysis is based on the classifications proposed by Dunham (1962) and Embry & Klovan (1971) and performed both on the field in respect of the microfacies, and at the Laboratory of Stratigraphic Geology (Department of Earth and Marine Sciences, University of Palermo), where about 20 thin sections have been analysed for microfacies characterization by means of a petrographic microscope Zeiss Laborlux associated to the Zen software for the acquisition of microphotographs.

The biostratigraphic analysis was based on the biozonal schemes proposed for the Cretaceous inner-carbonate platforms of the Western Tethys (Chiocchini et al. 2008 and references therein).

The geosite of Isola delle Femmine

IdF is a small island located about 300 m N of the Tyrrhenian coastline between Capo Gallo and Punta Raisi in northwestern Sicily (Fig. 1). The island, also known “Isola di Fuori” in some geographic maps, gave the name to the Municipality of Isola delle Femmine, located onshore facing the island.

This island has an oval shape (about 580 m long and 325 m wide) with a maximum elevation of 38 m a.s.l. Its topographic profile is asymmetric with a steep northern cliff and a gentle southern slope.

A tower dating back to the sixteenth century and known as *Torre di Fuori* dominates the island's highest point (Fig. 2). This tower was part of a system of watchtowers created by the Florentine architect Camillo Camilliani. All the Camilliani's watchtowers have the same structure with a squared base, few internal divisions and a large tank to collect rainwater. Nowadays, it is possible to observe the northern side of the tower while the southern part is collapsed down (Fig. 2).

In 1997, the Sicilian Region inserted IdF among the protected areas of Sicily (i.e. *Riserva Naturale Orientata Isola delle Femmine*) to safeguard the island as a whole and specifically the geological aspects, the floristic-vegetational heritage and the local entomofauna. This natural reserve is entrusted to LIPU (Italian League for Bird Protection) and extends for about 15 hectares and includes a zone of integral protection comprises the herbaceous and shrubby vegetation typical of the Mediterranean bush that consists of numerous habitats, from the garrigue to the steppe, from the grasslands to the rocky coasts.

In 2002, the marine area between Capo Gallo and Isola delle Femmine was erected as a marine protected area that extends for 2,173 hectares and is subdivided into zones three zones (i.e. A, B, and C) according to different protection levels (Fig. 3). The zone of integral protection (A) is located in the area comprising the north-western and north-eastern sectors of IdF and the western sector of Capo Gallo. The zone of the general reserve (B) surrounds the A zone. Finally, the zone of the partial reserve (C) covers the remaining part within the perimeter of the marine protected area (Fig. 3)

Geological setting

The geological setting of IdF partly reflects the lithologies (mostly carbonates) and the geological structures cropping out in the larger area of the Palermo Mountains. This latter is part of the Apennine-Maghrebian chain and consists of south-verging thrust sheets of Mesozoic and Cenozoic piled up during Miocene times. The Mesozoic and Cenozoic carbonates are overlapped by Plio-Quaternary calcarenites and clays through a deep erosional unconformity (Catalano et al. 1996 and references therein).

The tectonic units cropping out in the northern sector of the Palermo Mountains consist of thick (some thousand meters) successions of shallow-water limestones that were part of a large Mesozoic paleogeographic domain of the south-western Tethys known as Panormide Carbonate Platform (PCP hereafter) (Giunta and Liguori 1972; Catalano and D'Argenio 1982). In this paleogeographic domain, peritidal and reef carbonates were deposited in 190 My ca., from the Late Triassic (Todaro et al. 2017, 2018; Todaro 2019) up to Eocene, though severe extensional tectonic phases affected the PCP during Jurassic (Zarcone and Di Stefano 2008) and Cretaceous times (Randazzo et al. 2020a, b).

Various reconstructions of the PCP have shown its development in a complex geodynamic area located during the Mesozoic between two oceans, the Ionian Tethys to the east and the Alpine Tethys to the west (Stampfli and Borel 2002; Rosenbaum et al. 2004). Despite the influence of long- and short-term sea-level fluctuations and palaeoceanographic perturbations, the repeated phases of uplift and erosion suffered by the PCP seem to be primarily associated with the geodynamic interaction of the two oceanic domains mentioned above (Zarcone and Di Stefano 2008; Capitanio et al. 2009; Zarcone et al. 2010; Frizon de Lamotte et al. 2011; Vitale et al. 2018; Randazzo et al. 2020b).

Based on the major occurrence of peritidal facies, the IdF area has been attributed to a tectonic unit that was part of the inner sector of the Mesozoic PCP. In particular, the presence of Upper Jurassic to Lower Cretaceous shallow-water carbonates was reported in previous contributions and geological maps concerning both the island and the facing coastal area (Bommarito 1982; Catalano et al. 2013). The Mesozoic carbonate succession of IdF was ascribed to a single formation (i.e. Calcari di Capo Gallo) in the recent 1:50.000 geological map (CARG Project, Sheet, 585-594 "Partinico - Mondello").

During the Plio-Pleistocene, the Palermo Mountains and the offshore sector including the IdF were affected by strike-slip and extensional faults related to the evolution of the Tyrrhenian margin (Giunta et al. 2000b; Pepe et al. 2004). In particular, the observed complex fault grid consists of NW-SE and E-W oriented dextral strike-slip faults, and N-S and NE-SW oriented sinistral strike-slip faults (Giunta et al. 2000b).

Lithostratigraphy

Differently from previous studies, the new geological survey of the IdF reveals that the geological substrate of the island consists of two lithostratigraphic units of Mesozoic age (Units A and B respectively) (Fig.4). They are covered by thin levels of Upper Pleistocene calcarenites (Unit C), eluvial-colluvial detrital covers, and landslide deposits (Fig.4).

Unit A - Dolostones and dolomitized limestones

This unit is exposed in the northern and central sector of the IdF and consists of whitish to grey massive dolostones and dolomitized limestones showing in places a brecciated, vacuolar texture (Fig. 5a). The observed lithofacies are crystalline carbonates and the pervasive dolomitization hindered their biostratigraphic characterization and thus the chronostratigraphic attribution. However, some poorly preserved "ghost" structures observed in thin-section may suggest the presence of calcareous sponges and therefore a shallow-water depositional environment. The thickness of the outcropping part of this unit remains undetermined. Analogous deposits are well known in the Palermo Mountains area and, in particular at the base of the Mt. Gallo succession, about 5 Km east of IdF.

Unit B - Grey limestones

Unit B consists of parallel-bedded grey, fossiliferous limestones cropping out in the southern part of the island. The bed attitude is almost constant, dipping 30-35° WNW and the thickness of the outcropping succession is about 200 m. This unit allowed a detailed analysis of the carbonate macro-and-microfacies (see chapter 7). On the base of the fossil content and, in particular, of the rudists, this unit can be subdivided in a lower part (Unit B1) that consists of Requienid limestones, well exposed in the south-eastern corner of the island, and in an upper part (Unit B2) made up by Caprotinid limestones occurring in the western sector of IdF.

Unit C - Pleistocene calcarenites

This unit consists of thin patches of skeletal calcarenites with molluscs, echinoids, benthic foraminifera and reddish algae. It lies in angular unconformity above the Mesozoic units through a subaerial erosional surface associated to dissolution cavities, and it is well exposed in the eastern margin of the island at an elevation of about 7 m a.s.l (Fig. 6a). Cavities and fractures are filled up by reddish to yellowish residual silt. The fossil association suggests an Upper Pleistocene age for this unit that is attributed to the Barcarello synthem (Di Maggio et al. 2009) (Fig. 6b). In particular, these deposits could probably correlate the MIS 5.5 highstand (Antonioli et al. 2006).

Eluvial-colluvial and rockfall deposits

The eluvial-colluvial deposits consist of reddish calcareous siltstones and sands, that show, in places, an early cementation. These deposits extend in the central and eastern part of the island, reaching a thickness of a couple meters. Several patches of dolomitic gravels also occur as result of rock falls, mostly in the northern part of the island. They were already mapped in the regional database of the hydrogeological hazard (Regione Siciliana, 2006).

Tectonic features

Among the tectonic features of IdF, worth of mention is the contact between Unit A and B, that is a low angle fault plane dipping about 15° to SE. This contact is observable both along the eastern and western coast (Fig. 7), while in the inner zone of the IdF it is covered by eluvial-colluvial deposits. The well-bedded grey limestones of Cretaceous age (dipping about 24-35° NW) are abruptly truncated by this fault pane. A similar and peculiar contact is observed at Raffo Rosso, a cliff in the eastern sector of Mount Gallo, not far from IdF. Also, in this locality it is possible to observe a low angle contact between Triassic dolostones and Cretaceous limestones. On the other hand, the occurrence of Low Angle Normal Faults (LANF) along the Apennine-Maghrebian chain is well known (Oldow et al. 1993; Collettini et al. 2006) and often related to the extension of the Tyrrhenian margin along the coast of Sicily (Nigro and Renda 2004)

In addition to the LANF between Unit A and B, two high-angle (50-70°), NNE-SSW oriented faults crosscut Unit A. These faults are related to the extensional-transtensional system that from the Lower Pliocene onward dislocated the thrust system of the Sicilian-Maghrebian chain (Giunta et al. 2000a).

Facies analysis of the Cretaceous limestones

As already mentioned in Chapter 5, unit B can be subdivided in two subunits on the base of the fossil content and the stratigraphic position. The main facies types are listed in Table 1.

Unit B1- Requienid limestones

This subunit crops out in the south-eastern sector of IdF and consists of well-stratified dark-grey limestones showing three main facies types, being: bindstones with *fenestrae* or bird eyes (F1), packstones/wackestones with benthic foraminifers and dasycladacaean algae (F2) and rudstones/floatstones with requienids (F3) (Fig. 8). These facies types are referable to intertidal (F1) and subtidal (F2, F3) environments, thus suggesting that Unit B was deposited in the innermost area of the PCP. F1 and F2 dominate this unit, while the occurrence of F3 is constrained to sporadic levels. The presence of abundant and often disarticulated rudist shells suggests that F3 was related to high-energy events, such as storms, carrying the bioclasts from the margin to the inner sector of the carbonate platform (Fig. 8c). The observed sedimentological features highlight a clear lateral continuity of the IdF succession with that exposed on the facing coast (Nicchitta, 1999). This is confirmed by the comparison between facies and biostratigraphic assemblage of samples collected from the onshore coast (samples N0-N6) and the IdF (samples F0-F7).

The assemblage in both samples mainly consists of benthic foraminifers *Pseudocyclammina* sp. (Fig. 9a), *Trochamminoides cf. coronus* LOEBLICH & TAPPAN, *Vercorsella arenata* ARNAUD VANNEAU (Fig. 9b), *Cuneolina camposaurii* (SARTONI E CRESCENTI), *C. laurentii* (SARTONI E CRESCENTI), *Cribellopsis* sp., *Praechrysalidina infracretacea* LUPERTO SINNI (Fig. 9c and d), *Pseudolituonella* sp., *Quinqueloculina* sp. and dasycladacaean algae *Salpingoporella* sp. (Fig. 9e) and *Salpingoporella dinarica* RADOIČIĆ (Fig. 9f and g). Other shallow-water skeletal grains are echinoids (fragments and spines), ostracods, brachiopods, gastropods and rudists mainly ascribed to the Requienidae. The assemblage shows in the whole good matches with the *Salpingoporella dinarica* taxon range zone by Chiocchini et al. (2008), thus suggesting an early Aptian age for Unit B1. Coeval taxa that are exclusive of backreef setting such as *Mesorbitolina texana* (Roemer) and *Dictyoconus pachymarginalis* Schroeder (Chiocchini et al. 2008) lack in this assemblage. Furthermore, fragments of rudist shells have been observed just in few isolated beds interpreted as storm layers.

Unit B2 - Caprotinid limestones

Unit B2 is exposed in the southwestern sector of IdF and represents the stratigraphic prosecution of Unit B1. The facies observed in Unit B2 are laminated limestones (F1), packstones/wackestones with benthic foraminifers (F2) and skeletal rudstones rich in rudists, mainly caprotinids (F4) and ostreids (F5). As well for Unit B1, F1 and F2 are the most common facies, speaking in favour of an inner platform depositional environment. As suggested by the occurrence of sporadic storm layers (F4, F5), the platform was still subject to high-energy events. Unit B1 and B2 thus share many sedimentological features, though caprotinids dominate the rudist assemblage of Unit B2. Furthermore, the assemblage of Unit B2 (samples F16-F14) also differs from the preceding one as it lacks in calcareous algae (e.g. *Salpingoporella dinarica*). *Vercorsella arenata, Cuneolina camposaurii, C. laurentii*, *Trochamminoides cf. coronus*, *Quinqueloculina* sp., cfr. *Sabaudia* sp. continued from Unit B1, while large benthic foraminifers such as *Haplophragmoides* sp. (Fig. 9h), *Pseudonummoloculina* sp. (Fig. 9i-k) and *Archaealveolina reicheli* (DE CASTRO) (Fig. 9l-n) firstly occur. Echinoids (fragments and spines), ostracods, brachiopods and gastropods complete the assemblage. The peritidal/inner platform depositional setting proposed for this section may be furtherly confirmed by the abundance of *Archaealveolina reicheli*, which seldom occurs in backreef settings (Chiocchini et al. 2008). The observed assemblage is well comparable with the *Archaealveolina reicheli* taxon range zone (Chiocchini et al., 2008) since it records the first occurrence of the index form and the lack of *Salpingoporella dinarica*, thus suggesting a late Aptian age for Unit B2. In the whole this succession is comparable to the lower part of the onshore succession well exposed at Pizzo Muletta, a locality about 4,5 km south of the IdF (Randazzo et al. 2021).

Facies stacking

The facies described in Unit B are organized in aggrading peritidal cycles with an average thickness of about 35 cm (Fig. 10). The dominant facies are laminated limestones (F1) that alternate to foraminiferal and algal limestones (F2) and/or to mollusc rudstones/floatstones (F3, F4, F5) along the whole section. Supratidal facies (e.g. thin levels of green marls) were not observed, though they are common in the onshore succession (Nicchitta 1999). However, in the case of IdF they have been likely obscured by the coastal erosion. The vertical stacking of the different facies appears very irregular, with symmetric and asymmetric cycles displaying either shallowing or deepening trends as already observed onshore in Lower Cretaceous successions (Nicchitta, 1999).

Speleothems

Peculiar calcite/aragonite speleothems are widespread at IdF, both along the coast and in the innermost area of the island both in Unit A and Unit B. They represent one of the most important geological features of the IdF. Besides some stalagmites, either individual (Fig. 11a) or coalescent (Fig. 11 b, organized in organ pipe structures) and flowstones, the most beautiful and widespread speleothems are cm to dm raggiate crystals. Part of these speleothems can be traced to a type of calcite known as mammillary calcite (vein calcite by Winograd et al. 1992). These bulbous bodies (cave clouds) are generally white to yellowish and typically form on the roof of overhanging walls of submerged embedded rock (Fig. 11c, d) under phreatic conditions near the water table.

Other spheroidal calcitic bodies are described as shelfstones (Hill and Forti 1997, p. 96). These globular bodies, which may reach several decimetres, also form at the bottom of pools. The abundant presence of this type of calcite, together with other speleothems such as stalagmites and floatstones, indicates the presence of long-lasting groundwater flowpaths throughout the island. This is not surprising as the glacio-eustatic oscillations caused sea-level falls up to 125 m in the Pleistocene, thus subaerially exposing and linking to the mainland Sicily, IdF and a large surrounding area during the glacial stages. Moreover, besides the karstic dissolution, the groundwater circuits could have been favoured by the extensional tectonics related to the opening of the Tyrrhenian basin that created fracture networks and caves (e.g. Riggs et al. 1994).

Worm reef

Among the geological peculiarities of IdF we consider the "worm trottoir" or "worm reef", an above-water bioconstruction produced by a family of molluscs, which follows the sinuosity of the shoreline by filling shallow cavities.

This bioconstruction is typical of the Mediterranean Sea, in many ways similar to coral reefs, and has been described for the first time as "worm trottoir" by Jean Louis Armand de Quatrefages 1854.

Worm reefs are the product of the building action of two species: the gastropod mollusc vermetid *Dendropoma (Novastoa) petraeum* (Monterosato, 1982) and the encrusting Rhodophycea *Neogoniolithon brassica- florida* (Harvey) (Setchell and Mason 1943).

From the description of the Sicilian reefs and the data present in the literature, it is possible to define a general structure model, along which the different components are distributed, according to a transverse transect from the coast towards the sea (Chemello et al. 1990; Chemello 2009):

(i) a "*proximal frame"*, a few centimetres thick and considered an upper marker of the reef, formed by the encrustations of two rhodophyceous algae, *Neogoniolithon brassica-florida* and *Lithophyllum byssoides*.

an encrustation of *Dendropoma petraeum*, referred to as the "*inner rim*," several centimetres thick and from a few centimetres to less than half a meter wide, depending on exposure to hydrodynamics;

(ii) one or more depressions in the platform, called "*cuvettes"*, with a diameter varying from a few decimetres to over a meter and a depth generally less than 50 cm;

(iii) an "*outer edge"*, consisting of a thick encrustation of *Dendropoma*, sometimes more than 40 cm wide and 50 cm thick, very articulated and fissured, which represents the actual active portion of the platform, expanding outward and upward;

(iv) an "*infralittoral belt"* of *Cystoseira amentaceous* var. *stricta*, placed inferiorly to the outer margin of the platform.

Therefore, a typical worm platform shows an articulated zonation between the lower mesolittoral and upper infralittoral planes (*sensu* Pérès and Picard 1964) and settles only on rocky coasts with increasingly less impressive formations depending on the rock substrate. In decreasing order of importance: calcarenites, limestones, dolomites, basalts and flysch (Chemello 1989; Chemello et al. 1990). However, the presence of an abrasion platform is the fundamental condition for the formation of a worm reef.

The worm reef observed at IdF runs mainly along the east coast and is only a few meters wide (Fig. 12). Components including the inner edge, couvette, and outer edge can be distinguished.

The Geological Track

The "Map of the Geological Peculiarities of the R.N.O. Isola delle Femmine", illustrates a geological track with the observation points of the geological features described above (Fig. 13).

Besides the geologic peculiarities, worth to mention are some anthropic structures as the already described watchtower *Torre di Fuori* and the remains of seven *cocciopesto* tanks, dating back to the Hellenistic period. These tanks were used for the preparation of *garum*, a sought-after fish sauce traded in the Mediterranean. This trace of a plant for fish processing together with the discovery of ancient anchors and remains of Punic and Roman amphorae in the adjacent submerged areas, makes the IdF geosite also important from an archaeological perspective.

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References

Antonioli F, Kershaw S, Renda P, et al (2006) Elevation of the last interglacial highstand in Sicily (Italy): a benchmark of coastal tectonics. Quat Int 145:3–18

Bommarito S (1982) Considerazioni sulla geologia della Tavoletta "Isola delle Femmine"(con carta geologica). Lav Ist di Geol Univ degli Stud di Palermo 1

Capitanio FA, Faccenna C, Funiciello R (2009) The opening of Sirte basin: Result of slab avalanching? Earth Planet Sci Lett 285:210–216

Catalano R, Basilone L, Di Maggio C, et al (2013) Note illustrative della Carta Geologica d'Italia alla scala 1: 50.000 del Foglio 594–585 "Partinico-Mondello." Progett CARG Dip di Geol e Geod Univ di Palermo

Catalano R, D'argenio B (1982) Schema geologico della Sicilia. Guid alla Geol della Sicil Occident 24:9–41

Catalano R, Di Stefano P, Sulli A, Vitale FP (1996) Paleogeography and structure of the central Mediterranean: Sicily and its offshore area. Tectonophysics 260:291–323. https://doi.org/https://doi.org/10.1016/0040-1951(95)00196-4

Chemello R (2009) Le biocostruzioni marine in Mediterraneo. Lo stato delle conoscenze sui reef a vermeti. Biol Mar Mediterr 16:2–18

Chemello R (1989) La bionomia bentonica ed i Molluschi. 5. Il piano Infralitorale: il marciapiede a vermeti. Not SIM 7:167–170

Chemello R, Pandolfo A, Riggio S (1990) Le biocostruzioni a Molluschi Vermetidi nella Sicilia nord-occidentale. In: Atti 53 Congresso UZI

Chiocchini M, Chiocchini RA, Didaskalou P, Potetti M (2008) Micropaleontological and biostratigraphical researches on the Mesozoic of the Latium-Abruzzi carbonate platforms (Central Italy). Memrie Descr della Cart Geol d'Italia 84:223

Collettini C, De Paola N, Holdsworth RE, Barchi MR (2006) The development and behaviour of low-angle normal faults during Cenozoic asymmetric extension in the Northern Apennines, Italy. J Struct Geol 28:333–352

de Quatrefages A (1854) Souvenirs d'un naturaliste. Librairie de Victor Masson

Di Maggio C, Agate M, Contino A, et al (2009) Unità a limiti inconformi utilizzate per la cartografia dei depositi quaternari nei Fogli Carg della Sicilia nord-occidentale. Quat 22:345–364

Frizon de Lamotte D, Raulin C, Mouchot N, et al (2011) The southernmost margin of the Tethys realm during the Mesozoic and Cenozoic: Initial geometry and timing of the inversion processes. Tectonics 30:

Giunta G, Liguori V (1972) Geologia dell'estremità nord-occidentale della Sicilia. Flaccovio

Giunta G, Nigro F, Renda P (2000a) Extensional tectonics during Maghrebides chain building since late Miocene: examples from Northern Sicily. In: Annales Societatis Geologorum Poloniae. pp 81–98

Giunta G, Nigro F, Renda P, Giorgianni A (2000b) The Sicilian-Maghrebides Tyrrhenian margin; a neotectonic evolutionary model. Boll della Soc Geol Ital 119:553–565

Hill C, Forti P (1997) Cave Minerals of the World: National Speleological Society, Huntsville, 463. Hill463Cave Miner World1997

Nicchitta D (1999) Stratigrafia e sedimentologia dei carbonati di piattaforma del Giurassico Superiore–Cretacico nel settore nord-orientale dei Monti di Palermo. PhD Thesis. University of Palermo

Nigro F, Renda P (2004) The contribution of the pre-existing structures in mountain belt evolution; the example

of the negative inversion in northern Sicily. Boll della Soc Geol Ital 123:175–187
Oldow JS, D'Argenio B, Ferranti L, et al (1993) Large-scale longitudinal extension in the southern Apennines contractional belt, Italy. Geology 21:1123–1126
Pepe F, Bertotti G, Cloetingh S (2004) Tectono-stratigraphic modelling of the North Sicily continental margin (southern Tyrrhenian Sea). Tectonophysics 384:257–273
Pérès J-M, Picard J (1964) Nouveau manuel de bionomie benthique de la mer Méditerranée. Station Marine d'Endoume
Randazzo V, Di Stefano P, Schlagintweit F, et al (2021) The migration path of Gondwanian dinosaurs toward Adria: new insights from the Cretaceous of NW Sicily (Italy). Cretac Res 104919
Randazzo V, Di Stefano P, Todaro S, Cacciatore MS (2020a) A Cretaceous carbonate escarpment from Western Sicily (Italy): biostratigraphy and tectono-sedimentary evolution. Cretac Res 110:104423
Randazzo V, Le Goff J, Di Stefano P, et al (2020b) Carbonate slope re- sedimentation in a tectonically- active setting (Western Sicily Cretaceous Escarpment, Italy). Sedimentology 67:2360–2391
Regione Siciliana Assessorato Territorio e Ambiente, Piano Stralcio di Bacino per l'Assetto Idrogeologico (PAI) 2006
Riggs AC, Carr WJ, Kolesar PT, Hoffman RJ (1994) Tectonic speleogenesis of Devils Hole, Nevada, and implications for hydrogeology and the development of long, continuous paleoenvironmental records. Quat Res 42:241–254
Rosenbaum G, Lister GS, Duboz C (2004) The Mesozoic and Cenozoic motion of Adria (central Mediterranean): a review of constraints and limitations. Geodin Acta 17:125–139
Setchell WA, Mason LR (1943) Goniolithon and Neogoniolithon: two genera of crustaceous coralline algae. Proc Natl Acad Sci U S A 29:87
Stampfli GM, Borel GD (2002) A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons. Earth Planet Sci Lett 196:17–33
Todaro S (2019) The Potential Geosite of the B Libeccio Antico ^ Quarries : a Sedimentological and Stratigraphic Characterisation of Ornamental Stone from Mt Cocuccio , Custonaci Marble District , Sicily
Todaro S, Di Stefano P, Zarcone G, Randazzo V (2017) Facies stacking and extinctions across the Triassic–Jurassic boundary in a peritidal succession from western Sicily. Facies 63:1–21
Todaro S, Rigo M, Randazzo V, Di Stefano P (2018) The end-Triassic mass extinction: A new correlation between extinction events and δ13C fluctuations from a Triassic-Jurassic peritidal succession in western Sicily. Sediment Geol 368:105–113. https://doi.org/10.1016/j.sedgeo.2018.03.008
Vitale S, Amore OF, Ciarcia S, et al (2018) Structural, stratigraphic, and petrological clues for a Cretaceous–Paleogene abortive rift in the southern Adria domain (southern Apennines, Italy). Geol J 53:660–681
Winograd IJ, Coplen TB, Landwehr JM, et al (1992) Continuous 500,000-year climate record from vein calcite in Devils Hole, Nevada. Science (80-) 258:255–260
Zarcone G, Di Stefano P (2008) Mesozoic discontinuities in the Panormide Carbonate Platform: Constraints on the palaeogeography of the central Mediterranean. Rend Online Soc Geol Ital 2:191–194
Zarcone G, Petti FM, Cillari A, et al (2010) A possible bridge between Adria and Africa: New palaeobiogeographic and stratigraphic constraints on the Mesozoic palaeogeography of the Central Mediterranean area. Earth-Science Rev 103:154–162. https://doi.org/10.1016/j.earscirev.2010.09.005

Figure captions

Fig.1 a) Location of Isola delle Femmine in a Google Earth satellite view of the Palermo area. b) Aerial view (from south) of IdF (mod. from https://viaggi.corriere.it/).

Fig. 2 Two views of the watchtower *Torre di Fuori* from north (a) and south (b)

Fig. 3 Marine protected area between Capo Gallo and Isola di Fuori (mod. from official cartography of Marine Protected Areas, D.M. 24/07/2002)

Fig. 4 Geological map of IdF

Fig. 5 a) Outcrop view and a b) detail of the whitish limestones

Fig. 6 Unit C, macro (a) and microfacies (b) of the upper Pleistocene calcarenites. a) The lower part of the calcarenites cover an irregular erosional surface on the dolostones of Unit A, filling also some fractures. b) the most common microfacies are skeletal packstone/wakestone rich in red algae, bryozoans and mollusks.

Fig. 7 Tectonic contact between the whitish dolostones of Unit A (left) and the Cretaceous grey limestones (Unit B) along the south eastern margin of IdF. Consider that the parallel bedded grey limestones dips WNW about 35° and are sharply truncated by the low angle fault plane (see geological cross-section in Fig. 4).

Fig. 8 Main facies types from Unit B: a) Laminated limestones (F1) passing upward to foraminiferal and algal limestones (F2); b) Requienid limestones (F3); c) foraminiferal and algal limestones (F2) capped by an Ostreid rud/floatstone (F5, storm layer) and, in turn, by foraminiferal and algal limestones (F2) and Laminated limestones (F1). d) Caprotinid rudstone (F4).

Fig. 9 Microfossil assemblage from Unit B: a) *Pseudocyclammina* sp.; b) *Vercorsella arenata* ARNAUD VANNEAU; c-d) *Praechrysalidina infracretacea* LUPERTO SINNI; e) *Salpingoporella* sp.; f-g) *Salpingoporella dinarica* RADOIČIĆ; h) *Haplophragmoides* sp; i-k) *Pseudonummoloculina* sp.; l-n) *Archaealveolina reicheli* (DE CASTRO).

Fig. 10 Peritidal cycles in Unit B that consist of laminated limestone (F1) and foraminiferal and algal limestones (F2).

Fig. 11 Quaternary speleothems, one of the most peculiar geological aspects of the IdF: a) part of a stalagmite surrounded by flowstones. b) coalescent stalagmites forming organ pipes structures; c) mammillary calcite coating the roof of a cavity in the dolostones of Unit A. d) line drowning of the raggiate crystals forming the mammillary structures in Fig. 11 c.

Fig. 12 Panoramic view of the worm trottoir along the eastern coast of IdF.

Fig. 13 Map of the Geological Peculiarities of the R.N.O. Isola delle Femmine that show the geological track and the position of the most noteworthy geological features.

Table 1 Main facies types differentiated among the Cretaceous grey limestones (Unit B)

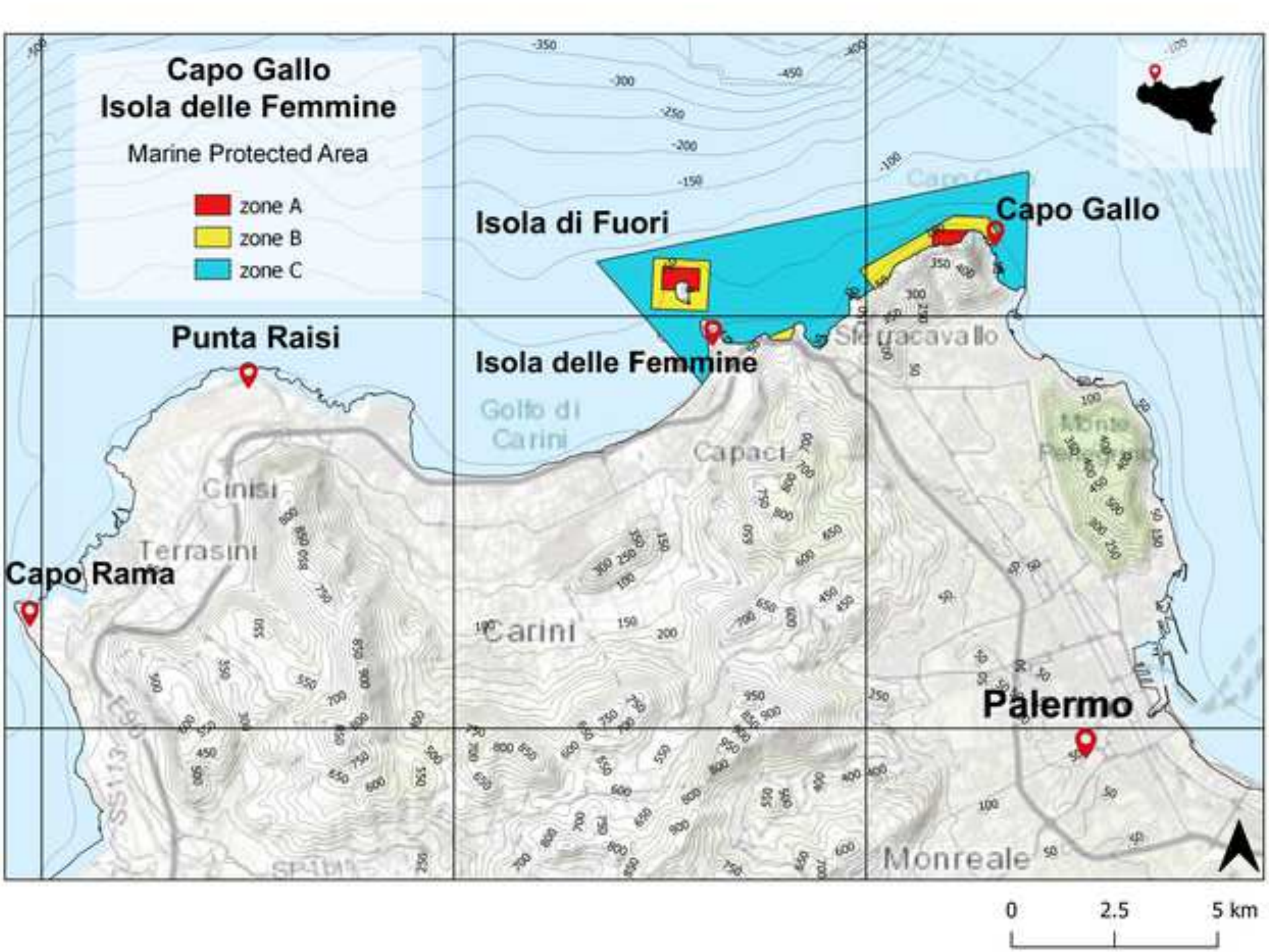
Figure

Click here to access/download;Figure;Fig1.jpg


a
b

Figure

Click here to access/download;Figure;Fig3.jpg



Figure

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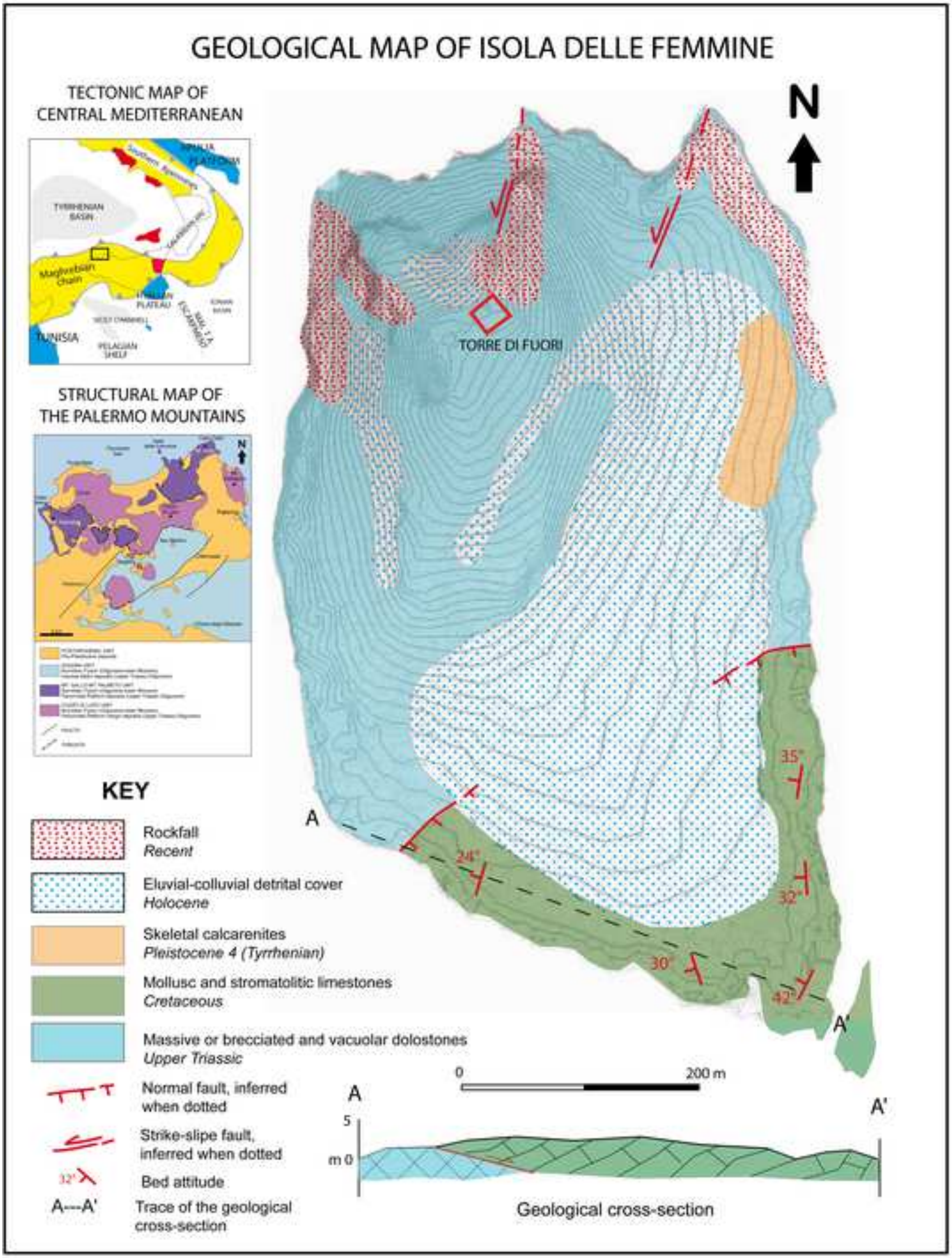

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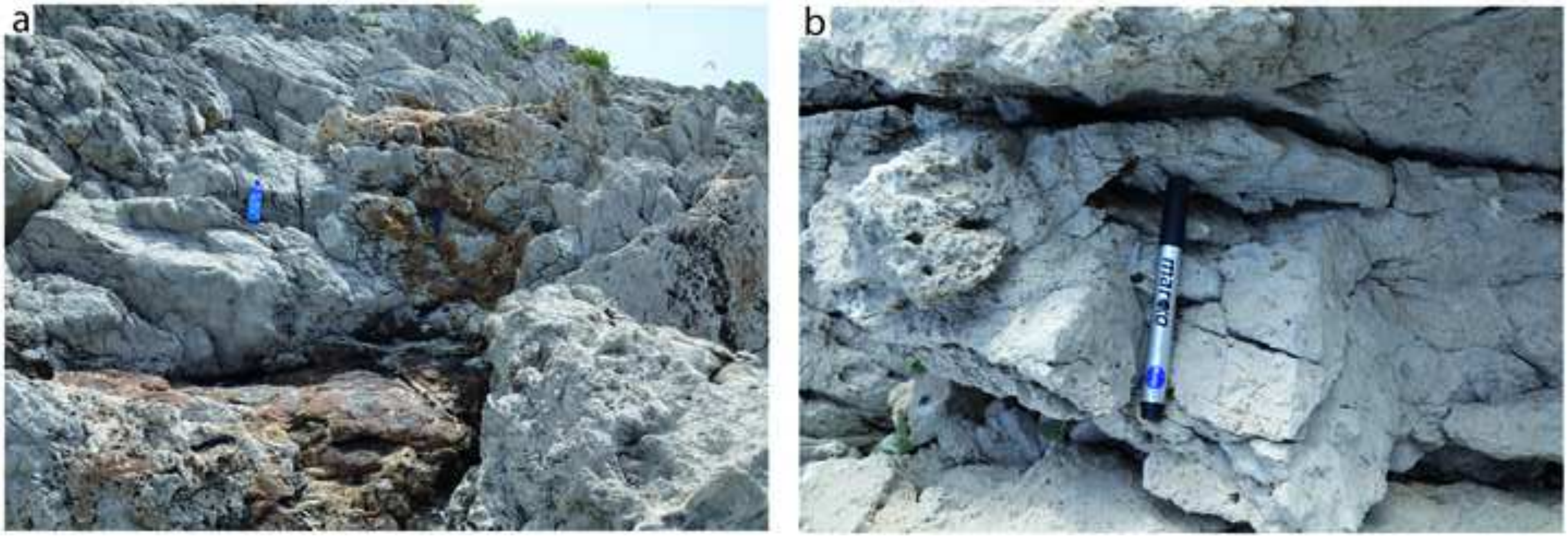

Figure

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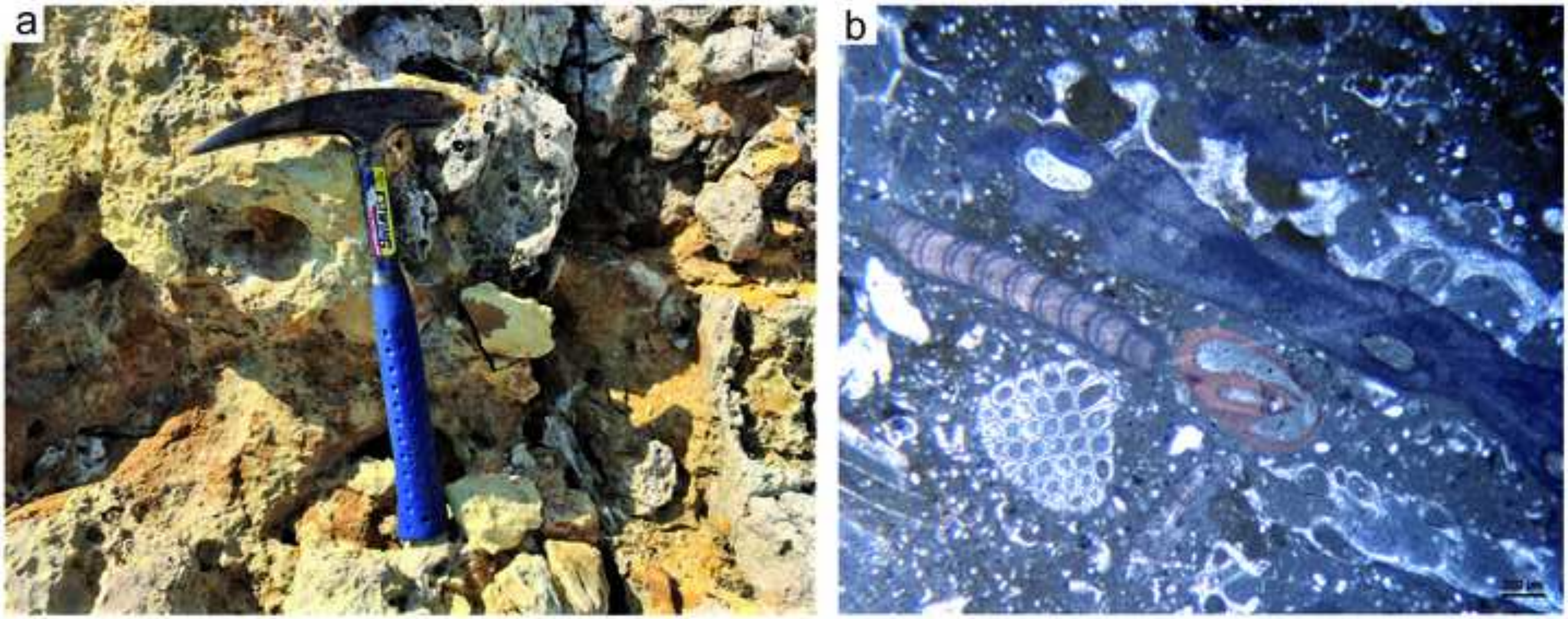

Figure

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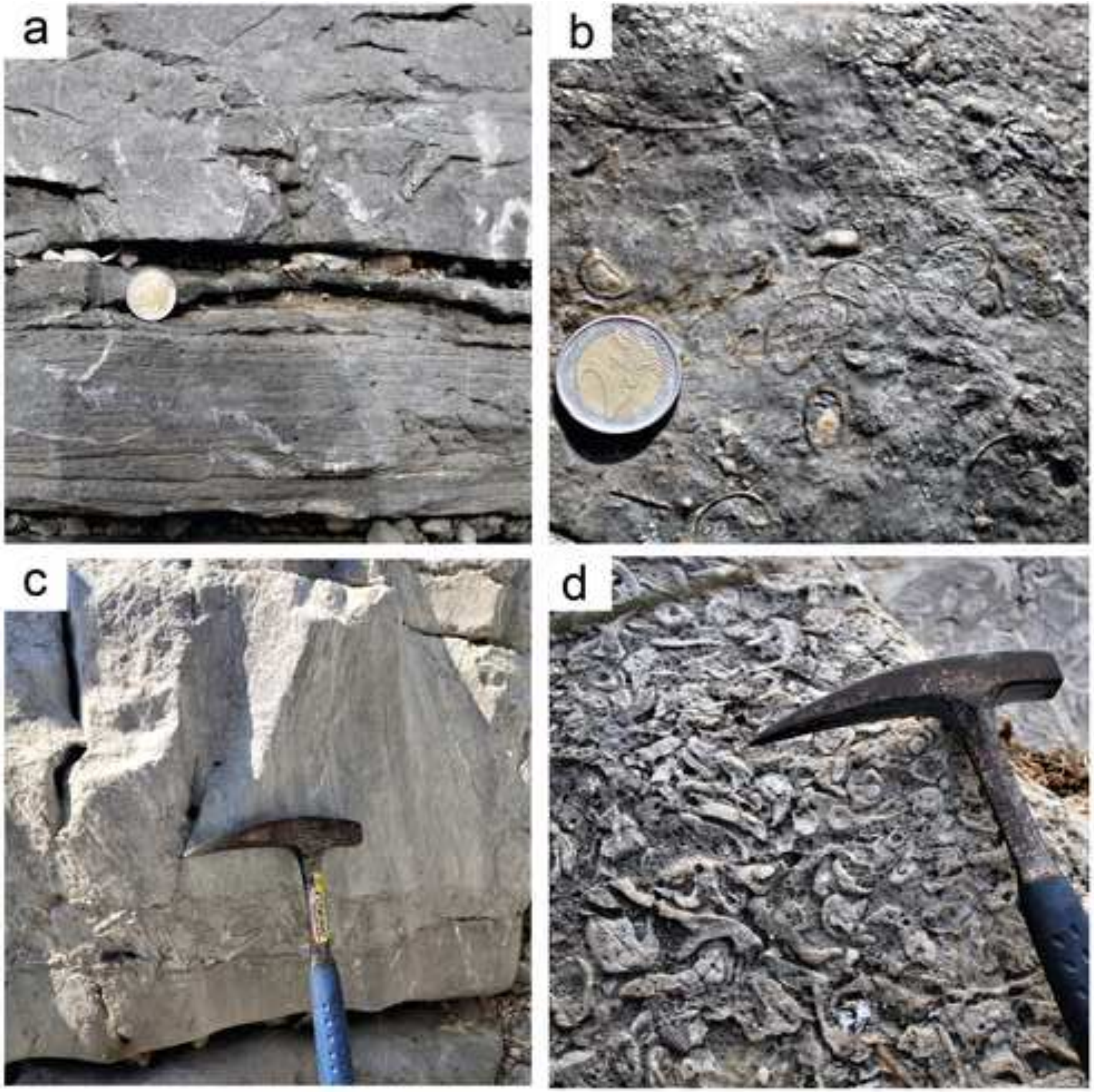
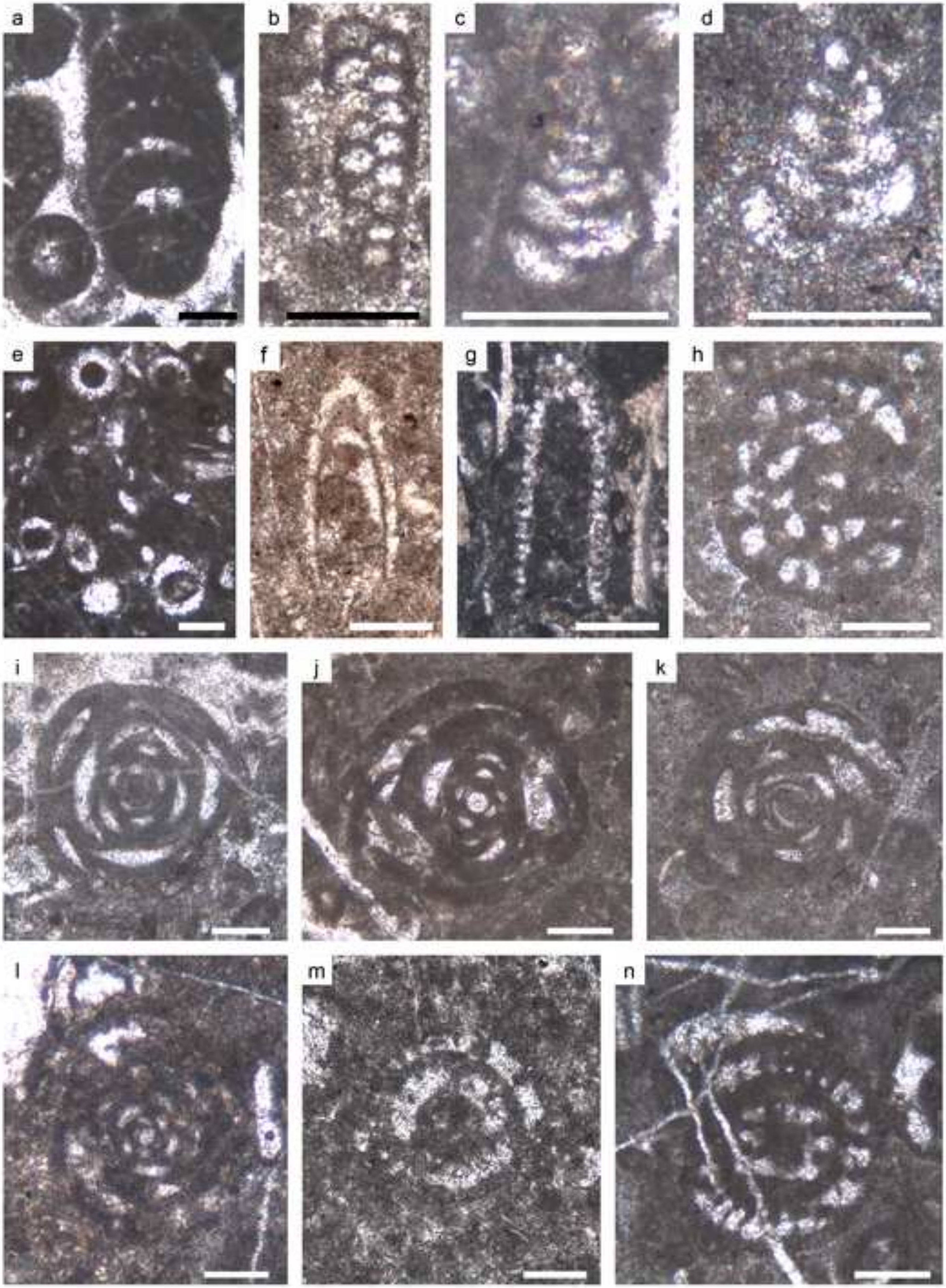

a
b
c
d

Figure Click here to access/download;Figure;Fig9.jpg



Figure

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Figure

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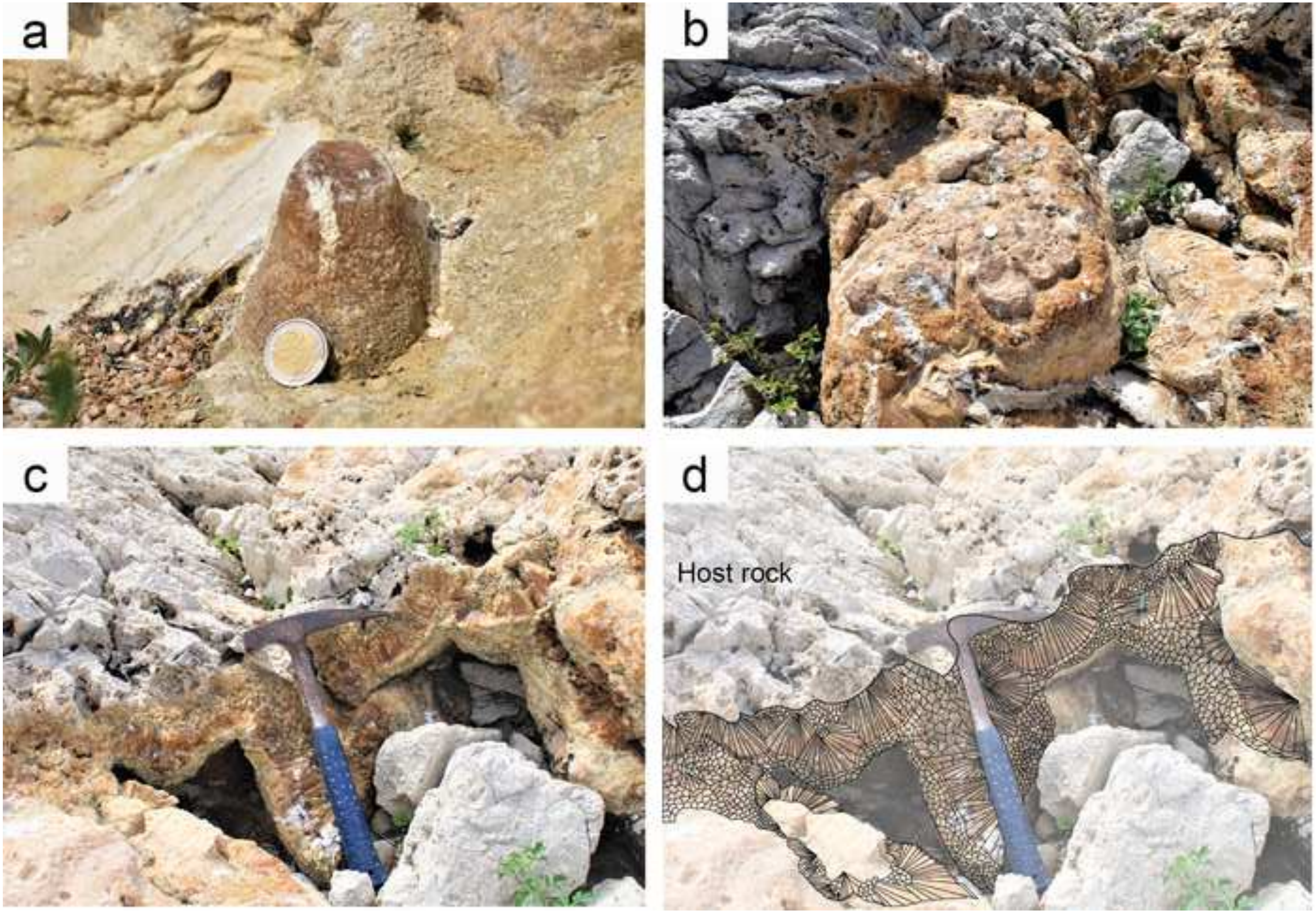

Figure

Click here to access/download;Figure;Fig12.jpg


GEOLOGICAL TRACK OF R.N.O. ISOLA DELLE FEMMINE
1
2
3
4
5
6
7
KEY
Track Trail
Point of interest
1 - Speleothems
2 - Speleothems
3 - Ostreid limestones
4 - Speleothems (Stalagmite)
5 - Rudist limestones
9 - Requienid limestones
10 - Laminated limestones
N
E
S
100 m

Facies	***Texture***	***Main constituents***	***Depositional setting***
Laminated limestones (F1)	Bindstone	Peloids, ostracod	Intertidal zone
Foraminiferal and algal limestones (F2)	Wackestone/packstone	Peloids, botryoidal lumps, ostracod, benthic foraminifers, dasycladalean algae, intraclasts	Low-energy subtidal zone
Requienid limestones (F3)	Rudstone/ Floatstone	Benthic foraminifers, gastropods, echinoderms, rudists (requienids)	Subtidal zone subject to storm events
Caprotinid limestones (F4)	Rudstone/ Floatstone	Benthic foraminifers, dasycladal algae, echinoderms, rudists (caprotinid), brachiopods, intraclasts	Subtidal zone subject to storm events
Ostreid limestones (F5)	Rudstone/ Floatstone	Ostreid shells	Subtidal zone subject to storm events