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INVENTORY, DISSEMINATION AND PRESERVATION OF THE GEOLOGICAL HERITAGE IN URBAN AREAS – LISBON CITY CASE STUDY

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Abstract: Through field work campaigns and with the colaboration of several public entities, were identified several outcrops in Lisbon city. Nineten of them were classified as Geomonuments. In consequence they were included in Municipal Planning Instruments, its acessibility and visibility was assured and description totems were developed. Involving the general public was the strategie adopted in order to proceed with the dissemination and preservation strategies. In urban areas is not expectable to find references of evolution and earth dynamics, mainly because of the general tendency that promotes the total ocupation of the ground with construction. However, in Lisbon it is still possible to observe some outcrops preserved among buildings and roads, some of them with large dimensions that materialize several geological formations since Cretaceous to Holocene Periods. The original paleoenvironments associated to the lithostratigraphic diversity presented in Lisbon area, leads to a great potentiality of the city aiming the preservation and dissemination of the geological heritage. The Lisbon Municipality, in cooperation with the MNHN (Nacional Natural History Museum), the Lisbon University and LNEG (Laboratório Nacional de Energia e Geologia – the portuguese institute with functions similar to a Geological Survey), developed field work campaigns aiming the inventory of the preserved outcrops in Lisbon city, with scientific, educational and cultural interest, liable to be classified as Geomonuments. After the classification of those outcrops, some projects were developed aiming the preservation and

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maintenance of those places and some dissemination strategies such as the development of thematic trails to general public and schools.

Key words: outcrops, geomonuments, urban geology, inventory, preservation, heritage, Lisbon

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INVENTORY OF OUTCROPS

Lisbon Municipality in colaboration with the Faculty of Sciences of the University of Lisbon proceded to field campaigns in order to identify outcroups in Lisbon city. Fourty six outcrops were identified covering all the 20 lithostratigraphic units that represents the geology of Lisbon. From those identified, 19 outcrops were selected concerning its regional geology representativity, scientific, pedagogical and cultural interest as well as its size and the possibility of conservation.

The 19 selected outcrops are shown in table 1 and figure 1.

Table 1. Inventory of Geosites
(Data source: Lisbon Municipality)

Outcrop	Lithostratigraphic unit	Lithology / age	Relevant aspects
G1. Rio Seco	*Formação de Bica*	Limestones / Cretaceous	Size, possibility of conservation, ancient quarry
G2. Rua Sampaio Bruno	*Argilas de Prazeres*	Muddy limestones /Miocene	Limestone with spherical carbonated concretions of bryozoa colonies
G3. Av. Duarte Pacheco	*Formação de Caneças* and *Formação de Bica*	Marls and limestones / Cretaceous	Size, possibility of conservation, ancient quarry
G4. Av. Calouste Gulbenkian	*Formação de Caneças* and *Formação de Bica*	Marls and limestones / Cretaceous	Size, possibility of conservation, ancient quarry
G5. Av. Infante Santo	*Formação de Bica*	Limestones / Cretaceous	Silex Nodules
G6. Aliança Operária	*Complexo Vulcânico de Lisboa*	Basalts / Neo-Cretaceous	Size, basalt with columnar jointing, ancient quarry
G7. Calçada de Carriche	*Formação de Benfica*	Mudstones / Oligocene	Thick conglomeratic series with reddish colour
G8. Rua Virgílio Correia	*Argilas de Prazeres and Areolas de Estefânia*	Mudstones and sandstones/Miocene	Unit Limit
G9. Quinta da Granja	*Argilas de Prazeres*	Mudstones / Miocene	Carboniferous layers, possibility of conservation
G10. Quinta do Lambert	*Areias com placuna*	Sandstones / Miocene	Thin sandy sediments, depositional cycles, unit limit
G11. Forte de Santa Apolónia	*Calcários de Quinta das Conchas*	Lumachelle layers / Miocene	Large size ostreidae fossil contents, possibility of conservation
G12. Rua	*Areias com placuna*	Limestones and	Unit Limit

Mouzinho de Albuquerque	*miocenica and Calcários de Musgueira*	Sandstones / Miocene	
G13. Rua Capitão Leitão	*Areias de Vale de Chelas*	Sandstones / Miocene	Sandy sediments with wind and water transport and depositional signatures, fossil contents
G14. Rua dos Eucaliptos	*Grés de Grilos*	Sandstones / Miocene	Possibility of conservation, fossil contents, lithology
G15. Rua do Armandinho	*Calcários de Marvila*	Sandstones and Limestones/Miocene	Fossil contents
G16. Parque da Pedra	*Formação de Caneças* and *Formação de Bica*	Marls and limestones / Cretaceous	Size, possibility of conservation, unit limit and ancient quarry
G19. Parque da Bela Vista	*Areias de Quinta do Bacalhau and Calcários de Casal Vistoso*	Limestones, sandstones and mudstones/Miocene	Size, unit limit, possibility of conservation, depositional cycles

Figure 1. Location of the Geosites in Lisbon

PALEOENVIRONMENTS AND THEIR GEOLOGICAL EXPRESSION

The oldest rocks that outcrop in Lisbon city are from Cretaceous Period (≈ 97 M.a.) and materialize a marine transgression episode (relative sea rise) (Pais et al., 2006). In Cretaceous, Lisbon was located in a marine environment with warm shallow waters, allowing the formation of marls intercalated with compact limestone layers. These aspects are visible in Av. Calouste Gulbenkian and in Av. Duarte Pacheco Geomonuments (figure 2).

Figure 2. Av. Duarte Pacheco Geomonument (Cretaceous formations)

Several fossils are associated with these sediments and can be found in the outcrops, among them bivalve, gastropod, crustaceous, equinoderm and some vertebrate. In the upper layers of this formations it is common to find rudists (Pais et al., 2006).

During the periods of sedimentation and compaction of these sediments in the reef, small lagoons were formed. Its connection with the sea would be temporary allowing the formation of thin limestone layers with few fossils and silex nodules. These layers are visible in Av. Infante Santo Geomonument (figure 3).

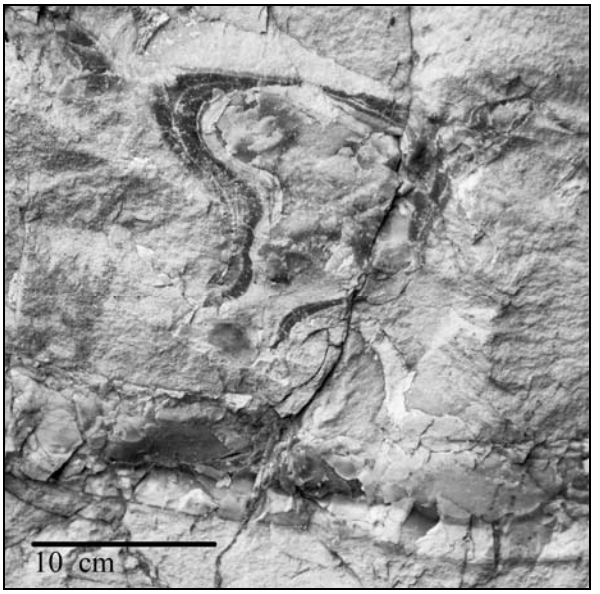

Figure 3. Silex Nodules (Av. Infante Santo Geomonument)

With the emersion of the formed rocks, differential erosion processes occurred (chemical dissolution of limestone along fractures), leading to karst and cave formation and highlighting textural heterogeneities (Pais et al., 2006). These caves were used for Palaeolithic settlements as shelter and the silex was used for weapons, tools and flint manufacturing (Galopim, 1989).

Cretaceous limestones were also explored for construction and ornamental materials and some quarries are known in Monsanto, Ajuda and Vale de Alcântara (Pinto, 2005). Building facades and Monuments, as well as sidewalks in Lisbon, are made predominantly from these materials.

In Late Cretaceous Period a volcanism event occurred in Lisbon area (≈ 65 M.a.). The intense fracturation originated by plate movement allowed the installation of several conducts, chimney and dikes that conduct magma to surface. This magma deposits covered the subjacent cretaceous formations originating the Lisbon Volcanic Complex (CVL) (Pais et al., 2006).

The most part of Lisbon Council is covered by basaltic sheets, a consequence of effusive events, intercalated with pyroclasts from explosive events (mainly composed by ashes). Their origin was probably one single volcanic building, located in Mafra region, higher than 2000m, with some inactive episodes showed by intercalated sediment materials. Its thickness can be as high as 400m, as in Carnaxide and Odivelas, but in Lisbon the CVL thickness rounds 100m (Pais et al., 2006).

The Aliança Operária Geomonument is an outcrop included in CVL and is located in an inactive quarry which is nowadays occupied by a sports complex "*Boa Hora Futebol Clube*". In those thick basaltic layers it can be observed columnar jointing (hexagonal columns), as a result of the contraction of the basalt during cooling (figure 4).

Figure 4. Columnar jointing in Lisbon Volcanic Complex (Aliança Operária Geomonument)

The basaltic lavas were explored in some quarries located in Lisbon, and applied as gravel (Pinto, 2005). They can be seen in some Lisbon street pavements.

Lava and ashes alteration originates high quality agricultural soils, leading to human occupation of those areas since past as a way of subsistence of populations. However nowadays, the urban expansion has lead to the extinction of those regions in Lisbon council. In Palaeogene Period (≈ 40 M.a.) an emersion phase occurred with a lack of sedimentation, caused by an intense tectonic activity which lead to relief building (Pais et al., 2006).

Lisbon, without Tagus river at south, exhibited a continental sub-arid landscape, where erosion processes acted intensely. Large volumes of heterogeneous sediments

(blocks and thin sediments) resulted from the destruction of those reliefs. Those materials were transported from higher areas to deposition basins by a drainage network pattern of torrential rivers (Pais et al., 2006).

Those basins, controlled by tectonic structures and with few connections to the sea, allowed the deposition of the thick conglomeratic series of Benfica Complex. The oxidation processes occurred in iron minerals presented in the transported sediments configures the reddish colour, typical of an oxidant deposition environment (Pais et al., 2006).

In Miocene Period (≈ 24 M.a.) and after an intense continental sedimentation phase, marine environment reinstalls as a consequence of subsidence, allowing the installation of Tagus Basin vestibular area (Pais et al., 2006).

Quinta da Granja Geomonument (figure 5) shows a transition phase between Palaeogene continental to a Miocene peri-continental environment, materialized by the occurrence of black carboniferous and mudstone layers.

The carboniferous layers were deposit in a lacustrine environment with continental signature, with low levels of oxygen, shallow depth and low hydrodynamics, allowing the organic matter and flora preservation.

Figure 5. Carboniferous layers (Quinta da Granja Geomonument)

Mudstone layers typical from "*Argilas de Prazeres*" formation exhibit a signature of peri-continental influence. This formation was explored by clay industries such as "*Cerâmica Lisbonense*" (Pinto, 2005).

During the next 16 M.a., sea level raises and falls several times, originating rocks typical from peri-continental and litoral environments, which correspond to characteristic sediments and fossils (figure 6). They can be seen around several outcrops in oriental part of Lisbon city (Pais et al., 2006).

CLASSIFICATION OF LISBON OUTCROPS AS GEOMONUMENTS

After the selection of these 19 outcrops, Lisbon Municipality made a proposal to the Faculty of Sciences, MNHN and LNEG aiming the classification of the outcrops as Geomonuments (Geological Monument) (Galopim de Carvalho, 1989, Galopim de Carvalho, 1999, Ramalho, 2004).

They were classified by the Lisbon Municipality Assembly and intregrated as Nature Exo-Museums (Galopim de Carvalho, 1999) in the municipality planning instruments, namely the Municipal Master Plan (http://pdm.cm-lisboa.pt). A minimum of a 10 m protection buffer was implanted in order to preserve the assessment and visibility of the Geomonuments and the construction of structures and infra-structures is conditioned in those areas.

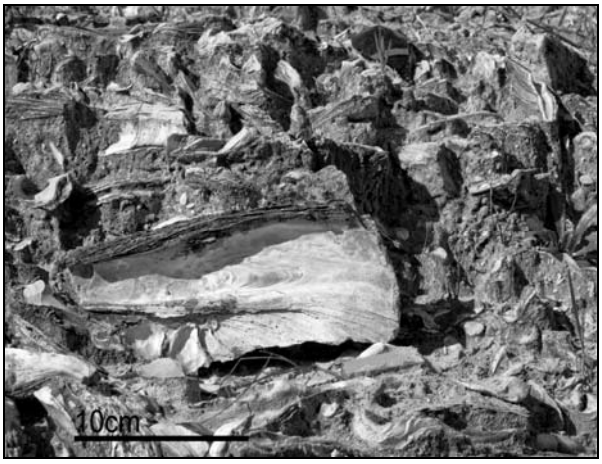

Figure 6. *Ostreidae* fossil in a lumachellic layer, characteristic of peri-continental and litoral environments (Forte de Santa Apolónia Geomonument)

DISSEMINATION AND PRESERVATION OF GEOMONUMENTS

The most powerful preservation method is through people's will. In this case it is a mission of the public entities to promote knowledge to the populations, giving them means and tools to understand the importance of the preservation of the geological heritage. As resumed by Mathis A. (2005): *Through interpretation, understanding; through understanding, appreciaton; through appreciation, preservation.*

Accordingly, thematic trails to general public and schools have also been developed, and one is an extremely sucessful trail – Ocidental area of Lisbon by bicycle, through six Geomonuments integrated in Monsanto's Natural Park and surrounding area.

A guide book with a portuguese and an english version about Parks, Gardens and Geomonuments of Lisbon was edited by the Lisbon Munipality in June, 2009, with descriptions of the places that can be visited (CML, 2009).

It has also been developed the contents to the information *totems* to implant in the Geomonuments with a brief description of the geological setting and its location in Lisbon city. Only one totem is already implemented – Rua Sampaio Bruno (figure 7).

Figure 7. Totem of Rua Sampaio Bruno Geomonument

Some landscape architecture projects that include and promote the Geomonuments have also been developed, such as in Rio Seco, Parque da Pedra and Quinta da Granja and can already be visited and used as Urban Parks.

FUTURE WORKS

The next step of the Project will be the constitution of a network, where Museums and Geomonuments can be connected by using public transportation, allowing general public and tourists to visit the places on their own.

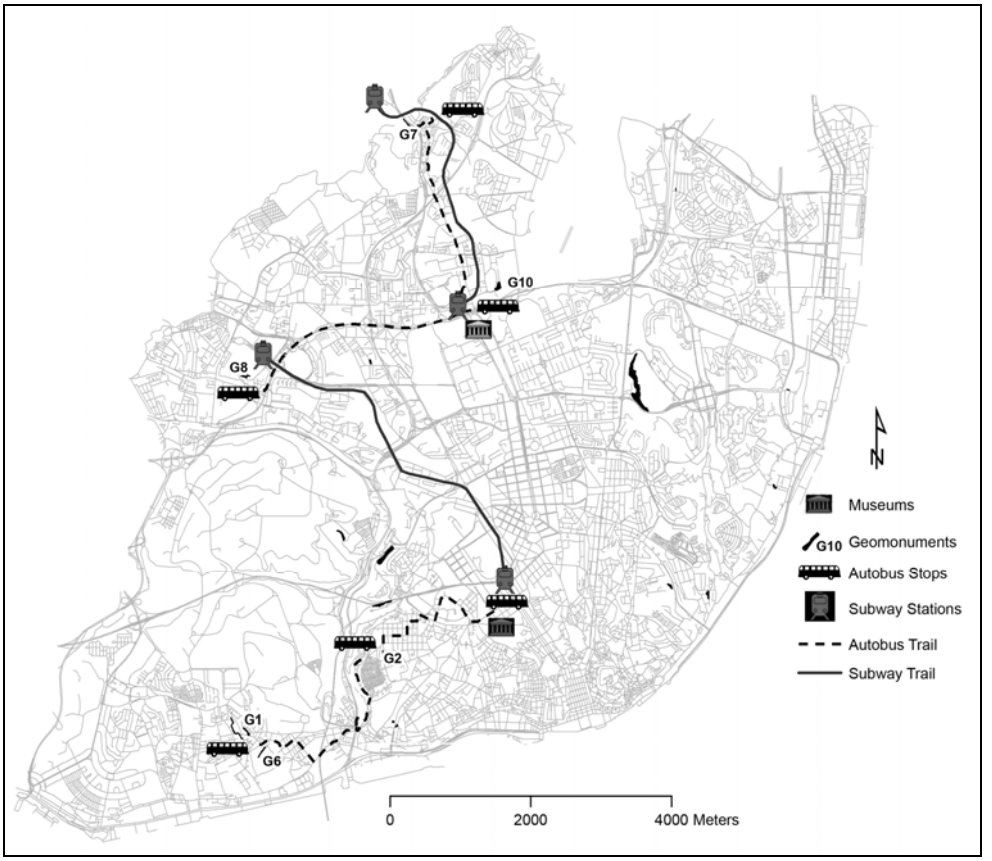

Figure 7. Totem of Rua Sampaio Bruno Geomonument

One of the thematic trails proposed is about a paleoenvironment sequence, from continental to marine. The trail begins in a continental environment, materialised by the conglomeratic series of the Calçada de Carriche Geomonument (G7). Then, a typical fluvial environment, with sandstones with wind signatures, materialised in the Quinta do Lambert Geomonument (G10). The sequence continues with a pericontinental environment shown by the mudstones and carboniferous layers presented in the Quinta da Granja Geomonument (G8). The next step will be in the Natural History Museum where a permanent exposition abou Lisbon Geology will be exhibit. The trails continues through the Sampaio Bruno Geomonument (G2), where a reef platform environment is presented. It can also be seen a muddy limestone with spherical carbonated concretions corresponding to bryozoa fossil colonies with few centimetres diameter.

The trail ends in a marine environment, materialised by the thick sequence of limestones with rudists fossils.

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