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Modernist architecture in Barcelona reveals a new trace fossil from the Miocene of Montjuïc (NE Spain)

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ABSTRACT

A new ichnotaxon, *Lapillitubus montjuichensis* nov. igen. nov. isp., is described from the middle Miocene (Serravallian) of Montjuïc mountain (Barcelona, northeastern Spain). This ichnotaxon consists of a horizontal to vertical, cylindrical burrow with an agglutinated lining exclusively composed of lithoclasts. *Lapillitubus montjuichensis* is interpreted as the result of the burrowing activity of a deposit- or suspension-feeding annelid worm. This new ichnotaxon extends the record of the informal group known as clast-armored or agglutinated trace fossils. In addition, since part of its type material is located in the blocks that make up the façades of several modernist buildings in the city of Barcelona, this new ichnotaxon highlights the importance of fossils in urban settings for those cases in which natural outcrops are reduced, restricted or even missing.

KEYWORDS ***Lapillitubus montjuichensis.*** **Bioturbation. Miocene. Architectural Modernism. Barcelona.**

INTRODUCTION

The presence of body-or trace-fossils in the ornamental stones that decorate the walls, façades or pavements of buildings, monuments, sculptures and streets is a common architectural feature either consciously or unconsciously appreciated in many cities of the world. For example, a Lower Cretaceous limestone rich in rudist bivalves from Vizcaya in northern Spain has been exploited both nationally and internationally as ornamental stone. This commercially sold stone is the so-called *Rojo Bilbao* or *Rojo Ereño* stone that was extracted from the second century B.C. until the end of the 1980s (Damas-Mollá *et al*., 2008, 2011). In Novelda (Alicante, southeastern Spain), a Miocene limestone is also exploited as ornamental stone under the commercial name of *Piedra Bateig* or *Piedra de Novelda*. Gibert and Goldring (2007, 2008) studied the *Bichordites* ichnofabric in one of the trade varieties of the *Piedra Bateig*, known as *Bateig Fantasía* (see also Bland *et al*., 2001). The commercial *Girona* or *Sant Vicenç* stones, consisting of Eocene nummulitic limestones from Catalonia (northeastern Spain) are also much appreciated as ornamental stones (Martinell and Domènech, 1986; Esbert *et al*., 1989, 1991; Álvarez, 2006). In summary, there are many examples for which the occurrence of body-or trace-fossils plays a key factor in the selection and exploitation of natural stones as ornamental stones; however, in other cases, its presence may be casual.

Frequently, the presence of this paleontological record preserved in our cities attracts the attention of passersby, and subsequent cultural and social events as geo-walks, guidebooks, and even smartphone- and tablet-apps have been created around such 'urban fossils', as they are colloquially known (*e.g.* McCann-Murray, 2001; Alonso and Díez-Herrero, 2007; van Roekel, 2007; Cornella i Solans, 2009; Williams, 2009; Castaño de Luis *et al.*, 2011; Díez Herrero and Vegas, 2011; Fernández-Martínez *et al.*, 2012; Donovan, 2014; Simpson and Broadhurst, 2014; Cabrera, 2016).

Occasionally, important or unique specimens, including even type material, have been found in monuments, buildings or sculptures. Marsh (1889, 1891) described a new dinosaur taxon from the blocks that constituted the abutments of a bridge over Bigelow Brook in South Manchester, Connecticut, USA. These blocks were saved during the demolition of the bridge (Galton, 1976). Shuler (1935) proposed the new ichnospecies *Eubrontes* (?) *glenrosensis* based on an uncollectible type specimen, since this track was and currently is embedded in the stone wall of the bandstand located in the Somervell County Courthouse square in Glen Rose (Texas, USA). Bland and Goldring (1995) described and figured Cambrian trace fossils of central England observed on the surfaces of several gravestones in various churchyards and cemeteries of Leicestershire in the United Kingdom. Ekdale and Bromley (2001, 2003) discovered the new ichnospecies *Gastrochaenolites oelandicus* and *Thalassinoides bacae* from the flagstones in the Geological Institute of Copenhagen University, although the type material was recovered from a known outcrop.

In the present paper, the new ichnotaxon *Lapillitubus montjuichensis* nov. igen. nov. isp. is described. *Lapillitubus montjuichensis* was first discovered in blocks of the façades and walls of different modernist buildings of the city of Barcelona in northeastern Spain. The rocks used in the construction of these buildings, Miocene sandstones from the Montjuïc mountain in southern Barcelona, are more valued for their architectural properties, such as hardness and resistance to environmental degradation than for their ornamental beauty. Despite the absence of body fossils, the so-called Montjuïc stone may be locally rich in trace fossils such as *Ophiomorpha nodosa* LUNDGREN, 1981; *Haentzschelinia ottoi* (GEINITZ, 1849) or the new ichnotaxon that is the subject of this study. The objectives of this paper are: i) to describe and name a new ichnogenus and ichnospecies; ii) to provide detailed historical and geological context on their provenance, since the study of this new ichnotaxon is mostly based in 'urban' specimens; iii) to offer an extensive and detailed discussion about the paleobiological interpretation and possible tracemaker of this ichnofossil and iv) to compare *L. montjuichensis* with other other ichnotaxa included within the informal group known as clast-armored or agglutinated trace fossils.

GEOLOGICAL AND GEOGRAPHICAL SETTING

The studied trace fossils are found at Montjuïc mountain, within the city of Barcelona in northeastern Spain; specifically at the South of its urban center, next to the industrial and cruise port (Fig. 1). The sedimentary rocks that constitute this mountain are part of the Miocene cover of the Barcelona Plain, also known as *Pla de Barcelona* (Cabrera *et al.*, 2004; Gaspar-Escribano *et al.*, 2004). This plain, consisting of a sequence of basement blocks bounded by southeastern dipping normal faults and covered by Miocene to Quaternary deposits, is located between the southeastern limit of the Catalan Coastal Ranges and the northwestern limit of the Barcelona Basin, the latter of which is an offshore extensional half-graben (Cabrera *et al.*, 2004; Gaspar-Escribano *et al.*, 2004; Fig. 1A, B). In addition, the Barcelona Plain is part of the onshore section of the Valencia Trough (Fig. 1A, B), an extensional system developed during the latest Oligocene and Miocene between the eastern part of the Iberian Peninsula and the Balearic promontory to the East (Fontboté *et al.*, 1990; Bartrina *et al.*, 1992; Roca *et al.*, 1999).

In this context and in more detail, Montjuïc mountain is located between the Collserola horst in the Northwest, which is a Northwest to Southeast trending Paleozoic uplifted tectonic block that constitutes the southeastern area of the Catalan Coastal Ranges, and the Barcelona Basin toward the Southeast (Fig. 1B). In turn, all these units are bounded by variously developed normal faults (Gómez-Gras *et al.*, 2001; Parcerisa, 2002; Salvany, 2013). The Miocene of Montjuïc mountain consists of a 200m thick succession of mudstones, marlstones, sandstones and conglomerates, which were deposited unconformably over Paleozoic, Mesozoic and lower Miocene deposits (Villalta and Rosell, 1965; Gómez-Gras *et al.*, 2001; Parcerisa, 2002; Parcerisa *et al.*, 2008; Salvany, 2013).

Villalta and Rosell (1965) studied 14 sections at Montjuïc mountain, and described 8 major units that provided a general stratigraphic overview of the mountain. Based on this study, Parcerisa (2002) differentiated 4 main lithostratigraphic units in the Miocene succession of Montjuïc. These are, from bottom to top: i) the Morrot unit (80m of sandstones and conglomerates); ii) the Castell unit (100m of mudstones, sandstones and conglomerates); iii) the Miramar unit (15m of marls) and iv) the Mirador unit (20m of mudstones, sandstones and conglomerates). Parcerisa (2002) interpreted these units, also from bottom to top, as a depositional sequence of delta plain, delta front and prodelta deposits. More recently, Salvany (2013) studied 190 drill cores from the Miocene deposits of Montjuïc and described three principal lithostratigraphic units: i) the Cyclic Lower unit; ii) the Massive unit and iii) the Cyclic Upper unit from bottom to top succession.

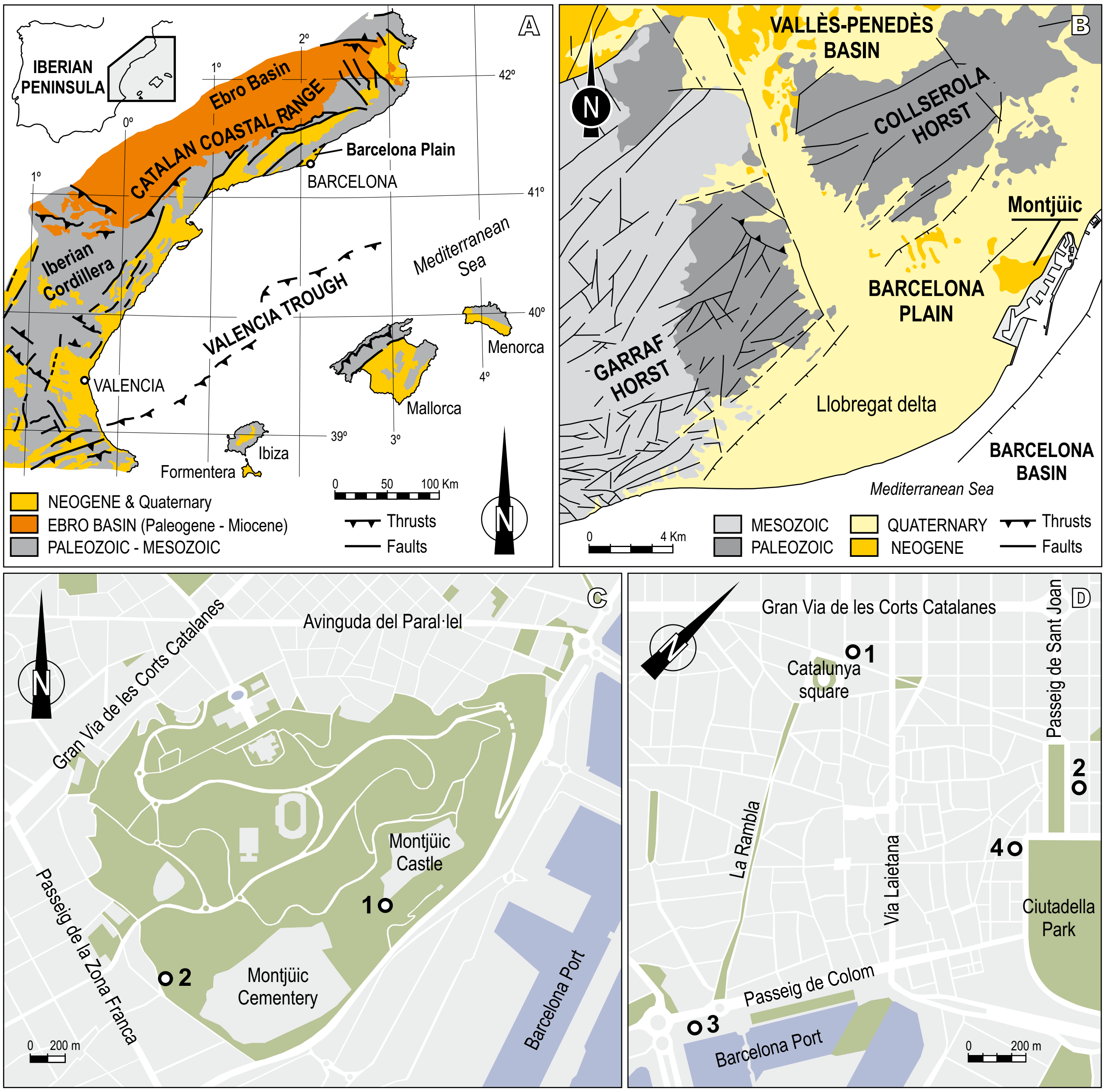

FIGURE 1. Geological and geographical setting of the studied area. A) Geological map of Catalan Coastal Ranges and Valencia Trough, showing their location in the Iberian Peninsula (modified from Roca and Guimerà, 1992). B) Simplified geological map of Barcelona, including the Miocene Montjüic mountain (modified from Parcerisa, 2002; Salvany, 2013; http://www.icgc.cat/). C) Simplified street map of Montjuïc mountain and location of Miocene outcrops containing *Lapillitubus montjuichensis*. Circle 1, outcrop located just below the southeastern wall of the Montjuïc castle; circle 2, Roman quarry. D) Simplified street map of downtown Barcelona and location of the four modernist buildings containing *L. montjuichensis* (circle 1: *Casa Pascual i Pons*; circle 2: *Palau de Justícia*; circle 3: *Duana*; circle 4: apartments house).

This author divided the Montjuïc mountain section in two main sectors (eastern and western) separated by the Miramar fault, a normal fault with the same southwest to Northeast trending orientation as the extensive fault system that originated the Valencia Trough and subsequently the Catalan coastline. Salvany (2013) proposed two main depositional events, a retrograding alluvial system, consisting of the Cyclic Lower and Massive units followed by a prograding deltaic system, forming the Cyclic Upper unit. Based on the foraminiferal associations, the Miocene deposits of Montjuïc have been dated as Serravallian (late middle Miocene; N9-N10 zones of Blow, 1969; see also Gómez-Gras *et al.*, 2001 and Parcerisa, 2002).

Trace fossils pertinent to this study have been observed in sandstone levels located just below the southeastern wall of Montjuïc castle (Fig. 1C) and at the Roman quarry on the *Carrer dels Ferrocarrils Catalans* (Catalan Railways Street) (Fig. 1C). These outcrops correspond with the Castell unit of Parcerisa (2002) and/or the equivalent Cyclic Upper unit of Salvany (2013). Other specimens have been examined in several modernist buildings in downtown Barcelona that have been constructed with Montjuïc stone (see next section).

HISTORICAL BACKGROUND

Montjuïc mountain, Barcelona's quarry

The first extractions of stone from the Montjuïc mountain were carried out by the Iberians during approximately the third to fourth centuries B.C. (Álvarez, 1988a; Roca, 2000 and references therein). However, it was the Romans (third century B.C) who performed a systematic and massive exploitation, by means of several quarries, during the construction of the settlement that eventually would become the city of Barcelona (Álvarez, 1988a; Roca, 2000). The extraction of Montjuïc stone was very active during the Middle Ages (thirteenth to fifteenth centuries), reaching its maximum exploitation from the second part of the nineteenth century throughout the major development of the city of Barcelona. The last active quarries were closed during the 1950s (Roca, 2000).

It is still possible to observe many quarries in the Montjuïc mountain, though most have been urbanized and converted to parking lots, botanical gardens, cemeteries or outdoor theatres. For instance, *El Fossar de la Pedrera*, that was once a big quarry, is currently a cemetery (Fig. 2C); similarly, the current *Teatre Grec* (a modern outdoor theatre) was constructed from a small quarry face (Fig. 2E) and the *Sot del Migdia*, a huge quarry, is now used for driving school instruction (Fig. 2F). Nevertheless, the most impressive quarry exposures are probably those facing the sea on the southwestern slope of the mountain, just below the Montjuïc castle (Fig. 2A, B, D) (see Álvarez, 1987, 1988a, b).

Many important buildings and monuments were constructed with the Montjuïc stone throughout the history of Barcelona. Examples include the Roman Temple of Augustus (built at the end of the first century B.C., of which only four columns are preserved; Fig. 3D); the Roman wall of the city, whose remains can be observed in different places; the Barcelona Cathedral, built during the thirteenth to fifteenth centuries (Fig. 3E); the churches of *Santa Maria del Mar* and *Santa Maria del Pi* of the fourteenth century (Fig. 3B, F); the historic building of the University of Barcelona, built during the late nineteenth century (Fig. 3C); and the oldest parts of the *Sagrada Familia* Temple, constructed at the end of nineteenth century (see Masriera *et al*., 2005 for details; Fig. 3A). Although the greater part of the extracted stone was used in Barcelona, it was also appreciated in other areas of Catalonia, Spain and even Europe (Salceda i Castells, 1987; Roca, 2000, 2003; Masriera *et al*., 2005). Roca (2000) estimated that an approximate volume of 28,000,000m^3 of Montjuïc stone has been extracted, representing 9% of the total volume estimated for the mountain.

Two principal constructional varieties of Montjuïc stone have been exploited. They are the *Blanquet* and *Rebuig* types. Whereas the *Blanquet* variety consists of whitish, compacted, well-cemented and silicified quartzose sandstones having a high constructional quality, the *Rebuig* variety (*Rebuig* in Catalan means waste) consists of easily friable, non-silicified or slightly silicified, opaline sandstones which are much less appreciated (Parcerisa, 2002).

Montjuïc stone in the Modernist architecture of Barcelona

Modernism constituted a movement of cultural renewal (*e.g*. in painting, sculpture, decorative arts, architecture, literature and philosophy) from the late nineteenth to early twentieth centuries, and emerged almost simultaneously both in Europe and the Americas. Although this cultural phenomenon adopted local features in each country, the common objective was based on the cultivation of arts and on the return to natural forms (Palés, 2004). In fact, based on the different countries in which modernism was developed, it was portrayed with various names such as *Jungenstil* in Germany, *Modern Style* in Britain, *Art Nouveau* in France and Belgium, *Liberty* in Italy, *Sezession* in Austria-Hungary or *Modernisme* in Catalonia, northeastern Spain.

In Catalonia, *Modernisme* methods were focused on architecture, which subsequently promoted an additional important development in the decorative arts, especially that of stonemasons (Palés, 2004). More than forty architects contributed to the development of the Catalan Modernism movement (Permanyer and Levick, 1992); among which is the remarkable body of work of Antoni Gaudí (1852-1926), Elies Rogent i Amat (1821-1897), Lluís Domènech i Montaner (1850-1923), Josep Puig i Cadafalch (1867-1956) and Enric Sagnier Villavecchia (1858-1931).

Montjuïc stone was broadly used throughout the Catalan Modernism. In fact, this cultural movement coincided with the maximum exploitation of this stone, especially the high-quality *Blanquet* variety (Roca, 2000; Parcerisa, 2002) (Fig. 4A, B). Notably, many modernist buildings of Barcelona were constructed of Montjuïc stone; for example the *Hospital de la Santa Creu* i *Sant*

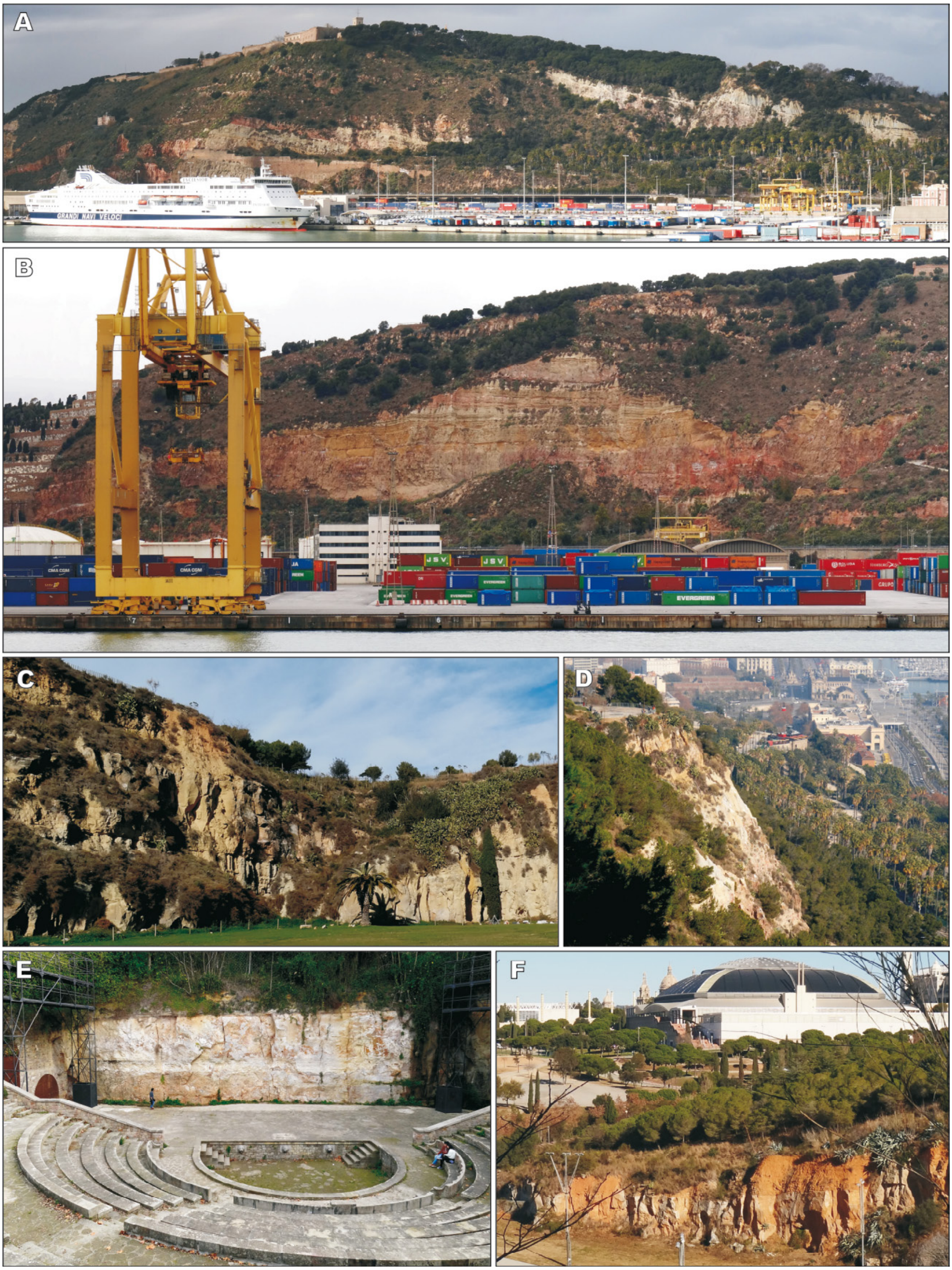

FIGURE 2. Montjuïc quarries today. A, B) Different views of the quarry high walls facing the sea on the southwestern part of the mountain, just below the Montjuïc castle. C) The *El Fossar de la Pedrera* quarry. D) The *Mirador de l'Alcalde* quarry. E) The *Teatre Grec* quarry. F) The *Sot del Migdia* quarry.

FIGURE 3. Examples of monumental buildings in Barcelona built with Montjuïc stone. A) *Sagrada Familia* Temple (XIXth century). B) Church of *Santa Maria del Mar* (XIVth centrury). C) Historic building of the Universitat de Barcelona (late nineteenth century). D) Roman Temple of Augustus (first century B.C.). E) Barcelona Cathedral (XIIIth to XVth centuries). F) Church of *Santa Maria del Pi* (XIVth centrury).

Pau, *Palau Güell*, *Sagrada Familia* Temple, *Casa Batlló*, *Casa Milà*, *Casa Vicens* and the *Park Güell* (Roca, 2000, 2003; Masriera *et al*., 2005).

Casa Pascual i Pons, *Palau de Justícia*, *Duana* and the modernist architect Enric Sagnier

Four modernist buildings within the city of Barcelona, constructed of Montjuïc stone (*Blanquet* variety) and designed by the architect Enric Sagnier, have been involved in this study (see below for more details; Fig. 1D). Enric Sagnier Villavecchia (Fig. 4F), involved in the design of more than four hundred buildings catalogued in Barcelona, was one of the most prolific architects of the Catalan Modernism (Barjau, 1985; Sagnier, 2007; Úbeda, 2009). His most famous work probably is the *Temple Expiatori del Sagrat Cor* located at the Tibidabo mountain and prominently visible from everywhere in Barcelona.

The principal historical, architectural and geographical features that characterize these four buildings are the following:

FIGURE 4. Historical pictures. A, B) Active quarries and stonecutters at Montjuïc (approximately 1890–1910). C) Catalunya square and the beginning of *Passeig de Gràcia*; *Casa Pascual i Pons* at the right side (approximately 1940). D) *Palau de Justícia* (approximately 1910); in the *Passeig de Lluís Companys* (main façade). E) *Duana*; Montjuïc mountain in the background (approximately1890). F) Architect Enric Sagnier Villavecchia (approximately 1915). (Photographs A, B and F are courtesy of A. Sagnier).

Casa Pascual i Pons (Figs.1D; 4C; 5D–F). This building, designed by Enric Sagnier and constructed from 1890 to 1891, is located in the city block bounded by *Passeig de Gràcia* (main façade), *Ronda de Sant Pere* and *Carrer de Casp* streets. Its ground floor, towers, courtyard, main staircase and balconies are constructed of Montjuïc stone (Rogent i Pedrosa, 1897; Sagnier, 2007). Originally this was an apartment building and currently is the office building of an insurance company.

Palau de Justícia (Figs.1D; 4D; 6E, F, I–L). This building, designed by Enric Sagnier and Josep Domènech i Estapà, was constructed from 1887 to 1908. It is located in the city block bounded by streets *Passeig de Lluís Companys* (main façade), *Carrer dels Almogàvers*, *Carrer de Roger de Flor* and *Carrer de Buenaventura Muñoz*. This monumental building, one of the most important works of Sagnier, is built almost entirely of Montjuïc stone (Roca,

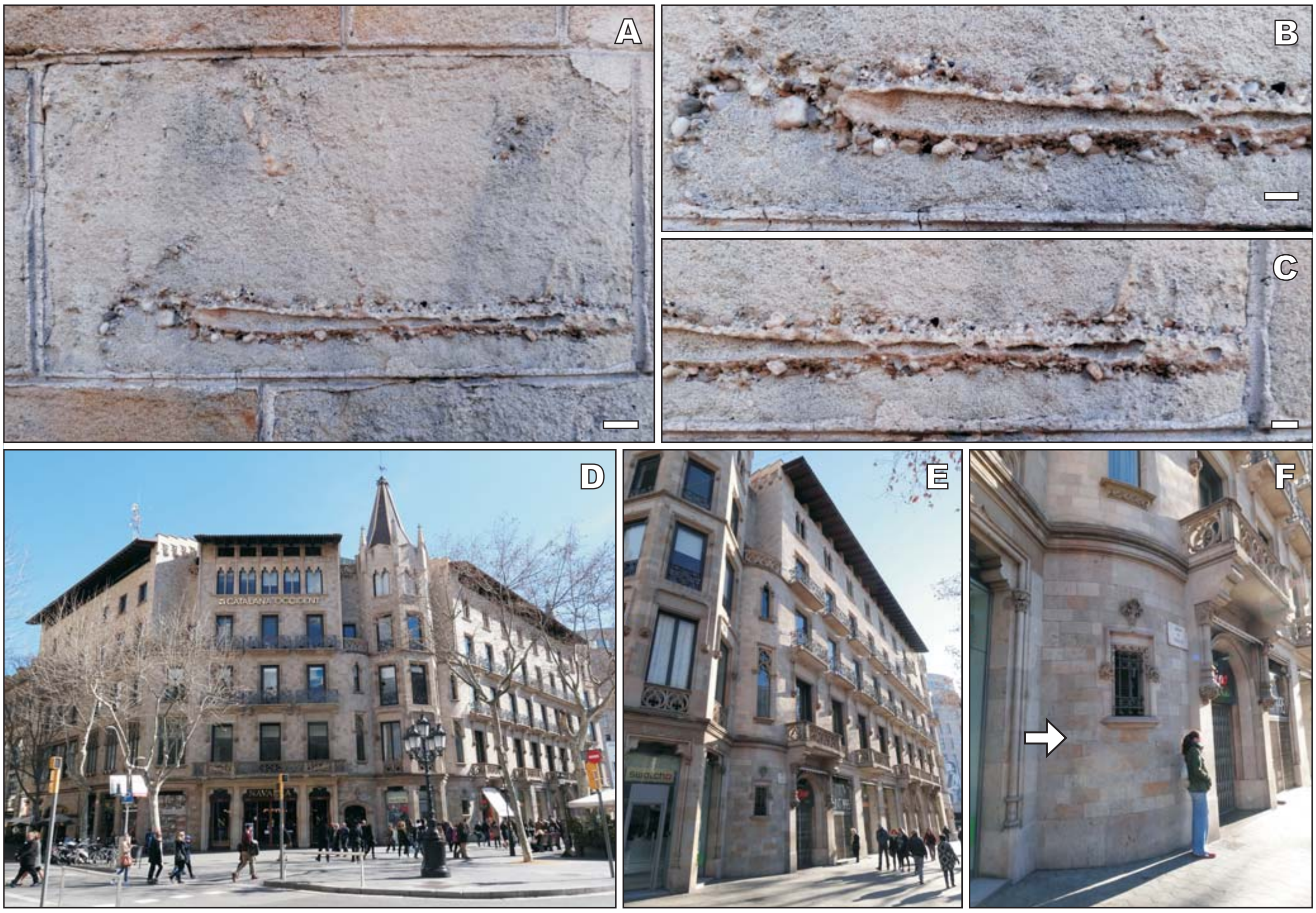

FIGURE 5. *Lapilitubus montjuichensis*. A–C) Holotype, overall view and two details (A scale bar: 2cm; B, C scale bar: 1cm). D) *Casa Pascual i Pons*, corner of *Passeig de Gràcia* (main façade) and *Carrer de Casp*. E, F) Detail of the corner and location (white arrow) of the holotype.

2003; Sagnier, 2007). Today, this building retains its original function.

Duana (Figs. 1D; 4E; 7B). This building was designed by Enric Sagnier and Pere Garcia Fària, and constructed from 1896 to 1902 (Pujol i Brull, 1902; Sagnier, 2007). It is located in the street *Passeig de Josep Carner* (n. 27-29), next to the port and just between the squares *Plaça de les Drassanes* and *Plaça del Portal de la Pau*. This building has lost its original function and now houses offices of the Tax Authority.

Residential apartments (Figs. 1D; 7G, H). This building, partially designed by Enric Sagnier, was constructed in 1886 at the corner formed by the streets *Passeig de Picasso* (n. 10 to 16) and *Carrer de la Princesa* (n. 58).

All mentioned buildings are protected under the legal concept of a 'Cultural Asset of Local Interest' (*Bé Cultural d'Interès Local* in Catalan, BCIL) stated by the Catalan Cultural Heritage Act (IDs 1506, 254,766 and 666–667 respectively, of the Architectural Heritage Inventory of Barcelona City Council). This protection, among other purposes, implies that the façades of these buildings must be protected and conserved; consequently, the studied trace fossils already are protected by law. Nevertheless, the presence of these trace fossils has been recorded in the respective technical files for the Architectural Heritage Inventory of each of these buildings. Therefore, if any of the involved buildings eventually undergo restoration or even damage that may affect these ichnofossils, the above institution is alerted and prepared to act for their preservation. Serendipitously, the presence of trace fossils in stone blocks of these buildings is entirely coincidental, and apparently did not serve any ornamental purpose.

SYSTEMATIC ICHNOLOGY

Ichnogenus. ***Lapillitubus*** nov. igen.

Type ichnospecies. *Lapillitubus montjuichensis* nov. isp.

Etymology. From Latin *lapillus* 'small stone or pebble' and *tubus* 'tube, pipe, trumpet', *i.e.* tube of small stones; referring to the diagnostic lining and architecture of these traces.

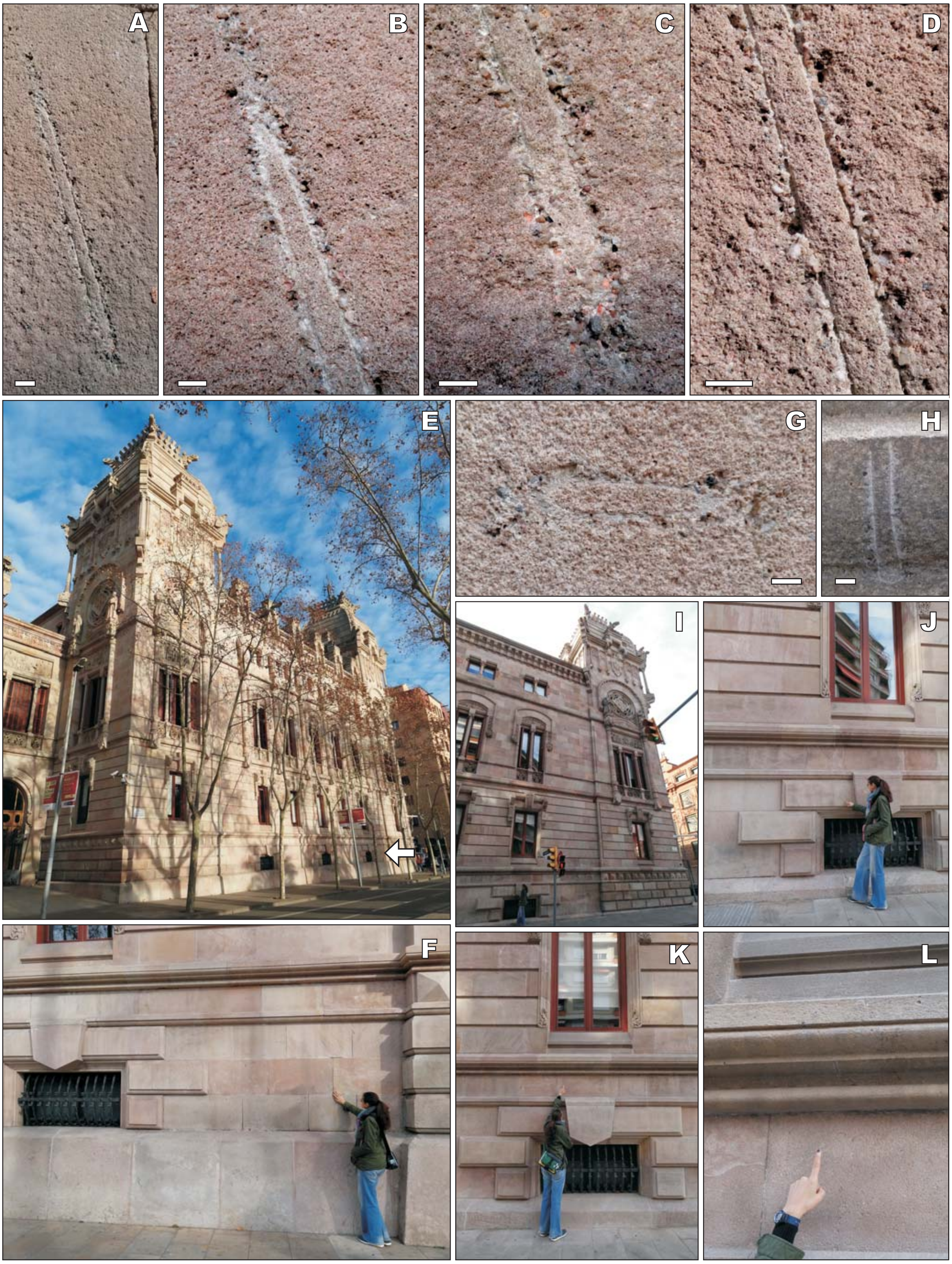

FIGURE 6. *Lapilitubus montjuichensis.* A–D) Paratype 1, overall view and three details (A scale bar: 2cm; B–D scale bar: 1cm). E–F) Location of A (white arrow; main façade of the *Palau de Justícia*, *Passeig de Lluís Companys*). G) Paratype 2 (scale bar: 1cm). H) Paratype 3 (scale bar: 1cm). I, J) Rear façade of the *Palau de Justícia* and location of G (*Carrer de Roger de Flor*). K, L) Location of H (Rear façade of the *Palau de Justícia*, *Carrer de Roger de Flor*; next window on the left with respect to J).

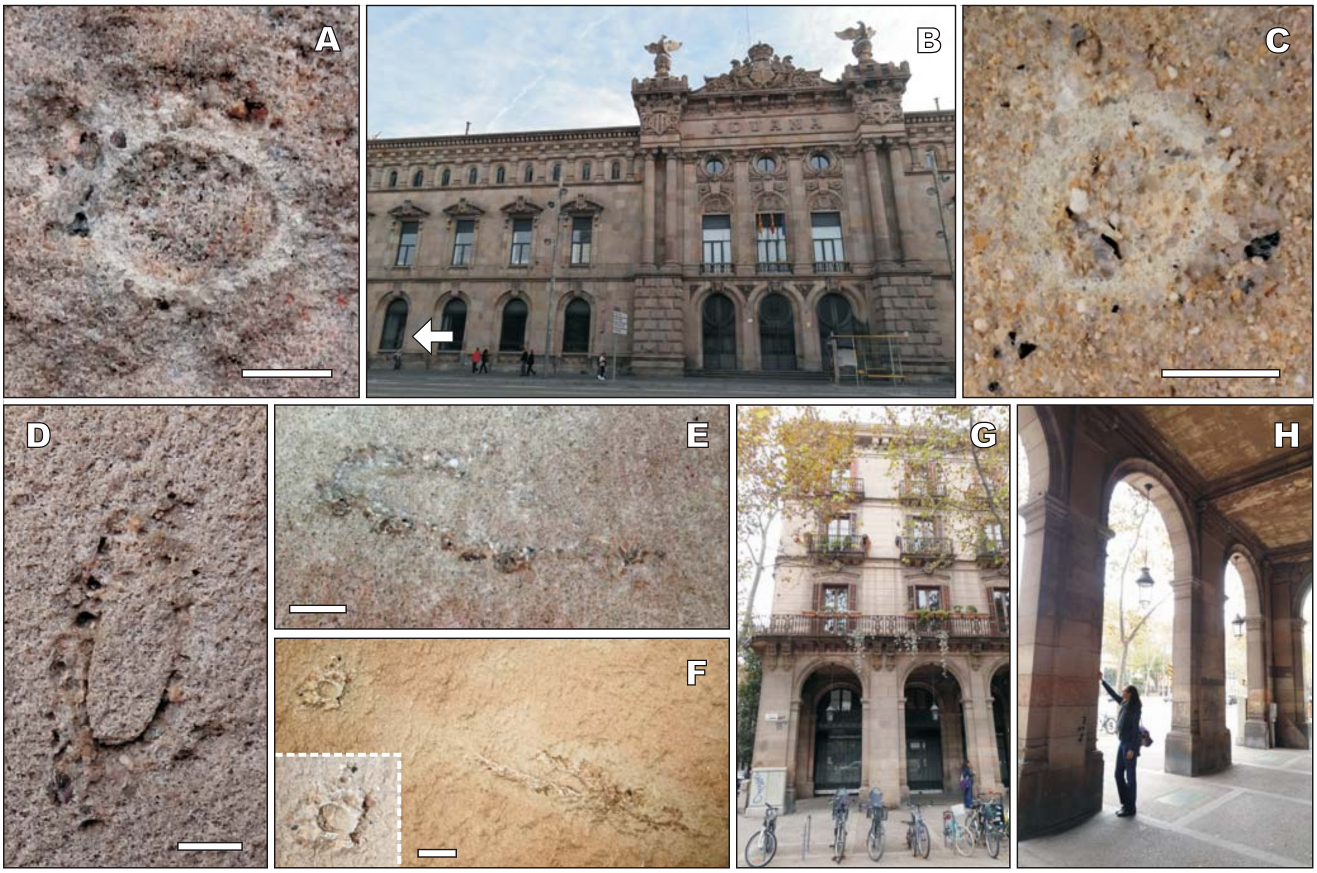

FIGURE 7. *Lapilitubus montjuichensis*. A) Paratype 4. B) Location of A (white arrow; main façade of the *Duana*, *Passeig de Josep Carner*). C) Paratype UB-IC 726. D) Paratype 5. E) Paratype 6. F) Paratype 7, and detail of its upper part. G) Location of D (corner formed by *Passeig de Picasso* and *Carrer de la Princesa*). H) Location of E and F (same column as G, but in the inner part of the arcade). Scale bars: 1cm.

Diagnosis. Vertical to subvertical, unbranched, rectilinear tubes, circular or subcircular in cross-section, with a lining composed of lithoclasts (never bioclasts) and mud-cemented sandstone.

Ichnospecies. *Lapillitubus montjuichensis* nov. isp. Figures 5–8

Etymology. After the Montjuïc mountain in Barcelona city, northeastern Spain, where the type locality is situated.

Holotype. An uncollectible specimen located in *Casa Pascual i Pons*, in the northwestern part of the façade facing the street *Passeig de Gràcia* (n. 2-4) (Fig. 5A–F).

Paratypes. Three uncollectible specimens located in the *Palau de Justícia*, specifically one in the southeastern part of the main façade (Fig. 6A–F) and two in the northwestern part of the rear façade (Fig. 6G–L); one uncollectible specimen located in the southwestern part of the main façade of the *Duana* (Fig. 7A, B); and three uncollectible specimens in the arcade of the residential apartments located in the *Passeig de Picasso* street (n. 10 to 16) (Fig.7D–H); and UB-IC 726 (Fig. 7C).

Material. Specimen UB-IC 726 is deposited in the Ichnological Collection of the Faculty of Earth Sciences at the University of Barcelona in Spain. This specimen was recovered from the warehouse of Montjuïc stone located in the municipality of Les Borges Blanques, in Lleida province, northeastern Spain. This warehouse stores the last stock of Montjuïc stone, which is reserved for the construction of the *Sagrada Familia* temple. The existence of type specimens has been registered in the *Patrimoni Arquitèctonic de l'Ajuntament de Barcelona* (Architectural Heritage inventory of the Barcelona City Council), within the respective technical files of each of the involved buildings (IDs 254, 666-667, 766 and 1506). The two specimens observed in the natural outcrops, just below the southeastern wall of the Montjuïc castle and at the Roman quarry located at the street *Carrer dels Ferrocarrils Catalans*, have not been collected because these areas are protected due to their antiquity and historical value (Fig. 1C; 8A–D).

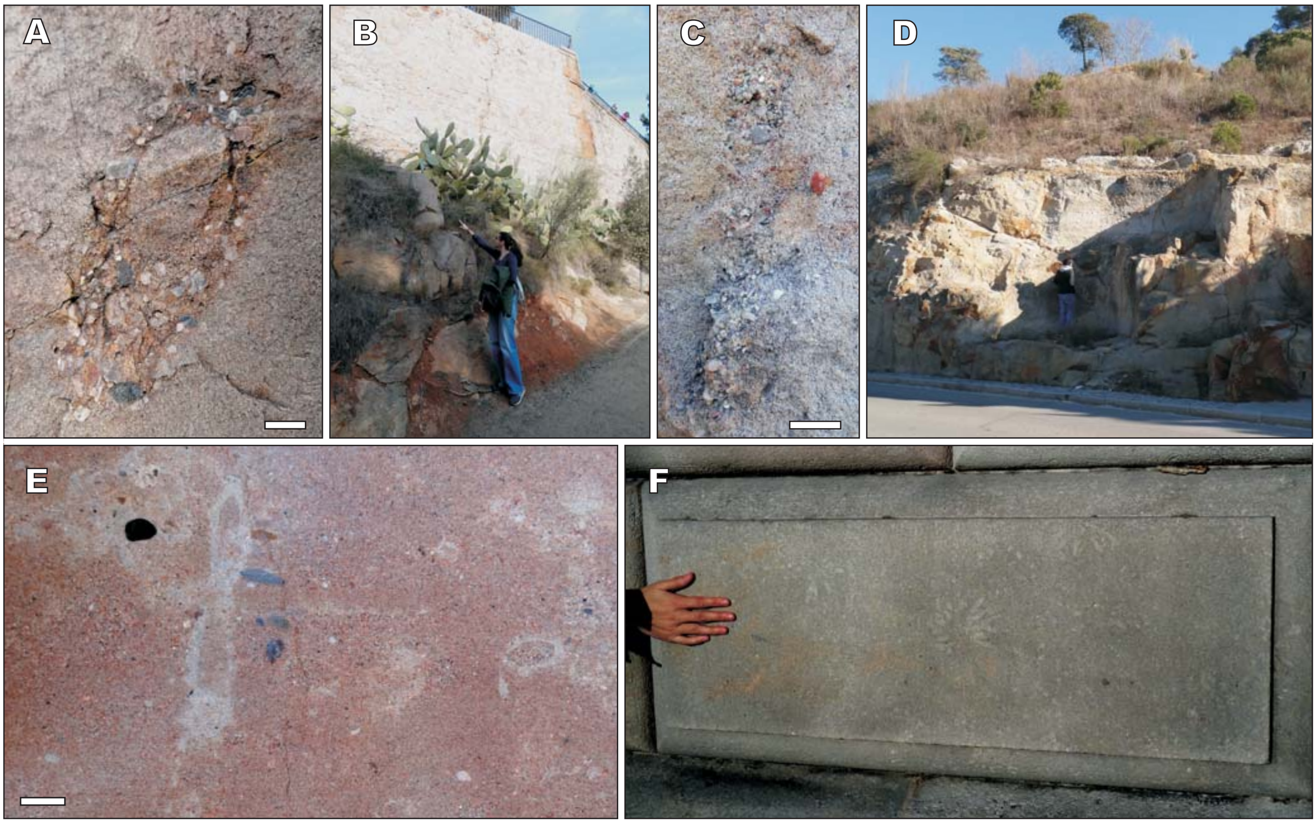

FIGURE 8. *In situ* specimens of *Lapillitubus montjuichensis* and associated ichnofabrics. A, B) Specimen located just below the southeastern wall of the Montjuïc castle (scale bar: 1cm). C–D) Specimen located in a Roman Quarry (*Carrer dels Ferrocarrils Catalans*) (scale bar: 2cm). E) *Ophiomorpha i*chnofabric. F) *Haentzschelinia* ichnofabric observed in one of the blocks of the main façade of the *Palau de Justícia*.

Type locality. Upper part of the Castell unit (*sensu* Parcerisa, 2002) of the Montjuïc mountain (Serravallian; late middle Miocene) in Barcelona, Spain (Figs. 1C; 8A–D). See the Geological and Geographical setting section.

Diagnosis. Same as the ichnogenus, but with the lining exclusively composed of rounded to subrounded lithoclasts with a random disposition.

Description. *Lapillitubus montjuichensis* is a simple, cylindrical and rectilinear burrow preserved as full relief and typically exposed as longitudinal, transverse or oblique sections (314mm of maximum observed length) (Figs. 1; 5–8). This ichnotaxon has no branching and bears a central lumen surrounded by an agglutinated lining. The infill of the lumen is the same sandstone that composes the rock matrix. By contrast, the lining consists of a basal (internal) layer of mud-cemented sandstone (corresponding to the finer-grained sediment of the matrix), which is internally smooth and externally agglutinates rounded to subrounded quarzitic lithoclasts (1 to 10mm in diameter) which display a random disposition (Figs. 5A–C; 6A–D, G, H; 7A, C–F; 8A). The lining may reach up to 10mm in thickness. The burrows are circular to subcircular in cross-section (Fig. 7A, C), with an average diameter of the lumen (internal diameter) ranging from 10 to 20mm, and those of the complete burrow (external diameter) ranging from 15 to 30mm.

Traces were studied both in natural exposures and in blocks embedded in the façades of different buildings (Figs. 5–8). The two specimens observed in the natural outcrops (Montjuïc castle and the Roman quarry; Fig. 8A–D) consist of vertical to oblique sections perpendicular to bedding. Additionally, in the Roman quarry outcrop, which contains *L. montjuichensis*, it is also possible to observe isolated specimens of *Ophiomorpha nodosa*. By contrast, those observed in building blocks were exposed during their extraction and cutting and consequently, depending of the polishing of these blocks, a variable amount of details can be observed. In these cases and in general, identification of their orientation with respect to bedding is not straightforward and may even be impossible.

Lapillitubus montjuichensis may occur isolated or as a minor component of ichnofabrics dominated by *Ophiomorpha*. Usually, *Ophiomorpha* is the most abundant ichnogenus both *in situ* in the outcrops in the Montjuïc mountain and in the constructional blocks of many buildings (Fig. 8E). In addition, ichnofabrics dominated by

Haentszchelinia ottoi have been observed in the blocks of several buildings (Fig. 8F).

Remarks. Diagnoses of the different ichnotaxa included within the informal group of clast-armored or agglutinated trace fossils (see the Discussion section) are mainly based on the compositional and architectural features of their respective linings. Since the features that characterize the lining and architecture of *L. montjuichensis* had not been registered until now nor included in these diagnoses, the erection of this new ichnotaxon is totally justified (see the Discussion section).

The holotype, preserved in the *Casa Pascual i Pons*, exhibits the best preservation; even showing a certain relief which allows observation of some aspects of its three-dimensional architecture. The paratypes, located in various buildings, consist of longitudinal to transverse sections with different degrees of preservation. Additionally, although one specimen has been collected (UB-IC 726) (see Material), it cannot be designated as holotype because it also consists of a transverse circular section that not defined the overall architecture of this new ichnotaxon.

From the 1950s to the present day, the extraction of Montjuïc stone has been forbidden and all quarries closed (Roca, 2000). Some of these quarries are currently protected for their antiquity and historical value, such as the Roman Quarry, while others have been urbanized and converted to parking lots, botanical gardens, cemeteries or outdoor theatres (see previous section). Consequently, it is not possible to extract samples from these sites. Occasionally, some walls of these quarries are partially to completely covered by plants, lichens or fences, thus hindering their further study.

With respect to ichnotaxonomy, the erection of new ichnotaxa from uncollectible type material that remains *in situ* at the outcrop or even immobile and embedded in monuments or buildings, is a typical practice. Harland (1978) erected the new ichnotaxon *Caprionichnus steinvikensis* from an uncollectible holotype preserved *in situ* at the type locality. Shuler (1935) proposed the new ichnospecies *Eubrontes* (?) *glenrosensis* from a type specimen embedded in the stone wall of a monument-type building (see Introduction), but took clay and plaster casts of the type specimen. However, since the casts currently are lost, Adams *et al.* (2010) generated a high-resolution, three-dimensional digital model of this track and proposed the term 'digitype' to define this kind of digital type material. Bromley *et al.* (2003) erected the new ichnogenus and ichnospecies *Hillichnus lobosensis* from the Paleocene of Point Lobos, California, USA; as the holotype is uncollectible, these authors described an iconotype which will remain at the type locality until it ultimately disappears through erosion.

The fourth edition of the International Code of Zoological Nomenclature (ICZN; Ride *et al.*, 1999) is not restrictive regarding disposition of type-material. Following its "Recommendation 16C - Preservation and deposition of type specimens", the ICZN recommends (not mandatorily) that "authors should deposit type specimens in an institution that maintains a research collection, with proper facilities for preserving them and making them accessible for study". Accordingly, in the present study, one of the paratypes has been deposited in an institutional collection, and it is noted that those specimens preserved in modernist buildings are: i) perfectly accessible; ii) included in the inventory of the Architectural Heritage of Barcelona and iii) protected by law due to the singular features of the buildings.

Such terms as plastotype, iconotype or digitype currently are not recognized by the ICZN (see also Adams *et al.*, 2010; Díaz-Martínez *et al.*, 2015), although they

TABLE 1. Clast-armored or agglutinated trace fossils (excluding fossil caddisfly cases). Age, Locality and Reference exclusively refer to those of the respective type material (*: Bohemian Cretaceous Basin)

Ichnogenus	Lining composition	Age	Locality	Reference
Baronichnus	Flat bioclasts (mainly bryozoans)	Upper Cretaceous	Touraine, France	Breton, 2002
Crininicaminus	Crinoid stem plates	Lower Carboniferous	Kentucky, USA	Ettensohn, 1981
Diopatrichnus	Bivalve, other mollusks, plant fragments, and other platy materials	Eocene	California, USA	Kern, 1978
Eklexibella	Lagenid foraminifera or nuculid bivalves	Lower Jurassic	Buttenheim, Germany	Keupp *et al.*, 2014
Ereipichnus	Tabular-shaped, skeletal particles	Lower Cretaceous	Alicante, Spain	Monaco *et al.*, 2005
Lapillitubus	Lithoclasts	Miocene	Barcelona, Spain	*This paper*
Lepidenteron	Fish skeletal fragments	Cretaceous	Germany & Czech Republic (*)	Fritsch, 1878
Nummipera	Nummulitid foraminifera	Eocene	Split, Croatia	Hölder, 1989

are used more and more often. Because type specimens sometimes are uncollectible, then only casts, three-dimensional models, pictures or movies may be deposited in an institution. Alternatively, it could be that no fossil material is deposited in an institution. Future editions of the ICZN should include a solution to this current issue.

DISCUSSION

Comparison with other clast-armored or agglutinated trace fossils

The diagnostic agglutinated lithoclastic lining of *Lapillitubus montjuichensis* allows inclusion of this new ichnotaxon within the informal group known as clast-armored or agglutinated trace fossils. Until now, the fossil record of these kind of burrows consisted of the following ichnogenera: *Lepidenteron* Fritsch, 1878; *Diopatrichnus* Kern, 1978; *Crininicaminus* Ettensohn, 1981; *Nummipera* Hölder, 1989; *Baronichnus* Breton, 2002; *Ereipichnus* Monaco *et al*., 2005 and *Eklexibella* Keupp *et al*., 2014. Because most of these ichnotaxa consist of unbranched burrows, the nature of the agglutinated material of their linings is the principal difference and their most significantly diagnostic feature (Table 1).

Lepidenteron is partially lined with bioclasts, typically fish skeletal fragments (see Bather, 1911; Suhr, 1988; Jurkowska and Uchman, 2013; Bieńkowska-Wasiluk *et al*., 2015). The lining of *Diopatrichnus* is principally composed of bivalve mollusks, but may also contain other mollusks, plant fragments, and other dominantly platy or needle-like materials (Kern, 1978; Gibert, 1996). The ichnogenus *Crininicaminus* exhibits a lining almost exclusively composed of crinoid stem plates (Ettensohn, 1981; Seike *et al*., 2014). Large foraminiferans of the family Nummulitidae make up the lining of the ichnogenus *Nummipera* (Hölder, 1989; Jach *et al*., 2011). Breton (2002) erected the ichnotaxon *Baronichnus* for simple burrows with flat bioclasts (mainly bryozoans) that are orthogonally arranged to the main axis of the tunnel. In the case of *Ereipichnus*, the lining is characterized by imbrication of tabular, skeletal particles, mainly orbitolinid foraminifers, flat fragments of bivalve and gastropod shells, and carbonate or siliciclastic grains (Monaco *et al*., 2005). Finally, the lining of *Eklexibella* may be composed, depending on the ichnospecies, of size-sorted, usually elongated, lagenid foraminiferans or of nuculid bivalves that lack a preferred orientation (Keupp *et al*., 2014). Therefore, based on these descriptions, *L. montjuichensis* shows a range of unique and unprecedented features (mainly the presence of lithoclasts instead of bioclasts, as outlined in the previous section), that allows its differentiation from other ichnotaxa already described as clast-armored or agglutinated trace fossils.

Also included within this informal group of clast-armored or agglutinated trace fossils are the ichnotaxa: *Indusia* Bosc, 1805; *Folindusia* Berry, 1927; *Ostracindusia* Vyalov, 1973; *Terrindusia* Vyalov, 1973; *Conchindusia* Vyalov and Sukatsheva, 1976; *Pelindusia* Vyalov and Sukatsheva, 1976; *Secrindusia* Vyalov and Sukatsheva, 1976; *Mixtindusia* Sukatsheva, 1980 and *Piscindusia* Jarzembowski, 1995. These ichnotaxa were erected in order to describe fossil cases (coated by mollusk shells, vegetal fragments, conchostracan valves, mineral matter, bivalve and gastropod shells, graded pellets, larval secretions, clasts and leaf bites, and fish bones, respectively) interpreted as produced by caddisflies (Insecta: Trichoptera) (Jarzembowski *et al*., 2016; Genise, 2017, and references therein). Despite having an agglutinated coating, since these ichnotaxa consist of cases (or body tubes) and not burrows, they are not compared with *L. montjuichensis*. Occasionally, some transverse or partial sections of some of these ichnogenera could be interpreted as *Lapillitubus*. However, its greater diameter and length, together with the absence of a blind end as well as a conical morphology, prevent its confusion with caddisfly cases.

Identity of the tracemaker

The use of bio-r lithoclasts to construct and/or to strengthen the lining of different types of burrows and/or dwellings is a common architectural behavior that diverse invertebrates conduct today. Among them, the marine tube-dwelling polychaetes and freshwater caddisfly larvae probably are the best known taxa engaging in these behaviors. While these polychaetes mainly generate dwelling structures consisting of permanent burrows or partially buried mobile tubes (*e.g*. Ekdale *et al*., 1984; Bromley, 1996), caddisfly larvae exclusively create mobile agglutinated cases that are used for many different functions (*e.g*. Williams *et al*., 1987; Boyero and Barnard, 2004). Because the latter consist of short body tubes and are not real burrowers, caddisflies have not been considered as possible trace-makers for the trace fossils mentioned herein.

Similar coated body tubes may also be constructed by modern polychaetes. Pectinariid polychaetes such as *Pectinaria gouldii*, *Lagis koreni* or *Cistenides gouldii* are informally known as ice-cream cone, tusk or trumpet worms because they construct conical dwelling-structures with an agglutinated wall of sand grains (Bromley, 1996; Finger *et al*., 2008; Martin, 2013). In fact, Finger *et al*. (2008) described Miocene foraminiferal concentrations arranged in tube-like structures very similar to those constructed by modern *Pectinaria*. Sabellariid or sandcastle worms such as the genera *Sabellaria* or *Phragmatopoma* live in highly populated colonies that can generate reefs of conjoined agglutinated tubes of mineral grains, although usually colonizing hard substrates (Vovelle, 1965; Wilson, 1970; Wang *et al*., 2010).

By contrast, many genera of modern polychaetes also are able to produce lined burrows comparable to *L. montjuichensis*. For example, *Diopatra cuprea* (family Onuphidae) constructs vertical tubes with an organic wall (a mucous lining) that can be reinforced, principally in its protruding upper part, with shell fragments, sediment or plant debris serving as the agglutinated particles (Myers, 1972; Howard and Frey, 1975; Bailey-Brock, 1984; Bromley, 1996; Gibert *et al*., 2013; Martin, 2013; Belaústegui and Muñiz, 2016). Other onuphid polychaetes such as *Onuphis microcephala* and *O. conchilega* also use shell fragments and sediment grains to partially reinforce the walls of their burrows (Schäfer, 1972; Martin, 2013). The construction of protruding chimneys, similar to those produced by *Diopatra*, also has been described for oweniid polychaetes of the genus *Owenia* (Howard and Frey, 1975; Bromley, 1996). Martin (2013) figured the shell-coated tube of the bloodworm *Glycera dibranchiata* (Family Glyceridae). Terebelloid and maldanid worms (*Lanice conchilega* and *Clymenella torquata*, respectively) also build their tubes with sand and/or shell fragments (Seilacher, 1951; Schäfer, 1972; Bromley, 1996).

Among these structures, Termier and Termier (1969) figured several tubes produced by modern terebelloid polychaetes in the western coast of Madagascar; such coated structures, built usually in a siliciclastic depositional setting, exhibit an overall morphology and a lithoclastic lining practically identical to that observed in *L. montjuichensis*. For these reasons, it is very probable that *Lapillitubus montjuichensis* would have been built by a suspension- or deposit-feeding, tube-dwelling annelid worm. Finally, in the case of *L. montjuichensis*, the choice of exclusively quartzitic lithoclasts to build the lining seems to respond to the use of only available material and not to a specific behavior. By contrast, the size fraction selected for these lithoclasts, commonly larger than that of the englobing sediment, could correspond to an explicit behavior.

CONCLUSIONS

Lithoclast-coated burrows from the late middle Miocene (Serravallian) of Montjuïc mountain in Barcelona city, northeastern Spain, are described as *Lapillitubus montjuichensis* nov. igen. nov. isp. This new ichnotaxon enlarges the fossil record of the group informally known as clast-armored or agglutinated trace fossils.

This new trace was likely excavated by suspension- or deposit-feeding, tube-dwelling worms in shallow marine conditions in a transitional depositional setting, probably in a river delta.

Urban fossils, such as those located in buildings, sculptures, pavements and other anthropogenic settings, may constitute a very important part of our paleontological heritage. Consequently, further study would be necessary to obtain better knowledge of the paleobiological and anthropogenic control of these interesting fossils.

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