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ORIGINAL ARTICLE

Urban Geodiversity and Decorative Arts: the Curious Case of the "Rudist Tiles" of Lisbon (Portugal)

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Abstract One key element defining the appearance of Lisbon is the whitish Cretaceous fossiliferous limestone locally known as "liós." The liós is abundantly used as ornamental stone in Lisbon's monuments and buildings. Ceramic tiles are also paramount in creating Lisbon's character. Their ubiquitous presence, their colourful patterns and even the unique way they reflect sunlight make them inextricable from the city's ambiance. In nineteenth century tiles, the urge to emulate liós—a noble and expensive building material—in building façades led to the use of the trompe l'oeil technique to mimic the appearance of the stone. The representation of the fossiliferous liós pattern is so realistic that Radiolitid and Caprinid rudists may easily be identified. At present, "rudist tiles" are not recognized as such by decorative arts experts. These tile panels are commonly seen as lesser productions depicting indistinct "marbled" patterns and often ignored or even discarded. This novel interpretation of rudist tiles leads to the clear recognition of the liós—a typical element of local geodiversity—depicted in them, thus revealing their uniqueness and close connection with the geodiversity and the cultural ambiance of Lisbon. Hopefully, this will boost the geoawareness of the public and art experts alike, making the need for the geoconservation of the liós and its palaeontological record and the preservation of these tiles as cultural heritage all the more obvious. This example of the influence of geodiversity in the creation of artistic concepts and representations and, consequently, in the shaping of the cultural landscape of Lisbon is all the more important now that the application of Portuguese tiles for inclusion on the UNESCO World Heritage List is being prepared.

Keywords Urban geodiversity · Lisbon · Fossils · Rudists · Ceramic tiles · Cultural heritage

Introduction

One essential, not to mention obvious, characteristic of geodiversity is the fact that it is diversified, and diversity, the condition of being different, i.e., of having many different forms, structures, origins, ideas, etc., is paramount. Be it biological, geological or cultural, diversity is the most fundamental value to safeguard. If we succeed in respecting and conserving diversity—both natural and cultural—everything else will be protected.

Another fundamental aspect of diversity is that from the interaction of its different manifestations—geological, biological and cultural—new elements arise, both quantitatively and qualitatively, that in turn will be integrated in the global diversity, changing it in the process.

Diversity is, therefore, an interactive and evolving entity. Geodiversity—here understood "sensu lato", as in Gray (2004), as the abiotic natural diversity generates biological diversity, and biodiversity originates new geological features. And both give birth to cultural diversity, which, in turn, has a huge impact in nature. Adapting the social metaphor of Fuch (1990) for contemporaneous North American culture, one could say that nature is an ever-changing interactive kaleidoscope of diversity.

Nevertheless, the deep impact of the natural world in cultural diversity is often neglected. Maybe because humans—especially in urban Western Culture—tend to be anthropocentric, frequently seeing themselves as entities detached from

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nature, existing beyond and above it, with an almost supranatural status. In this respect, as in many others dealing with nature, Western Judeo-Christian culture, for instance, is ambivalent. According to the Christian Bible, humankind was created by a supranatural entity: "(…) God created man in his own image, in the image of God created he him; male and female created he them" (King James Bible, Genesis 1:27). However, God—in different mythologies and modern religions alike, from Sumerian to Egyptian and Classical Greek, and in Islam—"(…) formed man of the dust of the ground (…)" (King James Bible, Genesis 2:7), from clay, a natural—geological!—substance, thus making man, from this religious and cultural standpoint, simultaneously is a supranatural being in its origin, but also a natural entity by virtue of its components.

However, the importance of nature in generating and supporting cultural diversity is probably one of the best arguments for boosting public awareness for its conservation. The fact is that human culture does not have an independent existence from nature. The Portuguese people, using a very simplistic example, are a beach loving, sardine eating and wine drinking lot. It would be quite difficult for Portuguese culture to arise in the mountainous regions of the Andean Plateau or in the middle of freezing Siberia.

In his discussion on why is it important to conserve and manage the geodiversity of the planet, Gray (2004: 70) enumerates its many values, one of them being the "cultural value". He then goes on to define it as: "(…) the value placed by society on some aspect of the physical environment by reason of its social or community significance." However, in order to place value—a subjective concept—on something it is paramount to know that that thing exists; only then it will be possible to realize that it may have some kind of worth. The problem is, as the Portuguese saying reveals (more or less): what you do not know, you do not see, meaning, we only pay attention and value the things that are part of our conscious experience. And this brings us to the topic of this work: the curious and up until now overlooked example of nineteenth century ceramic tiles depicting Cretaceous rudist limestone used for covering the façades of many buildings in Lisbon.

Inadvertently, the fossils of rudists—a conspicuous element of liós, the beige to rosy Cretaceous limestone so amply used in Lisbon façades (e.g. Silva 2009, 2016; Carvalho et al. 2013), as well as in urban settings all over the world where the Portuguese cultural influence is important (for example, in Brazil, see Del Lama et al. 2015)—made their way from geodiversity into decorative arts. By trying to imitate liós in tile patterns, artisans also copied—sometimes vividly—the contour of the cross sections of the fossils in it and now their depictions may be seen in many tile-clad building frontages of Lisbon (Silva 2005). By doing so, unwillingly, the artisans, more than building walls and façades, built bridges between geodiversity and decorative arts, making the cultural value of the Cretaceous rudist fossils from the Lisbon region—we hope—all the more obvious for geologists, decorative arts experts and the general public alike.

Many works in the past focused on a variety of aspects of geology and geodiversity in urban settings, ranging from urban geoheritage conservation to urban geoturism and from educational applications to historical implications and interpretations (e.g. Díaz Martinez and García Pardo 1988, Prosser and Larwood 1994, Zinko 1994, Dove 1996, Silva and Cachão 1998, Del Lama et al. 2015, Palacio-Prieto 2015, Rodrigues and Agostinho 2016). There are also a number of very interesting papers dealing with geological aspects relevant for the analysis and interpretation of visual works of art (e.g. Tobisch 1983; Pizzorusso 1996), but none on the relevance of particular ornamental stones in generating decorative arts patterns specifically created to mimic them, namely in tiles.

This paper will address an overlooked aspect of the impact of local geodiversity on the cultural character of the capital of Portugal. Also briefly discussed will be its potential role in rising the public's understanding of the values of geodiversity, namely its cultural value, thus boosting geoawareness and, hopefully, compelling people to take action and influence political decisions supporting geoconservation and cultural heritage protection. The discussion will be centred on the remarkable example of typical Lisbon nineteenth century decorative ceramic tiles reproducing the distinctive fossiliferous pattern of liós, the Cretaceous rudist limestones quarried locally and copiously used in the monuments and façades of the capital of Portugal.

Cretaceous Rudists and Urban Geodiversity in Lisbon

During "Geology in the Summer" activities in Lisbon, geology popularization actions sponsored by the Portuguese science and technology agency "Ciência Viva" (Live Science) from 1998 up to 2014, the participants in urban geodiversity interpretation trails set in Lisbon (Silva and Cachão 1998; Silva 2009, 2016) were told that from then on they would start seeing fossils of rudists everywhere. From that moment on, they would come across rudists in the façades of their homes, on the stairways of shopping centres, on subway walls and pavements, and not to mention on their kitchen countertops. That is how common liós (also spelled "lioz"), the Cretaceous whitish fossiliferous limestone with rudists, and its varieties, is in Lisbon buildings, making it a fine example of an ex situ—albeit local—geodiversity element with high cultural value (in the sense of Brilha 2016).

Liós is a commercial name, not a lithologic type. Therefore, the name liós is used lightly to characterize ornamental stones quarried in the Lisbon region having in common the fact that they are Upper Cretaceous fossiliferous limestones with a patchy look. The more traditional liós is whitish or beige. Varieties of this type of rock are distinguished on the basis of their general pattern (more or less fossiliferous or with stylolites) and general colour: abancado (reddish), azulino (bluish-grey), St. Floriant Rose (rosy), etc. (ORNABAE 2012).

The Rudists: a Very Successful Mesozoic Group

Hippuritaceans, informally known as rudists, are an extinct group of Mesozoic bivalves. Rudists dominated late Mesozoic Tethyan tropical shallow seas. They become the most important reef builders during that time (e.g. Dechaseux et al. 1969, Hernández 2011). This group includes some of the most specialized and successful bivalve molluscs that ever lived. Rudists evolved in the Late Jurassic, Oxfordian and—although a reduction in their diversity and abundance is perceived already in the Campanian record (Philip 1998)—they persisted up until the end of the Cretaceous (Steuber et al. 2002), probably falling victims of the same global mass extinction event that wiped out their cephalopod molluscan relatives—the Ammonoidea—in the seas, and non-avian Dinosauria, on land, among many others.

Rudists were benthic, filter feeding organisms as most bivalves are. They are known for their varied and exuberant shell shapes. In fact, this morphological plasticity was paramount for their diversity and dominant role in shallow water ecosystems across the tropical Cretaceous Tethys Ocean. In the Cretaceous upper Cenomanian stratigraphic sequence of Lisbon (Fig. 1), the source of the liós limestone and its varieties, two groups of rudists stand out: the Caprinidae (caprinids) and the Radiolitidae (radiolitids).

Caprinids evolved in the early Hauterivian (Early Cretaceous) and, together with the Radiolitidae, they were an important element of the Cenomanian Rudist faunas of the Tethys, just before their extinction at the end of the Cenomanian (Ross and Skelton 1993; Hernández 2011). *Caprinula* is the most representative caprinid genus in the lowermost Upper Cretaceous of Lisbon. Together with the radiolitid *Sauvagesia sharpei* (Bayle 1857), they build the framework of a large number of bioherms preserved in these Cenomanian sequences (Callapez 2004). Their smooth shells show a strait elongated lower (or adherent) valve and a loosely coiled upper (free) valve (Fig. 2). The walls of *Caprinula* display distinctive pallial canals: an inner polygonal series and outer pyriform series; the polygonal series decreases in diameter from the interior of valves outward (Dechaseux et al. 1969). *Caprinula* rudists had a semi-erect mode of life attained by means of their elongated lower valves (Hernández 2011).

On the other hand, the oldest Radiolitid rudist fossils are known from the lower Barremian (Lower Cretaceous). The members of the family thrived in Cretaceous shallow seas until their final demise at the end of the Maastrichtian. Radiolitids experienced a boost in diversity and abundance, not to mention in body size, in the Cenomanian (Hernández 2011). *Sauvagesia* is the most abundant radiolitid genus—with *S. sharpei* (Bayle 1857) as the most common species—in Lisbon Cenomanian limestones, namely in liós. The *Sauvagesia* shells display a conical to cylindro-conical lower valve, ornamented with longitudinal ribs and showing two finely costulate siphonal bands, separated by an interband that usually bears two costae (Fig. 2). The upper valve is operculiform, with radial folds (Dechaseux et al. 1969). The wall structure of the *Sauvagesia* shell is fine polygonal celluloprismatic. These rudists had an erect mode of life—elevators—by means of their conical lower valves (Hernández 2011).

The Cretaceous Cenomanian of Lisbon

Rudists played a major role both in the ecosystems of the Tethyan Cretaceous carbonate platform environments and—today—in the biostratigraphic subdivision of their carbonate sedimentary sequences (Philip 1998). They become the most important reef builders during the late Mesozoic, dominating the carbonate shelves on the margins of the Tethys Ocean during the Cretaceous Period (e.g. Dechaseux et al. 1969; Hernández 2011). The carbonate precipitated in these marine environments together with the fossilized remains of the rudist shells and reefs are the main constituents of the Cretaceous upper Cenomanian limestones of the Lusitanian Basin outcropping in the Lisbon region.

In the Cretaceous, the Tethys Ocean was a low latitude east-west oceanic domain. The Tethys separated the Cretaceous continental masses into a northern—North America and Eurasia—and southern groups—South America, Africa, Antarctica, India and Australia. It merged at both west and east extremities with the Panthalassa or proto-Pacific Ocean (Ricou 1996: 3; Fig. 1). During the Cenomanian, Iberia was located on the north-western margin of the West Tethys Ocean, occupying a low to mid-latitude position, at approximately 30° N (Ricou 1996; Fig. 1) to 25° N (Voigt et al. 2004: Fig. 1). Geological and palaeontological records show that the climate of the Early Cretaceous was relatively cool, possibly even marked by the development of continental ice sheets. In the Upper Cretaceous, warming peaked in the Turonian when sea surface temperatures in equatorial and high-latitude regions exceeded 36 and 20 °C, respectively (Moriya 2011). Rudist bivalves thrived under these climatic conditions, producing

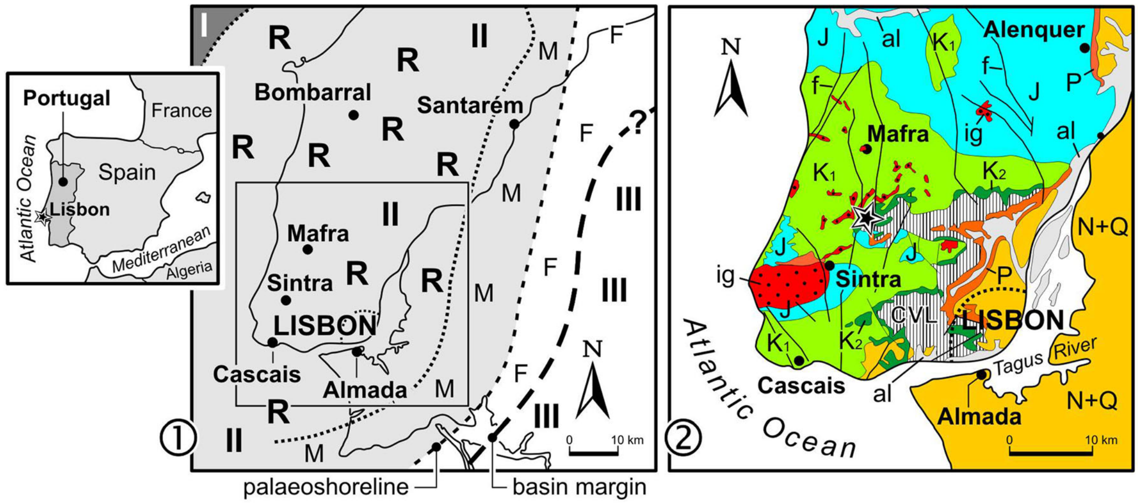

Fig. 1 Geographical location, Cretaceous palaeogeography and geology of the Lisbon region. *1*—Late Cenomanian palaeogeography and depositional environments: *I*—outer carbonate platform, *II*—inner carbonate platform, *III*—emerged land; *R*—inner platform rudist build-ups, *M*—inner platform mixed environments, *F*—proximal fluvial environments. Adapted from Dinis et al. 2008. *2*—Simplified geological map: *J*—Jurassic, K_1—Lower Cretaceous, K_2—Upper Cretaceous, *P*—Palaeogene, *N+Q*—Neogene + Quaternary, *ig*—intrusive igneous rocks, Cretaceous, *CVL*—Volcanic Complex of Lisbon, Cretaceous, *al*—Alluvium, *f*—faults. Geological map adapted from Oliveira et al. (1992). The star in the centre of the map 2 marks the location of the Terrugem-Pero Pinheiro-Negrais quarrying area

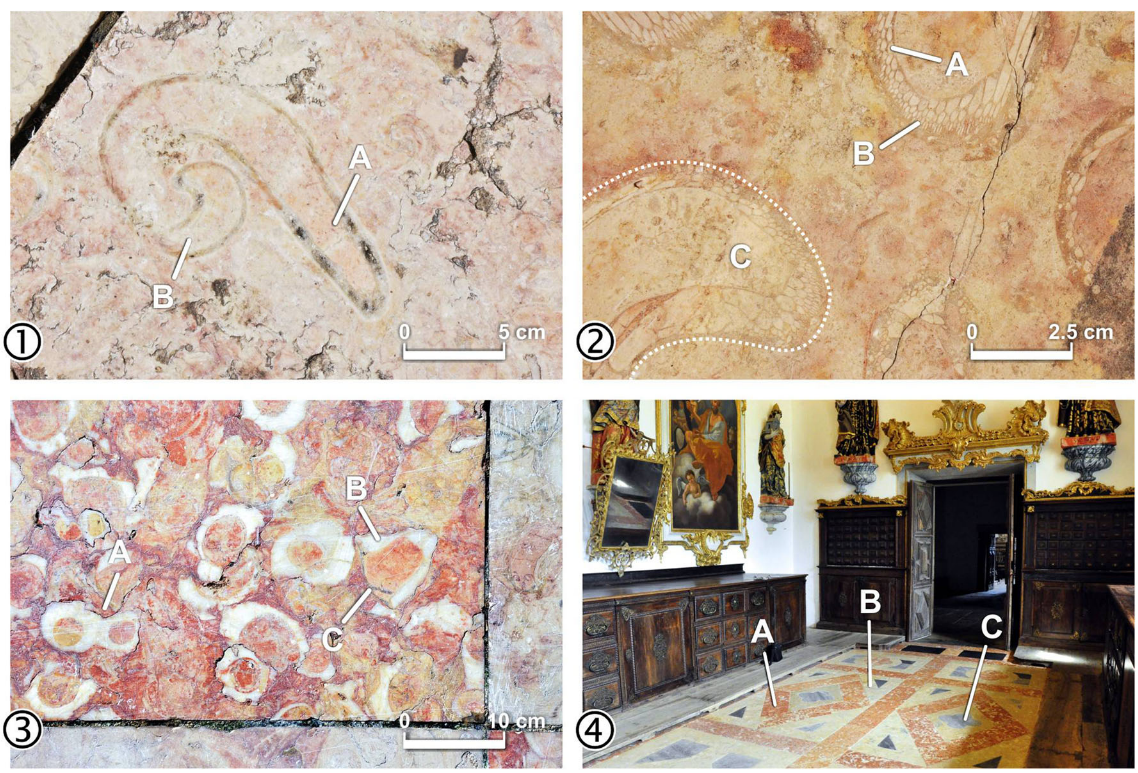

Fig. 2 Cross sections of caprinid and radiolitid rudist fossils in the liós limestone of pavements of Lisbon and Braga (Portugal). *1*—Cross sections of *Caprinula* caprinid rudists (Rossio square, downtown Lisbon), *1A*—longitudinal section of the strait and elongated lower valve, *1B*—transverse to oblique section of the loosely coiled upper valve. *2*—Oblique section of the upper valves of *Caprinula* showing pallial canals (Quinta da Regaleira, Sintra), *2A*—inner broad polygonal canals, *2B*—outer narrow pyriform canals, *2C*—typical kidney-shaped contour of the oblique cross sections of upper caprinid valves. *3*—Cross sections of *Sauvagesia* radiolitid rudists on the pavement of the Praça do Comércio square (downtown Lisbon, Portugal), *3A*—perpendicular sections of the lower vale of two cemented together specimens in the reddish "abancado" variety of liós, *3B*—longitudinal section of the lower valve, *3C*—perpendicular section of the upper valve. *4*—Example of the use of different varieties of Portuguese ornamental stones in pavements (in the sacristy of the Tibães monastery, Braga), *4A*—redsish variety of liós (abancado) with *Sauvagesia* fossils (as seen in *3*), *4B*—more typical beige liós (as seen in *1*), *4C*—"Azul de Sintra" marble, a different kind of ornamental rock from the Lisbon region

vast build-ups in carbonate platforms around the circum-equatorial Tethyan domain worldwide (Hernández 2011).

The Lusitanian sedimentary basin evolved on the West Iberian Margin during part of the Mesozoic as a result of the fragmentation of Pangea and the opening of the Northern Atlantic Ocean. It is characterized as a distensive basin set on a non-volcanic rifted Atlantic continental margin (Kullberg et al. 2006, 2013). The Cretaceous Cenomanian palaeontological assemblages of the Lisbon region (Fig. 1), e.g. with abundant records of rudist bivalves, reflect a dominant Tethyan influence. Towards the end of the period, this influence tends to fade due to the closure of the Tethys Ocean. Upper Cretaceous fossil assemblages of the Lusitanian Basin show an increasing Boreal influence resulting from the northward spread of the opening of the Atlantic Ocean (Dinis et al. 2008).

The classical lithostratigraphical sequence of the mid-Cretaceous, Albian to Cenomanian, carbonate platform deposits of the Lusitanian Basin in the Lisbon region (Fig. 1) was originally defined by Choffat (1885, 1886, 1900): (from bottom to top) (1) the "*Knemiceras uhligi* level", (2) the "*Polyconites subverneuili* level", (3) the "*Exogyra pseudafricana* [= *Ilymatogyra pseudoafricana*] level", (4) the "*Pterocera incerta* level" [= *Harpagodes incertus*] [units 1 to 4 correspond to the old regional "Belasian stage" of Choffat (1885)], (5) the "*Neolobites vibrayeanus* beds" and (6) the "rudist limestone". The unit "Beds with *Neolobites vibrayeanus* and rudist limestones" is used on the 1:50,000 geological map 34-A of Sintra, north of Lisbon and dated as upper Cenomanian by Ramalho et al. (1993).

In the last 30 years, the Albian-Cenomanian stratigraphy of this region has undergone revision. Units (1) and (2) of Choffat were redefined, respectively, and have the Água Doce and Ponta da Galé members of the uppermost lower to upper Albian Galé Formation (Rey 1992; Rey et al. 2006); units (3) and (4) are now united in the lower-middle Cenomanian Caneças Formation, and the two top units—(5) and (6)—now correspond to the upper Cenomanian Bica Formation (Rey et al. 2006: 31). For an updated synthesis—with further literature—of the onshore Cretaceous geology and stratigraphy of the Portuguese Lusitanian Basin, please refer to Dinis et al. (2008). The liós limestone and its commercial varieties copiously used in Lisbon monuments, buildings and pavements correspond to the limestones with rudists of the Bica Formation.

The Rudists and the Liós of Lisbon's Buildings and Pavements

In the past, the ornamental liós stone—and other building stones of the Lisbon area—was extracted in numerous quarries in and around the capital city, some of them within the urban limits of present-day Lisbon. Most of these historical quarries are now abandoned or have vanished due to urban expansion. Nowadays, liós is mainly quarried in the Terrugem-Pero Pinheiro-Negrais region (Carvalho et al. 2013), some 20 km northwest of the capital city of Portugal (Fig. 1). Building stone extraction in the region goes back to classical antiquity as testified by the discovery of a Roman quarry dated between the first and third centuries AD in the locality of Colaride, some 10 km south-east of the Terrugem-Pero Pinheiro area (Coelho 2002). However, intensive quarrying of the liós and other construction stones in this region only started in the second half of the eighteenth century urged by the need of quality building materials for the reconstruction of the capital of Portugal in the aftermath of the Great Lisbon earthquake of 1 November 1755 (Carvalho et al. 2013).

Liós is a commercial stonemasonry designation. The term resulted from the adaptation to the Portuguese language of the old French word *liois*, today *liais*, used—according to the etymological dictionary of the English language of Skeat (1888: 330)—to express "a very hard free-stone whereof stone-steps and tomb-stones be commonly made". Again, according to Skeat (1888), this would also be the etymology of Lias, Liassic, the name of the Lower Jurassic.

Based on ORNABASE (2012) and Carvalho et al. (2013), the ornamental stone generally known as liós—including its varieties, such as the reddish "abancado", the bluish-grey "azulino", the rosy "encarnadão", the rosy-beige "montemor", etc.—could be commonly characterized as a coarse beige to rosy or bluish-grey microcrystalline fossiliferous limestone, bioclastic (with remains of rudists) to reefal and calciclastic, with more or less stylolites. According to the Dunham (1962) classification system for carbonate sedimentary rocks, liós could be characterized as a calcirudite packstone to boundstone (Fig. 2 (3A)) held together by fossils of cemented *Sauvagesia* rudists.

The liós and its varieties are a high-quality prestige material used in building projects to produce impressions of elegance and excellence. It is used for architectural and ornamental purposes both in interior design and exterior projects such as façades, paving, monuments and many other exterior projects. Indoors, polished liós slabs and tiles are used in countertops, tile floors, stair treads and many other design elements. This ornamental stone is widely used all over Lisbon, but especially downtown (Fig. 3). Liós and its varieties may be also encountered in projects all over Portugal, both continental and insular, and abroad, especially in countries that were once part of the Portuguese overseas territories: Brazil, Cape Verde, Angola, Mozambique, Goa (India), Macao (China), East Timor, etc.

Azulejos: The Portuguese Ceramic Glazed Tiles

Portugal has abundant "azulejos". The use of glazed tiles in interior pavements in Portugal goes back, at least, to the

Fig. 3 Aspects of the pervasive presence of liós limestones in Lisbon's everyday life. *1*—In monuments, as in the late eighteenth century, neoclassic Praça do Comércio (the Square of Commerce) in downtown Lisbon, also known among the English community as the "Black Horse Square", *2*—In modern interior walls and pavements, as in the Santa Apolónia subway station, *3*—In the façades of housing buildings (note that in nineteenth century houses, liós is more often used on the ground floor, the rest of the façade being covered with tiles; also note the Portuguese pavement pattern on the sidewalk), and even *4*—In furniture, on restaurant table tops (in this case, the reddish "abancado" variety in downtown Lisbon)

thirteenth century. However, only in the early sixteenth century, azulejos (singular "azulejo") started being used extensively in interior wall revetment. The knot work and geometric patterns typical of these early azulejos were inspired on the classical polychrome motifs of the Islamic Hispanic-Moorish tiles produced at the time in Seville and Toledo. Throughout the sixteenth century European motifs—mainly colourful naturalistic, faunal and floral gothic and renaissance elements—gradually replaced the early Hispanic-Moorish designs. But, as may be seen in the sixteenth century Manueline Arabic rooms of the Sintra National Palace, 25 km west of Lisbon, the use of Arabic geometric patterns endured. It is small wonder, therefore, that the Portuguese word azulejo has an Arabic origin. According to Sousa (1789), it originated from the Arabic word "Azzalujo", or "Azzelij", which in turn derives from "zallaja", meaning smooth, slippery.

The use of azulejos in interior wall revetment reached monumental proportions in the seventeenth century (Fig. 4 (1)), first supported by ecclesiastical patrons and, latter, also by the Portuguese nobility. Entire walls covered by ceramic tiles were not uncommon in this period. Seventeenth century tiles were polychrome, with yellow, blue, white and violet manganese tones dominating (Simões 2010; Matos 2016).

However, it was only in the eighteenth century that azulejo become a truly Portuguese artistic expression with the extensive use of large panels with varied figurative scenes, ranging from religious to mythological and mundane (Fig. 4 (2), (3)). This century is frequently referred to as the Golden Age of Portuguese azulejo. The characteristic Baroque exuberance is well represented in the large and intricate tile panels typical of this period. Interestingly enough, the colour range used in tiles in this phase is reduced. Starting from late seventeenth century a change in European taste occurs, and the colours of azulejos, both in Portugal and in other European countries—e.g. in the Netherlands—changes from polychrome to predominantly blue and white (Simões 2010). This colour shift probably reflects the influence of imported Chinese porcelain patterns and the success of coeval Dutch blue and white tile production (Matos 2016). This is abundantly represented in the late seventeenth century so-called carpet compositions (Fig. 4 (1)), because the patterns in them were designed to simulate tapestries, previously used to cover large wall surfaces (Matos 2016: 70).

Although already in use earlier, in the eighteenth century panels "architectural frames" and the depiction of architectural elements become common, especially in mundane scenes. These frames, commonly encircling the main motif of the panel, frequently depict stone architectural elements such as columns, pilasters, balustrades, corbels, plinths, friezes, etc. The architectural elements, using the "trompe l'oeil" technique (also known as Illusionistic painting), were rendered in such a way that, from a particular viewpoint, the perception of it would be the same as that of three-dimensional objects. The expression comes from the French language and literally means "fool the eye".

Since these elements were made of stone, the trompe l'oeil would sometimes mimic the stone patterns themselves, occasionally very realistically. In these baroque tile panels, we see the first clear depictions of liós limestones with fossils of rudists (Fig. 4 (3)). Other patterns were created to emulate different types of ornamental stones (Fig. 5), but, so far, only the rudist pattern in the liós limestone is clearly identifiable.

The rock patterns were created using different techniques. The tiles could be hand-painted in a way that would look like

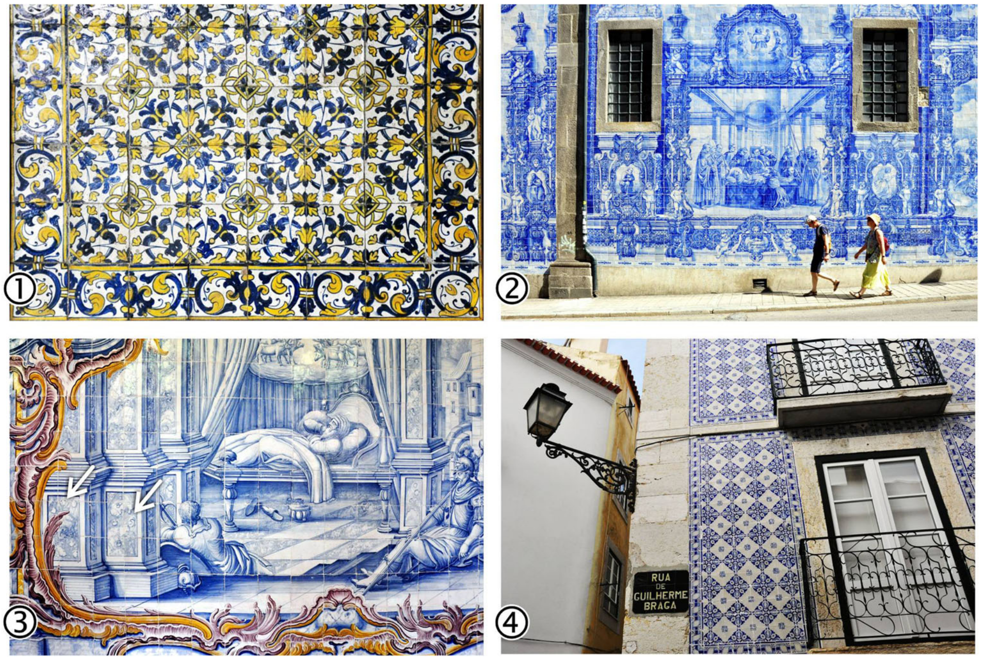

Fig. 4 Three centuries of Portuguese tiles in one glance: *1*—Seventeenth century yellow and blue tiles from the locality of São Romão de Arões (Fafe). *2*—The impressive eighteenth century tiled outer walls of the Capela das Almas (Chapel of the Souls) in Oporto. *3*—Detail of the 1785 tile panels in the chapter house of the Tibães monastery (Braga) depicting the life of Joseph of Egypt (Chronology after Simões 2010). Note the round shapes (marked by *arrows*) mimicking the rudist pattern of liós on the trompe l'oeil architectural elements depicted on the left side of the panel. *4*—Nineteenth century tiles covering the façade of a housing building in the Alfama barrio of Lisbon. Tile dimensions, approximately 12 cm

stone (Fig. 5 (1)) or, using some type of broad-brush, in a marble-like pattern know in Portuguese as "marmoreado" (i.e., marbled) or produced with the help of a sponge, the "esponjado" (sponged, i.e. painted or applied with a sponge; Fig. 5 (2)). In the eighteenth century, the esponjado—with a more or less realistic effect—was frequently used in skirting boards of larger azulejo panels in order to convey the rugged look of the so-called pedra torta or rough stone, which unlike dressed stone was unpolished (e.g., see Matos 2016: 96 and Fig. 5 (3) herein for different aspects of esponjado). The

Fig. 5 "Trompe l'oeil" rock patterns in Portuguese tiles. *1*—Indistinct rock patterns in eighteenth century tiles in Tibães Monastery (Braga). *2*—Marbled, mottled eighteenth century tiles in the 1787 Fonte da Pipa (Barril Fountain) in Sintra (note the imitation of the mottled leopard-like rudist pattern of the liós limestone, marked with *arrows*, and the reddish "esponjado" on the plinth). *3*—Esponjado pattern in the skirting board of a larger seventeenth century tile panel in Biscainhos Palace (Braga). *4*—Customized hand-painted nineteenth century tiles mimicking rudist limestone in 5 Merca-Tudo St. in 2004, now sadly vanished, replaced with modern tiles (note the round outline of radiolitid rudists lower valve in transverse section, *4A*, and the irregular jagged lines mimicking stylolites, *4B*). Tile dimensions, approximately 12 cm

simulation of stone patterns was not exclusive of Portuguese tiles. It may be seen in several panels produced in the workshop of the Dutch artisan Willem van der Kloet, dated 1707, displayed in the Nogueira da Silva Museum, in Braga and in the National Tile Museum of Lisbon (see Simões 2010: plate IX; Matos 2016: 76).

In the nineteenth century, during the Romantic Period, tile production became industrialized and their use democratized. Due to mass production, tiles were no longer expensive luxury items and, therefore, their use was extended to the exterior of more modest houses and used as widespread covering of façades (Queiroz and Portela 2014) (Fig. 4 (4)). Tiles became less figurative and flamboyant, evolving to a more utilitarian use, with the same pattern being applied in entire façades of urban multi-storey buildings. Wealthy Portuguese immigrants brought this new trend of tile use from Brazil, where Portuguese tiles were used extensively to protect façades from the harsh local tropical climate (Terol 1992). During Romanticism, tile panels may have become more down-to-earth, but the ambition of the new ascending bourgeois class—although usually a lot less wealthy than eighteenth century clergy or nobility—did not. And the desire of owning something different, more refined and sophisticated that would make them stand out of the rest, remained. Hence, the use of hand-painted customized tile panels that would recreate the appearance of (the much more expensive) stone. Obviously, in Lisbon, the quality ornamental stone *par excellence* was and still is the liós (Fig. 5 (4)).

Rudist Tiles: Decorative Arts Inspired by Geodiversity

Despite the fact that the oldest unequivocal representations of liós in architectural elements depicted in azulejos came from early eighteenth century Baroque indoor tile panels (e.g., in the circa 1731 São Bento, or St. Benedict, chapel of the Tibães Monastery, Braga), becoming more frequent in the second half of the century (e.g., in the 1785 chapter house tiles of the Tibães monastery, Fig. 4 (3), or in the 1787 Pipa Fountain of Sintra, Fig. 5 (2)), in this particular paper, we will focus on the exterior nineteenth century Romantic tiles most commonly seen in Lisbon building façades.

Contrary to the more usual trend of industrialization and mass production of tiles in the 1834–1900 Romantic Period in Portugal, the "rudist tile panels" of nineteenth century Lisbon remained, judging by their unique characteristics, mostly artisanal. Whilst mass production patterned tiles were used indiscriminately to cover entire building frontages (e.g., Figs. 3 (3) and 4 (4)) as if they were a "ceramic paint" of sorts, the tiles simply being cut and fitted to the intricacies of the façades, rudist tile panels were used sparsely, in well-defined settings, and especially produced to be laid in those specific situations (e.g. Fig. 6). This type of requirements for "rudist tiles" could only be met by artisanal production.

In wealthy nineteenth century bourgeois housing buildings, the frontage of the ground floor was frequently covered with liós, a noble building material (e.g., Fig. 3 (3)). Liós is an expensive material and tiles, although not cheap, are much more affordable. Therefore, tile panels mimicking liós were used in more modest households in the same way and in the same place as real stone: on the façade of ground floors (Fig. 6 (1)). Rudist tile panels were also used on the façades of commercial stores, also occupying the ground floor (Fig. 6 (3)). Isolated architectural elements depicted in tile panels showing the liós pattern were common in very different situations, but entire panels emulating a liós frontage were typical of ground floors.

Rudist tile panels were specially tailored to perfectly fit the façade they were intended for. Tiles were fashioned and hand painted to reproduce architectural elements such as stone bocks, ashlar block veneers, jointed architraves and friezes adapted to the intricacies—doors, window contours, and every nook and cranny—of the frontage and to deliver the illusion that it was covered with stone, with liós. To convey that impression the trompe l'oeil technique was used and, sometimes, in order for it to be credible, great pains were taken to reproduce not only the three-dimensionality of the architectural elements but also the mottled pattern created by the rudist fossils in the liós (Fig. 7), as well as other geological features such as stylolites (Fig. 5 (4)).

The rudist trompe l'oeil in these panels is generally so realistic that the two types of Cretaceous hippuritacean bivalves present in liós are readily recognizable. Radiolitids (see Cretaceous rudists and urban geodiversity in Lisbon, above) are usually depicted as round and void in the centre shapes—as "pineapple slices," as they are described for the lay public in popularization activities—typical of the transverse cross sections of the conical lower attached valve, as seen in Figs. 6 (2) and 7 (1) (see Fig. 7 (2) for comparison). Even the gregarious habit of *Sauvagesia* Radiolitid rudists—often forming aggregates of several individuals cemented together (Fig. 7 (2))—did not escape the craftsman's keen eye for every minute detail of the rock pattern (Fig. 7 (1)). The same attention to details applies to the portrayal of the irregular jagged lines mimicking stylolites (Figs. 5 (4B) and 6 (2)). Since the panels where artisanal and unique, no two are alike, the accuracy and the realism of the representations varied significantly, and more naïve and stereotyped renditions of rudist fossils are also known, such as the ones depicted in Fig. 5 (4). In the tile representation of liós, reddish sponged areas are also present, in order to graphically express the heterogeneous aspect and hue of the polished rock surface as seen in Figs. 6 (2) and 7 (1).

Due to the complex shape of the Caprinid shell, with conical and coiled valves, its representation on the rudist tiles is

Fig. 6 Lisbon Romantic tile façades mimicking the rudist pattern of liós limestones. *1*—Façade of the 231–235 Rosa St. *2*—Detail of the panel depicted in *1*, note the Radiolitid circular and elliptical cross sections (transverse and oblique, respectively) of the lower valves and the naïve representation of stylolites as an honeycomb pattern formed by irregular jagged lines. *3*—Façade of the 5c João das Regras St. *4*—Detail of the tile panel depicted in *3*, marked with *arrow* (note the Caprinid kidney-shaped oblique sections and the elongated sections of the upper and lower values, respectively, see also Fig. 7 (3))

more diverse, making it sometimes harder to recognize. Although less common than the Radiolitid trompe l'oeil, various representations of Caprinids in cross section may be found (Fig. 6 (4)). The most recognizable are the spiral-shaped transverse sections of the loosely coiled upper valves of Caprinids as seen in Fig. 7 (3A) (see Fig. 7 (4A) for comparison). Representations of longitudinal sections of the lower elongated valve (Fig. 7 (3B)) and kidney-shaped oblique cross sections of the upper spiral valve (Fig. 7 (3C)) are also identifiable.

In the Cenomanian limestones of the Lisbon region, namely in liós and its varieties, rudist assemblages are very homogeneous: Radiolitid assemblages and Caprinid assemblages are clearly separated with only a reduced number of situations when fossils of both rudist families occur together. Interestingly enough, this very same fossil assemblage consistency may be seen in the rudist tiles of Lisbon. Representations of Radiolitid rudists and Caprinid rudists are not usually found together in the same tile panel.

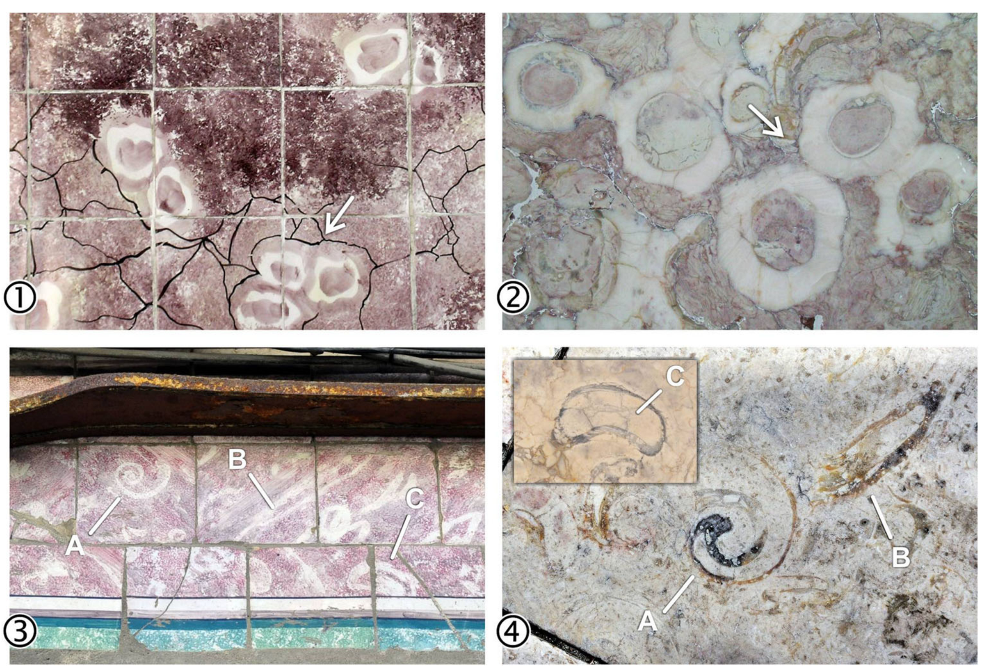

Fig. 7 Tiles mimicking the rudist pattern of liós limestones and the actual limestones, for comparison. *1*—Detail of the tiles in the façade of the 39 Poço do Borratém St building, imitating cemented together radiolitid rudists; *2*—Aspect of liós showing transverse sections of lower valves of rudists cemented together. *3*—Detail of the tiles in the façade of the 9 Praça da Figueira Sq building, imitating caprinid rudists, compare with *4*. *4*—Cross sections of rudist fossils in liós limestones: *4A*—transverse section of upper caprinid valve, *4B*—longitudinal to oblique section of lower caprinid valve, and *4C*—oblique section of caprinid upper valve

In order for the liós trompe l'oeil to accomplish its purpose, the representation of the stone elements had to be realistic. By excelling at their job, tile painters accurately reproduced the rudist pattern of liós making it possible for the trained eye to recognize it as a local rock pattern and to distinguish it from an indistinct marbled or sponged pattern with no connection to local geodiversity (Fig. 5 (3)). Moreover, it made it possible to recognize a fossiliferous pattern that is typical of a particular rock in the Lisbon region, making it an extraordinary example of the importance of local geodiversity in the shaping of cultural manifestations—in this case, in the decorative arts—that are so typical of the capital city of Portugal.

Local geodiversity, in this particular case ex situ with high cultural value (in the sense of Brilha 2016), represented by liós and its varieties, plays a fundamental role as inspiration for the rudist tiles. In this context, local geodiversity, within the frame of the "abiotic ecosystems services" model first suggested in Gray (2011) and later matured in Gray et al. (2013), i.e., from the perspective of the benefits (goods and services) that society obtains from abiotic nature, stressing its wider utilitarian values rather than the inherent scientific ones, would qualify as the provider of artistic inspiration for the making of rudist tiles. The Lisbon liós would therefore fall into the category of "Cultural Abiotic Ecosystem Services, 19. Artistic inspiration", described in Gray et al. (2013: 661; Fig. 1).

However, this is only one aspect—albeit significant—of the role geodiversity in this curious case of the rudist tiles. The Cretaceous fossiliferous limestone of Lisbon cannot be seen merely as a source of inspiration. As shown above, being a cherished element of local urban identity and a symbol of economic status, the liós pattern was actively and meticulously copied and employed on nineteenth century tiles used to cover the façades of many Lisbon buildings. In this second aspect, local geodiversity, the liós, following Gray's (2011) and Gray's et al. (2013: 661; Fig. 1) abiotic ecosystems services model, should also be seen as providing a sense of place and social status, an aspect contemplated in their topic "18. Cultural, spiritual and historic meaning", within the cultural abiotic ecosystem services category. Apart from the rock pattern copied by the tile artisans, the social status provided by the much more expensive liós was also being imitated by the people using the rudist tiles to cover the façades of their homes.

At present, the geological and geoconservation community have widely adopted the concept of geodiversity (e.g., Gray 2004, 2008; Gray et al. 2013). Gray (2004) enumerates and discusses its many values, and Gray et al. (2013) state that the concept of geodiversity encompasses both the broader values of geoheritage elements for society and its role in supporting biodiversity. The example of the rudist tiles of Lisbon is a fine illustration of the fact that, apart from supporting biological diversity, geodiversity (hand in hand with biodiversity) also plays an important role in generating cultural diversity.

Rudist tiles are also a compelling way of showing the public the paramount role of local geological diversity in shaping the cultural character of the city. Side by side with urban geological elements, namely the liós, they have been successfully used in geology popularization actions set in Lisbon (Silva 2009) to demonstrate the role of urban geodiversity as source of artistic inspiration, local identity and social status and consequently to boost the public's understanding of the values of geological diversity (in this case, its cultural value). In other words, rudist tiles may be used to increase the public's abstract perceptiveness of geodiversity, enhancing geoawareness and rising the social fruition and appreciation of geodiversity, both potentially leading the public to take action and influence political decisions supporting geoconservation, as thoroughly advocated and discussed in Pena dos Reis and Henriques (2009).

Conclusion: Geodiversity and Cultural Identity in Lisbon

Urban character or urban personality is basically defined by two major aspects: the geological setting of the city and its human cultural element. Both are closely connected. Lisbon, in an obvious hint to the Eternal City of Rome, is known as the "City of Seven Hills". The capital of Portugal is, truly, a very hilly city. Are the hills actually seven? That is arguable. Lisbon is also sometimes referred to as "Mother of seamen". Both these epithets evoke the physical relation of the city with its geological context: the fact that there are hills and its location near the mouth of the river Tagus and the Atlantic Ocean (Silva 2009). In addition, local geological building materials determine the general aspect of the city.

But local geodiversity has an even more profound impact in shaping the city, one that is not customarily recognized: a cultural impact. For example, most of Lisbon's monuments and historical buildings were built using a particular type of stone, the whitish Cretaceous rudist limestone known locally as liós (Fig. 3). "In The White City" is a 1983 film shot in Lisbon by the Swiss film director Alain Tanner. And then there are the glazed tiles.

Tiles are an inherent characteristic of Lisbon. Their ubiquitous presence and colourful patterns, as well as the way sunlight is reflected onto the streets by their glazed surfaces, are intrinsic parts of the city's urban ambiance. Tiles are also made of geological materials, once again reinforcing the link between geodiversity and city character. However, apart from the materials they are made of, some Lisbon tiles also reproduce the pattern of the noble building material *par excellence* of the region; the liós with its rudist fossils. By doing so, these rudist tiles become a link between local geodiversity and the unique cultural character of the City of the Seven Hills.

The artistic studies of azulejos up until now have focussed mainly on eighteenth century figurative aspects, the most recognizable being the ones depicting religious and mythological scenes, military, hunting and fishing, rural, nautical and mundane scenes and even teaching or "didactic azulejos", portraying subjects connected with astronomy and geometry. Recently, new themes such as Fauna and Flora (e.g. Costa et al. 2014) and China (the country, not the porcelain) (e.g. Curvelo 2013) have become the subject of attention and investigation, as well as the patterns used in nineteenth century romantic tiles (Queiroz and Portela 2014). Yet so far, no studies have been conducted focussing specifically on aspects of geodiversity depicted in Portuguese tiles. Geological and geomorphological features of the landscape and the stone used in architectural elements, as well as fossils and other geological features in it, constitute a world of opportunities to explore in what concerns the study of tile representations.

This lack of geological themes in tile representation research, and in particular studies, focussed on the types of rocks or fossils is not difficult to explain. The fact is that, on the one hand, we humans have a challenging time recognizing irregular non-figurative patterns, and, on the other hand, tile studies are not usually conducted by researchers trained in geology or palaeontology: the rudist pattern of the liós depicted in the tiles is not easy to recognize by the untrained eye. Consequently, representations that are not readily identifiable (human and mythological figures, fauna and flora, military, nautical and everyday objects, etc.) are commonly relegated to that indefinite category of "landscape", in general, or, if we are talking about geological materials, are simply described as "marbled" or "simulated stone" aspects of "stonemasonry" or "architectonic frames" (as for example in Matos 2016: 92).

The result is that a key aspect of these rudist tiles so characteristic of Lisbon—the fact that they represent liós with fossils of rudists, a typical element of local geodiversity and city culture—is not acknowledged at all, therefore hampering the recognition of its true uniqueness and making its protection more difficult. These tiles are frequently neglected, and even destroyed and replaced by newer, trendier patterns, since they are often seen by the public and the cultural authorities alike as lesser indistinct representations of ill-defined stonemasonry elements.

This very eloquent example of the rudist tiles, a typical cultural element of Lisbon resulting from the attempt to create decorative tile patterns inspired by local geodiversity and seeking to reproduce it, generating new artistic concepts and representations in the process, provides compelling evidence of the fact that, apart from supporting biological diversity (e.g. Gray 2004; Gray et al. 2013), geodiversity also plays a fundamental role in generating cultural diversity.

The curious case of the rudist tiles herein presented and discussed is all the more important now that the application of Portuguese tiles for inclusion on the UNESCO World Heritage List is being prepared by the Direção-Geral do Património Cultural (General Directorate for the Cultural Heritage), the Portuguese agency for cultural heritage, in cooperation with the Laboratório Nacional de Engenharia Civil (National Laboratory for Civil Engineering) and the Portuguese National UNESCO Commission (DGPC 2015).

Hopefully, recognizing the representation of liós and its characteristic fossils in the rudist tiles will finally reveal their uniqueness and their fundamental connection with the geodiversity and the cultural character of Lisbon, rising the geoawareness of the public and making the need for the geoconservation of the liós and the preservation of these tiles as cultural heritage all the more obvious.

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