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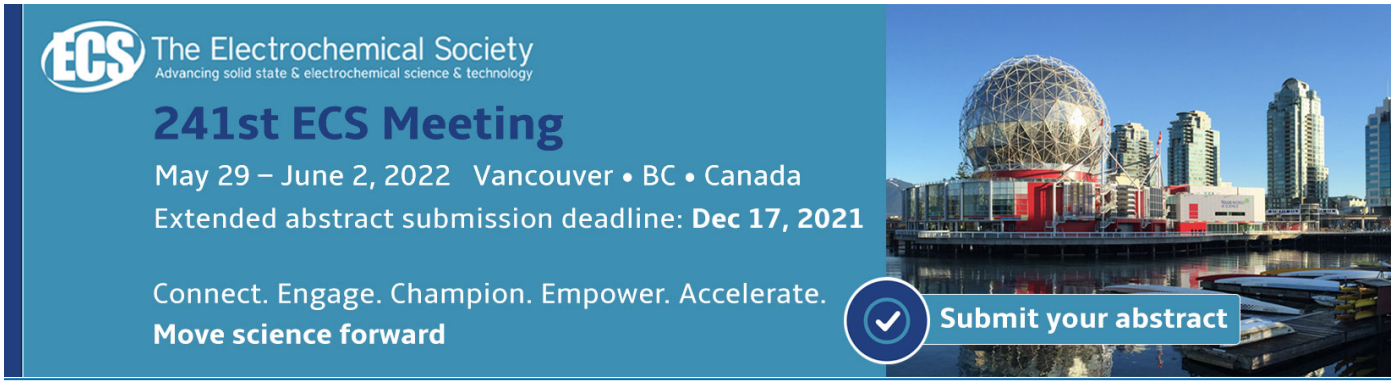

Drystone walls in the Algarve, Portugal. Characterization and interconnection with the geology and lithology

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Abstract. Drystone walls can be frequently observed along the Algarve, south region of Portugal, performing both support and property division. This region is also known by its geological diversity and, consequently, lithology, which are intimately related to the orography. The combination of all these factors allowed the proliferation of this traditional drystone walls during the last centuries, and they represent not only an important element of the landscape, but also a perspective of the social, economic and technical bases of Algarve's heritage. This article intends to present this diversity and the relationship between its various facets. In order to achieve the objectives, several field surveys were carried out to different geological zones, with the intention of gathering information related to the natural material used and its construction technique, as well as interaction with local inhabitants. These visits were supported by bibliographic and "Web-graphic" research, to substantiate the hypotheses. Based on the data results it is possible to identify a close interconnection between the geology and wall structure typology, since they are made with the natural rock fragments (raw material) found nearby. However, its function is more related to the orogeny and lithology, the latter defining also the type of agricultural culture. The study is enriched by the enormous diversity of rock types, although the Algarve is a relatively small region. The main limitations found during the development of the study are related to the physical access to the walls and the interviews with the locals. These constrictions were due to the lack of land maintenance, allowing vegetation to growth naturally, invading and covering the walls, and also due to the pandemic situation brought by the COVID-19 virus, which interdict the interaction between persons and also the travels. Despite the restrictions mentioned, the fieldtrips gave enough data to support the correlation between the geology, lithology and the raw material used on the drystone walls, as well as their relation to the terraces that proliferate in specific areas of Algarve. In view of the scarcity of bibliographic elements associated with this subject, in the studied territory, the elaboration of documents that allow the identification, characterization, geo-location and dissemination of the object of study, is considered as an asset for this theme. Finally, the study aims to alert and counter the tendency to abandon this type of heritage, valuing it and making it known.

1. Introduction

The drystone walls are a significant and extremely important constructed heritage in the Algarve region, although forgotten and unquantified. Its impact on the landscape persists, nevertheless they are "invisible" for the majority of the people, that look without seeing "behind and in between".

The drystone walls are structures with environmental, landscape and aesthetic value recognition, to the same extent that they provide favourable conditions for the development and shelter of fauna and flora in sloping regions. This type of construction is one of the most used soil protection measures since

Antiquity, with the main function of increasing the infiltration of water on the slopes and minimizing its erosive effect, which has a positive impact in reducing natural risks and increasing biodiversity. Therefore, they can have a positive impact on regional sustainability.

In 2018, UNESCO, recognized the "Art of drystone walls, knowledge and techniques" as an Intangible Cultural Heritage of Humanity, which recognizes the importance of this construction technique. Such art, concerns to the construction of stones stacking on top of each other, without mortar, in order to build stone terraces, ponds, housing and other constructions [1].

Although there are other types of drystone constructions, the study hereby presented will only be focused on the walls, whether they are function as a retaining earth structure or only as property partition or fence.

The raw materials used on its construction depend upon the lithological and geological regional characteristics, so, to study the different construction drystone walls' typology, these themes must be addressed as well. The research developed included work field and several fieldtrips to establish these relationships and interconnection, however some unexpected difficulties occur along the way. The three main limitations are related to the physical access to the walls, to the impossibility of travelling or circulating and the interaction with the locals. The first brought some challenges since the abandonment of the rural areas and subsistence agriculture, lead to a lack of land maintenance, allowing vegetation to invade and destroy walls, and therefore masked them among the chaotic vegetation. In order to overcome this limitation, Google Earth was occasionally used, which proved to be a valuable tool. The second and third limitations were associated to the COVID-19 pandemic situation, which was impossible to overcome. Finally, the work developed aims to alert the municipality stakeholders to the maintenance of this elements, counter the tendency to abandon this type of heritage, valuing it for the residentials and making it an attraction for visitors.

2. Algarve Characterization

2.1. Geography

The Algarve region covers 4997 km^2 [2], corresponding to 6% of the Portugal continental surface and it incorporates 16 municipalities [2, 3]. This region is bordered by Alentejo on the North, on the South and West by the Atlantic Ocean and to the East by the Guadiana River, which is a natural border with Spain.

As a consequence of its geomorphological characteristics, the region is divided into three zones or areas, being one located along the coastline, designated as "Litoral", an interior mountain region, named by "Serra", and an intermediate range, between the previous two, known as "Barrocal" (Figure 1). The litoral is a narrow strip and the South-facing and Western-facing coastlines are roughly of 155 km long and 50 km respectivally. The three most important mountains, located on the "Serra" region, are "Serra de Monchique", "Serra do Caldeirão" and "Serra de Espinhaço de Cão". The geographical singularities points of the Algarve region includes:

- Fóia, wich is the highest point, reaching an altitude of 902 m and located in "Serra de Monchique";
- Saint Vincent Cape, located on the Western point of Algarve, located in the "Litoral";
- Ria Formosa Lagoon, a Natural Park (CORINE, RAMSAR [4]) which includes some islands and islets, that covers over 170 km^2 and is a stopping place for hundreds of different species of birds. This is located on the "Litoral" Southeast coastline;
- The notable limestone caves and grottoes, located on the "Litoral" Western costline, being the result of the action of the sea waves over this sedimentary rocks.

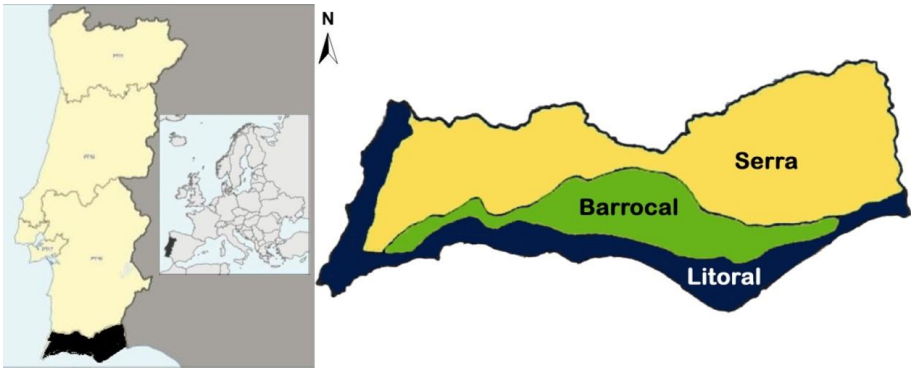

Figure 1. Left: location of the Algarve and Portugal (based on [5]); right: the three main areas of the Algarve region (based on [6])

2.2. Geology and lithology

Algarve is a Mesozoic sedimentary basin and has a wide geological and lithological variety. The oldest geological formations (Paleozoic) are located on the West and North of the Algarve, while the most recent (Jurassic, Cretaceous, Miocene, Pleistocene, Pliocene and Holocene) are located in the South and Southeast [7] - Figure 2.

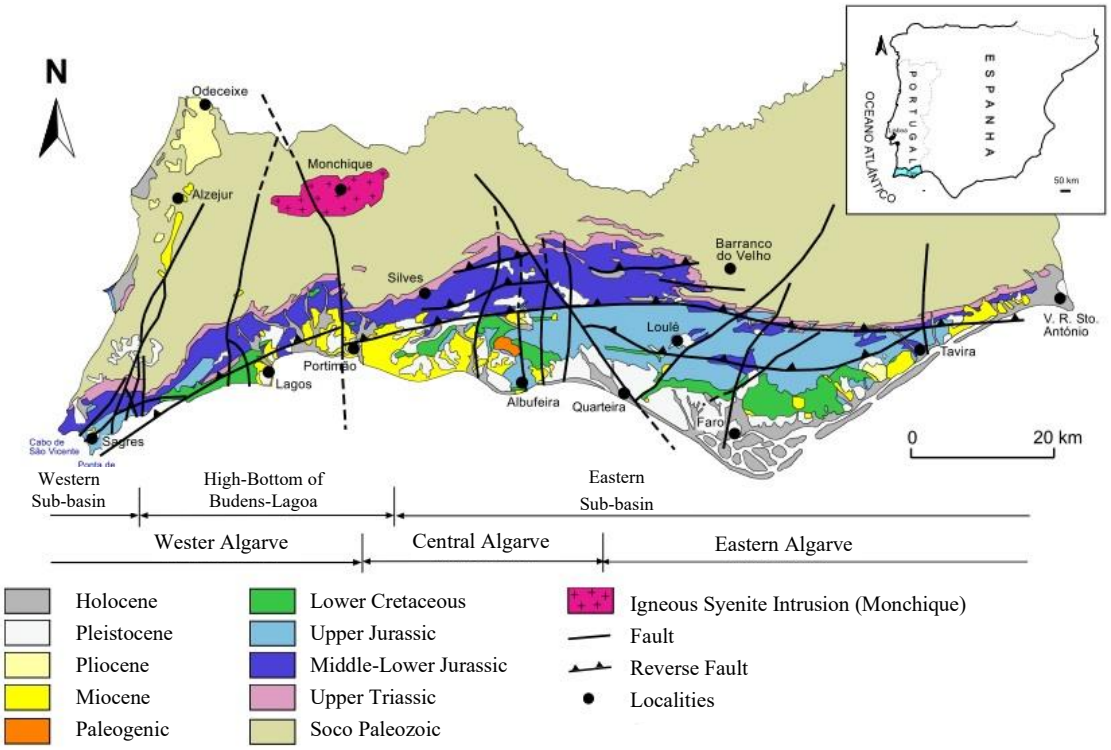

Figure 2. Simplified geological map of Algarve (adapted from [8])

The Algarve lithology is also very diverse since it depends on the geology. The sandstones, conglomerates and sands are the dominant type of rock massifs along the South coastline, and they are associated to sedimentary formations. On the "Serra" the dominant type of rocks are clay shales and graywacke, however, "Serra de Monchique" is located on an igneous formation intrusion, constituted by nepheline syenite rocks. "Barrocal", the strip that makes the transition between these extremely different zones, are mainly constituted by limestones, dolomites and also sandstones [7] - Figure 3.

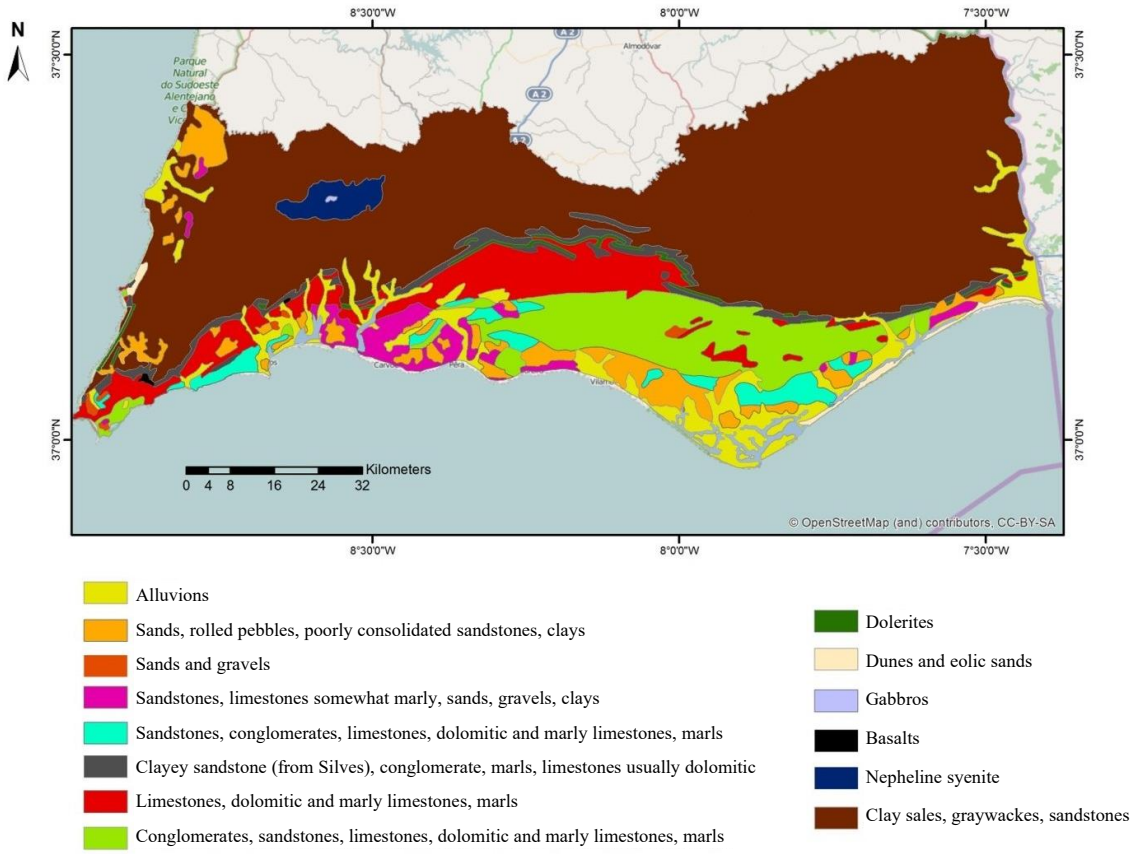

Figure 3. Lithological map of the Algarve (based on [7])

2.3. Geomorphology

As a consequence of the geology and lithology, Algarve's morphology is a mixture of different landscape. The "Serra" region is characterized by steep slopes with rounded hills, with the exception of "Serra de Monchique", presenting dispersed rocky outcrops. "Barrocal" follows, approximately, the "Serra" pattern, but slightly rugged, where the limestone hills are covered by Mediterranean vegetation, forming a unique landscape. Regarding the "Litoral" coastline, the Western part is characterized by rocky cliffs and the Eastern part by sandy dunes, islands and long beaches [7].

3. Drystone walls in the Algarve region

Drystone walls are a construction system very common on rugged landscapes, helping man to settle down, to control floods, to slope stabilization and to create terraces for crops. There are many examples of the drystones walls importance and uses around the world, like the Incas' terraces in Machu Picchu, the vineyard terraces in the Mediterranean and the rice terraces in Asia.

The technique of terraces with drystone walls is also used to regulate water supply systems, like Monchique case study in Algarve, where the SOWAMO project – "Sowing Water in Monchique Mountain", was developed with the aim of retaining water in the soil. Also, some parishes of the municipalities of "Silves" and "Monchique", in Algarve, developed a project with the goal of reducing the spread of forest fires and reordering the landscape on that zones, designated as "Reorganization and Landscape Management Program of the Monchique and Silves Mountains" [9]. At the present moment, one of the main axes of action and research in the Algarve region, is related to the study of systems of terraces with drystone walls [9]. These projects demonstrate the timeliness of this ancestral technique

and the importance of this heritage. Therefore, these structures systems must be maintained and estimated, disseminating the environmental, social, economic and cultural advantages associated to it. Algarve is an excellent region for the study of these structures since they occur in abundance.

In order to establish a relation between the geology and lithology of the Algarve region, several field trips were performed. The timeline of the study was reduced due to the pandemic situation brought by COVID-19, and therefore all the fieldwork was done during the time break of the 2020 and 2021 desconfinement, approximately in 8 months. The areas covered by the field trips were carefully chosen, to incorporate different places located on "Serra", "Barrocal" and "Litoral", as well as places with different geologies and lithologies.

Despite of the geological and lithological diversity, not all types of stones have sufficient strength characteristics to build drystone walls. Although expected, fieldtrips allow us to take that conclusion, since no significant walls were found on the "Litoral" Eastern sandy coastline. Figure 4 represents the integration of the geographical position of some drystone walls with the type of the stone material used on its construction, and the correspondence between the lithology and the construction materials is almost precise.

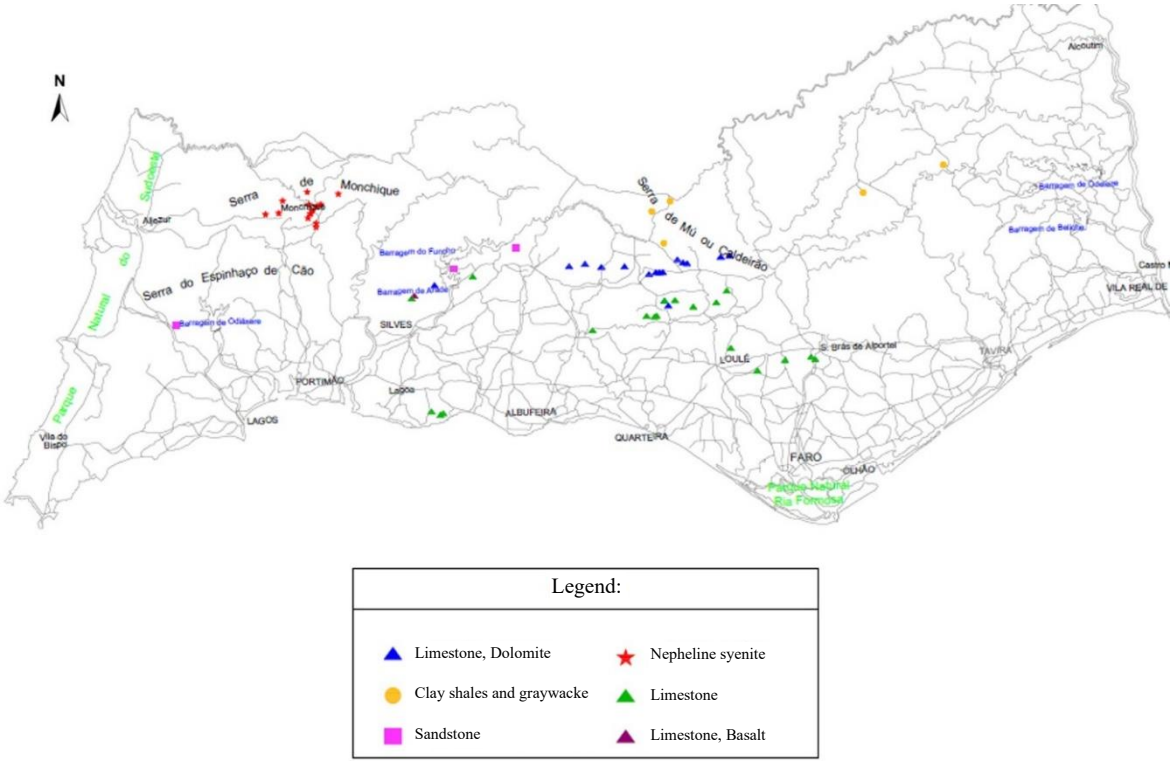

Figure 4. Map of distribution of drystone walls found in the Algarve (authors)

So, in "Serra de Monchique" the drystones structures are made with local nepheline syenite stones, whilst on the other parts of "Serra" the common material is clay shale and graywacke. On the border/transition between "Serra" and "Barrocal", some basalt and limestone elements were found, but the dominant raw material used on the "Barrocal" are the limestones and dolomites. Along the coastline the presence of walls is extremely reduced, due to the implementation of urban areas and touristic resorts. However, on the upper "Litoral" strip, where the agriculture is still the dominant human activity, limestone drystones walls are commonly used as property division.

At this moment, it is important to highlight the difference on structural and non-structural drystone walls. The first ones are earth retaining structures, constructed to sustain earth pressures, and design considering their gravity and stone interconnection (friction). They are essential on the creation of terraces. The second ones, the non-structural walls, are also smaller in high and width, since they do not support significant horizontal earth pressures. Nonetheless, its construction must ensure its stability and their design also consider the weight. These elements are applied on property division, but they can also serve other purposes like limiting paths.

Gathering the above information, it is evident why drystone walls density is higher on the "Barrocal", as well as on the "Barrocal/Litoral" transition, where the slopes are accentuated and consequently terraces proliferate. On the "Serra", terraces are most commonly observed near small communities. On the upper "Litoral" there are fewer and smaller terraces, and sometimes they pass imperceptible, due to the lack of maintenance and vegetation invasion.

3.1. "Serra"

3.1.1. Igneous Formations ("Serra de Monchique"). In the walls constructed with nepheline syenite from "Serra de Monchique" (Figure 5), the wall rigging is of the "with rigging or crisscrossing" type (careful but still irregular rigging) according to Rebelo et al. [10], partly due to the shape of the stone being uneven and slightly rounded. The finishing of the walls is generally "leveled" (rectangular blocks arranged longitudinally, without unevenness) [10] and very regular. The type of access to the terraces is made in two possible ways: ramp and stairs; the ramps are of two types: either in the direction of the slope and perpendicular to the walls, or forming a zig-zag and located at the end of the walls; the stairs can also be of two types: "parallel of symmetrical slab" (stairway parallel to the wall, with steps of the same size) (Figure 5) and "parallel of detached slab" (stairway parallel to the wall with staircases detached from the wall and suspended) [10]. The "change of direction" of the wall, that is, the corners, are important and delicate points for the resistance of the wall, so heavier and more regular stones are used in order to optimize locking and increase stability. In syenite walls, these elements are constructed at an angle, usually right-angled, between the two directions of the wall but there are also cases where the corners are rounded (Figure 6).

Figure 5. Drystone walls in the "Serra". A and B: nepheline syenite; C and D: shale/graywacke (authors)

3.1.2. Clay shales and greywacke Formations ("Serra"). In the walls made with shale/graywacke, the stones are flat and angular, their thickness being a function of the schistosity or the diaclases of the massif. The surfaces are relatively regular, being easier to lay out in layers (Figure 5), so their rigging is of the "with some rigging" type (stones with good fit but leaving interstices between the blocks) [10]. In some villages, walls finishing with cap stones were found and also "raised elevation with perpendicular slab" (finishing with slabs perpendiculars to the wall) but, as a general rule, the finish is "leveled", often "raised", since "*the finishing of the wall is done… above the level of the ground"* to reduce soil loss [10]. The type of access to the terraces is made by a ramp, forming a zig-zag (Figure 5). The corners of the walls that were found to be built in shale/graywacke are usually right-angled, but round corners were also found (Figure 6).

Figure 6. Corner examples: right-angled corner (on the left), rounded corner (on the right) (authors)

3.2. "Serra/Barrocal" transition

The walls built with basalt/limestone generally have smaller dimensions in height, since the stones are relatively irregular, and consequently the fit becomes more complex. The rigging is generally of the "with some rigging" type, but there are also specimens "with rigging or crisscrossing" (Figure 7) and "polygonal" rigging (very regular shaped stones with almost perfect fit) [10]. When the contact between the elements is only punctual, there is a tendency for instability to occur, given the difficulty in accommodating the stones in the face of deformations. The finishing is of the "leveled" type. [10]. The type of access to the terraces is mainly through a ramp (Figure 7) and the corners are, as a general rule, at right angles. The similarity of pairing between these types of walls and those made up of nepheline syenite is great, although the dimensions of the latter are greater. The limestone rocks are lighter compared to the previous ones, observing that their dimensions are very variable. The dimensions of the walls can reach dimensions greater than the previous ones, however their widths are larger and the corners are either rounded, when the stone is small and irregular, or right-angled, when the stone is rectangular.

Figure 7. Drystone walls in the "Serra/Barrocal" transition zone. A and B: basalt/limestone; C and D: sandstone (authors)

In the walls constructed with sandstone, the stones are more regular (Figure 7), so their rigging is of the "with some rigging" type [10]. An interesting detail in the rigging of these walls is the fact that, from time to time, stones with enormous dimensions appear, disproportionate to the others. The finishing is "leveled", showing some care in its execution. The type of access to the terraces is made by a ramp, (Figure 7) or by stairs. In this case, the stairs found were of the "imbedded" type (stairway inserted in the wall and perpendicular to it) [10]. The corners of the walls built in this type of stone are angled, usually straight.

3.3. "Barrocal"

Regarding the walls made with limestone or with limestone/dolomite (Figure 8), the wall rigging is of the "with rigging or crisscrossing" type [10], partly due to the irregular shape that raw material present with different dimensions. In the case of limestone/dolomite walls, the stones show alteration. If a

finishing to the wall is consider, then it will be of the "leveled" type [10], however, there does not seem to be much concern with this detail when the construction of the walls. The type of access to the terraces is made through ramps at the end of the terraces, forming a zig-zag. The corners form an angle, usually straight, with rounded corners being rare.

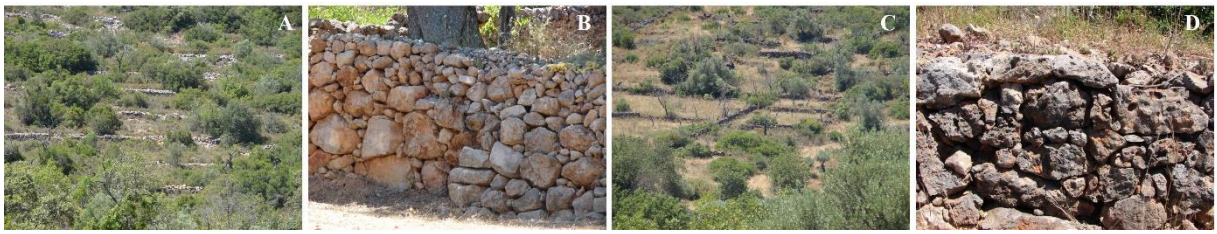

Figure 8. Drystone walls in the "Barrocal" area. A and B: limestone; C and D: limestone/dolomite (authors)

3.4. "Litoral"

In the walls found on the coast, being made with limestone, they have the same characteristics as the limestone walls of the previous section (Figure 9). However, support walls were rarely found constituting terraces, the majority having property dividing walls function.

Figure 9. Drystone walls in the "Litoral" area (authors)

4. Results and discussions

Algarve landscape is brushstroke with drystone walls. The quantity of this elements founded since the beginning of this study are incredibly huge. They perform several functions, and all of them are important and have an impact on the social, economic, hazard control, environment, biodiversity (fauna and flora) and on the regional development. In spite of their different uses, a special attention was given to the structural types, which are the responsible for containing the soil terraces and considered as retaining walls, as well as to the property dividing walls, being the majority considered as non-structural, since they do not have to support horizontal soil forces. The drystone walls, structural and non-structural, are designed as gravity elements, thus their total weight play an important role. Since the weight is the product of the stone volumetric weight by their volume, and since these elements are very long, they can be study as bidimensional instead of tridimensional since the length is adopted per meter. Consequently, regarding the wall itself, their width and high are the two most important geometric dimensions, along with the stone weight. Nonetheless, there are also other important factors affecting the drystone walls stability, namely the stone format (rounded, angular or flat), its texture (rough or smooth), dimensions (small, intermediate or big), fracturing, weathering, strength, stiffness, and finally the construction method. The contact and the friction between the stones, along with its paring, are fundamental for the horizontal stability of the ensemble. Drystones walls constructing can be compared to playing "Lego", it requires the ability to fit in the pieces at your disposal and simultaneously warranty its safety. To do so, stones are the main material, but time, patience and knowledge are also required.

Drystone walls performing as retaining walls, must warranty the stability against sliding and tumbling due to earth pressures, however it is important to ensure water percolation through the spaces left between the stone contacts. If the water gets retained in the soil terrace immediately behind the wall, it will generate an additional pressure and the stability can be threatened. According to [11, 12], due to intense rainfall some stones leave their place and damage the structure of the wall, so erosion or landslides may occur as a consequence of this. The geology and lithology dictate the dominant stone type in the region, and there is a direct relation between this natural existing material at our disposal, and the type of drystone walls encountered. It is important to remind that these are ancient structures, from an age where no technology and machinery was available, and manpower was the working driving force, so it is natural to find the interconnection, which was one of study purposes.

The study also allowed to have a good perspective of the stone characteristics, namely format, texture, dimensions, fracturing, weathering and constructing aspects, including paring. Usually, the bigger, regular, flatter stones and less weathered are used for the wall foundation, as well as for the corners, since these are vital points for the wall stability. This is a common aspect to all type of stone types, when it is possible to find a variety of dimensions and format. If the stones format and dimensions are relatively homogeneous, then wall does not present a regular pattern and the void spaces between stones are filled with others of much smaller dimension. Usually, the corners of this walls tend to be rounded. Limestones, sandstones and dolomites are among this last type of walls, and their contact points tend to crush under heavy weight, since they are softer rocks. They are also more subject to weathering phenomena associated to climate (temperatures, water, carbonation). Depending on the clay shale and greywacke fracturing, walls tend to show a well-defined pattern and paring or a dispersed and confused mixture of formats and dimensions. Although the graywacke is a very stiff and stable rock, the clay shale tends to be weathered, being the responsible for the wall's destabilization. Igneous rocks, like basalt and syenite, are very heavy, stiff and stable rocks, so they maintain their characteristics along time. The basalt drystone walls discovered in the region are concentrated in a specific zone and their high is relatively small, despite their resistance. Further studies much be done to better understand this geometric characteristic, but their dimensions, format and roughness may point us on a way. Regarding the syenite drystone walls, they are also concentrated in a specific zone ("Serra de Monchique") and the pattern and paring depends greatly of their characteristics. In this case, it was possible to identify walls with more than 2 meters, which indicates the suitability of this material for retaining earth structures.

Unfortunately, it was remarked that this type of elements is gradually deteriorating. This phenomenon is related with the rural exodus that began after the second half of the 70s in the Algarve, associated to the tourism boom in the region [11, 12]. The younger residents left their communities on the search for easier and more well-paid jobs. Gradually, the "Serra" and "Barrocal" population was reduced to the elderly and the land abandoned. The interruption of the agrarian, silviculture and pastoral activities allowed the native vegetation to grow and invade the terraces as well as the drystones walls. So, due to the lack of maintenance drystone walls become unstable and fall down, some only partially, but others completely, and consequently some terraces are no longer accessible. Other impact associated to it, are the forest fire, soil erosion and flood risks, since the water retention in the soil is reduced, thus becoming an environmental problem.

5. Conclusions

The existence of drystone walls in the Algarve are closely linked with the morphology and the need for humans to adapt their live conditions to sharp natural slopes, leading them to create more favorable resources for their subsistence. These elements transform the landscape radically, being the responsible for supporting the terraces, which allow the rural communities to establish themselves in the territory. These retaining structures are also accountable for the soil erosion control, reduction of the superficial water velocity during rainfall and forest fire control.

The great geological and lithological diversity of Algarve territory originates different types of rocks and stones. The data collected from the fieldtrips allowed to establish a direct relationship between the geology and lithology of the three different Algarve regions, namely the "Serra", "Barrocal" and "Litoral" with the type of materials used on the drystone walls. An additional and interesting finding, is associated to the discover of basalt drystone walls on the "Serra/Barrocal" transition, matching geographically with the geological and lithology maps where this igneous intrusion formation appears. The geometric characteristic of a drystone wall, namely is high and width, depend upon the type of the building material (stones), their dimensions, format, weight and strength, as well as the construction method. Although the strength materials and the constructions particularities were not the main goal of the paper, it is important to highlight it. So, a glimpse of the relationship between these various facets and their interconnections with the stone types (lithology) was mentioned.

The work field is fundamental, as well as the access to the drystone walls, and without it, there is no way of verifying the materials and characteristics of these structures. To optimize the time and the field trips, they were prepared in advance, especially during the COVID-19 pandemic period. Thus, Google Earth support was an important software tool, that helped to confirm the presence of terraces in a certain region. Finally, it is important to draw the attention to the maintenance of the drystone walls, or its lack, since they make part of the Algarve's landscape and its heritage. This building heritage must be recovered and maintained, valuing it for the residentials and making it an attraction for visitors.

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