Megaliths and Geology

Megálitos e Geologia

MEGA-TALKS 2

19-20 November 2015 (Redondo, Portugal)

Edited by

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Introduction

Megaliths and Geology: a journey through monuments, landscapes and peoples

This book is the result of the MegaGeo project, under the direction of Rui Boaventura, with the purpose of analysing the raw material economy in the construction of megalithic tombs in multiple territories, showing the representation of several prehistoric communities that raised them and their relationship with the surrounding areas.

Following the meeting of the previous year, it was decided to hold MegaTalks 2, wich brought together national and international experts who have developed work related to Megalithism and Geology, in its various perspectives, from the funerary depositions to the raw material construction of the tombs, as indicators of mobility and interaction with the surrounding physical environment.

Since the original meeting, held in Redondo on 19-20 November 2015, there have been several changes in the alignment of discussion and participants involved. However, the core of the analysis, regarding Megalithism and Geology, has not changed..

The alignment of the contributions sought a generically regional organisation, either in a national scale, or later in a peninsular and a European scale.

The volume opens with the presentation of a case study developed within the MEGAGEO project in the megalithic nucleus of Freixo (Redondo, Portugal) coordinated by R. Boaventura, Patrícia Moita and J. Pedro. This paper presents the analysis of the raw material of several clusters of megalithic tombs in Freixo region (Redondo, Alentejo). Broadly speaking, there was an exploration of proximity, most likely opportunistic, but in which other criteria were taken into account in the selection of the supports for the construction of monuments.

The following two contributions focus on the work carried out on the Megalithism of Beira Baixa (Central Portugal). João Luís Cardoso's work presents a general perspective on the Megalithism of this region, highlighting the documented architectural diversity, indicating structural polymorphism, contradicting linear development interpretations. The mobility of raw materials is understood essentially from the viewpoint of votive depositions in a funerary context, documenting contacts and circulation with the closest geographical regions, such as Estremadura and Alto Alentejo.

The next contribution, under the coordination of João Caninas, but using an extensive team, presents a novel investigation of Megalithism in the region of Proença-a-Nova, as well as Beira Baixa, Portugal. It is a set of works in progress revealing a diverse and complex reality that indicates contacts and circulation of goods and people at an interregional level, especially lithic artefacts. Concerning the raw material economy, there is a use of the raw material available locally, although one of the slabs may have a more distant source, more than 10 km away.

In the following chapter, Marco Andrade focuses his analysis on the raw materials of the votive objects deposited in megalithic contexts, trying to understand their sources of lithic supply, and thus seeking mobilities and circulation in the upper Alentejo's pre-history (Southern Portugal). This work presents us with a very in-depth perspective on the wide range of interaction in the upper Alentejo region for the purposes of amortization of votive objects in megalithic contexts, allowing us to understand the complexity of circulation and supply.

José António Linares brings us an innovative and detailed perspective on a region whose peculiar Megalithism has long been known. For the Sierra de Huelva (Southwest Spain), this author brings us a careful assessment of each monument and each group of tombs, which allowed him to verify the presence of a very fine and diverse knowledge of the territory and its potential. This knowledge was used for the construction of complex structures, where the different geological elements were carefully selected in response to the physical and ideological needs that presided over the construction of the tombs. The micro-analysis carried out for the Los Llanetes group, made it possible to emphasize the relevance of the Phyllite blocks. Simultaneously, the gathering and using of different types of stone for the construction of complex tumuli showed a clear chromatic and textural combination, evidencing all the effort to build the structure.

Heading north, towards the Douro River basin in Northern Spain, the work of Cristina Tejedor and Manuel Rojo present a chrono-typological perspective on the tombs of this wide and diverse region. The region presents a very different reality from the previous areas, marked by the polymorphism of the megalithic monuments that were only a small part of a diverse funerary architecture, with whom shares concepts and common cosmogonies. Architectural polymorphism, even if dependent on local developments and different diachronic processes, seems to be clearly rooted in this wide region. Despite this diversity, there is a use of essentially local raw materials, although this sometimes requires a few kilometers journey. This fact does not prevent the use of a diverse set of lithologies that allow a certainly significant chromatic combination that, in some situations, may be mimicking the landscape in which it fits, thus seeking to incorporate the geological elements of a certain landscape identity.

Following a long-time precursor line of research, Chris Scarre points out that there is a huge European affinity between Megalithism and its relationship with Landscape, an ancestral landscape certainly distinct from the current one. Thus, the author underlines the clear emergence of Megalithism in landscape contexts previously dominated by the large concentrations of stones, whether endogenous or dragged, as is the northern areas affected by glacier advance and retreat. In these landscapes of abundant stone and rock outcrops, the action of building the tombs from the local stones reinforces its connection to a territory and to the creation of a Landscape.

Mike Parker Pearson brings us a greater example of Megalithism and Geology, Stonehenge, due to its long researched history, to which is now added an important set of new data. The geological origin of the sarsen and bluestones has long motivated extensive studies and analyses, with the origin of the latter being well defined to the west, in the Preseli Mountains of Wales. However, a number of recent studies have allowed for the investigation into the specific origin of extraction such as Carn Goedog or Craig Rhog-y-felin, where ancient traces of these same works have been documented. Following this new data, it is believed possible that the bluestones were initially implanted in another stone circle, close to the extraction area. In a later moment, when it seems that a period of West-East rapprochement and union was developing, the bluestones of these ancient Welsh monuments would have been moved for the construction of Stonehenge, an area that seems to have had specific geological and historical characteristics. Stonehenge was an identity monument of that union, where the geological elements present would act as a mark of the ancestors. Different studies seem to prove that this displacement would have been accompanied by the installation of new people from the West in the Stonehenge region, being able to go back the different origins of the communities, even to the first Neolithic settlers.

At the end of the book, the results of the extensive investigation in Swedish Megalithism, in particular in the interior region of Falbygden, give us a very similar perception to the one documented on the opposite end of Europe, where we started this volume. Karl-Göran Sjögren's work shows us how the Megalithism of the Falbygden region adapts in a very particular way to the geological pre-existences, using them in a very structured way and as a reflection of the surrounding Landscape, which they somehow mimetize. However, some choices, even in local stones, or as a result of the dragging action of glaciers, are clearly due to options that are not merely functional or structural, but rather seem to respond to symbolic perceptions inherent in certain geological choices. In this way it is believed that there are recurring choices of raw materials, all local or locally available, for the construction of specific components of the tombs, such as the slabs of the chambers or the cover stones, which are not determined by their physical characteristics or robustness. Another vector of analysis is the ability of local groups to aggregate workforce to build such a large number of monuments. Despite the lack of data, the occupation sites would not have had a large enough population needed for the construction of the monuments and, therefore, their construction should imply the aggregation of different groups, regional or not. The monument would emerge as a greater symbol of group identity, but also as an impeller of social dynamics and sense of intergroup competition in the region, representing the capacity of regimentation and cohesion of the groups that built them, even at a long distance. Geological choices, even on a local basis, seem to represent identity discourses that justify the diversity of choices. The various strontium isotope studies carried out on the populations buried in Falbygden show that a quarter of the population would be allochthonous making clear the establishment of broad networks of solidarity with more remote regions.

As an epilogue, it is important to underline some aspects. This work was born from the will and vision of Rui Boaventura, who organised it in the last moments of his life, making clear that, instead of the closed Portuguese context, Megalithism at European level was once more in a very dynamic moment, structured in areas of multilinear research, where pressing issues of the study of European Prehistory were combined, from mobility to questions of identity, including the foundation of Neolithic Landscapes.

In this respect, the connection between Megalithism and Geology, whether in its structural aspects, in raw material economics, but also identity or symbolic aspects, is assumed as a multidisciplinary research line that needs to continue to be deepened and diversified, like Rui well knew.

Rui, you will continue to be one of the foundation stones of our Megalithism. May the Slab be with you!

Moving megaliths in the Neolithic - a multi analytical case study of dolmens in Freixo-Redondo (Alentejo, Portugal)

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Abstract: In this work a multi-disciplinary and multi-analytical approach was developed with the aim of better understanding the effort and selection criteria involved in the search for slabs used for the construction of dolmens during the Neolithic. Nine dolmens within a strip with ~15x10 km^2 on south Portugal (Freixo, Alentejo region), within magmatic and metamorphic geological basement were studied. Based on their chronology and geographic positioning the dolmens studied were systematized as follows: dolmens of the Freixo Group (7), dolmen of Godinhos (1) and dolmen of Candeeira (1). The work developed consisted of an intensive geological survey associated with a sampling protocol. These data combined with the results obtained through microscopy and whole-rock geochemistry on samples from dolmens and outcrops allow us to infer some conclusions about distances involved. The nearest exposures were not used as the unique collection site. Although the distances from dolmen to nearest outcrops varies between 150 m and 780 m the complete match including size, shape, petrography and geochemistry was obtained for several dolmens providing for group of Freixo, distances between 800 and 3500 m, the dolmen of Godinhos use very local material ~350 m, and for dolmen of Candeeira, a local provenance of 170 m was established based on singular macroscopic features. Other nearby, available lithology (gabbro) and with compatible size was deprecated due to other reasons than functional.

Keywords: Neolithic; Provenances; Multidisciplinar-Mulianalytical; Archaeometry; Dolmens

Movendo megálitos no Neolítico - um caso de estudo multi-analítico de dolmens no Freixo-Redondo (Alentejo, Portugal)

Resumo: Desenvolve-se aqui uma perspectiva multidisciplinar e multianalítica, com o objectivo de melhor compreender o esforço e os critérios de seleção envolvidos na procura de lajes utilizadas para a construção de dólmens durante o Neolítico. Foram estudados nove dólmens numa faixa com ~ 15x10 km^2 no sul de Portugal (Freixo, região do Alentejo), com um substrato geológico magmático e metamórfico. Os dólmens estudados foram sistematizados da seguinte forma: dólmenes do Grupo Freixo (7), dólmen de Godinhos (1) e dólmen de Candeeira (1), com base na cronologia e posicionamento geográfico. O trabalho desenvolvido consistiu num levantamento geológico intensivo associado a um protocolo de amostragem. Estes dados, combinados com os resultados obtidos através de microscopia e geoquímica da rocha total em amostras de dólmens e afloramentos permitiram inferir algumas conclusões sobre as distâncias envolvidas. Os afloramentos mais próximos não foram usados como o único local de análise. Embora as distâncias de um dólmen aos afloramentos mais próximos variem entre 150 m e os 780 m, a associação perfeita, incluindo tamanho, forma, petrografia e geoquímica, foi obtida para vários dólmens tendo-se obtido para o grupo do Freixo distâncias entre 800 e 3500 m, para o dólmen de Godinhos, que usa muito material local, ~ 350 m, e para o dólmen da Candeeira, uma procedência local de 170 m foi estabelecida com base em características macroscópicas singulares. Outras litologias disponíveis nas proximidades (gabro) e com tamanho compatível foram preteridas devido a outras razões que não funcionais.

Palavras-chave: Neolítico; Proveniências; Multidisciplinar-Multianalítico; Arqueometria. Dólmens

1. Introduction

Dolmens are the most conspicuous remains of the populations of mainly the 4th millennium BCE. These tombs are impressive not only for their monumentality, but also because of the socioeconomic investment they represent for Neolithic communities who built it. Although dolmens have been studied for their funerary content and typologies, an interdisciplinary approach toward the geological characterization and sourcing of stones used in these constructions has not received enough attention from researchers. In fact, as highlighted by Thorpe *et al.* (1991) little attention has been paid in published discussions of megaliths to the relationship between rock types and the geological sources utilized. When studied, most archaeological analyses are limited to brief description of rock types of slabs and geological settings and whether they were the same. When a megalith is found to be made of non-local stones origin this is usually highlighted but rarely and thoroughly investigated. When rigorous geological identification is conducted for specific dolmens, rarely is any attempt made to verify if there are similar patterns of slab selection on neighbouring dolmens and what relationship it might have with its geological background.

Previous works (Kalb, 1996; Kalb & Höck, 1996; Boaventura, 1999-2000; 2000) demonstrated a tendency for the use of local (1-2 km) stones, mainly in small- to middle-size dolmens (approximately 1-2 m high and 2-4 m long by 2 m wide). In larger tombs there were a few cases of megaliths sourced to outcrops at greater distances (6-8 km). The proximity and cost/benefit of slab extraction as well as its transport and erection could explain the selection of local stones, but the need for more suitable stones (that were larger or flatter), might explain the use of more distant sources. Nevertheless, the intrinsic and phenomenological qualities of certain rocks or geological contexts may have also influenced community's choices, as much as the prestige and power that those endeavours would give to its members.

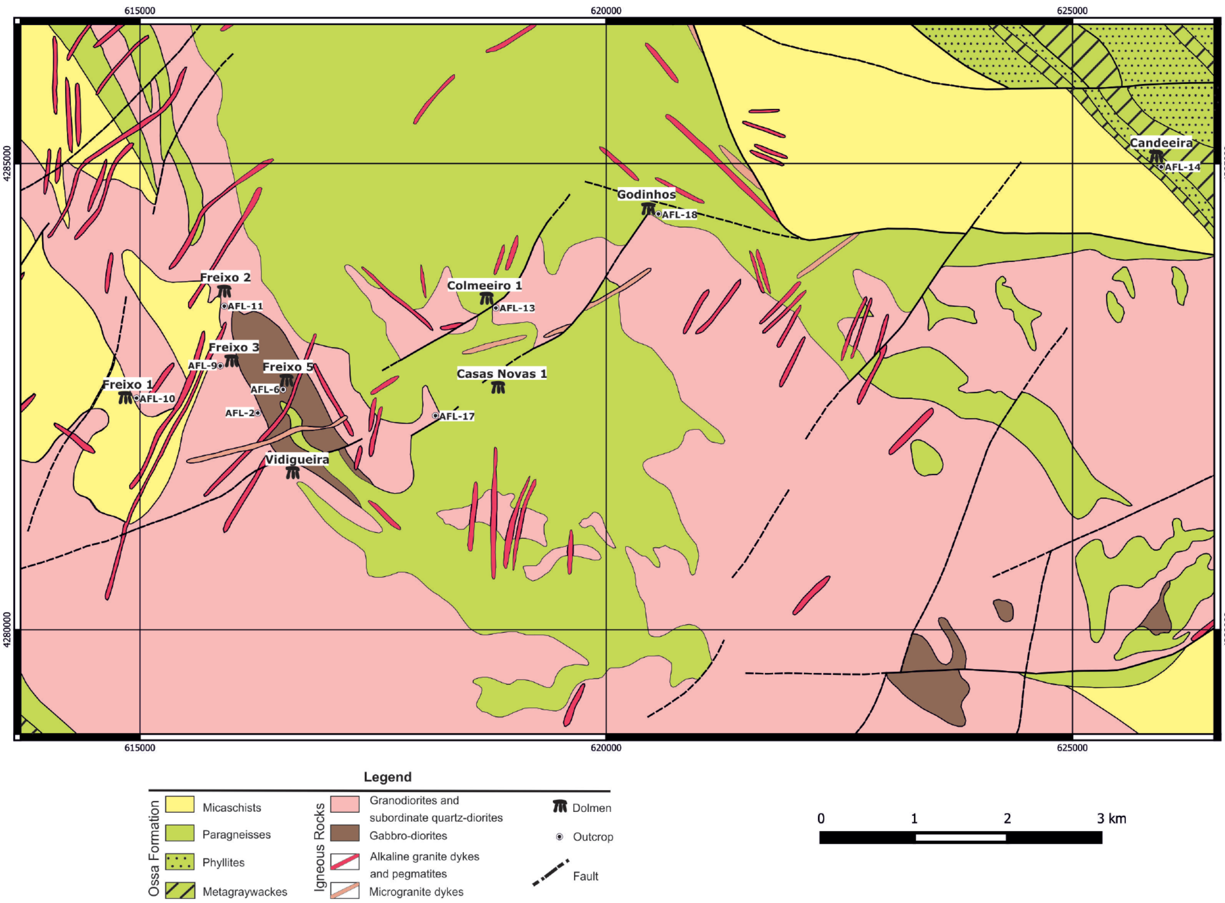

Figure 1 – Geological map adapted from Carvalhosa et al. (1987). Dolmens and outcrops of the Freixo-Redondo studied in this work.

In this work an integrated geo-archaeological approach is applied to systematically establish the relationship between the distribution of nine dolmens in the Freixo-Redondo area (Alentejo region, South Portugal, Fig. 1), and their source materials within the geological landscape. In this sense several data (archaeological information, field data, petrographic observation and elemental geochemistry) from slabs and probable outcrop sources, are presented and discussed. It is implied the comparison of dimension/geometry between dolmen slabs and blocometry from outcrops that might have been selected as the source of raw materials. Within that frame of results, it is the main goal of this work to establish a minimum distance necessary to carry heavyweight stone blocks for the erection of megalithic tombs that should reflect the effort of a community involved in such endeavour.

2. Methodology

In order to achieve the goals of this work it was initially developed a geological field survey using the cartography from Laboratório Nacional de Energia e Geologia at 1:50.000 scale (Carvalhosa *et al.*, 1986); this work embraces in a first approach the lithological characterization of dolmen slabs and mapping of geological surroundings for probable sourcing. The preliminary lithological classification of megaliths was non-destructive and comprised an in loco observation by hand magnifying lenses. These observations were in certain cases affected or precluded by rock surface weathering due to climatic and/or biological processes, which limits an accurate observation and classification. In these cases, a small-scale sampling by drilling was needed. Additionally, and besides this situation's samples were taken by drilling to have the opportunity to acquire a set of petrographic/geochemical data not attainable in another way.

The selection of outcrops source that were probably the site for slabs extraction was achieved by considering several features such as mesoscopic lithological characterization (at outcrop/hand sample scale), joint surfaces, morphology and dimensions of blocks/outcrop as result from weathering and faulting (Fig. 2). Another important characteristic for the selection of the outcrop source was the evidences of absence of blocks, that is to say voids of compatible sizes as slabs (Fig. 2). Whenever it was verified the presence of several hypotheses the studied outcrop was the one that is nearest the dolmen - the Nearest Mesoscopically Compatible Outcrop (NMCOutcrops).

Figure 2 – Example of an outcrop (AFL-10) with lithological and morphological macroscopic features compatible with the nearest dolmen slabs. The absence of blocks (i.e. negative) agrees with its use as for the production of raw material.

The drilling campaign followed a defined protocol, approved by national heritage institution - Direção Geral do Património Cultural. The slabs were sampled (Fig. 3) on hidden surfaces with a drill core (2.5 cm diameter; 5-6 cm long) leaving a hole which was subsequently mitigated by a restorative conservative procedure (Fig. 4).

The geological samples from NMCOutcrops were processed following specific laboratory requirements for polished thin sections and geochemical analyses. The subsequent detailed characterization of the rock specimens includes petrographic characterization and elemental whole rock geochemistry. The drilled samples from the dolmens were processed in the same way as those from the outcrops.

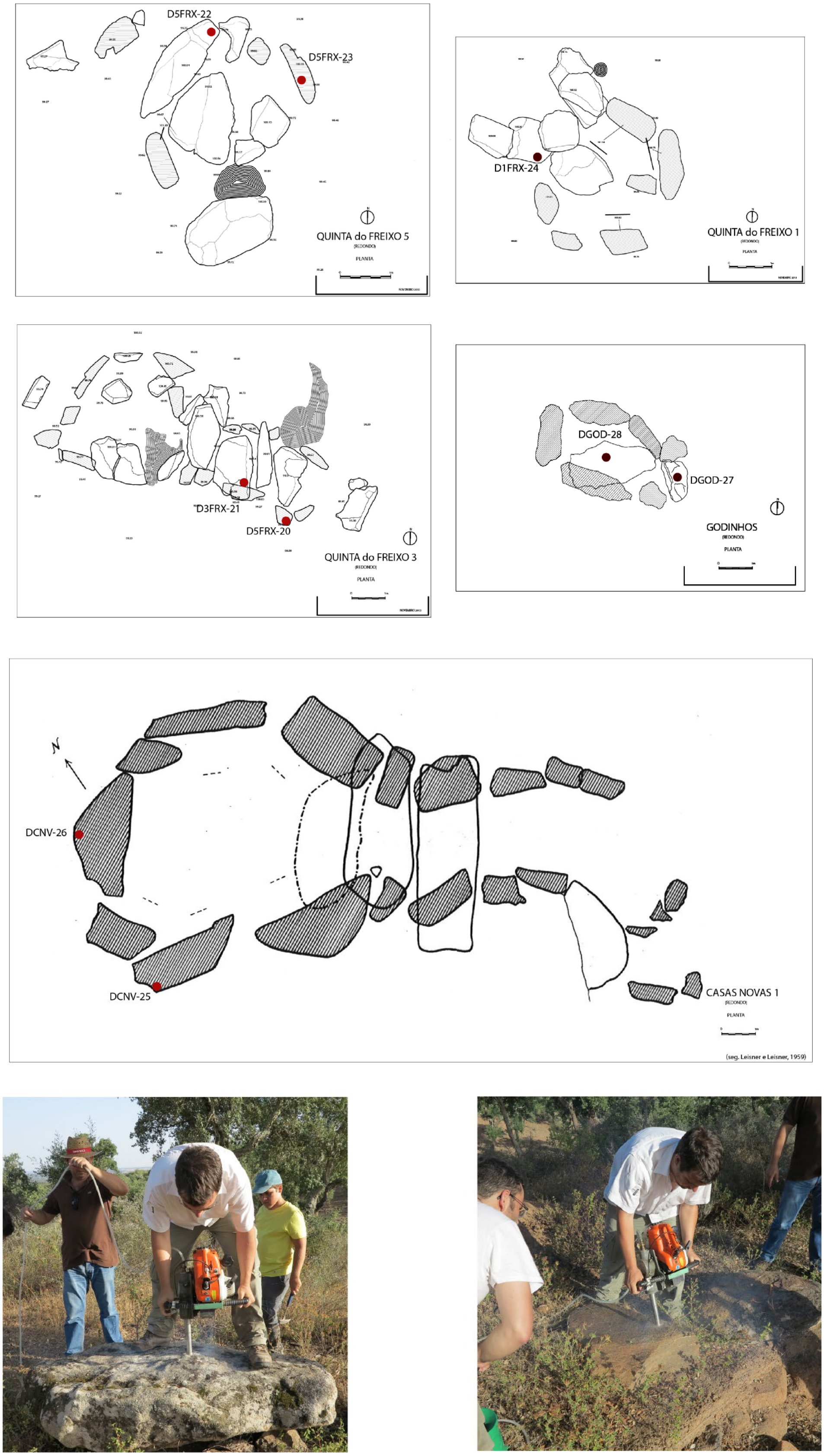

Figure 3 – Map of dolmens with sampling location

A refined petrographic and geochemical characterization of geological materials were performed in dolmen and outcrop samples. The obtained data are presented and discussed in the following points. As a remark, all the data were gathered in a SIG data base and used for geo integrated analyses (Nogueira *et al.*, 2015).

Figure 4 – Dolmen sampling by drilling and mitigation by restorative conservative procedures.

3. Archaeological context

There is a concentration of dolmens along the outskirts of Ossa mountain, either on its Northern and Southern borders (Calado & Mataloto, 2001; Mataloto *et al.*, 2015; Mataloto *et al.*, 2017). Within a set of 33 dolmens, 9 dolmens from the Freixo-Redondo area were selected (Tab. 1, Fig. 5); the group of Freixo with 7 dolmens (Quinta do Freixo 1, 2, 3 and 5, Vidigueira, Casas Novas 1 and Colmeeiro 1), Godinhos and Candeeira. Their choice was the result of the archaeological context, geographical dispersion and the type of lithological bedrock implantation. The Freixo dolmens present a geographical and typological coherence that allows us to clearly isolate them as a regional cluster, composed, however, by small groups aggregated by landscape units, which usually present some internal diachrony.

Early in the 19th century three dolmens from Redondo were identified (Cartailhac, 1878) and soon after became National Heritage: dolmens of Candeeira, Colmeeiro 1 and Vidigueira. Despite this early attention, the region only had its first attempt of systematic inventory with the German researchers Georg and Vera Leisner (1959) that visited the region in 1945-46. Nevertheless, although plans and pictures have been taken, no site excavations were conducted. By the end of the 20th century the list of tombs was expanded, namely with the dolmens from group of Quinta do Freixo (Calado & Mataloto, 2001), and in the past decade several dolmens have been studied in more detail (Mataloto & Rocha, 2007; Mataloto & Boaventura, 2009; Mataloto *et al.*, 2015; Mataloto *et al.*, 2017). This made possible to verify that small megalithic tombs, such as Godinhos, have been erected during the middle and second half of the 4th millennium BCE, and bigger megalithic structures followed those with more standardized plans despite the variation in size - varying from small, middle and large size (Mataloto *et al.*, 2015). Most of the latter tombs seems to have been erected during the second half of the 4th millennium and possibly in transition to the next millennium BCE, as might be the case of Quinta do Freixo 4 (Mataloto *et al.*, 2015).

The dolmens from group of Freixo are related with the small village of Freixo, located half way between Évora and Redondo towns, on the southern border of the Ossa mountain range (Fig. 1). Within this area 7 dolmens were considered; Quinta do Freixo 1, 2, 3 and 5, Vidigueira, Casas Novas 1 and Colmeeiro 1.

Table 1 – Typological features of the studied dolmens. (*Age based on typology; ** Dolmens size: small ~0,5 m high; medium 1-1,5 m high; large 1,5-2 m high; very large higher than 2 m; *** Number of slabs with each lithology.)

Dolmen	Age *	Size **	Corridor/ Cover	# Slabs Chamber	Bedrock	Preserved Slabs Chamber ***
Quinta do Freixo 1	3500 BCE 3rd Millenium	Medium		7	Micaschist	Granodiorite (7)
Quinta do Freixo 2	3500 BCE 3rd Millenium	Medium		7	Granodiorite	Granodiorite (7)
Quinta do Freixo 3	3500 BCE 3rd Millenium	Medium		7	Granodiorite	Granodiorite (7)
Quinta do Freixo 5	3500 BCE 3rd Millenium	Medium		7	Gabbro-diorite	Granodiorite (5) and Quartz-Diorite (1)
Colmeeiro 1	3500 BCE 3rd Millenium	Medium	Yes/ Yes	7	Paragneiss	Granodiorite (7)
Casas Novas 1	3500 BCE 3rd Millenium	Very Large	Yes / Yes	7	Paragneiss	Granodiorite (7)
Vidigueira	3500 BCE 3rd Millenium	Very Large	Yes inc / Yes	7	Granodiorite	Granodiorite (7)
Godinhos	3500 BCE -3250 BCE 3rd Millenium	Small		6	Gneiss and Migmatites	Muscovite-Granite (4) and Gneiss-Migmatite (2)
Candeeira	3500 BCE 3rd Millenium	Large	Yes inc / Yes	7	Phylite	Porphyroblastic-Schist (7)

The largest and better-preserved dolmen from group of Freixo is Casas Novas 1. Although is missing the capstone, still maintains all chamber slabs and lintel, as well as the passage slabs and lintels. Vidigueira and Colmeeiro 1, although well preserved, being the only dolmens of the area with the capstones, are slightly smaller in comparison with Casas Novas 1. From the remaining dolmens, only the Quinta do Freixo 1 is fairly complete, the dolmens of Quinta do Freixo 2, 3 and 5, although with sufficient plan information o allow its classification, have suffered partial destructions.

This group can be subdivided in two models of location: an immediate one to the plain, exactly in the transition between the hills that precedes the elevations of Ossa mountain (Vidigueira, Freixo 1, 2, 3 and 5), and another one composed by dolmens embedded in the valleys, further away from the plain (Casas Novas, Colmeeiro 1). Thus, while the first one is located in flat areas, and with open landscapes, the latter is on small elevations overlooking small water lines, and with more limited horizons. However, in architectural terms, and in spite of the variation in size, they present great homogeneity, with polygonal plants of seven slabs and middle size corridors. The dolmen of Godinhos is isolated from others known until present and has an intermediate location between the dolmens from group of Freixo and the dolmen of the Candeeira (Fig. 1). As mentioned above this dolmen seems to represent an early type of tomb, followed by more common type of polygonal chamber tombs, varying in size (small, medium and large). However, dolmen of Godinhos presents already some standard characteristics: chamber made with slabs covered by a capstone, opening to the rising sun and been all covered by a structured mound with a peripheral "kerb".

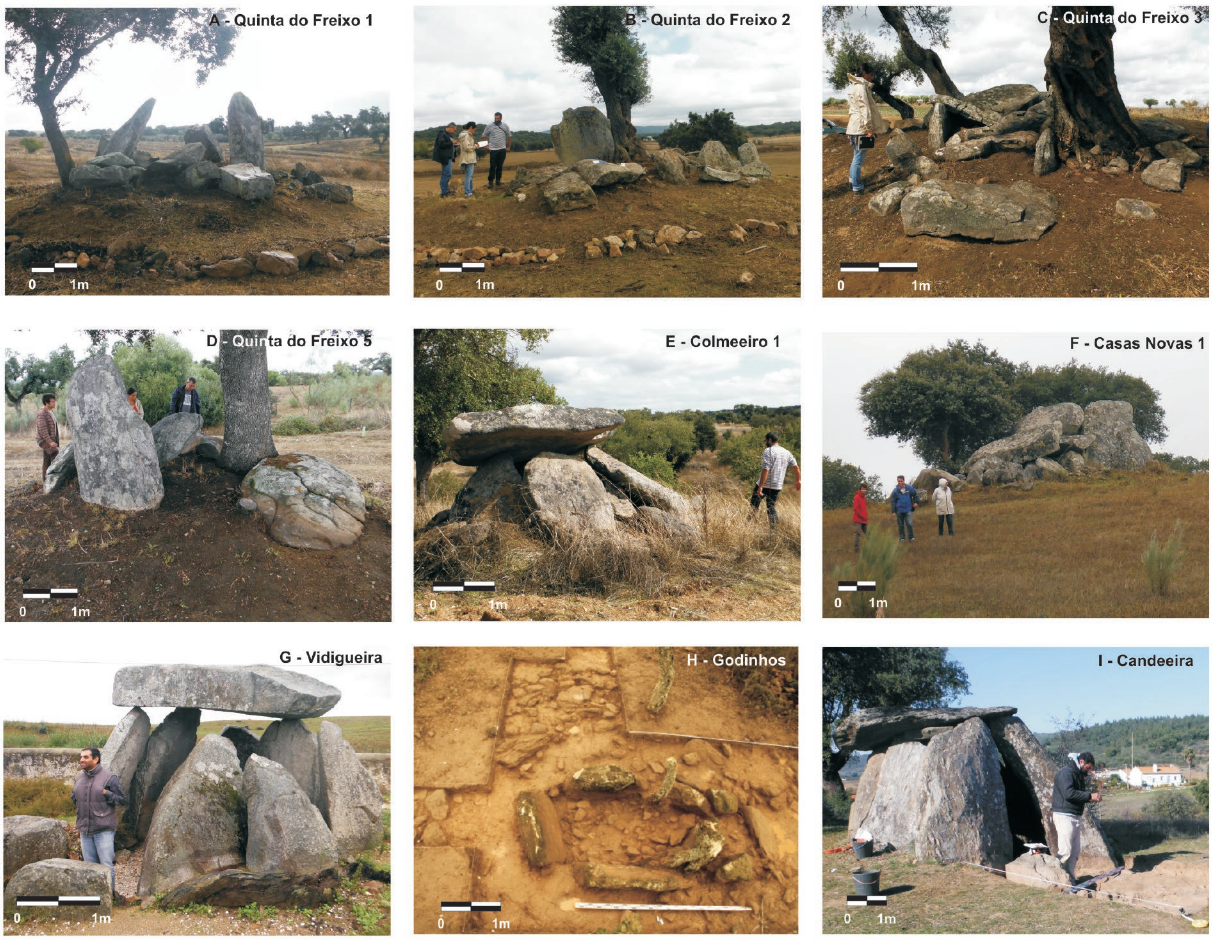

Figure 5 – Selected dolmens for this study, from Freixo-Redondo área: A) Quinta do Freixo 1, B) Quinta do Freixo 2, C) Quinta do Freixo 3, D) Quinta do Freixo 5, E) Colmeeiro 1, F) Casas Novas 1, G) Vidigueira, H) Godinhos and I) Candeeira.

The dolmen of Candeeira is nowadays sort of isolated on the immediate outskirts of the mountain, around 6.6 km north of Redondo town (Fig. 1). However ancient reports point to the existence of other similar structures at the Convento da Serra premises (Leisner & Leisner, 1959: 160). It is likely the first dolmen to be drawn in Redondo, around 1867, and two decades later again together with dolmens of Vidigueira and Colmeeiro 1 (Boaventura *et al.*, 2014). The singularity of a hole on the headstone called the attention of national and international researchers - although likely a mediaeval operation, the chronology of this feature is still open to discussion. Based on the typology of the tomb, with seven chamber slabs and a short passage, and presenting the capstone still, it is plausible to admit the erection of the structure at the second half of the 4th millennium BCE that is, contemporaneous with dolmens from group of Freixo.

Given the available information from the dolmens mentioned above, it was possible to establish a generic chronology for them: besides Godinhos earlier chronology, erected around middle and second half of the 4th millennium BCE whereas the other studied dolmens, based solely on its typologies seem to have been erected at least during the second half of the 4th millennium BCE.

4. Geological setting and outcrops availability

The dolmens of Freixo-Redondo area are implanted in the Portuguese sector of the Ossa-Morena Zone, one of the major NW-SE geotectonic divisions of the Iberian Variscan Belt. The Freixo-Redondo area comprises metamorphic and igneous rocks that are structurally controlled by the Redondo Antiform (Carvalhosa *et al.*, 1986).

Figure 6 – Examples of outcrop features: A) macroscopic features used to establishment of provenances such as mafic microgranular enclave within granodiorite; B) gabbro-diorite tabular block.

The metamorphic rocks belong to the Ossa Formation unit mainly composed of paragneisses, micaschists and phyllites, with subordinate metagraywacke intercalations. Planar and linear fabrics are present in those lithologies. Also, most of their lithological limits have the typical NW-SE orientation present in Ossa-Morena Zone and are in agreement with regional scale structures in Iberian Variscan Belt.

Paragneisses display a NW-SE foliation with vertical dipping and alternating layers of quartz-feldspar and biotite, while micaschists and phyllites develop a NW-SE schistosity. In particular the quartz-feldspathic nature of the paragneisses provide rare, usually very weathered, small and tabular slabs. Micaschists and phyllites, with great amounts of phyllosilicates are also suitable to weathering and do not provide or provide scarce and very weathered outcrops. In fact, due to his mineralogical constitution (mainly muscovite) the micaschists and the phyllites are very fragile and usually just slightly emerge in the surface. Although not differentiated in cartography the paragneisses unit also includes anisotropic and deformed levels of gneiss-migmatites and small bodies of muscovite-granites. Due to their mineralogical and structural features this lithologies provide very weathered and scarce outcrops.

The igneous rocks correspond mainly to the granodioritic Redondo massif, an irregular NW-SE elongated pluton with approximately 10-15km long that enclose a NW-SE elliptic gabbro-diorite body with 2.5 km long. The Redondo massif intruded the Ossa Formation and was responsible for the development of a contact metamorphism aureole in the surrounding pre-existent metamorphic rocks. It produced metamorphic recrystallization and macroscopic appearance of porphyroblast phases, like andalusite in phyllites. This lithology presents a silica enrichment with develops silica veins which probably contributes for preservation of some outcrops that enables them to provide metric and tabular blocks. The Freixo-Redondo area is also characterized by a profusion of granitic dykes, with variable orientation without/or limited cartographic representation.

Especially prominent in the field relations are the interactions of granodiorite with the gabbro-diorite intrusion; these two melts interacted before cooling and crystallization which is manifested by interpenetration between the two rock types as well by the presence of rounded mafic microgranular enclaves (Fig. 6). This type of relations (mingling of magmas) provided macroscopic fingerprints that can be related with the proximity to limits of the gabbro-diorite.

In the studied area the plutonic rocks are better preserved than the metamorphic being the dominant lithology a granodiorite: it is a light-coloured medium size grained where the mafic minerals correspond mainly to biotite and occasionally to hornblende. Typically exhibits rounded mafic granular enclaves and angular metamorphic enclaves. The granodiorite provides some large outcrops with fracturing patterns that originated metric rounded to tabular blocks. The gabbro-diorite is very coarse grained, sometimes with cumulated textures and provide very fresh tabular blocks (~1 m length).

5. Dolmens and outcrops features

The geological survey in the area allows to identify/select and geo-reference the outcrops (Tab. 2) that have mesoscopic (outcrop scale) and blocometry compatibility with the slabs from the dolmens. Most of the selected outcrops exhibited evidences of extraction of raw material such as negative structures (Fig. 2), that is a clear absence of stone blocks and/or more recent extraction (roman, medieval/modern) activity by notch marks. Outcrop identification fieldwork with respective GPS-location made possible to locally redraw the cartographic geological limits of the studied area (*e.g.* AFL-2, 12, 13). Upon selection of outcrops by the above mentioned criteria these were sampled according with the nearest proximity to the dolmen (NMCOutcrops). In most of cases, the NMCOutrops (Tab. 2) are at a visual distance, between 20-310 m away from the dolmen. In this way minor distances were obtained, although not denying the hypothesis that more distant outcrops were used. Currently, besides the dolmen of Quinta do Freixo 5, there are no clear and unequivocal outcrops under the dolmens, suggesting that the implantation of slabs is in soil horizon. Nevertheless, it was not the object of this work to control the soil thickness and the deep of the alveoli.

5.1. Dolmens from group of Freixo

Several dolmens from group of Freixo (Quinta do Freixo 2, 3, 5, Vidigueira) stands out in the area dominated by interaction between two types of igneous rocks - granodiorite and gabbro-diorite - and the bedrock correspond to one or other (Tab. 1). The dolmens of Colmeeiro 1 and Quinta do Freixo 1 are associated with the geologic limits between granodiorite-paragneisses and granodiorite-micaschists respectively. The dolmens of Casas Novas 1 Colmeeiro 1 lies over the paragneisses whereas the dolmen of Quinta do Freixo 1 is implanted over micaschists (Tab. 1).

Granodiorite is ubiquitous in the dolmen slabs from group of Freixo (Tab. 1). In fact, within this group almost all the preserved slabs have a similar granodioritic composition between monuments. This granitoid variety has typically a light colour (i.e. dark minerals such as biotite and hornblende are less than 15-20% of modal composition) and it is medium to coarse grained. Some small differences between them include grain size variations, proportions between mafic phases (dark minerals), as well as the presence of quartz veins and enclaves. These variations are also observed in the outcrops.

Dolmens of Quinta do Freixo 1, 2, 3 and 5, and Colmeeiro 1 have smaller slabs, when compared with Vidigueira and Casas Novas 1 megalithic tombs – approximately half the size. Thus, for the smaller-middle size dolmens there are more outcrops availability that covers the requisites mentioned in methodology. The selected outcrops for a more detailed comparison with slabs from dolmens of Quinta do Freixo 1, 2, 3 and 5, and Colmeeiro 1 are 20-180m apart (Tab. 2) and exhibit blocks size of more than 1,5-2 m long and 1 m wide.

Table 2 – Distances between dolmens and Nearest Mesoscopically Compatible Outcrops (NMCOutcrops).

Dolmen			NMCOutcrop				Distance (m)
Ref.	Coordinates		Ref.	Coordinates		Lithology	
	Latitude	Longitude		Latitude	Longitude		
Quinta do Freixo 1	38,683861	-7,679611	AFL-10	38,683500	-7,678250	Granodiorite	125
Quinta do Freixo 2	38,696667	-7,667528	AFL-11	38,691750	-7,668083	Granodiorite	240
Quinta do Freixo 3	38,687303	-7,666806	AFL-9	38,686750	-7,668000	Granodiorite	120
Quinta do Freixo 5	38,684778	-7,659806	AFL-6	38,684861	-7,659667	Gabbro-diorite	20
			AFL-7	38,683278	-7,659139	Granodiorite	180
Colmeeiro 1	38,692675	-7,634889	AFL-13	38,693722	-7,633778	Granodiorite	150
Casas Novas 1	38,688420	7,593319	AFL-17	38,681760	-7,642060	Granodiorite	780
Vidigueira	38,676422	-7,659564	Not identified				
Godinhos	38,702692	-7,615100	AFL-18	38,700278	-7,613750	Muscovite-Granite	300
			AFL-18	38,699917	-7,615611	Gneiss-Migmatite	
Candeeira	38,704353	-7,553539	AFL-14	38,703278	-7,554889	Porphyroblast-Phyllite	170

Regarding the dolmens with bigger size slabs, Casas Novas 1 and Vidigueira, the possibilities of outcrop sourcing are reduced. In the case of dolmen of Casas Novas 1 an extensive outcrop (AFL-17; Fig. 1) near the Freixo stream, southeast from the dolmen, present blocks with sizes similar to those in the dolmen as well as evidences of extraction.

As in the remaining dolmens, Vidigueira tomb also has granodioritic slabs. Nevertheless, this dolmen stands out not only by the size of the slabs but also for the profusion of enclaves (black rounded globules) as well for the quartz veins with few centimetres thickness. The presence of mafic micro-granular enclaves in the slabs of dolmen of Vidigueira is geologically compatible with its implementation near the limit between the gabbro-diorite and the granodiorite. Unfortunately, this dolmen was erected between the edge of the village, nearby a farmstead house and a crop field with no outcrops within a radius of 1km. Although no outcrops were observed these could have existed and are presently hidden under farm infrastructures. (Fig. 1).

The dolmen of Quinta do Freixo 5 is the only that was erected over the gabbro-diorite bedrock and exhibit different lithologies (Tab. 1). One of the preserved slabs is darker (dioritic affinities) whereas the others correspond to granodiorites. Located over the gabbro-diorite bedrock, the dolmen was erected away from the concentration of available basic outcrops but above a later intrusion of a pegmatitic dyke.

5.2. Dolmen of Godinhos

The preserved slabs from dolmen of Godinhos correspond to gneiss-migmatite and muscovite-granite lithologies. The slabs are very weathered and are relatively small, which agrees with the size of the available outcrops in the area. There are two gneiss-migmatite slabs, the head slab and one other, that have a heterogeneous appearance with felsic (mainly quartz and feldspar minerals) igneous layers alternating with metamorphic mica-rich layers. The other slabs including one of the probable capstone, are made of muscovite-granite that is also very weathered. They are light coloured (yellowish due to alteration) without mafic minerals reflecting the different geological processes of formation of this granite when compared with granodiorite.

Around the dolmen of Godinhos the outcrops of gneiss-migmatites are rare. They have an orientation parallel to the NW-SE anisotropy of the rock. At a distance of approximately 300 m, it was identified an outcrop presenting adequate size blocks. The muscovite-granites outcrops were not found. Nevertheless, this lithology can be found as abundant blocks, boulders and as sand in the soil associated with blocks of paragneisses, gneiss-migmatites and micaschists. It is not surprising that muscovite-granites do not constitute significant outcrops due to the strong alteration as well to the fact that they occur as small "pouches", without cartographic representation. It is important to note that these two lithologies present in the dolmen of Godinhos as well in the outcrops are not individualized in the Ossa Formation unit (Carvalhosa *et al.*, 1986), both are included in the unity of the paragneisses.

5.3. Dolmen of Candeeira

The chamber slabs and capstone of dolmen of Candeeira correspond to andalusite-porphyroblast phyllite. This singular lithology is characterized by the growth of andalusite crystals over the mica schistosity, projecting in the surface. The slabs are very identical within each other but displaying slight variations in size and abundance of andalusite crystals. The andalusite-porphyroblast phyllite is a relatively fragile/soft rock due to their large proportion of phyllosilicates (muscovite, sericite).

Around the dolmen (4-5 m to west and south) there are small outcrops that slightly emerge from the soil. However, although constituted of schist they do not have andalusite crystals. More to the south (170 m) a protuberant outcrop (AFL-14) constituted by andalusite- porphyroblast phyllite, with quartz veins, was selected for sampling. Regarding the size and fractures of the outcrop, it would have been possible the extraction of large blocks as those used in the dolmen of Candeeira.

6. Petrographic analysis

The microscopic petrography allows the identification and quantification of mineralogy present in the rock. Not only the main mineralogy, but also accessory mineralogy as well as textural relations between the different mineral phases. The aim of this type of analysis is to identify unique petrographic features that might be identified in samples of slabs and outcrops. It were analysed 30 thin sections representing outcrops and slabs, whose main features are presented on Tab. 3 and Fig. 7. In what concern the dolmens of Colmeeiro 1, Vidigueira and Candeeira, classified as National Heritage Monuments, no samples were taken because of its very distinctive macroscopic mineralogy/texture and fragility of the slabs. Moreover, considering the same archaeological and geological features between the dolmens of Quinta do Freixo 2 and 3 to reduce the impact of sampling and preclude the duplication of data only the dolmen of Quinta do Freixo 3 was sampled.

Table 3 – Main petrographic feature of samples from dolmens and outcrops.

	OUTCROP															
Field Ref.	AFL-2	AFL-2	AFL-6	AFL-8	AFL-9	AFL-10		AFL-11			AFL-13			AFL-17	AFL-18	
Sample ID	FRX-2	FRX-2	FRX-5	FRX-6	FRX-7	FRX-8	FRX-9	FRX-10	FRX-11	FRX-12	FRX-13	FRX-14	FRX-15	FRX-17	FRX-18	FRX-19
Rock Type	Grd	Grd	Gb-Drt	Grd	Hb-Grd	Hb-Grd	Hb-Grd	Qz-Drt	Qz-Drt	Qz-Drt	Grd	Grd	Grd	Grd	Gns-Mig	Msc-Gr
wt %																
SiO2	61,31	61,31	48,10	61,74	61,71	61,43	60,41	48,41	58,32	48,17	60,18	61,31	61,02	61,81	70,01	74,26
Al2O3	17,95	17,95	17,04	17,70	18,11	17,53	17,73	19,83	18,71	20,15	18,17	18,23	18,11	17,05	15,49	14,13
Fe2O3	6,04	6,04	10,51	5,78	4,92	5,62	6,19	9,64	6,66	10,05	5,93	6,17	6,26	5,40	6,36	0,66
MnO	0,09	0,09	0,17	0,09	0,07	0,11	0,11	0,20	0,12	0,20	0,10	0,10	0,10	0,09	0,18	0,03
MgO	2,45	2,45	7,41	2,28	2,91	2,55	2,92	5,35	2,99	6,24	2,39	2,44	2,51	2,22	1,76	0,11
CaO	4,99	4,99	8,72	4,82	5,54	4,64	5,50	9,86	6,12	9,39	5,22	4,87	5,05	4,47	0,13	0,33
Na2O	2,91	2,91	2,65	2,98	2,92	3,13	3,11	2,47	3,19	2,49	3,15	2,87	2,91	2,88	0,30	2,61
K2O	2,80	2,80	1,52	2,83	2,35	2,89	2,50	1,31	2,26	1,72	2,48	2,60	2,76	2,77	2,31	4,95
TiO2	0,71	0,71	1,07	0,69	0,60	0,63	0,65	1,16	0,77	0,91	0,65	0,71	0,76	0,65	0,60	0,06
P205	0,23	0,23	0,26	0,20	0,23	0,19	0,20	0,24	0,23	0,21	0,27	0,22	0,23	0,19	0,04	0,07
LOI	1,52	1,52	3,05	1,08	1,12	1,43	1,00	1,69	1,11	1,42	0,93	1,08	1,02	1,05	1,53	1,30
ppm																
Y	10,60	10,60	30,00	8,30	6,50	21,40	26,70	50,10	22,60	33,70	12,60	17,40	16,80	13,00	16,80	8,60
Zr	181,00	181,00	93,00	151,00	176,00	145,00	143,00	134,00	156,00	111,00	170,00	171,00	226,00	168,00	83,00	24,00
Nb	8,60	8,60	4,90	8,90	5,20	7,40	10,50	7,40	7,90	4,70	12,60	8,20	10,00	11,70	10,70	11,50
La	34,30	34,30	18,40	15,40	4,98	30,10	34,00	20,60	22,90	16,40	44,80	16,60	75,00	39,50	38,40	6,99
Ce	81,80	81,80	46,60	29,00	10,80	60,70	66,80	58,40	48,70	44,10	78,60	32,70	150,00	75,20	74,00	11,20
Pr	7,44	7,44	6,47	3,30	1,50	6,89	7,68	8,91	5,81	6,30	9,08	3,73	16,50	8,20	8,35	1,29
Nd	27,30	27,30	30,50	13,30	7,15	27,10	30,00	44,40	24,70	29,50	32,80	15,50	60,90	29,90	30,40	4,30
Sm	4,54	4,54	7,10	2,65	1,55	5,27	6,21	11,00	5,07	7,21	5,02	3,41	9,78	4,98	5,83	0,92
Eu	1,41	1,41	1,63	1,18	0,93	1,22	1,22	2,15	1,28	1,59	1,24	1,14	1,49	1,11	0,98	0,37
Gd	3,14	3,14	6,17	2,10	1,24	4,12	5,11	9,81	4,44	6,26	3,52	2,76	6,19	3,40	4,23	0,90
Tb	0,43	0,43	1,01	0,31	0,19	0,65	0,86	1,66	0,76	1,12	0,44	0,51	0,80	0,52	0,65	0,21
Dy	2,31	2,31	5,73	1,61	1,10	3,85	4,96	9,10	4,16	6,47	2,38	3,17	3,66	2,76	3,48	1,47
Ho	0,38	0,38	1,12	0,27	0,20	0,75	0,94	1,74	0,76	1,22	0,46	0,62	0,64	0,50	0,65	0,27
Er	1,05	1,05	3,06	0,66	0,63	2,06	2,75	4,99	2,22	3,38	1,31	1,74	1,60	1,32	1,78	0,77
Tm	0,16	0,16	0,42	0,08	0,09	0,30	0,45	0,74	0,32	0,48	0,19	0,26	0,20	0,20	0,28	0,13
Yb	1,17	1,17	2,61	0,53	0,59	1,91	2,77	4,87	2,00	3,01	1,22	1,63	1,16	1,35	1,83	0,85
Lu	0,20	0,20	0,43	0,10	0,09	0,28	0,37	0,69	0,31	0,49	0,19	0,24	0,18	0,19	0,25	0,12
Hf	4,20	4,20	2,20	3,20	3,80	3,20	3,60	3,20	3,40	2,50	4,40	3,60	4,90	4,00	2,20	0,80
Ta	0,70	0,70	0,42	0,98	0,57	0,64	0,80	1,51	0,49	0,30	0,57	0,76	0,78	1,08	0,95	2,29
Th	10,10	10,10	2,42	4,08	0,49	7,67	9,06	2,15	3,98	1,03	11,00	6,38	21,40	11,20	12,10	3,05

	DOLMEN							
Field Ref.	Freixo-1	Freixo-3		Freixo-5		C. Novas1	Godinhos	
Sample ID	D1FRX-24	D3FRX-4	D3FRX-20	D5FRX-22	D5FRX-23	DCNV-26	DGOD-27	DGOD-28
Rock Type	Grd	Hb-Grd	Grd	Qz-Drt	Grd	Grd	Gns-Mig	Msc-Gr
wt %								
SiO2	64,45	65,30	63,55	49,92	67,54	63,52	51,96	74,99
Al2O3	16,70	16,56	17,09	18,78	15,60	17,43	25,00	14,46
Fe2O3	4,96	4,59	4,16	10,53	3,55	4,66	9,82	0,93
MnO	0,10	0,09	0,08	0,17	0,06	0,09	0,15	0,03
MgO	1,97	1,81	1,75	4,92	1,46	1,82	1,59	0,15
CaO	3,76	4,12	4,06	8,82	3,46	4,55	0,15	0,42
Na2O	3,26	3,03	3,38	1,94	3,18	3,46	0,73	2,71
K2O	2,56	3,34	2,80	2,07	2,51	2,51	5,82	5,39
TiO2	0,54	0,49	0,56	1,08	0,38	0,51	1,12	0,07
P205	0,18	0,15	0,15	0,19	0,20	0,20	0,14	0,14
LOI	1,38	0,91	0,98	1,36	0,94	0,82	2,79	1,12
ppm								
Y	23,50	21,70	13,50	32,80	16,00	16,40	37,30	15,50
Zr	140,00	134,00	122,00	105,00	110,00	157,00	165,00	28,00
Nb	10,30	6,20	8,00	8,60	9,30	9,40	18,80	16,00
La	55,30	13,30	30,60	16,70	88,40	43,20	62,50	5,77
Ce	110,00	26,30	58,40	40,30	164,00	82,70	119,00	11,50
Pr	11,90	3,56	6,74	5,83	17,30	8,82	14,10	1,33
Nd	43,30	14,60	25,30	27,50	60,40	31,90	53,70	5,07
Sm	7,36	3,50	4,82	7,08	8,74	5,64	10,80	1,36
Eu	1,10	0,99	1,09	1,62	1,19	1,05	2,02	0,23
Gd	4,61	3,30	3,36	6,25	5,09	3,68	7,45	1,65
Tb	0,73	0,60	0,48	1,06	0,70	0,56	1,25	0,38
Dy	3,97	3,64	2,65	6,48	3,52	3,12	6,92	2,52
Ho	0,81	0,71	0,50	1,20	0,61	0,56	1,36	0,49
Er	2,45	2,13	1,44	3,53	1,45	1,67	3,92	1,39
Tm	0,41	0,35	0,21	0,54	0,15	0,31	0,59	0,21
Yb	2,62	2,22	1,26	3,33	0,81	2,34	3,73	1,37
Lu	0,39	0,35	0,18	0,48	0,11	0,39	0,53	0,21
Hf	3,60	3,10	3,20	2,80	3,50	3,70	4,40	1,10
Ta	1,12	0,95	0,86	0,55	1,24	0,99	1,42	3,29
Th	23,60	4,78	7,98	2,35	24,20	9,86	20,90	3,87

Grd: Granodiorite; Gb-Drt: Gabbro-Diorite; Hb-Grt: Horneblende-Granodiorite; Qz-Drt: Quartz-Diorite; Gns-Mig: Gneiss-Migmatite; Msc-Gr: Muscovite-Granite

6.1. Dolmens from group of Freixo

The granodiorite present in the dolmens from group of Freixo, has a typical plutonic igneous texture – (hypidiomorphic medium to coarse grained). The light colour of the rock - leucocratic - is the result of dominant presence of felsic minerals over mafic minerals. As main mineralogical felsic phases exhibit plagioclase, quartz and ±K-feldspar, whereas biotite is the main mafic phase occasionally accompanied by hornblende. Allanite, apatite and zircon are accessory phases usually in minute amounts. Chlorite is present in some samples due to later low-temperature mineralogical reactions. The dolmen samples are usually not weathered and as consequence plagioclases are well preserved without or with vestigial sericitization. One of the minerals used as reference/comparison between granodiorites (dolmens and outcrops) was the hornblende. This mineral is an amphibole with green colour under transmitted polarized light and exhibits a typical prismatic section (diamond shape). Its size on average is between 200 and 500 μm.

Petrographic analysis show both differences and similarities between pairs of dolmens and NMCOutcrops. All the petrographic features on dolmens and outcrops are compatible and expected at the scale of the granodiorite intrusion, related with their genesis, evolution and crystallization. The petrographic diversity results from differences in texture, for example, whether there is anisotropy (mineral alignment) or quartz recrystallization, but mainly observed by the abundance (modal composition) of mafic phases such as biotite and hornblende.

It was observed a clear match between dolmen samples of Casas Novas 1 and its NMCoutcrop (samples DCNV-25 and DCNV-26 from dolmen with sample FRX-17 from outcrop AFL-17) that is all samples present similar isotropic texture as well biotite as the only mafic mineral phase.

The sample from dolmen of Quinta do Freixo 3 (D3FRX-4) and NMCoutcrop (sample FRX-7 from outcrop AFL-9) have strong similarities where in this case both amphibole and biotite are present with similar volumetric amounts. On the other hand, the sample D3FRX-20 does not present amphibole in its modal composition and does not match with the petrography observed in NMCoutcrop. This observation suggests different sources of material, that is, different outcrops, for a single dolmen.

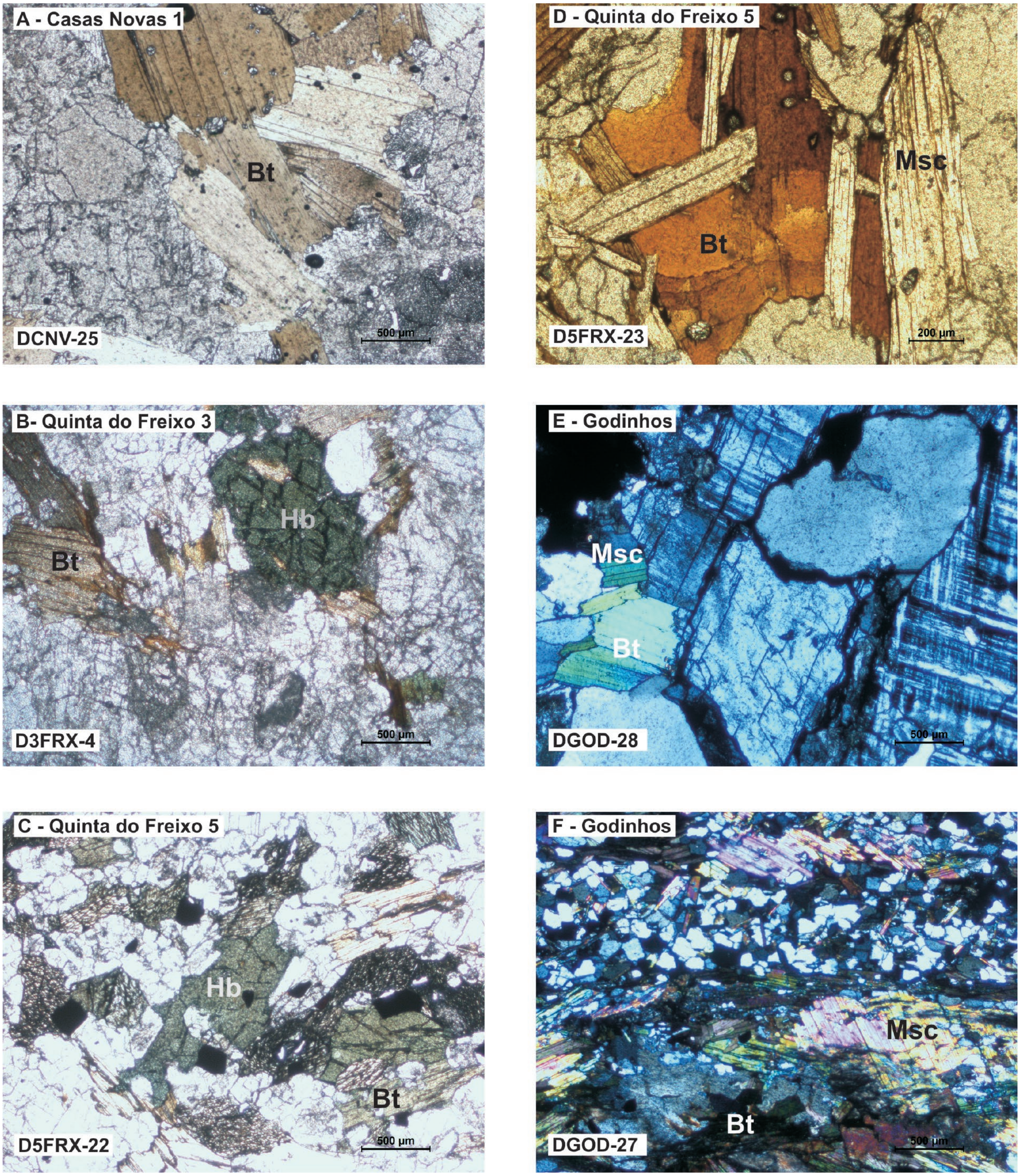

Figure 7 – Microphotographs of samples from dolmens showing main mineralogical and textural features. Bt – Biotite, Hb – Hornblende, Msc – Muscovite. Images with parallel (A, B, C, D) and crossed (E, F) Nicols.

The outcrop selected for sampling near dolmen of Quinta do Freixo 1 (AFL-10) with clear evidences of exploitation (Fig. 2) would not have been the place for the provenance of the sampled slab (D1FRX-24). In fact, the outcrop samples (FRX-8 and FRX-9 from outcrop AFL-10) show hornblende and biotite as the main mafic mineral phases within an isotropic texture and these features contrast with the anisotropic texture (mineral alignment) and absence of hornblende (Fig. 7) in dolmen sample.

The petrographic features of the gabbro-diorite sample (FRX-5), from NMCOutcrop (AFL-6), enclose the presence of plagioclase, hornblende and subordinate pyroxene within a hypidiomorphic medium grained texture. Although dark at mesoscale and similar to quartz-diorite, sample from dolmen Quinta do Freixo 5 (D5FRX-22), does not correspond to the same lithology. In terms of texture as well modal composition the mafic mineral phases (biotite and hornblende) represent 30 to 40% of modal composition in quartz-diorite. Regarding the other sample from the same dolmen (D5FRX23), the presence of muscovite in their granodioritic paragenesis inviable the match with the granodiorite (FRX-6) sampled from the NMCOucrop (AFL-8) where this accessory mineral phase was not observed.

The exercise of confronting the petrography of the dolmens lithologies with more distant outcrops provided similarities. For example, the granodiorite sample from dolmen Quinta do Freixo 3 (D3FRX-20) it is not compatible with the hornblende-granodiorite from the nearest outcrop (AFL-9), but match with the granodiorite outcrops AFL-2 (at 757 m; sample FRX-2) and AFL13 (at 3000 m, samples FRX-13, 14 and 15). Other example is the sample D5FRX-22 from dolmen Quinta do Freixo 5 that matches with the hornblende-rich diorite outcrops AFL-10 (at 1600 m; sample FRX-10), AFL-11 (1100 m; sample FRX-11) and AFL-12 (2400 m; sample FRX-12).

6. 2. Dolmen of Godinhos

As mentioned before dolmen of Godinhos slabs have different lithologies – muscovite-granite and gneiss-migmatite as building material. The muscovite-granite found in dolmen of Godinhos has an anatetic nature and exhibits a medium grained allotriomorphic texture, mainly composed by quartz and K-feldspar (microcline). These are followed in volume amount by muscovite and biotite as accessory phases. Also, vestigial amphibole can be observed. The most intense alteration in this lithology, observed in both samples (dolmen sample DGOD-28 and sample FRX-19 from outcrop AFL-18) is specially expressed on plagioclase by formation of clay minerals.

The gneiss-migmatite samples (DGOD-17 from dolmen and FRX-18 from outcrop AFL-18), are very heterogeneous presenting a well-developed planar fabric that consists in the alternation of micaschist (biotite within a lepidoblastic texture) and granite (quartz and feldspar within a granoblastic texture) layers.

7. Geochemistry

It was selected 24 samples (16 from outcrops and 8 from dolmens) for geochemical analyses at the Activation Laboratories - ACTLABS (Canada) using the lithium metaborate/tetraborate fusion for ICP and ICP-MS. The data for major and trace elements from analysed samples are presented in Tab. 4.

Within the cartographic unit of granodiorite, it is verified that despite being a cartographically homogeneous body there is, as also observed in petrography, a compositional variability (Fig.8) where, namely, the MgO varies considerably between 1.46 and 6.24 wt%.

For a better comparison between samples (dolmen and NMCOutcrop) it was adopted the chondrite-normalized (Sun & McDonough, 1989) multi-element diagram (Fig. 9) that compare simultaneously the abundances of a set of trace elements, with different geochemical behaviour. The outcome geochemical patterns result from the modal composition and represent for each sample elemental ratios.

Table 4 – Major and trace element composition of samples from dolmens and outcrops. (Grd: Granodiorite; Gb-Drt: Gabbro-Diorite; Hb-Grt: Horneblende-Granodiorite; Qz-Drt: Quartz-Diorite; Gns-Mig: Gneiss-Migmatite; Msc-Gr: Muscovite-Granite; Qz: Quartz; Hb: Horneblende; Plg: Plagioclase; Alk: Alkaline Feldspar; Bt: Biotite; Pyr: Pyroxene; Epd: Epidote; Msc: Muscovite)

Sample			Mineralogy (%)			Texture
	ID	Rock type	Qz	Feldspar	Accessory phases	
Outcrops	FRX-2	Grd	20	Plg ± Alk	Bt	Hypidiomorphic
	FRX-5	Gb-Drt	-	Plg	Hb + Pyr ± Bt	Hypidiomorphic
	FRX-6	Grd	25	Plg ± Alk	Bt (± Epd)	Hypidiomorphic
	FRX-7	Hb-Grd	30	Plg ± Alk	Bt ± Hb	Hypidiomorphic
	FRX-8	Hb-Grd	20	Plg ± Alk	Bt ± Hb	Hypidiomorphic
	FRX-9	Hb-Grd	15 - 20	Plg ± Alk	Bt ± Hb	Hypidiomorphic
	FRX-10	Qz-Drt	5 - 10	Plg ± Alk	Hb ± Bt	Hypidiomorphic
	FRX-11	Qz-Drt	15	Plg ± Alk	Bt + Hb	Hypidiomorphic
	FRX-12	Qz-Drt	10 - 15	Plg ± Alk	Hb + Bt	Hypidiomorphic
	FRX-13	Grd	25	Plg ± Alk	Bt	Hypidiomorphic
	FRX-14	Grd	25	Plg ± Alk	Bt	Hypidiomorphic
	FRX-15	Grd	20 - 25	Plg ± Alk	Bt	Hypidiomorphic
	FRX-17	Grd	25 - 30	Plg ± Alk	Bt	Hypidiomorphic
	FRX18	Gns-Mig	(Qz + Plg) 50 - 70		Bt + Msc	Layered-Granoblastic-Lepidoblastic
	FRX-19	Msc-Gr	30 - 40	Alk	Msc	Alotriomorphic
Dolmens	D1FRX-24	Grd	25 - 30	Plg ± Alk	Bt	Hypidiomorphic
	D3FRX-4	Hb-Gd	20 - 30	Plg ± Alk	Bt ± Hb	Hypidiomorphic
	D3FRX-20	Grd	25 - 30	Plg ± Alk	Bt	Hypidiomorphic
	D5FRX-22	Qz-Drt	20 - 30	Plg ± Alk	Bt + Hb	Hypidiomorphic
	D5FRX-23	Grd	30 - 40	Plg ± Alk	Bt (± Msc)	Hypidiomorphic
	DCNV-26	Grd	20 - 25	Plg ± Alk	Bt	Hypidiomorphic
	DGOD-27	Gns-Mig	(Qz + Plg) 50 - 70		Bt + Msc	Layered-Granoblastic-Lepidoblastic
	DGOD-28	Msc-Gr	30 - 40	Alk	Msc + Bt	Allotriomorphic

The profile of the granodiorites presents roughly a similar structure; this is a general pattern with an enrichment of more incompatible elements (on the left) compared to the less incompatible elements (on the right). This distribution is truncated by the negative anomalies for the elements Nb-Ta and Ti more and less pronounced.

As in the petrographic analysis, similarities and differences were found for elemental geochemistry for samples from dolmens and respective NMCoutcrops. The petrographic match verified for the dolmen of Casas Novas 1 (sample DCNV-26) is corroborated by the geochemistry (Fig. 9a) of sample FRX-17 from the NMCOutcrop (AFL-17 at 750 m distance) with a clear overlap of the multi-elements diagram.

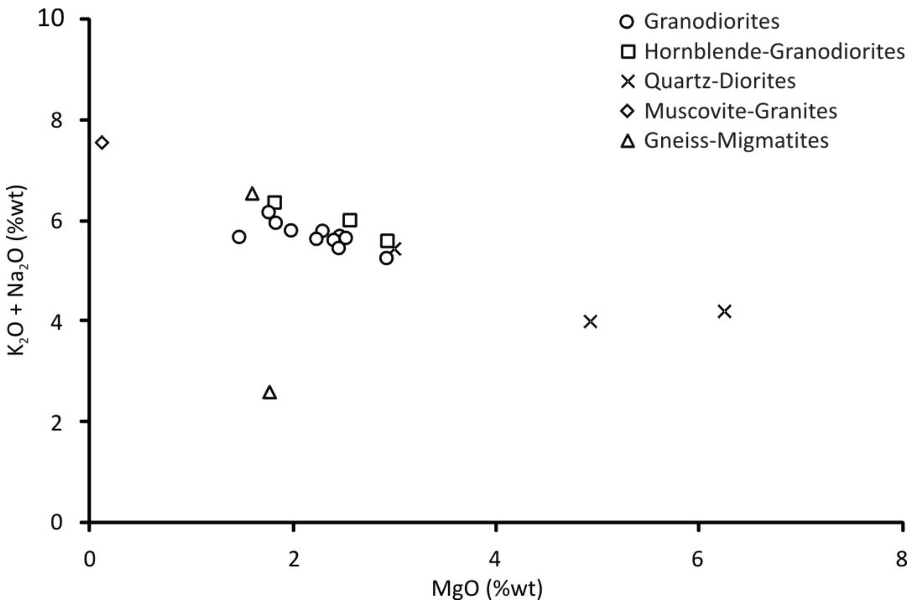

Figure 8 – Projection of dolmens and outcrops analyses for major elements (alkalis and magnesium) highlighting geochemical variability.

On the other hand, the petrographic correspondence verified in the pair D3FRX-4 (from dolmen of Quinta do Freixo 3) and FRX-7 (NMCOutcrop AFL-9) is contradicted by the geochemistry of the outcrop sample that shows an anomalous pattern regarding all the other samples from granodioritic intrusion (Fig. 9b). Nevertheless, that hornblende-granodiorite sample is geochemically and petrographically compatible with FRX-8 and FRX-9 samples from outcrop AFL-10 (1000 m distance). For the same dolmen Quinta do Freixo 3 the other studied sample (D3FRX20) should be related with the granodiorite from outcrop AFL-2 (sample FRX-2 at 750 m distance) because of its similar geochemical patterns.

As also deducted from petrography, the granodiorite sample D1FRX-24 from dolmen of Quinta do Freixo 1, cannot be related with the hornblende-granodiorites samples FRX-8 and FRX-9 from the NMCOutcrop AFL-10 (150 m distance). Nevertheless, the advanced hypothesis based on petrography for the provenance of sample D1FRX-24 echoes in the geochemistry with a good match of the multi-elemental diagrams (Fig. 9c); the sample D1FRX-24 that does not match with its NMCOutcrop, can be related with the granodiorite samples from outcrop AFL-2 (sample FRX-2 at 1600 m distance), outcrop AFL-13 (sample FRX-15 at 3200 m distance) or outcrop AFL-17 (sample FRX-17 at 4100 m distance) with similar petrographic features and multi-elemental patterns.

For the dolmen of Quinta do Freixo 5 where it was observed the more mafic lithology (quartz-diorite: D5FRX-22) other source than the NMCOutcrop is required; in fact, the quartz-diorite samples FRX-11 and FRX-12 from outcrop AFL-11 (1000 m distance) have petrographic features and multi-elemental patterns (Fig. 9d) similar with the above mention dolmen sample. Still for this dolmen, the granodioritic slab sample (D5FRX-23), it is not compatible with the nearby granodioritic outcrop (sample FRX-6 from outcrop AFL-8 at 330 m distance). Still this slab can be related with the granodiorite sample FRX-15 (Fig. 9d) from the outcrop AFL-13 that is further away (2500 m distance), but geochemically and petrographically similar.

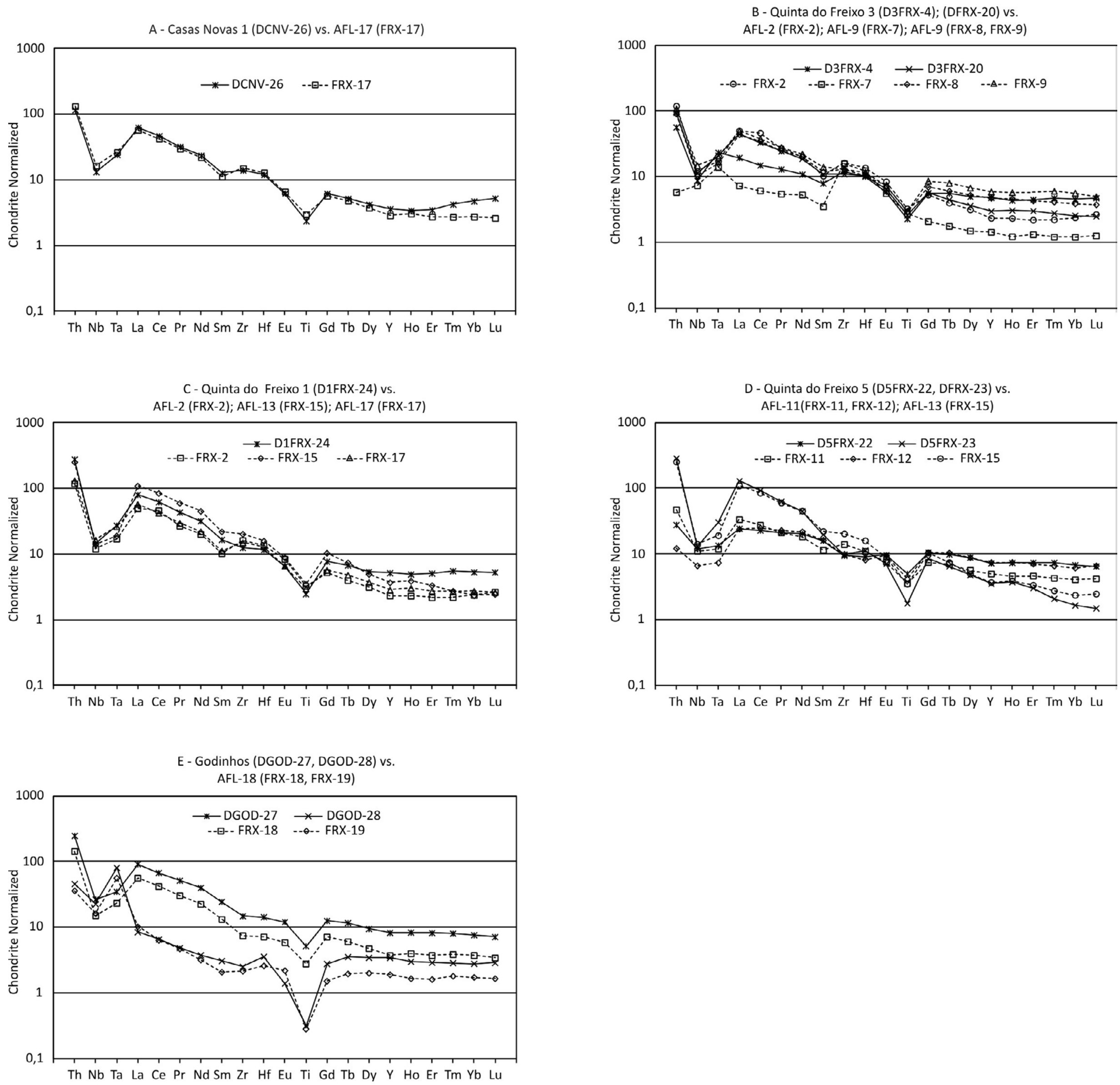

Figure 9 – Multi-elemental diagrams for dolmens and outcrops samples. A) dolmen of Casas Novas 1 vs AFL17, B) Dolmen of Quinta do Freixo 3 vs AFL-2, AFL-9 and AFL-10; C) Dolmen of Quinta do Freixo 1 vs AFL-2, AFL-13 and AFL-17; D) Dolmen of Quinta do Freixo 5 vs AFL-11, AFL-13; E) - Dolmen of Godinhos vs AFL-18.

The geochemical signature of the muscovite-granite is distinct from that of the granodiorite, namely in the positive anomaly in Ta and the most pronounced negative anomaly in Ti, both associated with impoverished multi-element profiles. The multi-element profiles of muscovite-granites for the dolmen of Godinhos (DGOD-28) and for sample FRX-19 from NMCOutcrop AFL-18 are similar (Fig. 9e) but diverging only in the Heavy Rare Earth Elements which may be justified by the presence of cryptocrystalline accessory mineral phases (in minute quantities).

Due to the heterogeneity (macro and microscopically) of the gneiss-migmatites, it is difficult to expect an overlap of the profiles. However, the parallelism for the data from the dolmen of Godinhos (sample DGOD-27) and the NMCOutcrop AFL-18 (sample FRX-18) establishes a clear relation between these samples, pointing to a probable local provenance around 300 m.

8. Discussion

The studied dolmens in this work (group of Freixo, Godinhos and Candeeira) are located in the Freixo-Redondo area (Alentejo region) with a low population density where the landscape should not have undergone major changes until the present time. It is dominantly an agricultural region with a small anthropogenic impact and in thus we can assume a topographic preservation as well a maintenance of outcrops availability. Some of them present evidence compatible with their use as a supplier of raw material, but the presence of notched marks reverts to more recent periods of use. However, the negatives of stone blocks are timeless and can be interpreted, or at least speculated, as Neolithic use. At distances less than ~300 m from the dolmens, usually at a visual distance, it is possible to identify a NMCoutcrop that has sizes and mesoscopic features compatible with the slabs.

Regarding the dolmens from group of Freixo, the slabs are broadly considered as granodiorites (rarely quartz-diorites) but it was verified some differences; namely in mesoscopic features (*e.g.* enclaves, quartz veins and dimensions of the slabs), petrography (mineralogical composition such as presence or absence of amphibole, and texture such as anisotropy) and geochemistry (major and trace elements). In this sense and although they are in a relatively circumscribed area there should not have been a single place – outcrop – that would supply the raw materials for the slabs of all dolmens.

Also, the variability found in a single dolmen, as in the case of the dolmen of Quinta do Freixo 5, points to provenance of slabs from different outcrops. This data agrees with what was observed by Pedro *et al.* (2015) in the Monforte area (northeast Alentejo region). Without constraints of size or shape the communities would have use a naturally fractured outcrops and single extraction of (partially) loosened blocks, followed by exploitation of more distant outcrops.

The mesoscopic geological monotony found in the slabs and outcrops was not reflected on the variability, however tenuous, from petrography and geochemistry. The conjunction of the presented data for the dolmens from group of Freixo highlights as shown in Table 5, that the NMCOutcrops were not always the suppliers for the studied slabs. Not denying the hypothesis of a very local provenance, in fact, the data obtained points to considerably higher distances.

As an exception, the dolmen of Casas Novas 1 stands out not only for its monumentality but also for its edification in a small hill. The petrographic and geochemical similarity between samples of dolmen and NMCOutcrop allowed to establish a correlation between both. Bedrock materials were not used, but rather large granodiorite slabs that outcrops at 780 meters down-hill associated with a marked slope.

In the case of dolmen of Vidigueira, the macroscopic characteristics are very typical. In this sense it is important to weigh the impact of sampling (even reduced and mitigated) with the added data that will come from it. In this case, sampling seemed unnecessary since the macroscopic comparison will always provide good information. The dimension of the slabs requires an outcrop(s) with a fracturing pattern that provides large blocks. Moreover, the slabs have frequent mafic microgranular enclaves and quartz veins. Thus, and fundamentally due to the dimension of the slabs a compatibility with the wide outcrop that occurs along the banks of the Freixo stream (AFL -17 and around) was verified. If the supply-outcrop is not covered under the existing construction around the dolmen, a considerable effort was required with a provenance of about 2000 m increased by topographical irregularities.

Table 5 – Inferred distances by matching petrography and geochemistry or mesoscopic-features.

Dolmen		**Outcrop**	**Dolmen - Outcrop**
Ref.	**Sample ID**	**Reference**	**Distance compatible (m)**
Quinta do Freixo 1	D1FRX-24	AFL-2	1600
		AFL-13	3200
		AFL-17	4100
Quinta do Freixo 3	D3FRX-4	AFL-10	1000
	D3FRX-21	AFL-2	750
Quinta do Freixo 5	D5FRX-22	AFL-11	1000
	D5FRX-23	AFL-13	2500
Colmeeiro 1	Not sampled	AFL-17	1350
Casas Novas 1	DCNV-26	AFL-17	780
Vidigueira	Not sampled	AFL-17	2000
Godinhos	DGOD-27	AFL-18	300
	DGOD-28		
Candeeira	Not sampled	AFL-14	170

The basement for dolmen of Colmeeiro 1 correspond to weathered paragneisses not used as building material. Immediately around metamorphic rocks, the granodioritic outcrops doesn't show morphological features of its use as a supplier and present incompatible huge rounded blocks. So, for the provenance of materials of dolmen of Colmeeiro 1 a more southeast outcrop should be invoked; taking into account the survey of the rare outcrops around the dolmen the occurrences that border the Freixo stream (AFL17 at 1350 m) appear as the most probable.

Despite the availability of granodiorites near the dolmen of Godinhos, for its construction there was the option of using different lithologies (muscovite-granites and gneiss-migmatites) that appear to the north of the dolmen. As mentioned, the muscovite-granite, which in the geologically surveyed area does not crop out, have a petrographic and geochemical affinity with the sample taken from the dolmen. The same match occurs with samples of gneiss-migmatites. This match was obtained with proximal sampling at a looking distance. On the contrary of the dolmens from Quinta do Freixo the slabs of dolmen of Godinhos are smaller and weathered which agrees with a higher facility of extraction from the surrounding lithologies.

Figure 10 – Detail of mesoscopic features of andalusite-porphyroblast phyllite used as slabs in dolmen of Candeeira.

In the case of dolmen of Candeeira, the material chosen for the slabs not only has a very fragile constitution, but also its mesoscopic characteristics are very distinctive. The bedrock of dolmen consists of schists as observed in the slabs but without the presence of porphyroblasts. Further south (170 m) and downhill there is an outcrop compatible with the slab sizes that additionally, as observed in slabs, shows the development of andaluzite crystal overgrowing over a strongly foliated matrix (Fig. 10).

Although gabbros naturally provides blocks of dimensions and forms compatible with those verified in the smaller dolmens, as a matter of fact, they were not used as a building material. We cannot ignore the hypothesis that there are dolmens to be discovered or excavated with this material, but with the available data to date one can only speculate and defend aesthetic reasons since the functionality would be similar to the granodiorite slabs.

The differences found especially for dolmens from group of Freixo, are tenuous and in some cases can be explained only by a geological variability that can even occur at the outcrop scale. With very different lithologies associated to significant differences in petrography and geochemistry such as the Monforte area (Pedro *et al.*, 2015) due to lack of hypothesis, the bonds become easier to establish. In this sense for the dolmens from group of Freixo, Godinhos and Candeeira there is no irrefutable data to attributes any outcrop as an unequivocal source of raw material for the production of slabs. To overcome this difficulty, one could think of a more extensive sampling, but an invasive sampling should not bring greater certainties. On the other way, an excavation campaign on some of more promising identified outcrops such as AFL-14 for dolmen of Candeeira or AFL-17 for dolmen of Casas Novas 1 would bring valuable proofs of use during Neolithic ages. Moreover, some of the smallest quarry/outcrop can no longer exist due to their full exploitation or modern activity.

The macroscopic features associated to a good awareness of outcropping geology have proved to be a major and important aspect to be taken into account for the establishment of provenances. On geological monotonous regions such as Freixo-Redondo area, sampling can be used to refine some aspects but quite never as an irrefutable proof of match/dis-match: because of the geologic variability at outcrops and small size of dolmen samples can biased data. Also, the unique texture of phyllite from dolmen of Candeeira or the muscovite-granite and gneiss-migmatite from dolmen of Godinhos, which variations are not represented in the cartography of the studied area (Carvalhosa *et al.*, 1986) are examples of the good knowledge of field.

With the engineering skills to raise up the stones went the capability to move them to the site, with Stonehenge the best-known example of an apparent long-distance transportation. While for Stonehenge (England), an apparent long-distance transportation was established (Thorpe & Williams-Thorpe, 1991) for the Freixo-Redondo area (Alentejo region, Portugal) the predominance of much smaller distances is obtained. These observations agree with Boaventura (2000) that favours a pragmatic attitude of Neolithic communities in the search of the appropriate slabs for construction.

The order of magnitude of the values obtained for this study (less than 4 km) are in agreement and within the radius usually attributed to these megalithic buildings of about 5 km (Thorpe *et al.*, 1991; Jiménez *et al.*, 2017; Vicens *et al.*, 2010). Moreover, contrary to Jiménez *et al.* (2017), the data obtained do not suggest the existence of a single quarry that would provide the generality of the blocks but rather the use of several outcrops dispersed throughout the area.

9. Conclusions

For the studied dolmens - group of Freixo, Godinhos and Candeeira - it were identified nearest mesoscopically compatible outcrops, that is, at mesoscale are compatible with the slabs from megaliths. The distances from dolmen to mentioned outcrop varies between 150 m (*e.g.* dolmen Quinta do Freixo 1) and ~780 m (*e.g.* dolmen Casas Novas1). Through field, petrographic and multi-elemental geochemical obtained data, it is noticed that almost never, the nearest ones were not used as unique collection site. The mesoscale characteristics, coupled with an exhaustive recognition of geology, have proved to be a fundamental tool in establishing provenances.

As observed in other areas of Monforte area (Alentejo region) dolmens were built with slabs from different outcrops. The complete match including size, shape, petrography and geochemistry was obtained for several dolmens providing for group of Freixo, distances between 800 and 3500 m. The oldest dolmen (Godinhos) use very local material and shorter distances (~350 m). The more weathered characteristic of geological materials makes them easier to quarry. For the dolmen of Candeeira, a local provenance of 170 m was established based on singular macroscopic features.

It is not possible to attribute a reason for one's provenances to the detriment of another outcrop. It could be related to the immediate availability of the material (loosened blocks) but nevertheless, the gabbro-diorites in the area were not chosen, at group of Freixo, for building purposes. Apparently for aesthetic/symbolic reasons since this lithology occurs as loosened blocks and presents similar sizes/ shapes to those found in medium dolmens of granodiorite. Confirmation of the use of certain outcrops by communities from the Neolithic period will be possible through excavation work.

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