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The Early Cretaceous coastal lake Konservat-Lagerstätte of La Pedrera de Meià (Southern Pyrenees)

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ABSTRACT

A state of the art of the Barremian Konservat-Lagerstätte of la Pedrera de Meià site (Southern Pyrenees) is compiled here including the acquisition of new geological data. The relevance of this site, together with the nearby la Cabroa site, is due to its paleobiotic richness and the fact that 113 holotypes and paratypes of flora and fauna have already been defined. Since its discovery at the end of the 19th century and its exploitation as a lithographic limestone quarry, the site has been the object of paleontological interest by national and foreign research teams that are summarized here (including the catalogue of 224 publications). A survey of the existing type specimens in collections all over Europe is also provided, being France and Germany, the countries where more fossils are hosted other than Spain.The geological frame of this site is also reviewed, by revisiting unpublished geological mappings (mainly that of Krusat, 1966) and integrating it in a comprehensive map that includes 4 revisited outcrops of lithographic limestone which could be potential paleontological sites. Previous stratigraphic sections did allow the precise framing of paleontological data and findings, that now can be allocated in new stratigraphic sections accounting for 50m and that contain a minimum of 40.000 laminae, being a minimum estimation of the years represented in the la Pedrera de Meià site.

KEYWORDS **Barremian. Konservat-Lagerstätte. Pyrenees. Lithographic limestone. Paleobiota.**

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INTRODUCTION

La Pedrera de Meià (LPM) site is an important Barremian Konservat-Lagerstätte (*i.e.* paleontological site with exceptional preservation) that has provided a large number of holotypes and paratypes of terrestrial biota, including one of the earliest flowering plants in the history of life and the first record of eusociality in insects (Gomez *et al.*, 2015; Gómez-Alba, 1991; Martínez-Delclòs and Martinell, 1995). This locality was discovered at the end of the 19th century and had a complex history, with fossils spread throughout Europe (Aragonès, 2018; Galobart *et al.*, 2022; Vidal, 1898). Furthermore, there is no accurate lithostratigraphic framework, which prevents the precise location of paleontological findings in a reference section. This limitation hampers any accurate correlation between paleoecological changes and other environmental proxies.

In this work, we update all the available knowledge (including unpublished relevant studies as Krusat (1966) and provide the essential frame for this site. Together with the Las Hoyas fossil site in the Spanish Cuenca Province (Poyato-Ariza and Buscalioni, 2016), LPM is a worldwide reference locality for the Early Cretaceous paleontology.

The site of LPM (of which "La Pedrera de Rúbies" is its synonym and appears in names of certain formations and units defined in the past) is among the most important sites resulting from the quarrying of lithographic limestones, which include the famous Upper Jurassic localities of Solnhofen (Bavarian region of Altmühltal, Germany), Causse Méjean (Lozère, France), Canjuers (Haute Provence, France), as well as Cerin in the Ain region (Jura Mountains, France, Moreau *et al.*, 2022) or Nusplingen (Baden-Württemberg, Germany, Dietl and Schweigert, 2004). Lithographic limestone quarrying started in 1796, when by chance, a novel printing technique using slabs of this rock was discovered. The new method not only reduced the costs of the printing industry, but also increased the value of limestones for lithography worldwide. From an industrial perspective, the homogeneous micrite of the lithographic limestone was easily broken into thick slabs, making them easy to process and use. But the industrial exploitation of this type of limestone included an unexpected side effect; exquisitely preserved the fossil remains of organisms. In a short time, lithographic limestone doubled its value, not only because it was the cornerstone of the 18th and 19th centuries printing industry, but also because of its paleontological relevance (Galobart *et al.*, 2018; Lacasa, 2016).

In the present work, we review the paleontological and geological data from LPM and related sites by compiling the available studies. This state-of-the-art will identify the need for new geological studies to achieve a complete understanding of the fossil site.

GEOLOGICAL SETTING

LPM site (see Fig. 1) is located in the Camarasa municipality and belongs to a larger set of outcrops of lithographic limestones in the Montsec de Meià (also unproperly named "Montsec de Rúbies" in some mappings). Two historical sites have been classically reported in the literature LPM itself and "La Cabroa" (also named "La Cabrua"), although some papers describe another outcrop named "El Reguer", a locality close to "La Cabroa". All these localities are located about 10 kilometers northwestward to the village of Vilanova de Meià (Fig. 1) (Barale *et al.*, 1984; Galobart *et al.*, 2022; Martín-Closas and López-Morón, 1996; Mercadé, 1991). The sites name presented here are given in accordance with current toponymy on the Institut Cartogràfic i Geològic de Catalunya (ICGC) at the date of publication. LPM has been dated as uppermost Hauterivian–Lower Barremian on the basis of charophyte studies (Martín-Closas and López-Morón, 1995).

Geologically, LPM is located in the Pyrenees, an alpine orogen (Choukroune and ECORS Team, 1989; Muñoz, 1992) resulting from the subduction of the Iberian microplate below the European plate in the Late Cretaceous. Before this subduction, the plate boundaries were part of the Pyrenean-Basque-Cantabrian rift (Tugend *et al.*, 2014). According to the chronology of the rock formations, is during this distensive setting when the LPM sediments accumulated in a coastal lake (Fig. 1A) (Barale, 1984). Structurally, LPM is in the Montsec thrust sheet, that is part of the Central South Pyrenean Unit (CSPU) (Séguret, 1972). The Montsec thrust sheet consist of 3000m of sediments from the Triassic to the Cretaceous (Garrido-Mejías and Ríos, 1972). The thrusting has been dated as late Eocene and is detached in the Keuper facies. Morphologically, the Montsec thrust sheet can be defined as a large flat-bottomed synformal fold with an anticline fold in its front (Teixell and Muñoz, 2000).

The chronological sequence of the sedimentary succession cropping out in the Montsec range starts with the Jurassic formations, which lie just above the detachment level of the Keuper evaporites. Above the irregular lower Liassic gypsum unit, which outcrops on the south of the Montsec ranges (Serres Marginals sheet), a non-continuous marls unit largely affected by tectonics is found. Above these marls the Dogger dark dolostones are deposited, whose thickness ranges from 20 to 300 meters. This thickness variation (Garrido-Mejías and Ríos, 1972; Puigdefàbregas and Souquet, 1986) is related to the previous rifting structures linked to the subsidence of the depocenters developed on the Triassic salt (Burrell and Teixell, 2021). A hiatus is recorded at the top of the dolostones, that corresponds to a non-sedimentation stage that encompasses most of the Malm

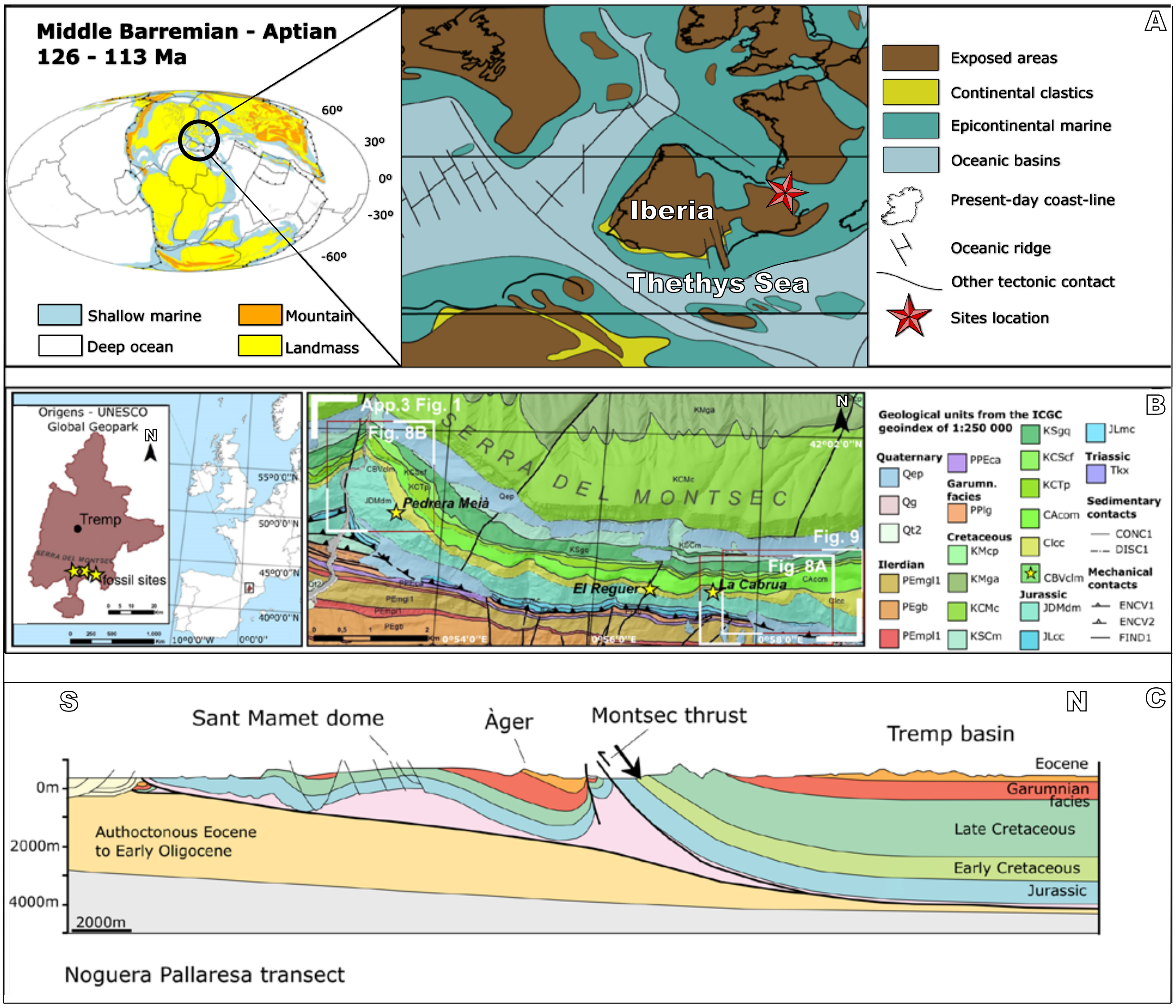

FIGURE 1. A) Paleogeography of Iberia during the Lower Cretaceous and global map of the same age (after Cao, 2019 and modifications by Pérez-Cano, 2021); B) Main lithographic limestone outcrops (yellow stars) in the Montsec range (modified from Galobart *et al.*, 2022, after several sources). Legend (see details in Geological units:- ICGC geoindex of 1:250 000): Qep, Qg and Qt2: Recent surface formations. PEmgl1, PEmpl1, KSCm and JLmc: Marls. PEgb, KMga and KSgq: Sandstones. PPEca: Limestone with alveolines. PPlg: Red shales, paleosoils, sandstones and chalks. KMcp and KCMc: Limestones and calcareous sandstones. KCScf: Limestones with rudists. KCTp: Limestones with prealveolins. CAcom: Marly limestones and lignite. Clcc: Limestones with charophytes. CBVclm: Lithographic limestones. JDMdm: dolostones. JLcc: Limestones, dolostones and breccias. Tkx: Shales, gypsum and evaporites. CONC1: concordant sedimentary contact. DISC1: unconformable sedimentary contact. ENCV1 and ENCV2: thrust. FIND1: fault. C: Geologic cross-section (Burrel and Teixell, 2021) with indication of the LPM site here studied (black arrow).

to Berriasian times. It is evidenced by the occurrence of karsts and ferruginizations (including bauxites). The karstification surface (Jurassic-Cretaceous transition) is covered by the so-called "boundary breccia", which is of marine origin and contains trocholinids and calpionellids. In turn, this breccia is underlying the lithostratigraphic unit of "La Serra del Montsec Charophyte Limestones". This last geological unit is the beginning of the transition to continental sedimentation in the area and includes the subunit of "La Pedrera de Rúbies Lithographic Limestones" (Barale *et al.*, 1984; Fregenal-Martínez and Meléndez, 1995; Peybernès, 1976). The largest outcrop and thickest section of these Uppermost Hauterivian to Lower Barremian lithographic limestones is that of LPM (see Figure 2). The maximum thickness of the section varies from 45 to 50m (Figure 2) and none of the published sections can be used as a framework to locate with precision any fossil finding. This is due to the low resolution and the lack of detail from the bottom of the section.

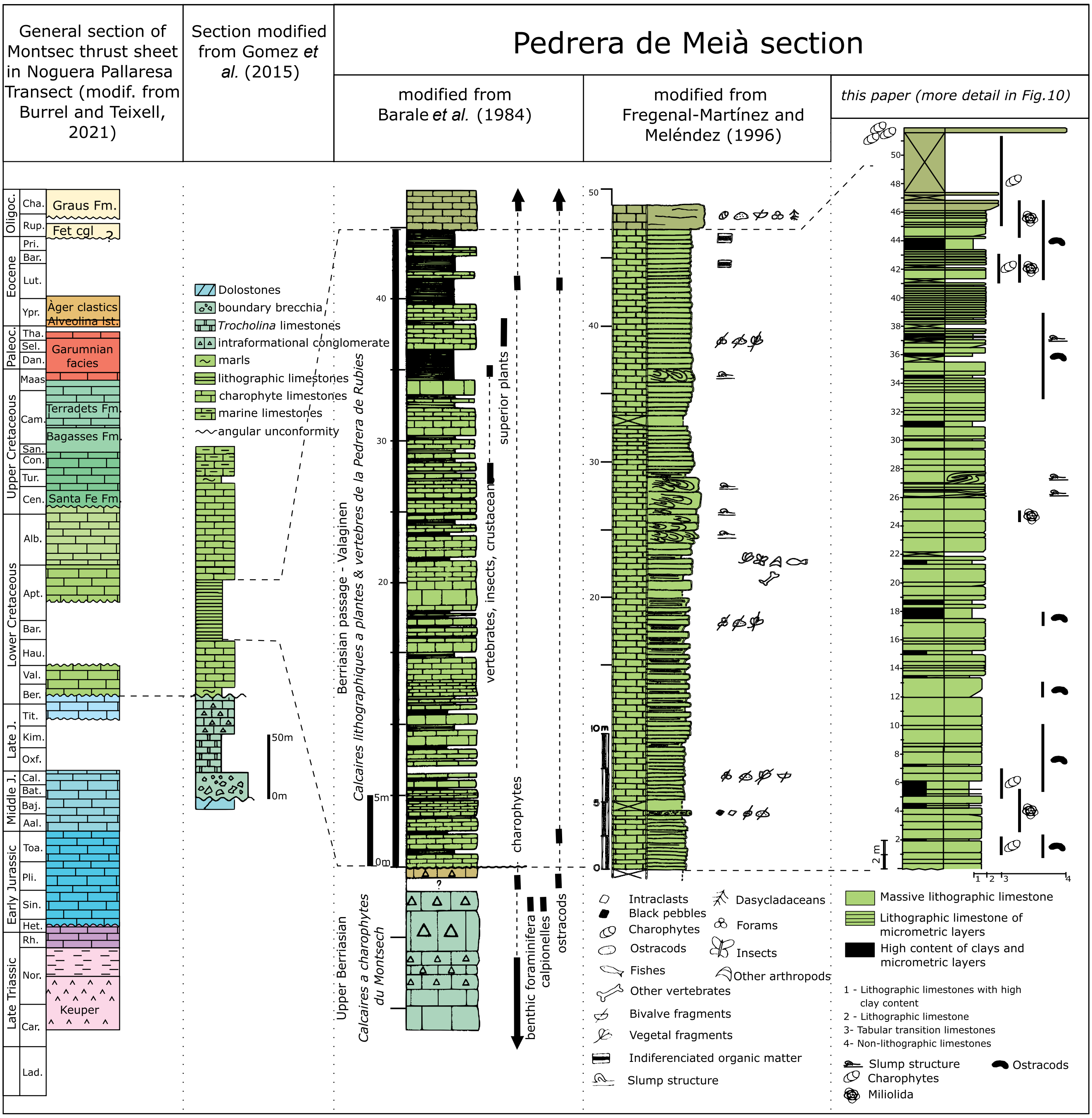

FIGURE 2. Stratigraphic logs compiled from different authors. Regional section of the Montsec thrust sheet (to the left, from Burrel and Teixell, 2021), regional/local section (Gómez *et al.*, 2015) and local section at of LPM by Barale *et al.* (1984), Fregenal-Martínez and Meléndez (1996) and composite site in this work (to the right, see later).

HISTORICAL REVIEW

The age of discovery of LPM is uncertain, but the first reference is from 1875 (Vidal, 1875). The first publication that already cites its exploitation dates to 1898 as well as the first time that the discovery of La Cabroa is cited (Aragonès, 2018). The exact period of limestone extraction in the quarry is not clear, but it was active for 10 to 15 years at most. From 1897 at least and to 1913 at most, when the society that exploited it (Calizas Litográficas) was dissolved (Lacasa, 2016; Vidal, 1915).

The first fossil discoveries were linked to industrial exploitation and rock removal during the first years of LPM history. The first fossils were studied by Vidal himself, who published several scientific papers on geology and paleontology (Vidal, 1898, 1902). The fossils collected by the workers were delivered to Mr. Vidal, who in 1902 published the description of the first fossil, a frog, the oldest found in the world until then, with the title 'Nota sobre la presencia del tramo Kimeridgense en el Montsech (Lerida) y hallazgo de un batracio en sus hiladas', starting then the history of research at LPM (Fig. 3). Since the 1910s Vidal continued his research at LPM (Bataller, 1956).

Until 1916 several scientific works were published by relevant European specialists in paleontology such as the curator of the Muséum d'Histoire Naturelle in Boulogne-sur-Mer H.E. Sauvage (who studied fishes), the curator of the Antwerpener Tiergartens F. Meunier (who worked on

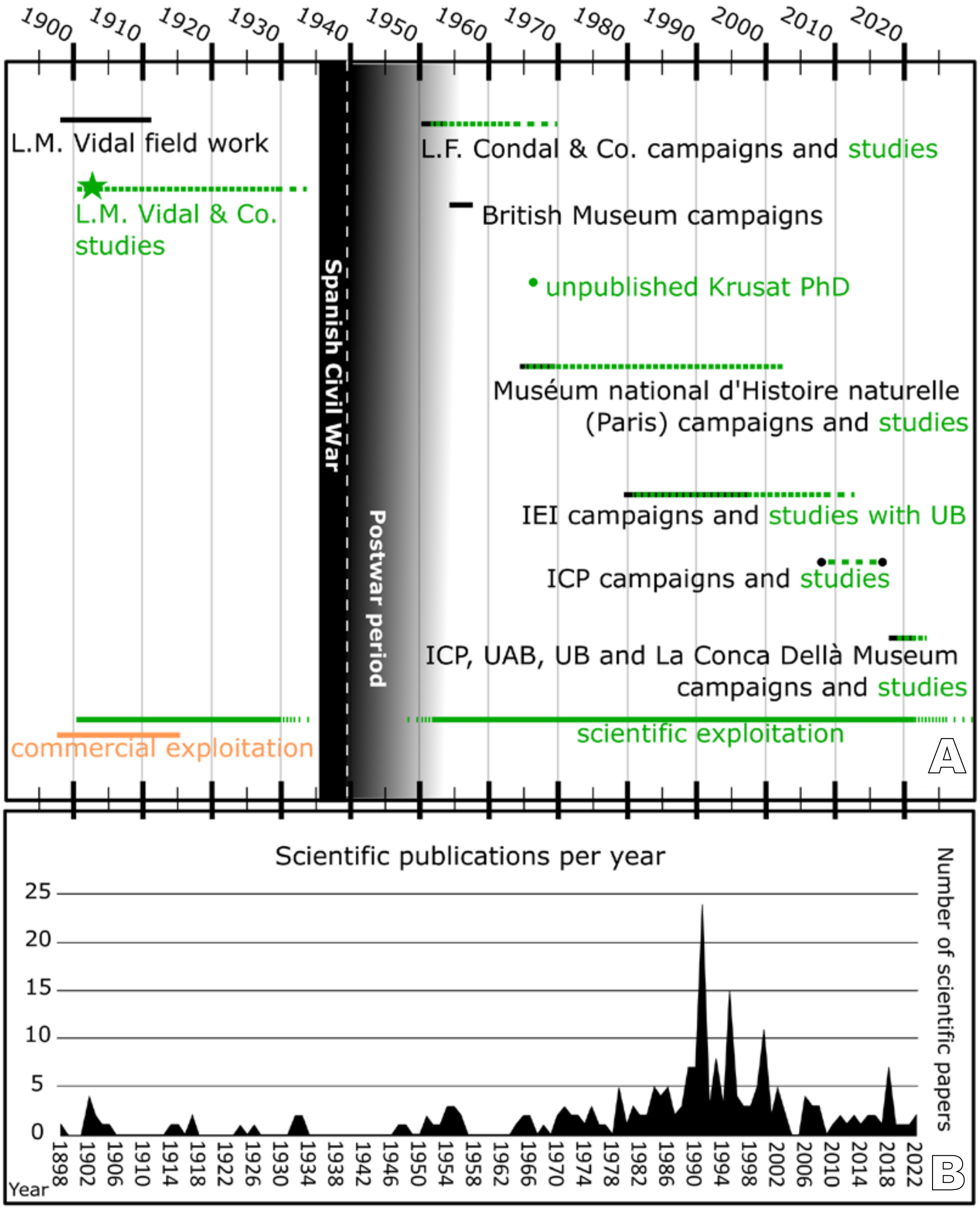

FIGURE 3. The lithographic limestones of the Serra del Montsec through historical times. A) uses from it's discovery around 1898 until present, with uses (mining vs scientific exploitation, in orange), field campaigns (in black) and main study periods and groups (green). B) number of publications per year. Note the lack of publications during civil war and post-war period. See the maximums due to the monographs by Martínez-Delclòs (1991, 1995) and the ensuing decline.

insects), the mine engineer C.R. Zeiller (who focused on plants, see Meunier, 1902; Sauvage, 1903; Zeiller, 1902) and many others, who described about 50 new species. Among them, the first lineage of angiosperms discovered so far, *Montsechia vidalii*, first studied by René Zeiller (Zeiller, 1902) and years later redescribed by Carles Teixeira (Gomez *et al.*, 2015; Krassilov, 2011; Teixeira, 1954).

Since the end of the commercial extraction of the lithographic stone around 1913, paleontological studies from LPM decreased, although continued until the 1930s. The Spanish Civil War (1936-1939) and the precariousness of the post-war period (1939-1959) lead to a long period of inactivity. In the 1950s, Dr. Lluís Ferrer i Condal rediscovered the fossiliferous site, finding the second fossil frog specimen recorded from the site (Ferrer Condal, 1955). In fact, Ferrer Condal's studies reactivated scientific interest of the fossil record of the LPM site (Galobart *et al.*, 2022; Lacasa, 1979) and it has been active until present.

The year 1966 is an important milestone in the geological study of the Montsec lithographic limestones. At that time, the geologist George Krusat defended his Ph.D in the Freie Universität Berlin (Germany). A copy of this document, housed in the library of the faculty of Earth Sciences of the University of Barcelona, includes an unpublished geological mapping documenting several isolated outcrops of lithographic limestones that have not been represented in successive geological maps of the area (see below).

Until 1970s, palaeontologists from the Universidade de Lisboa (UL), the Muséum National d'Histoire Naturelle in Paris (MNHN), the British Museum of Natural History in London (BMNH), the Universitat de Barcelona (UB), and the Institut Paleontològic de Sabadell (currently Institut Català de Paleontologia Miquel Crusafont with the acronym ICP) studied fossils collected by Dr. Ferrer i Condal (*e.g.* Ferrer Condal, 1951, 1955; Hecht, 1970; Wenz, 1964, 1968).

In 1972, Peybernès and Oertli studied the ostracod content of this unit and established the formal definition of "Calcaires lithographiques à Plantes et Vertébrés de la Pedrera de Rúbies" (lithographic limestones with plants and vertebrates of La Pedrera de Rúbies). In 1976, Peybernès included them in what he defined as "Ensemble de Calcaires à Charophytes du Montsech" (Ensemble of limestones with charophytes from Montsec). Both represent the beginning of current geological and paleontological studies (Martínez-Delclòs *et al.*, 1991). Later, Barale *et al.* (1984), make the first paleoenvironmental interpretation and suggest the LPM formed in a coastal freshwater lake, with occasional marine connections.

During the late 1970s, a group of amateur palaeontologists known as "Amics de la Paleontologia" (Friends of Paleontology) affiliated to the Institut d'Estudis Ilerdencs (IEI; Lleida) performed a series of annual excavations under the direction of Dr G. Barale of the University of Lyon (France). From 1987 to 1996, Dr. X. Delclòs from the Universitat de Barcelona replaced Dr. Barale in the direction of the excavations, but always with the collaboration of "Amics de la Paleontologia". Apart from the discovery of new specimens, the paleontological team started the excavations at the lithographic limestone outcrop of La Cabroa (Galobart *et al.*, 2018; Martínez-Delclòs, 1991, 1995), which is only exploited for research purposes.

As a result of all these years of field work, the extensive paleontological collection of the IEI was created, which currently has more than 4000 specimens. This number of specimens is complemented by others housed in several European scientific institutions. For decades, mainly during the 50s and 70s of the last century, institutions of different countries and amateur collectors have been searching for fossils in the lithographic limestone outcrops of the Montsec range, taking advantage of a legal loophole of the past. Today, the specific laws for the protection of Natural Heritage and Cultural Heritage protect all fossil sites, the lithographic limestone deposits of Montsec. Additionally, LPM is an important spot in Orígens Geopark. Nowadays, the scientific excavation of the outcrops continues, since recent years the ICP in collaboration with the Museu de la Conca Dellà (MCD, Isona) has resumed the excavations and, more recently, since 2019 also in collaboration with the Universitat Autònoma de Barcelona (UAB).

All this history of collecting and studying at LPM have yielded thousands of specimens from a large variety of taxonomic groups (see Figures 4 and 5), including insects with representation of termites as the oldest social insects (Lacasa and Martínez-Delclòs, 1986; Martínez-Delclòs and Martinell, 1995), arachnids with the first possible spiders weaving orbicular webs (Selden, 1990), crustaceans, molluscs, fishes, amphibians, lizards, crocodiles, birds and feathers. A large number of algae and plants have also been found, such as charophytes, "pteridophytes" and spermatophytes (Galobart *et al.*, 2022; Gómez-Alba, 1991; Martínez-Delclòs *et al.*, 1995). An outstanding and abundant element are the remains of *Montsechia vidalii* (Gomez *et al.*, 2015), which is among the oldest corroborated flowering plants. Older angiosperms from the Jurassic of China (Liu and Wang, 2015) are currently under discussion (Herendeen *et al.*, 2017), among others. In any case, the biotic assemblage of LPM is a window to the beginning of current ecosystems (Galobart *et al.*, 2018).

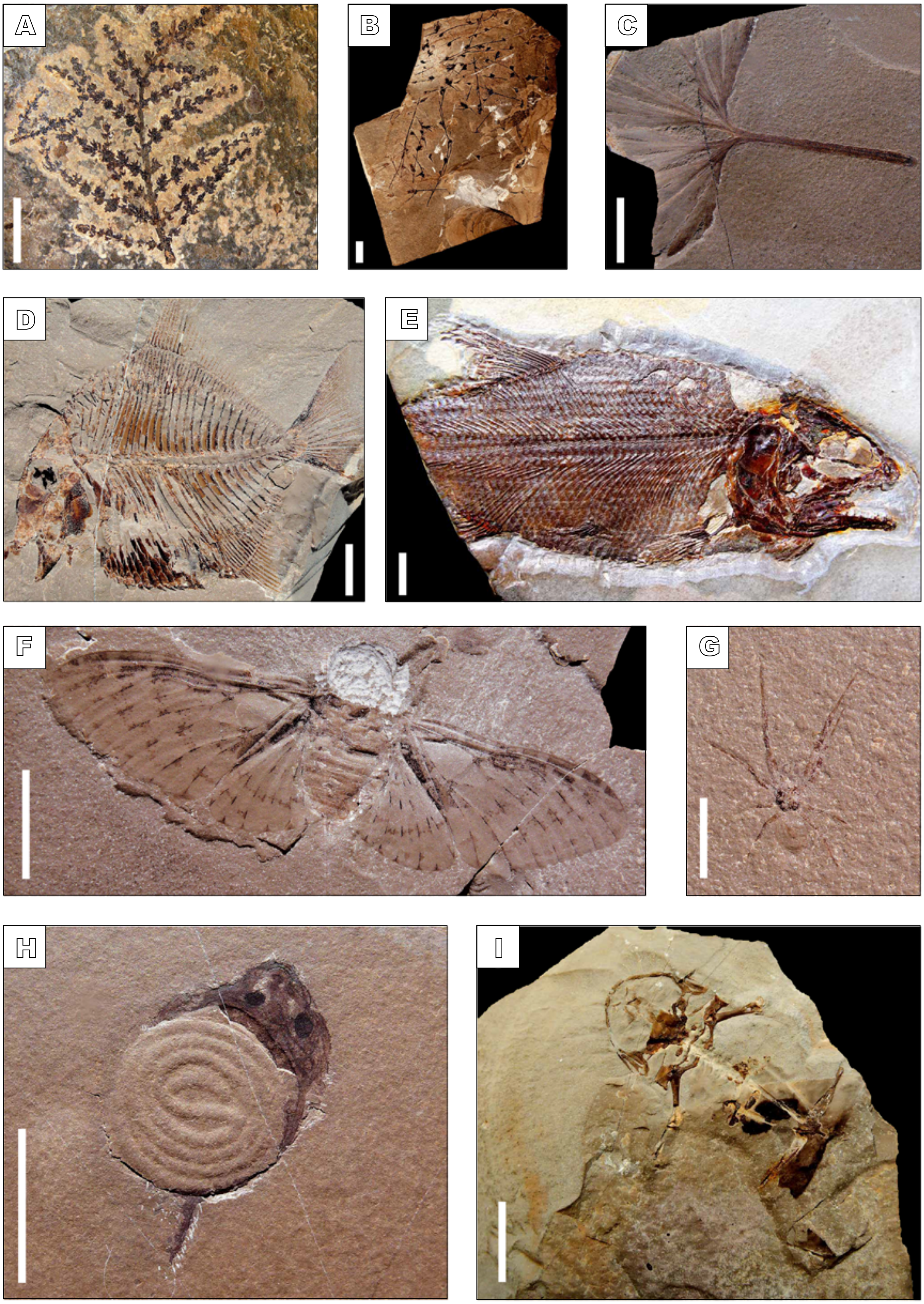

FIGURE 4. Examples of the Koservat-Lagerstätten fossil record from LPM (modified from the catalogue 'Paleontologia de les terres de Lleida' by Galobart *et al.*, 2018, with permission from Diputació de Lleida). A) *Montsechia vidalii*, B) *Ranunculus ferreri*, C) *Ginkgo* sp., D) *Ocloedus subdiscus*, E) *Caturus tarraconensis*, F) *Pachypsyche vidali*, G) *Macryphantes cowdeni*, H) tadpole, *Anura indet*. I) *Eodiscoglossus santonjae***.** Images from Galobart *et al.* (2018). Pictures by Antoni Lacasa Ruiz. Scale bar 1cm.

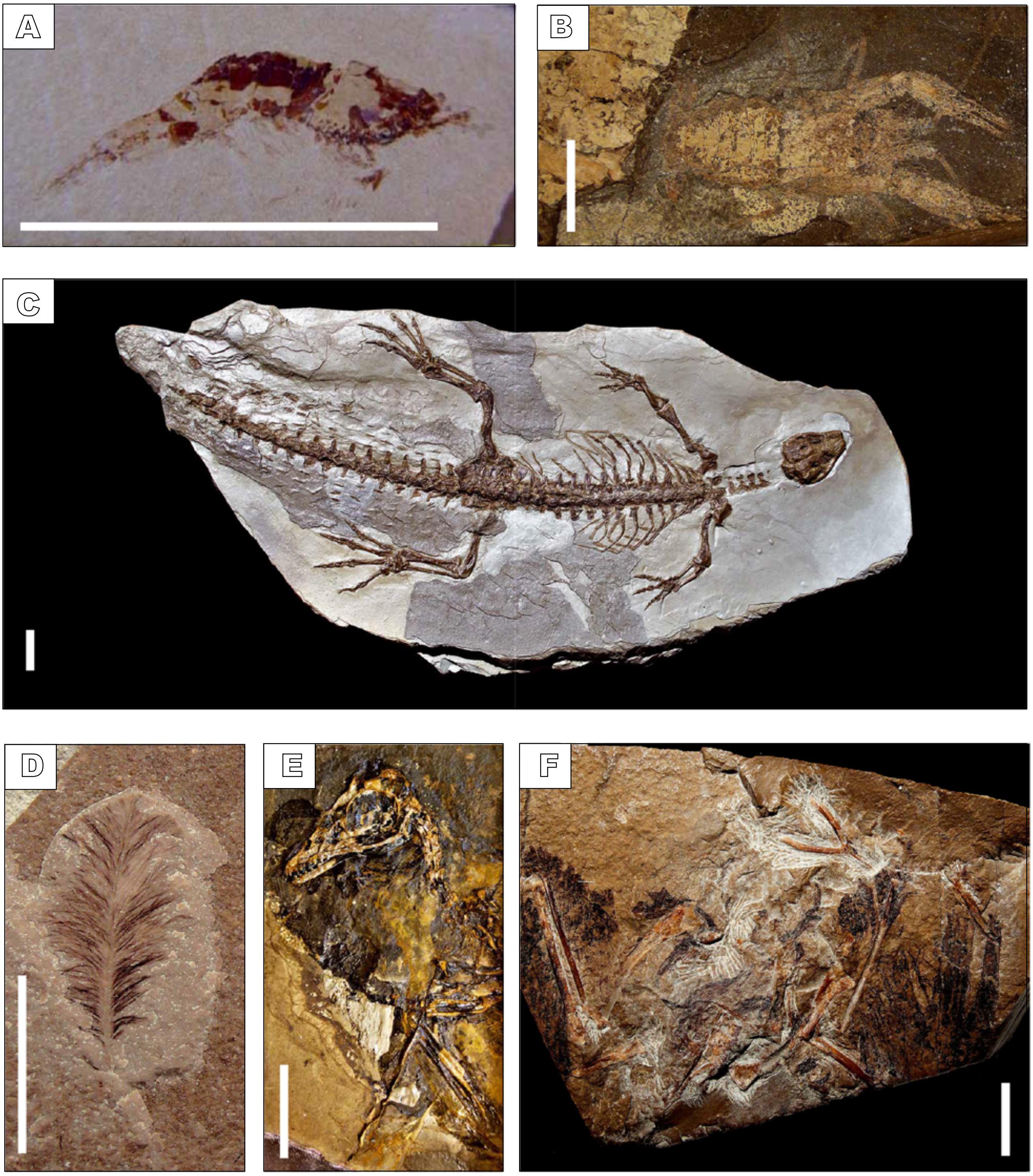

FIGURE 5. A) *Delclosia roselli*, B) *Austrapotamobius llopisi,* C) *Montsecosuchus depereti*, D) *Ilerdopteryx viai*, E) *Enantiornithes indet.*, F) *Noguerornis gonzalezi.* Images from Galobart *et al.* (2018), with permission from Diputació de Lleida. Pictures by Antoni Lacasa Ruiz. Scale bar 1cm.

METHODS

The methodology used for the present study includes: a comprehensive bibliographic compilation, geological mapping and logging, and sampling from the LPM local section.

A comprehensive bibliographic compilation included the scanning of several publications that are not available in internet. The digitalization of old printed publications was performed using two different methodologies depending on the state of preservation of the document: by scanning with EPSON Stylus SX100 or taking pictures with a digital camera Canon Powershot SX 520 HS. Older documents, including some books, show extremely delicate preservation conditions, such as broken bindings, broken stitches, fragile and old paper support –like an original copy of Vidal (1902)–, or loose inks that are difficult to read. The files were transformed into portable document format (.pdf) and are now easier to view and share.

The compilation of fossils, including type series (holotypes and paratypes) of the LPM site, has to face their dispersal throughout Europe over a long time. It should also be considered that private collectors could sample freely at LPM as there were no heritage protection regulations until 1985 in Spain and until 1993 in Catalonia. The display of holotypes and paratypes and their hosting institution together with the taxonomic group's abundance is based on the work by Martínez-Delclòs (1991) and Galobart *et al.* (2022).

The revision of all available geological mappings started with the ground checking of the lithographic limestone outcrops of the unpublished map by Krusat (1966), which was scanned, georeferred and converted to a vectorial format (with ArcMap v10.3.1 and Inkscape 0.91 software). Outcrops revisiting also permitted improvements in the contours of the lithological contact. All these data were further overlapped with the ICGC 1:25.000 maps by Pi *et al.* (2002, 2003): sheets Llimiana 290-1-2 (65-24) and Sant Salvador de Toló 290-2-2 (66-24), respectively.

With the aim to obtain a detailed stratigraphic column of 1cm resolution, a significant portion of the LPM site was prepared, including the removal of rubble and vegetation. Given the impossibility to obtain a single continuous section, mainly because the presence of local faults or by safety reasons, the final composed section is based on the correlation of several subsections.

Forty-three lithological samples were obtained along regular spacing of LPM 50m section. These samples were taken from the centimetric point: 45, 225, 472, 551, 734, 818, 960, 1065, 1206, 1345, 1475, 1575, 1612, 1755, 1827, 1906, 1933, 2012, 2165, 2286, 2386, 2525, 2692, 2930, 3030, 3150, 3285, 3520, 3645, 3753, 3840, 3955, 4035, 4130, 4265, 4370, 4465, 4515, 4570, 4600, 4640, 4665 and 4732. Each sample was prepared as standard petrographic thin-section of 30 mμ, non-covered and polished at the Universitat Autònoma de Barcelona (UAB) facilities, allowing future studies under Scanning Electron Microscope (SEM). Thin-sections were analysed by using optical microscope Nikon ESTATIVO ECLIPSE CI-POL of Departament d'Estratigrafia of UAB.

RESULTS

Compilation of bibliography and fossils

The bibliographic compilation resulted in an inventory of 224 publications (see Appendix I). This compilation contains all the knowledge on the Montsec lithographic limestones, and mostly consist of paleontological papers from LPM and/or La Cabroa sites. Works that are unavailable (very old and no longer published journals, unpublished thesis, books of limited dissemination, etc.) have been scanned and are being uploaded for public use at webpage https://pedrerademeia.geoparcorigens.cat/. This web domain is hosted by the UNESCO Global Geopark – Orígens. A remarkable feature of the publications of LPM is that the geological contents have only been published as a complement to paleontological data and not as a target in itself (except chapters in monographs where limited information is provided). That is the reason why the present paper puts special focus on the geological context, providing a clear geological frame to be used as a reference to paleontological information. The most relevant papers including geology are by Peybernes (1972, 1976, 1979), Mercadé (1991), Fregenal-Martínez and Meléndez (1995) and Gibert *et al.* (2000). The plotting of the number of publications per year (see Fig. 3, bottom) display the breakdown of the civil war plus a maximum in the late 80s and early 90s and a decline until present days. The peak of productivity of the early 90scorresponds to the publication of 20 papers in a monography on the lithographic limestones of the Montsec (Martínez-Delclòs, 1991).

The compilation of fossil type series (holotypes and paratypes) from LPM and La Cabroa (see Galobart *et al.*, 2022; Martínez-Delclòs, 1991) is here summarized (Figs. 6; 7A) and shows that most of specimens are housed in Catalan museums (*e.g.* Institut Català de Paleontologia, Institut d'Estudis Ilerdencs, Museu de la Conca Dellà), which act as legal custodians of this paleontological heritage. The rest of specimens are mainly housed in institutions located in Paris, London, Berlin, Göttingen and Madrid. Figures 6 and 7 show the type series list, together with the hosting institution (enlarged data from Galobart *et al.*, 2022). It

Institut d'Estudis Ilerdencs, Spain
? Anaglyphites pluricavus Soriano and Delclòs, 2006 (LP-097-G/IEI)
Angarosphex penyalveri Rasnitsyn and Martínez-Delclòs, 2000 (LP-0163-G/IEI)
Antemnacrassa monreali Gomez Pallerola, 1979 (LP-260-G-IEI)
Araucarites pedreranus Barale, 1989 (LP-731-IEI)
Bolbonectus lithographicus Ponomarenko and Martinez-Delclós, 2000 (LP-1222-P/IEI)
Brenthorrhinoides lacasai Gratshev and Zherikhin, 2000 (LC-1374-IEI A-B)
Brochocoleus indibili Soriano and Delclòs, 2006 (LC-4636-IEI)
Chresmoda aquatica Martínez-Delclòs, 1989 (LP-94-IEI A-B)
Cionocoleus longicapitis Soriano and Delclòs, 2006 (LP-0164-G/IEI)
Coptoclavella inexpecta Soriano et al., 2007 (LC-3955-IEI A-B)
Cretaholocompsa montsecana Martínez-Delclòs, 1993 (LC-1704-IEI, LP-005-G/IEI A-B)
Cretaraneus vilaltae Selden, 1990 (LC-1150-EI)
Cretobestiola hispanica (Martínez-Delclòs and Rasnitsyn, 1999) (LP92/SC/3662-IEI)
Cretochoragus pygmaeus Soriano et al., 2006 (LC98/18P/5037-IEI)
Cretonanophyes rugosithorax Zherikhin and Gratshev, 2000 (LC-1653-IEI, LC-1654-IEI)
Cretoscolia montsecana Rasnitsyn and Martínez-Delclòs, 1999 (LC-1962-IEI)
Cretoserphus gomezi Rasnitsyn and Martínez-Delclòs, 2000 (LP-0652-G/IEI)
Dammarites coriacea Barale, 1992 (LP-1579-IEI B)
Distenorrhinoides simulator Gratshev and Zherikhin, 2000 (LC-2031-IEI A-B)
Distenorrhinus (Distenorrhinus) ocularis Soriano et al., 2006 (LC-3087-IEI)
Eosyntexis catalonicus Rasnitsyn and Martínez-Delclòs, 2000 (LC-2456-IEI)
Eretmoglossa lacasae Barale, 1981 (LP-27/29-IEI)
Gobicar hispanicus Gratshev and Zherikhin, 2000 (LC-4669-IEI)
Hispanocar kseniae Soriano et al., 2006 (LC92/25-36/3705 A-B)
Ilerdopteryx viai Lacasa, 1985 (LP-715-IEI)
Karataus hispanicus Rasnitsyn and Martínez-Delclòs, 2000 (LC-1427-IEI, LC-1460-IEI)
Lissodus palustris Gomez-Pallerola, 1992 (LP-088-G/IEI)
Lleidoaeschnidium valloryi Nel and Martínez-Delclòs, 1993 (LP-1080-IEI)
Macryphantes cowdeni Selden, 1990 (LC-1753-AP/IEI)
Manlaya ansorgei Rasnitsyn and Martínez-Delclòs, 2000 (LC-2782-IEI)
Meiaghilarella cretacica Rasnitsyn and Martínez-Delclòs, 2000 (LC-1360-IEI)
Meiatermes bertrani Lacasa Ruiz and Martínez-Delclòs, 1986 (LP-1701-IEI)
Microbrenthorrhinus martinezi Gratshev and Zherikhin, 2000 (LC-2220-IEI A-B)
Montsecanomalus zherikhini Soriano, Gratshev and Delclòs, 2006 (LC-3005-IEI)
Montsecarachne amicorum Selden, 2014 (LC-3780-IEI A-B, LC-2936-IEI A-B)
Montsecosphex jarzembowskii Rasnitsyn and Martínez-Delclòs,2000 (LP-4132-IEI) par.
Nogueroblatta fontllongae Martínez-Delclòs, 1993 (LC-2386-IEI A-B)
Noguerornis gonzalezi Lacasa-Ruiz, 1989 (LP-1702-P/IEI)
Orbablattula infrequens Martínez-Delclòs, 1993 (LC-1786-IEI A-B)
Palaeodocosia cabruae Blagoderov and Martínez-Delclòs, 2001 (LC-2722-IEI)
Palaeouloborus lacasae Selden, 1990 (IEI-1755 (LP-1755-AP/IEI) par.
Proraphidia gomezi Jepson and Jarzembowski, 2008 (Lérida-29 in UK notation) par.
Zygadenia martinclosas Soriano et al., 2006 (LC-2663-IEI)
Zygadenia oculata Soriano et al., 2006 (LC-3675-IEI)
?*Pompilopterus noguerensis* Rasnitsyn and Martínez-Delclòs, 2000 (LP-2673-IEI)
The Natural History Museum London, United Kingdom
Artitocoblatta ?hispanica Whalley and Jarzembowski, 1985 (In.59505 (W)
Condalia woottoni Whalley and Jarzembowski, 1985 (In.59491 (B)
Frenelopsis rubiesensis Barale, 1973 (V41214/V32328-41206 to 41213-41534)
Jarzembowskia edmundi Zherikhin and Gratshev, 1997 (In.49648)
Mesopalingea leridae Whalley and Jarzembowski, 1985 (In.59509 (W)
Montsecbelus solutus Whalley and Jarzembowski, 1985 (In.59510 (W)
Pseudochrysobothris ballae Whalley and Jarzembowski, 1985 (In.59501 (B)
Sphenopteris wonnacottii Dilcher and Hill, 2003 (BMNH-V41257)
Wonnacottella pulcherrima Whalley and Jarzembowski, 1985 (In.59486 (W)
Muséum National d'Histoire Naturelle Paris, France
Hirmoneura neli Mostovski and Martínez-Delclòs, 2000 (MHNP-B48821a-b)
Hirmoneura richterae Mostovski and Martínez-Delclòs, 2000 (MHNP-B48822a-b)
Ilerdosphex wenzae Rasnitsyn, 2000 (MNHN LP-S11456a-b)
Nageiopsis hispanica Barale, 1989 (MNHN-17375/MNHN-17873a,b)
Ocloedus subdiscus Wenz, 1989 (MNHN MSE 341)
Pompilopterus montsecensis Rasnitsyn, 2000 (MNHN LP-B.848826a-b)
Ranunculus ferreri Teixeira, 1954 (MNHN 17163)
Private - Ferrer i Condal collection, Spain.
Notagogus ferreri Wenz, 1964 (-) par.

Museu Ciències Naturals de Barcelona, Spain
Acocephalites breddini Meunier, 1904 (MGB 505)
Amiopsis woodwardi (Sauvage, 1903) (MGB 533)
Caturus tarraconensis Sauvage, 1903 (MGB 514)
Ephialtites jurassicus Meunier, 1903 (MGB 517)
Holophagus leridae (Sauvage, 1903) (MGB 563)
Hybodus woodwardi Vidal, 1915 (MGB 519a)
Ichthyemidion vidali (Sauvage, 1903) (MGB 509)
Lepidotes ilergetis Sauvage, 1903 (MGB 525)
Meyasaurus faurai Vidal, 1915 (MGB 534)
Monsechobatrachus gaudryi (Vidal, 1902) (MGB 541)
Montsechia vidalii (Zeiler) Teixeira, 1954 (MGB 553-1)
Montsecosuchus depereti (Vidal, 1915) (MGB 512)
Pachypsyche vidali (Meunier, 1902) (MGB 543/544)
Pagiophyllum pedreranum Barale, 1989 (MGB 539-1/MNHN 17638 a-b)
Palaeaeschna vidali Meunier, 1914 (MGB 540)
Pedrerasaurus latifrontalis Bolet and Evans 2010 (MGB 47250)
Propterus vidali Sauvage, 1903 (MGB 550)
Vidalamia catalunica (Sauvage, 1903) (MGB 530)
Universitat de Barcelona, Spain
Andrenelia pinnata Rasnitsyn and Martínez-Delclòs, 2000 (LC-036-EP)
Cretosyntexis montsecensis Rasnitsyn and Martínez-Delclòs, 2000 (UB LC-035-EP)
Iberomosca kakoeima Mostovski and Martínez-Delclòs, 2000 (UB LC-34-EP)
Ilerdaegomphus pallerolae (Gómez, 1979) (IEI-11 (LC-11-GDGP))
Montsecephialtites zherikhini Rasnitsyn and Martínez-Delclòs, 2000 (UB LC-033-EP)
Montsecia martinezdelclosi Mostovski, 1999 (UB LP-043-XMDa-b)
Nogueroblatta nana Martínez-Delclòs, 1993 (LP-021-GDGP)
Synapha rubiesensis Blagoderov and Martínez-Delclòs, 2001 (LC-041-EP)
Tetraphalerus brevicapitis Ponomarenko and Martínez-Delclòs, 2000 (LP -037-EP)
Tetraphalerus penalveri Soriano and Delclòs, 2006 (DEPGM LP-58)
Museu de Geologia del Seminari, Spain
Austropotamobius llopisi (Via, 1971) (MSGB-21001)
Delclosia roselli (Via, 1971) (MGSB-21000)
Mesoblattina colominasi (Meunier, 1914) (MSGB-26948)
Palaega ilerdensis Calzada and Gómez Pallerola, 1994 (MGSB-46864)
Institut Català de Paleontologia Miquel Crusafont, Spain
Leptolepis crusafonti Wenz, 1968 (IPS-2535/2536)
Ophiopsiella montsechensis (Wenz, 1968) (IPS-1991/1992)
Rubiesichthys gregalis Wenz, 1984 (IPS-2537, MSE 427 (IPS PR-4)
Museo Nacional de Ciencias Naturales , Spain
Eodiscoglossus santonjae Villalta, 1954 (MNCN PV-4723)
Bereich Paläontologie - E. Moritz Arndt Univ. Greifswald, Germany
Angarosphex lithographicus Rasnitsyn and Ansorge, 2000 (MA-7)
Archisphex catalunicus (Ansorge, 1993) (FGG 101 (MA-29 1/2) Par.
Manlaya lacabrua Rasnitsyn and Ansorge, 2000 (MA-15)
Meiagaster cretaceus Rasnitsyn and Ansorge 2000 (MA-22)
Prosyntexis montsecensis Rasnitsyn & Ansorge, 2000 (MA-6)
Inst. für Geographie und Geologie - E. Moritz Arndt Univ. Greifswald, Germany
Chalicoridulum montsecensis Szwedo and Ansorge, 2015 (GG 410 (MA-26 a,b)
Nanoraphidia lithographica Jepson et al., 2011 (FGWG 147 MA-20 a,b)
Ptiolinites almuthae Mostovski et al., 2000 (FGWG 137)
Vitisma occidentalis Vršanský and Ansorge, 2001 (FGWG 147 (MA 8)
Geowissenschaftliches Zentrum der Univ. Göttingen, Germany
Iberoraphidia dividua Jepson et al., 2011 (GZG.RF.7563)
Mimamontsecia cretacea Szwedo and Ansorge, 2015 (GZG.RF.9311)
Paläontologische Museum, Humboldt Univ. Berlin, Germany
Cretephialtites pedrerae Rasnitsyn and Ansorge, 2000 (MA-101)
Leridatoma pulcherrima Rasnitsyn and Ansorge, 2000 (MA-100)
Freie Universität Berlin, Germany
Neusibatrachus wilferti Seiffert 1972 (MB.Am.1469a,b (FUB 33A,B)
Bayerische Staatssammlung für Paläontologie und Geologie Munich, Germany
Cretobibio montsecensis Skartveit and Ansorge, 2020 (GG 490 (MA 13))

Arachnids · Crustaceans · Insects · Plants · Vertebrates - non-fishes · Vertebrates - fishes (*pisces*)

FIGURE 6. List of holotypes and paratypes from LPM, current location and reference work (modified and enlarged from Galobart *et al.*, 2022).

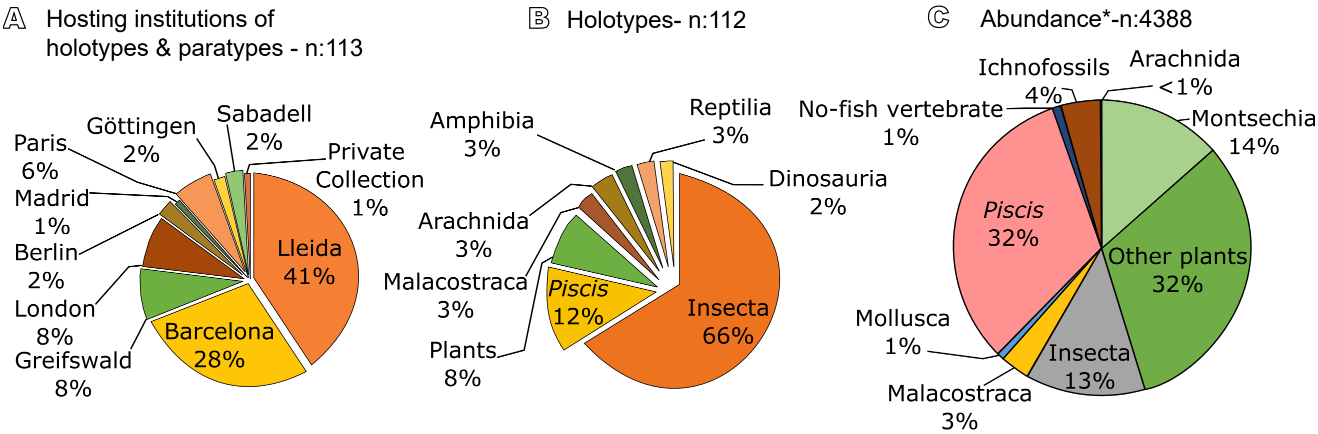

FIGURE 7. Pie-chart diagrams representing A) the current repository location of the holotype specimens. Lleida (Institut d'Estudis Ilerdencs), Barcelona (Museu de Ciències Naturals de Barcelona, Museu de Geologia del Seminari and Universitat de Barcelona), Sabadell (Institut Català de Paleontologia), Madrid (Museo Nacional de Ciencias Naturales), London (Natural History Museum London), Paris (Muséum National d'Histoire Naturelle Paris), Greifswald (Bereich Paläontologie and Institut für Geographie und Geologie – Ernst Moritz Arndt Universität), Göttingen (Geowissenschaftliches Zentrum der Universität Göttingen) and Berlin (Paläontologische Museum, Museum für Naturkunde, Humboldt Universität Berlin and Freie Universität Berlin). B) the relative abundance of taxonomic groups only based on holotypes and paratypes from the Montsec sites and C) the relative abundance of taxonomic groups based on 4388 fossils from three fully documented collections: Muséum National d'Histoire Naturelle de Paris (Paris, France), the Collection RMP of Museu de la Conca Dellà (Isona, Spain), collection of Museu de Geologia de Barcelona (Spain) according to Gómez-Alba (1991) and collection of Institut d'Esdtudis Ilerdencs (Lleida, Spain) according to Martínez-Delclòs and Ruiz de Loizaga (1991).

can be observed an artifact of fossil representation groups in the paleobiological record, i.e. the number of described species of a group is not always consistent with the expected diversity of that group in the paleoecosystem.

Geological mapping

The lithographic limestone outcrops are discontinuous and resulting from their sedimentation on top of the 'Lower Cretaceous unconformity', produced at the top of the Jurassic carbonated as a result of suggested early halokinetic movements (Burrel and Teixell, 2021). As shown in Figure 8 the geometry of the LPM limestone is characterized by a limited lateral extension (some 300m), by an irregular base and by a flat top. This geometry results from the infill of local depocenters on top the underlying Jurassic carbonates. These depocenters are first infilled by the Berriassian breccia (Pi *et al.*, 2003) and later by the lithographic limestone until the fulfilment (see cross section in Figure 8).

An updated, digitally redrawn version of the geological map performed by Krusat (1966) is shown in Table I of Appendix II and Figure I of Appendix III. The new map (Fig. 9) shows other new outcrops of lithographic limestones mentioned in addition to the LPM discovered and figured by Krusat op. cit., which are here named as: La Cabroa W, La Cabroa E, Clot de la Coma, Feixans W, St. Alís from Rúbies, Escallissos, Feixes de la Cova de l'Onso and Planta del Domingo. Another outcrop was identified by Dr. Martin-Closas from the Earth Science Faculty of the UB (2021, personal communication) near the C13 road, at kilometre point 70. All these lithographic limestone outcrops are shown in Figure 9 and illustrate the discontinuous character of the lithographic limestone resulting from their sedimentation on top of the 'Lower Cretaceous unconformity', produced at the top of the Jurassic carbonated as a result of suggested early halokinetic movements (Burrel and Teixell, 2021). As shown in Figure 8 the geometry of the LPM limestone is characterized by a limited lateral extension (some 300m), by an irregular base and by a flat top. This geometry results from the infill of local depocenters on top the underlying Jurassic carbonates. These depocenters are first infilled by the Berriassian breccia (Pi *et al.*, 2003) and later by the lithographic limestone until the fulfilment (see cross section in Figure 8).

It is worth noting that despite the large fieldwork effort in searching for lithographic limestone outcrops towards the easternmost region of the Montsec de Meià (Pas Nou zone) and in the Montsec d'Ares, no additional lithographic sites have been detected (J.M. Samsó, personal communication; Pi *et al.*, 2002, 2003). For the moment, lithographic limestones have only been reported from Montsec de Meià.

Lithostratigraphy

A complete detailed lithostratigraphic section at LPM site is provided for the first time (Fig. 10). The section has a one-centimetre resolution, and it can be used as a framework

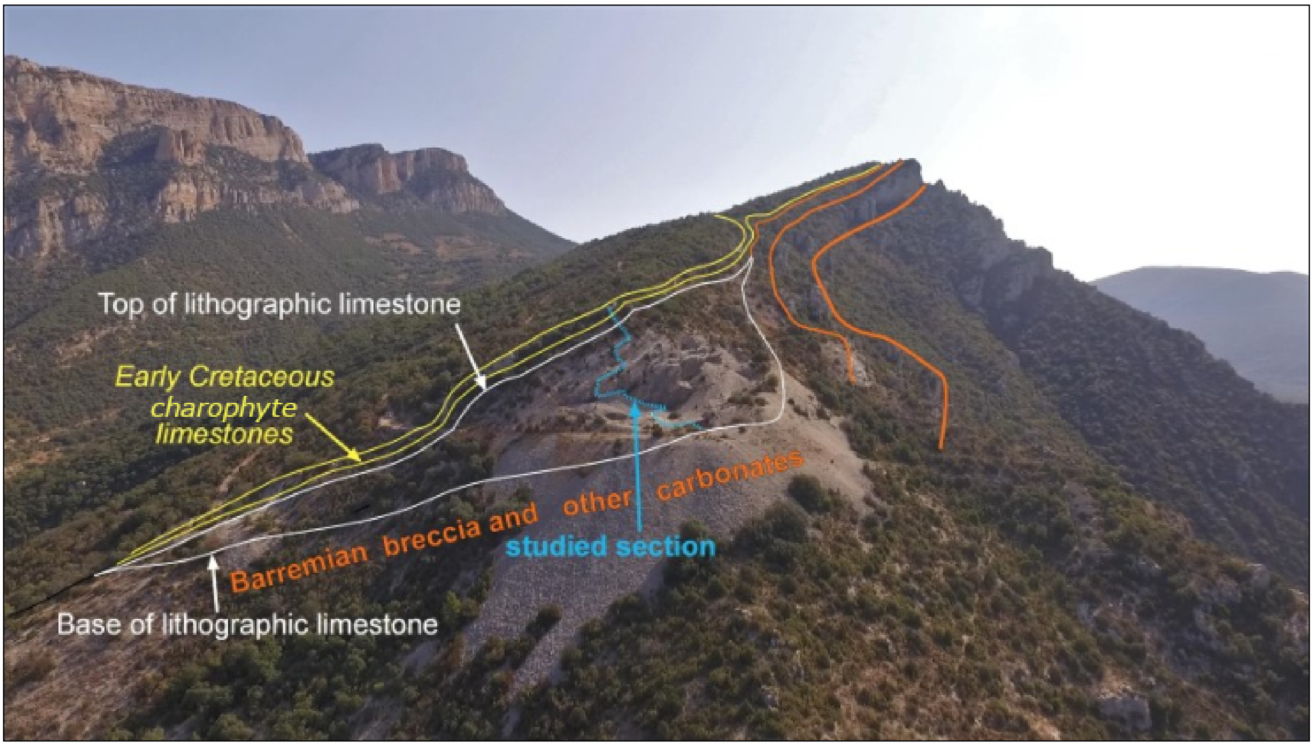

FIGURE 8. Boundaries of the "Pedrera de Meià" lithographic limestone after drone image.

for further studies. Up to 6 sub-sections have been stablished to cover the whole lithostratigraphic succession (see Fig. 10). The study of the petrographic thin-sections (Fig. III from Appendix III) revealed a general monotonous lamination throughout the section. Two main textures are found: i) a hardly laminated charophyte wackestone (see Fig. IIIC), which are only abundant to the base and the top of the section (see location of charophytes in Fig. 10), and ii) laminated mudstone (see Fig. IIIB), being darker the organic-matter rich levels and lighter the poorer one. Some laminae display accumulations of grains of quartz, organic matter or alochems (ostracods, foraminifers, charophytes, intraclast, etc., see Fig IIIA). These alochems are particularly abundant from meters 41,30 to 43 and from 44,65 to the top of the section. Postdepositional structures are restricted to few slumping at mid-high of the section (see Fig. 10).

A general trend in textural changes is observed. In the basal part (from 0cm to 800cm) lamination is distinctive, (contrasted light and dark laminae couplets). Basal mudstones contain miliolids as well as disarticulated charophyte algae, and broken ostracod shells. Dark organic-rich levels may contain plant remains or filaments. All these elements are attenuated upwards in the section (from 800cm to 4100cm), with weakly contrasted laminae and fossil skeletal fragments, mainly ostracod shells. The upper part of the stratigraphic section resembles the basal interval but is thicker (from 4100cm to 4600cm) and is transitional with the above unit "Limestone with charophytes from the Montsec" (see Fig. IIIC). It is remarkable that the boundary between the highest part of lithographic limestones and the "Limestones with charophytes from the Montsec" (CBac, unit in Pi *et al.*, 2003) is transitional as also observed in thin sections.

Laminae counting was performed on 40 thin-sections. As a result, 966 laminae were counted in a 59,9cm stratigraphic interval, providing a mean value of 16,12 laminae per centimetre. By assuming an annual deposition for each lamina couplet (dark and light laminae representing distinctive depositional conditions linked to annual seasons, i.e. dry and wet seasons), the 50 meters-thick LPM outcrop would represent a minimum time interval of 40,317 years.

DISCUSSION

For more than 100 years, the exceptional fossil content from the lithographic limestone sites from the Montsec de Meià has drawn the attention and aroused the interest of numerous paleontological research institutions and amateurs. Since arthropods are the largest taxonomic group in lacustrine ecosystems and considering taphonomic processes, it is not surprising that they are the most abundant number of species to be recovered in the outcrop with the exception of plants (more abundant in number of fossil

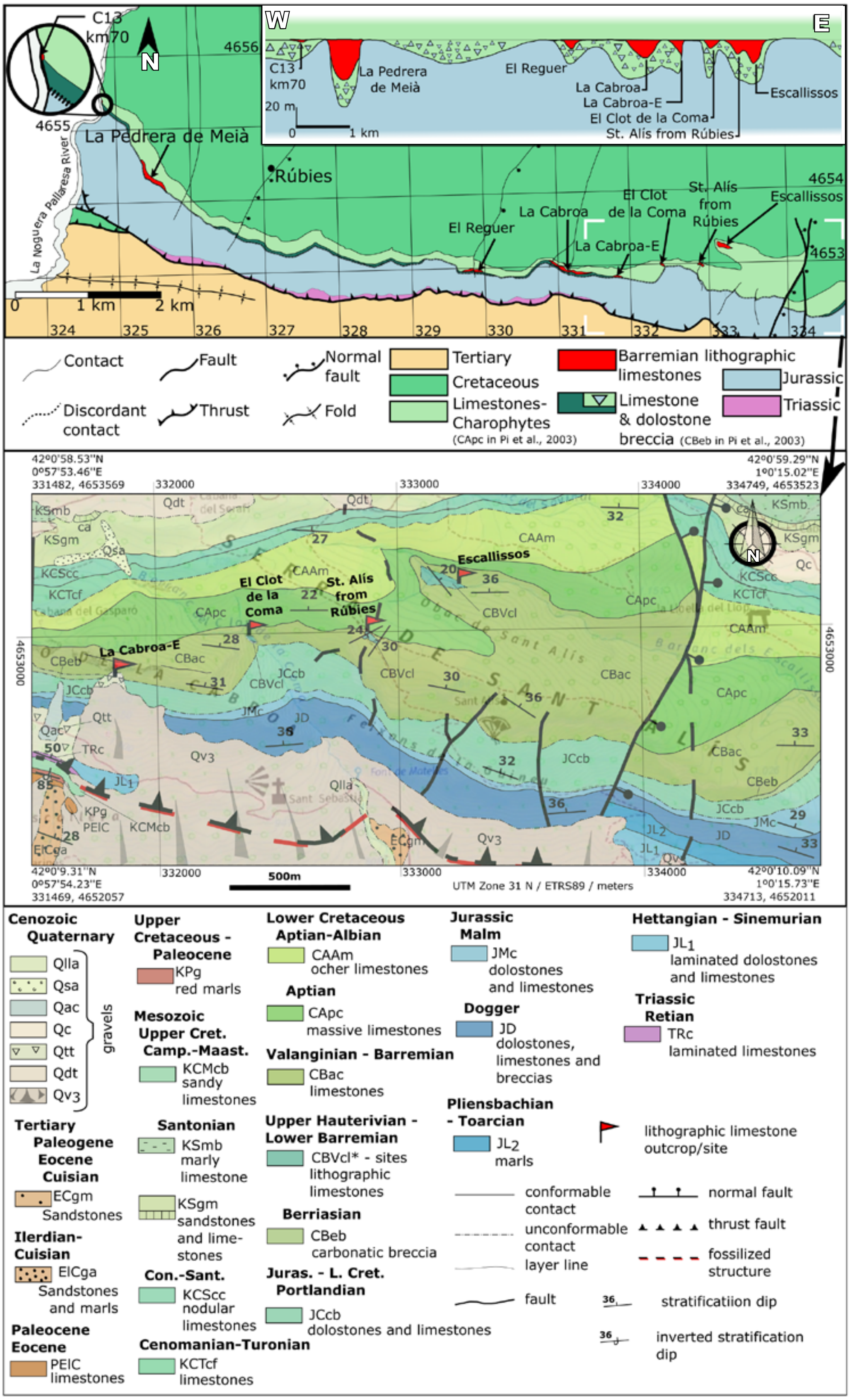

FIGURE 9. Updated geological map of the outcrops west from La Cabroa, including own information and data from Pi *et al.* (2002, 2003) (partial sheets 65-24 and 66-24), illustrating the location of rediscovered lithographic limestone outcrops. Topographic base: Mapa topogràfic de Catalunya 1:25.000. *In spite of unit CBVcl is considered from Berriasian-Valanginian stage by Pi *et al.* (2003), the present pape assigns the unit to the Uppermost Hauterivian to Lower Barremian stage, as Martín-Closas and López-Morón (1995) concludes. See text for more details.

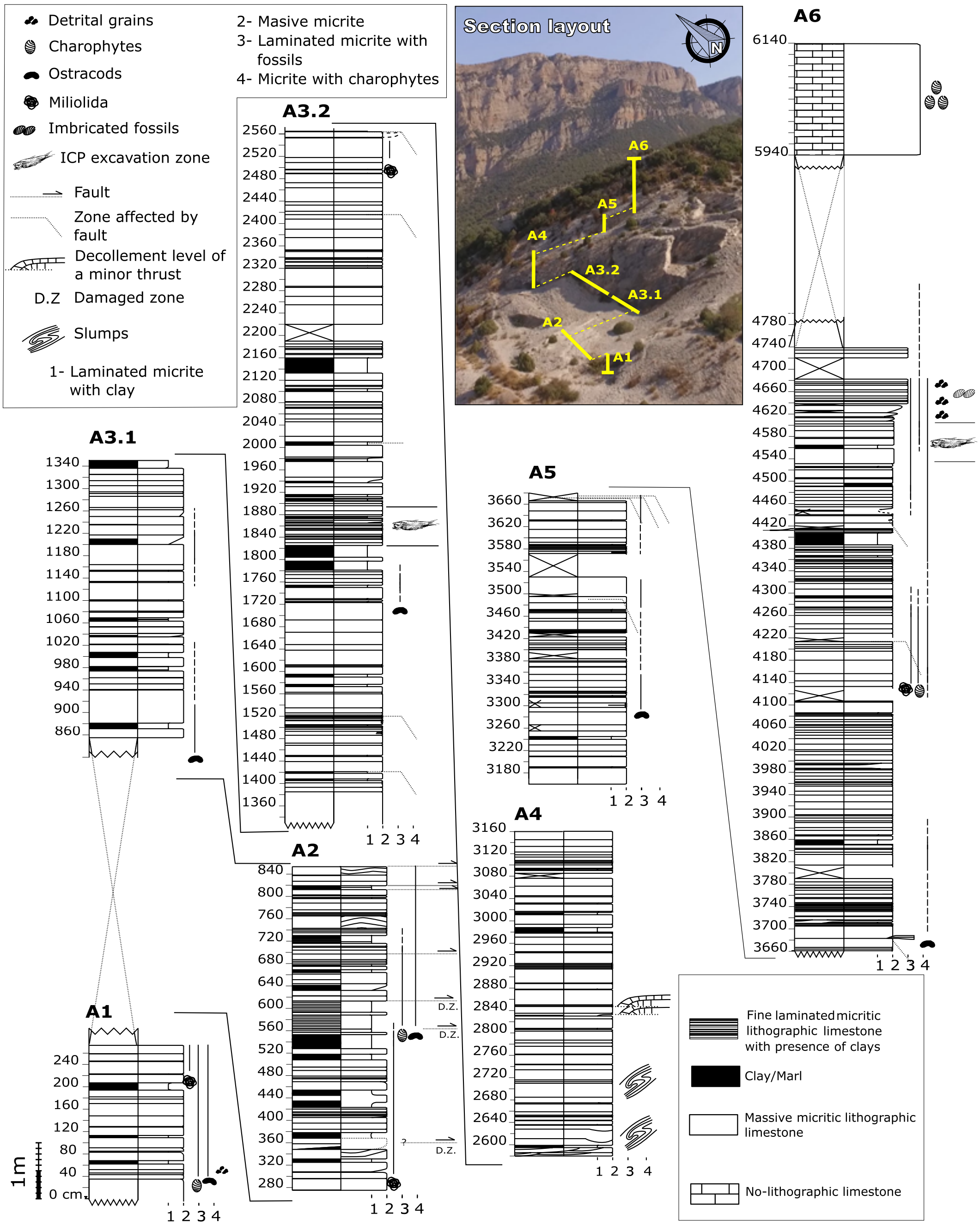

FIGURE 10. Composite stratigraphic section of La Pedrera de Meià (LPM) site. Yellow lines in drone image track the subsections.

findings, Fig. 7). However, we detected a significant bias in the museum collections depending on the interests of each institution. For instance, there is an overrepresentation of fishes in the Muséum National d'Histoire Naturelle de Paris due the particular interest of Dr. Sylvie Wenz (crustaceans are also overrepresented in this museum, but the institution did not provide us with further information). Crustaceans are also the predominant group in the paleontological collection of the Museu de Geologia del Seminari Conciliar (Barcelona), while vertebrates are overrepresented in the Institut de Palentologia Miquel Crusafont, and insects in Universitat de Barcelona and several German institutions. These observations must be considered when trying to model a fossil ecosystem from a single collection, because the resulting interpretations may be highly biased.

Although the map and work by Krusat (1966) is of high resolution in aspects such as the lithographic limestone distribution, it fails in the identification of the ferruginization horizon at the Jurassic-Cretaceous transition. On the other hand, Pi *et al.* (2002, 2003) do identify this last horizon and do not consider data in Krusat (1966). Our work aims at integrating and reviewing these two sources of information(see Figure 9).

The limited extension of the lithographic limestone (Fig. 9) was already explained by Krusat, but in four cases we could not find the outcrops due to afforestation of the area from 1960s to present. This is the case of "La Cabroa W", "Feixans W", "Feixes de la Cova de l'Onso" and "Planta del Domingo". In the case of "Planta del Domingo" site, the occurrence of units CBac and CBeb (see Appendix II of Fig. I for acronyms) in this zone strongly suggest their occurrence. Unfortunately, the access is very difficult. For future research, drone technologies are considered to approach the potential outcrops of lithographic limestones.

Finally, the fact that no lithographic limestones are found nor in Montsec d'Ares neither in the Montsec d'Estall, could also result from the scarcity of good outcrops for this interval (due to vegetation, colluvium, Montsec d'Ares landslides, etc.). A thorough prospection could lead to the discovery of some minor outcrop there. We must consider that the C13-Km70 site, in fact is adjacent to the Montsec d'Ares and was only detected after the roadcut.

To date, biostratigraphic and paleoenvironmental interpretations of the LPM site are based on the charophyte assemblages, which were firstly reported by Barale *et al.* (1984). These authors identified at least three charophyte-bearing levels at the LPM –mainly at the base, abound 38m from the previous point, and at the top stratigraphic section– while Fregenal-Martínez and Meléndez (1995) reported five levels with charophytes or their fragments. However, our field observations and thin-sections analyses allowed to identify further levels containing charophyte remains. They are present from the base of the outcrop to meter seven and are specially abundant and continuous throughout the upper part of the section, up to meter forty-one, near where Barale *et al.* (1984) indicate a punctual occurrence of charophytes. At the uppermost part of the section, the Charophyta presence continues into the lithographic limestones and transition to tabular limestones (see Fig. 10). We also observe that the occurrence of ostracods is relevant and rather continuous. Barale *et al.* (1984) indicate their presence at the bottom and to the top of the series, but we observe shells sporadically or concentrations of broken shells at some levels throughout the outcrop, as reported by Fregenal-Martínez and Meléndez (1995). These authors also find foraminifers with certain regularity at LPM, highlighting the common occurrence of miliolids only at the bottom and top of the section.

Thus, the transition to charophyte limestone both at the base and top of the section indicate that the middle part of the section (*i.e*. from 800 to 4100cm) correspond to the deepest and fully lacustrine part of the section. The fact that the charophytes above and on top of the section are of marine/transitional origin reinforces that the lithographic limestones at LPM formed in a coastal lake, which is basically in agreement with Frenegal-Martínez and Meléndez (1995) and Barale *et al.* (1984). A similar trend was observed by Mercadé (1991) to the east, at La Cabroa outcrop.

The biostratigraphic use of charophytes (Martín-Closas and López-Morón, 1995) was not successful at LPM. Instead, they identified in *Atopochara trivolvis* var. *triquetra* (an uppermost Hauterivian to lower Aptian species) in strata "(…) which pass laterally and vertically to the lithographic limestones of the Montsec, but not in the lithographic limestone". According to the geometry obtained in our study (see Figure 8 and 9), any charophyte lateral to the lithographic limestones, must be older or slightly older. Additionally, this dating is in conflict with those by Pi *et al.* (2002, 2003) who provide a Berriasian-Valanginian age without any details. Thus,a Lower Barremian age as assigned by Martín-Closas and López-Morón (1995) must be kept for now.

CONCLUSIONS

La Pedrera de Meià (LPM) has been the target of, at least, 224 scientific works that are here compiled, being the first the one published by L.M. Vidal in 1898 (Appendix I). Successive research by different scientists lead to a maximum of publications around the 1990s. Since then, publications have decreased. A minimum of activity (field work and publications) is observed during the Spanish civil war and post war (1936 to early 1960s)

An updated geological map integrating all the outcrops of lithographic limestones from Serra del Montsec has been compiled. Significantly, we include the unpublished outcrops described by Krusat (1966): "Escallissos", "St. Alís from Rúbies", "Clot de la Coma" and "La Cabroa E". Additionally, the new "C13-Km70" outcrop, in the western edge of the study region, is also incorporated.

The 50m thick LPM lithostratigraphy has been measured in detail. Except some charophyte wackestones at the base and top of the section, the succession is entirely built up by lithographic mudstones. Laminations counting suggest a minimum of 40,317 years being represented in LPM.

Geological fieldwork together with mappings, depict a site formation process starting with a regional unconformity (including ferruginization and bauxites) developed at the top of Jurassic marine carbonates. This depositional hiatus is locally followed by tens of meters of a discontinuous marine breccia or "Breccia Limit" *sensu* Peybernès (1976) above of which the lithographic limestone is recorded. LPM provide the thickest (50m) and the laterally most extensive (300m) outcrop of lithographic limestones. Above these, the succession is followed by palustrine charophyte limestones. Thus, lithographic limestones accumulated in restricted coastal lakes, with very limited connexion with seawaters, where anoxic/disoxic deep or restricted bottoms permitted fossil preservation.

Plants and fishes are the most common groups in number of fossil record at LPM and the other lithographic limestones from the Montsec de Meià range. About 72% of the type specimens (112 holotypes) are housed in Catalan museums, being the other 28% rather scattered. 112 type specimens have been described, being mostly insects (66%) and fishes (12%).

Reappraisal at LPM excavations is leading to significant new paleontological discoveries. Future and ongoing studies (which may include La Cabroa outcrop) require further understanding of the environmental lake evolution both in paleontological and sedimentary terms. From one side, isotopic, elemental, and mineralogical proxies will provide the paleolimnological evolution. The current and accurate location of fossils from present excavations in the lithostratigraphic scheme will provide a new view of paleontological succession. The resulting integrated paleoecological succession will ultimately contribute to better understand the Barremian continental biotas interrelationship and evolution.

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APPENDIX I

List of the available works from La Pedrera de Meià ordered from older to younger. References with more than 3 authors are simplified as '*et al.*' Some of the oldest (and inaccessible) works are available at https://pedrerademeia.geoparcorigens.cat/

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APPENDIX II

The stratigraphic units proposed by Krusat (1966) are similar to those proposed by Pi *et al.* (2002, 2003), although they differ in boundary position, ages, and lithology (see Appendix II Table I) This revision avoids the pre-Barremian units, that are anyway reproduced in Figure I, Appendix III.

TABLE I. Equivalence table between the nomenclature of geological units in the maps by Krusat (1966) map and ICGC maps

Krusat map units	ICGC map units	Dominant lithology	ICGC Age
Hangschutt und Hangschuttbrekzie, Bergrutsch and Alluvionen	Qt0, Qlla, Qdel, Qac, Qtt, Qdt, Qcd1 and Qv3	sand, gravels and river terraces	Quaternary
Oberes Ilerdien (Kalksandsteine, Mergel, Konglomerate)	EICga, Elm and Elgg	sandstones and marls	Ilerdian and Cuisian
Unteres Ilerdien (Alveolinenkalke, Mergel, Konglomerate)	Pelc	alveoline limestone, micritic limestone and bioclastic calcarenite	Ilerdian
Oberes Garumnien (Rote Mergel, Algenkalk)	Kpg	Garumnian facies	Paleocene and Maastrichtian
Unteres Garumnien (Kalke, Kalkesandsteine, Margel, Lignite)	KMcg, KMq3 and KMgc2	sandstone, micritic limestones and marls	Maastrichtian
Übergang Campan - Maastricht	KCcb2	sandy limestones and bioclastic limestones	Campanian
Campan – Maastrichtian (Rudistenkalke, kalksandsteine)	KCMgc1, KCcb2 an KCcb1	limestones of rudists and calcarenite	Maastrichtian and Campanian
Santon e (Rudistenkalmergel, Sandstein)	KSmb, g	limestone, grey marls and sandstone	Santonian
Santon d (Mergel, Knollenkalke)	KSmb	limestone and grey marl	Santonian
Santon c (Lacazinenkalk)	KSgm, ca	Grey and red sandstones and bioclastic limestones	Santonian
Santon b (Sandsteine, Sandmergel)	KSgm	Grey and red sandstones	Lower and Middle Santonian
Santon a (Lacazinenkalkmergel, Rudistenkalk)	KSgm, ca	Grey and red sandstones and bioclastic limestones	Lower and Middle Santonian
Coniac (Rudistenkalk, Trümmerkalk)	KCScc, KSgm	limestones, sandy limestones and marls	Coniacian-Santonian
Turon (Globotruncanenkalk)	KCTcf, KCScc	micrite limestones	Cenomanian – Turonian
Cenoman (Praealveolinenkalk)	KCTcf	micrite limestones	Cenomanian - Turonian

TABLE I. Continued

Krusat map units	ICGC map units	Dominant lithology	ICGC Age
Urgo-Apt (Nerineen- un Orbitolinenkalke un -mergel, Lignite)	CAAm, CApc	ocher limestones, marls, micritic limestones and bioclastic limestones	Aptian-Albian
Wealden 2 (Lithographischen, Plattenkalk)	CBVcl	lithographic limestones	Uppermost Hauterivian to Lower Barremian (Martín-Closas & López-Morón, 1995)
Wealden 1 (Characeenkalke)	CApc, CBac	micrite limestones and bioclastic limestones	Aptian - Barremian
Dogger-Malm (Dolomite, Kalke, dolomitbrekzie)	CBeb, JCcb, JMc, JD	carbonated breccia, limestones and dolomite	Jurassic-Lower Cretaceous
Pliensbachien - Unteres Bajocien? (Ammonitenmergel un -kalke)	JD, JL2	dolomite and limestone	Dogger
Unter Lias (Kalke, Dolomite, Oolithkalk)	JD, JL1	marls, limestones and dolomitic marls	Pliensbachian - Toarcian
Rhät? (Carniolas)(Plattenkalk)	JL1, TRc	limestones and dolomite	Sinemurian - Rhaetian
Keuper (Gipstone)	Tk	clay and gypsum	Keuper
Basalt	Tok	ophite	Upper Triassic

APPENDIX III

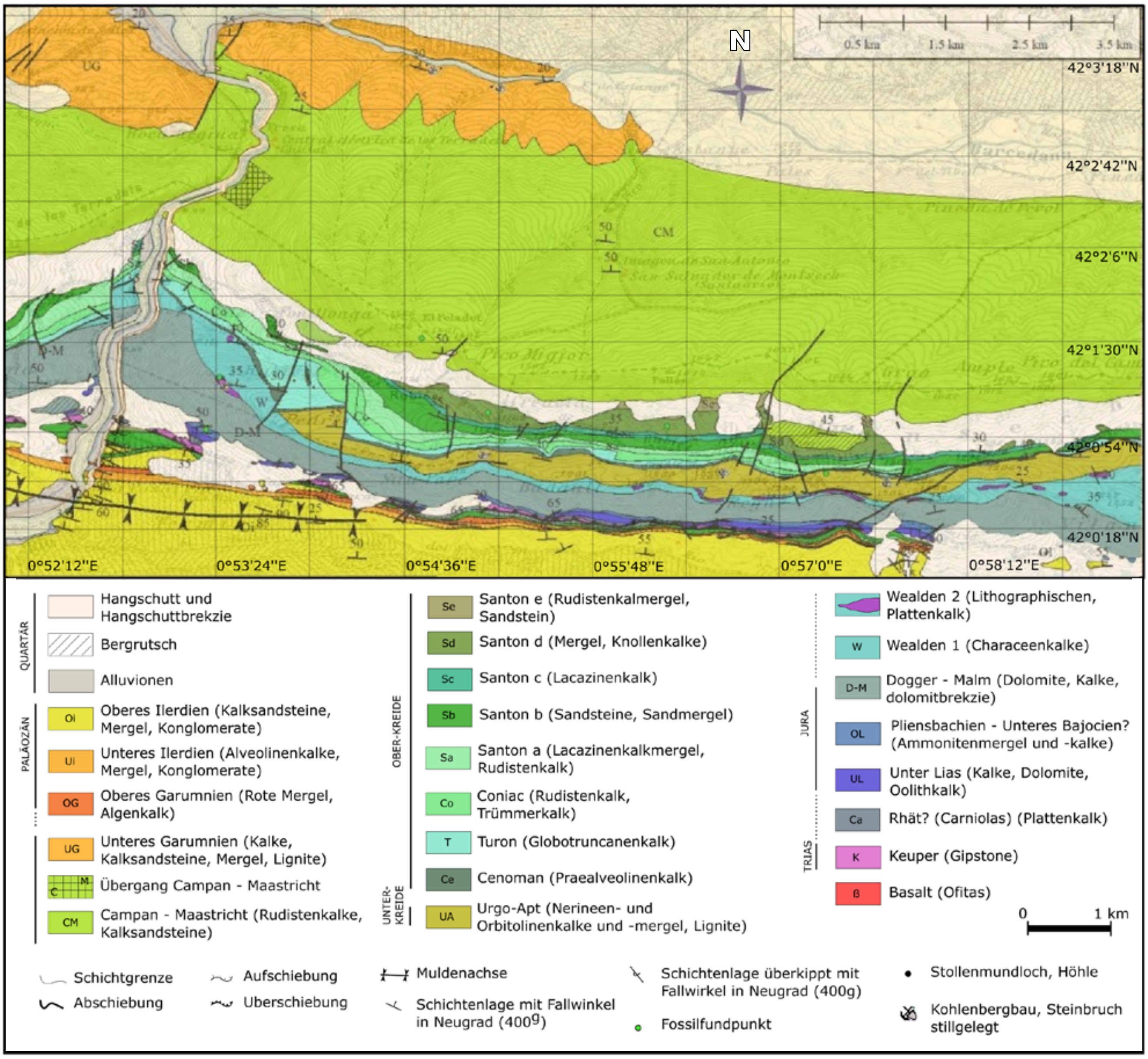

FIGURE I. A digitally redrawn version of the unpublished geological map of Krusat (1966). The original geological map was based on the 1:50.000 topographic base map of Isona-290 from 1950 by Dirección general del Instituto Geográfico y Catastral.

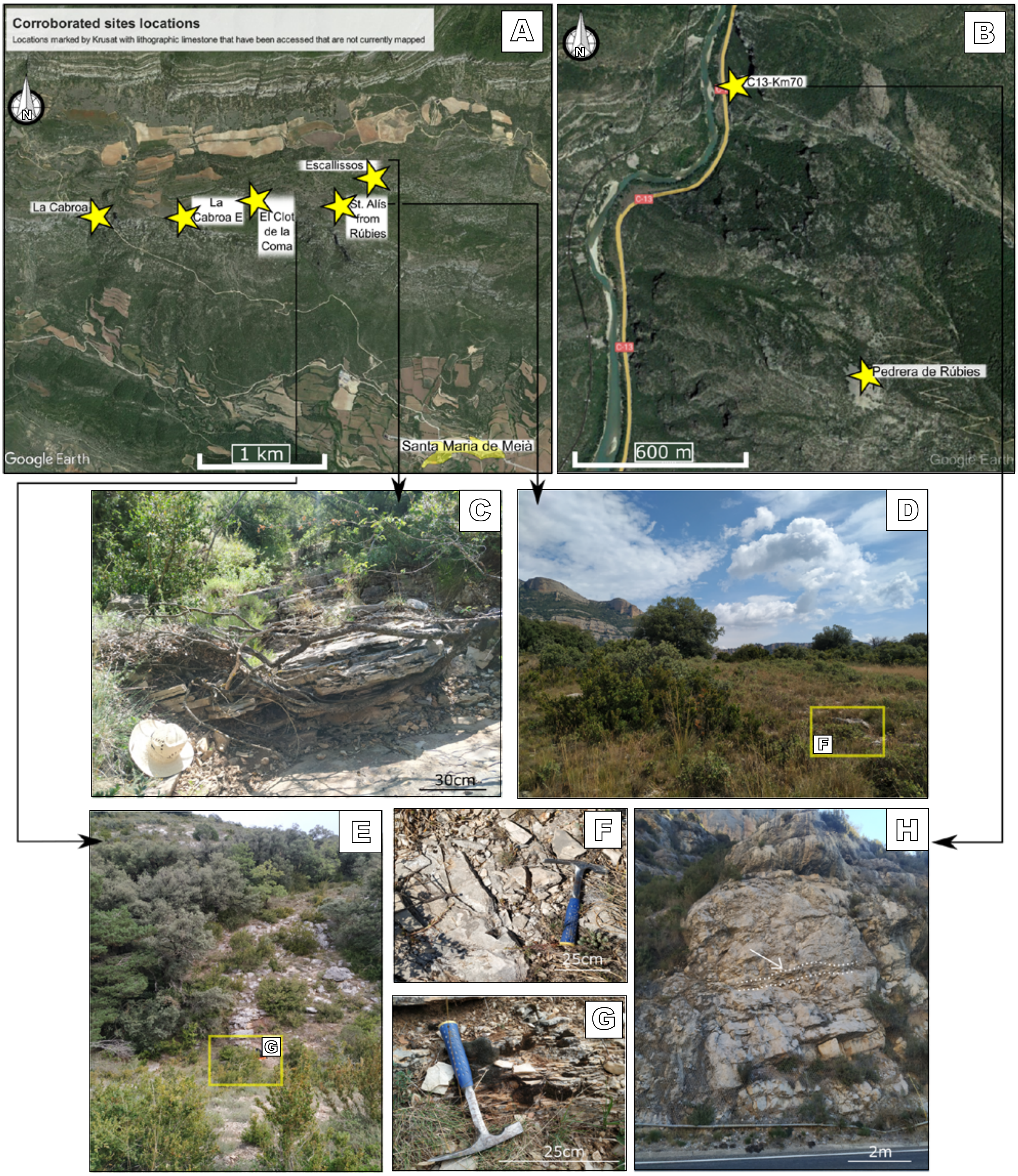

FIGURE II. Location of the lithographic limestone outcrops at Serra del Montsec after Google Earth and ground images. A) Locations marked by Krusat in his PhD thesis in 1966 that later were not mapped (Escallissos site, St. Alís from Rúbies site, Clot de la Coma site, La Cabroa E site); B) Location (Martin-Closas personal communication) near the road C13 (C13-km70); C) Escallissos outcrop; D) St. Alís from Rúbies outcrop; EL Clot de la Coma outcrop; F) St. Alís from Rúbies detail; G) El Clot de la Coma detail; H) C13-km70 outcrop.

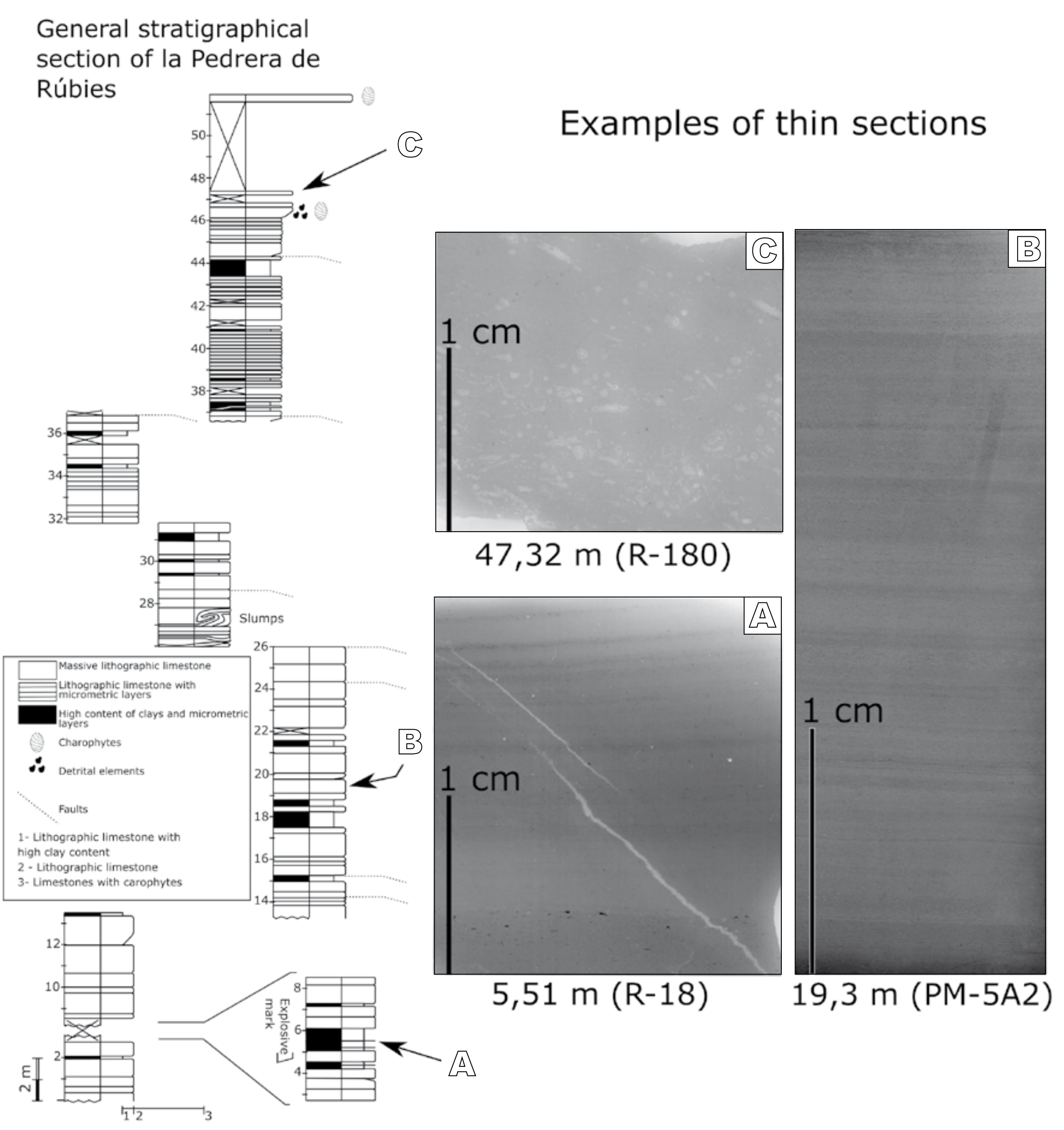

FIGURE III. Thin sections from la Pedrera de Meià and its location in the lithostratigraphic column (left). Thin section A is a laminated mudstone with occasional layers of grains (quartz, bioclasts etc.). Thin section B is an entirely muddy laminated interval. Thin section C is a wackestone with charophytes.