Drones and Stones - Using UAV SfM photogrammetry to investigate petroglyph degradation of Neolithic megaliths at Cromeleque dos Almendres, Portugal.

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Sarah Emily Mercer

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Acknowledgements

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Dedication

To Matthew, who walked every step with me, and my parents who have always supported and encouraged me to be the best version of me I can be, and to all the friends who have offered support and help over the past year.

Introduction/literature review

This study will examine the current state of the petroglyphs at the Almendres Cromlech, a megalithic enclosure likely constructed by people of the Neolithic period. Using UAV SfM photogrammetry, and comparing the petroglyphs with previous surveys to investigate discrepancies, investigations into divergences in results will be conducted, focusing on methodological differences, human error, and weathering. The people of the Neolithic period had a widespread impact, and evidence of their existence can be seen in the megalithic monuments constructed around the world. The Iberian Peninsula is densely populated with Neolithic monuments, and is it is here that the Almendres Cromlech is located, in the Évora municipality, Portugal. Megalithic structures are constructions made of large stones, usually standing upright, the earliest of which were singular standing stones and megalithic enclosures (Calado, 2002). Megalithic enclosures in Portugal consist of several individual standing stones, often arranged in a horseshoe shape (Calado, 2015). Unlike dolmens, or structures such as Stonehenge, there is no balancing of stones on top of one another.

The chronology of the development of megalithic enclosures in the Iberian Peninsula is much discussed. There is sparse evidence dating the sites, though it is generally accepted that the creation of the megalithic enclosures is related to the Mesolithic to Neolithic transition occurring around 5600 cal BC (Gomes, 2008; Carvalho, 2010; Salazar-García and García-Puchol, 2017). The Mesolithic to Neolithic transition consisted of a general shift from the hunter gatherer way of life, to an agro pastoral one. It is known that Neolithic culture (agro pastoralism) spread from the Mediterranean, and reached Portugal along the Atlantic coast (Pozzi, 2014; Salazar-García and García-Puchol, 2017). Ancient DNA records indicate that there was significant colonisation of the region by incoming farmers around this time (García-Martínez de Lagrán *et. al.,* 2018) though it is debated as to whether the Mesolithic indigenous populations also adopted the Neolithic culture (Calado, 2002; Soares and Silva, 2004), transitioning to a dependence on agriculture (Straus, 1991), or whether the incoming Neolithic people did not coincide with the Mesolithic population, instead settling in areas that had been previously inhabited by the indigenous populations (Zilhão, 2003; Monteiro-Rodrigues and Angelucci, 2004).

It has been suggested that the earliest megaliths were constructed by these late Mesolithic groups (Bradley, 1998; Calado, 2002), though this is no longer a widely supported theory. Calado (2004) proposes they could have first been built during the first half of the Neolithic, perhaps as a manifestation of the colonization and control of new areas. Others suggest that is it more likely that the megaliths appeared later in the Neolithic transition (Diniz, 1994 in Calado, 2002). Vierra and Carvalho (2017) argue that the building of megalithic structures began due to societal inequalities in Neolithic communities during the second half of the 5th millennium. Using C14 samples collected from the Meada menhir founding pit, Oliveira (1997) discovered a likely origin date of the middle of the 6th millennium BC. This date roughly matches with that suggested by the discovery of Neolithic ceramics found at other sites, such as Portela de Mogos (Calado, 2003; Gomes, 2011). As these competing theories indicate, the difficulty of accurately dating megalith sites means we cannot say for certain what the origins of these sites were. For the purpose of this article, we will follow the dominant archaeological theory – that the megalithic enclosures originate in the earlier part of the Neolithic period, between the 5th and 6th millennium BC (Bueno *et. al.,* 2007a; 2015a).

What we do know is that Central Alentejo is home to a high density of megalithic enclosures, such as Vale Maria do Meio and Portela de Mogos, and these sites often follow similar structural patterns (Calado, 2000, 2002; Gomes, 2011). These sites often coincide with the locations of Neolithic settlement sites (Calado, 2004), highlighting the structures' importance to the Neolithic people. The stones are exclusively of granite, and the enclosures are located within a few miles of the granitic outcrops from which they came, though never on granitic bed rock, as if to create a physical separation between the natural and the manmade (Calado, 2002). The megalithic enclosures are often located on areas higher than the surrounding, and always just below the crest of a hill facing east. Many, including the Almendres Cromlech, appear to have been placed in relation to watersheds (Alvim, 2006; Calado and Rocha, 2008b, 2008a) which would have been vital to Neolithic communities, again emphasizing the megaliths' importance to the Neolithic population. There is also a strong indication that the sites have an astronomical relationship, as there is evidence that many are orientated according to the position of the sun and the moon at the equinoxes (Sarantopoulos, 1997; Alvim, 2006; Pimenta and Tirapicos, 2008; Oliveira and Silva, 2010).

The exact purpose of these megalithic monuments is difficult to understand, and though it is not what this thesis focuses on, it is useful to have background knowledge when investigating a site. It is generally accepted that they are not funerary, as there is no evidence of funerary practices such as graves (Calado, 2004). However, it is shown that some stele-menhirs were later moved to become part of dolmens (funerary monuments of the later Neolithic), though this did not occur commonly (Bueno *et. al.,* 2015). Calado (2005) suggests they were associated with economic, social and symbolical transformations during the adaptation to the Neolithic culture. Valenta (2017) suggests they were ceremonial. Sarantopoulos (1997) theorises that the enclosures were social places, where communities came together for religious, political, astral or other reasons.

Additionally, many of the megaliths in these enclosures are decorated with petroglyphs. Petroglyphs are rock carvings, and there is evidence that the earliest megalithic art coincided with the creation of the earliest megalithic monuments such as solitary menhirs between the 5th and 6th millennium BC (Bueno *et. al.,* 2007). Petroglyphs appearing on structures within megalithic enclosures (those with multiple stones) appeared soon after. The style of art was also slightly modified. Petroglyphs on single megaliths include both relief and engraved petroglyphs (Bueno *et. al.,* 2007), while the petroglyphs on menhirs in megalithic enclosures in Central Alentejo are predominantly in relief, most often on the east facing side. The features protrude a few millimetres to centimetres from the surface (though there are exceptions to this rule). The dominant shapes are faces (represented by circles and a rectangle), smile or necklace (crescent), crosiers, breasts (circles, sometimes double circles), belts, and cup marks (Gomes, 2002; Díaz-Guardamino, 2010). It is important to note that ‘rock art’ is constituted by both the petroglyphs and the shape of the stone (Calado and Rocha, 2008a); just as the shape of a building is as much art as the decoration on it. Rock art is a ‘graphic language’, a form of communication (Bradley, 2002). To better understand the purpose of the petroglyphs, Bradley (2002) highlights the need to understand the intended audience of the rock art. Its meaning may have depended on the audiences’ social class, age, previous experience, and relationship with religion/ideology, amongst many other factors. Megaliths (and petroglyphs) may have been used to communicate ideological or symbolic messages (Calado and Rocha, 2008a), or perhaps were thought to have potency (Gell, 1998), much as religious symbols do today. Calado and Rocha (2008a) suggest that the rock art could be related to territories, perhaps as territorial marks. Additionally, meanings may have changed throughout time, depending on the variations in social structure and ideologies of the Neolithic people (Bradley, 2002).

Throughout Portugal, and elsewhere, it is thought that Neolithic petroglyphs often represent anthropomorphic figures. The most obvious examples of anthropomorphism are located near Évora (Díaz-Guardamino, 2010), and the Almendres Cromlech contains several. It is thought that the anthropomorphism of the stones developed slowly over time (Calado, 2004), resulting in an 'unprecedented focus on the human figure' (Calado, 2015). This is usually represented in the form of a face with a necklace, crosier and possibly a belt (Figure 1a). It is suggested that this anthropomorphism is a reflection of ideological changes, placing the role of human beings at the centre of existence, rather than as one part of a whole (Hodder, 1990; Gomes, 2011). Some suggest the anthropomorphic figures represent supernatural entities (Gomes, 2011), heroes, or perhaps an entire community (Calado, 2015). The idea of the increasing dominance of humans in general attitudes is supported by the prevalence of the crosier, also known as a crook (Figure 1, arrow). This is a symbol that could represent human's domination over other animals and the landscape, a symbol of power (Calado, 2004).

However, anthropomorphism is not the only theme to be found in the petroglyphs of the Iberian Peninsula.

Examples of other themes include cup marks, which are usually found independent of any other markings. There are a few interpretations of what these indicate. They may have been used for holding rain water or liquids such as blood (Pozzi, 2014). Others suggest they were used to grind seeds, seeds being crucial to the agricultural lifestyle

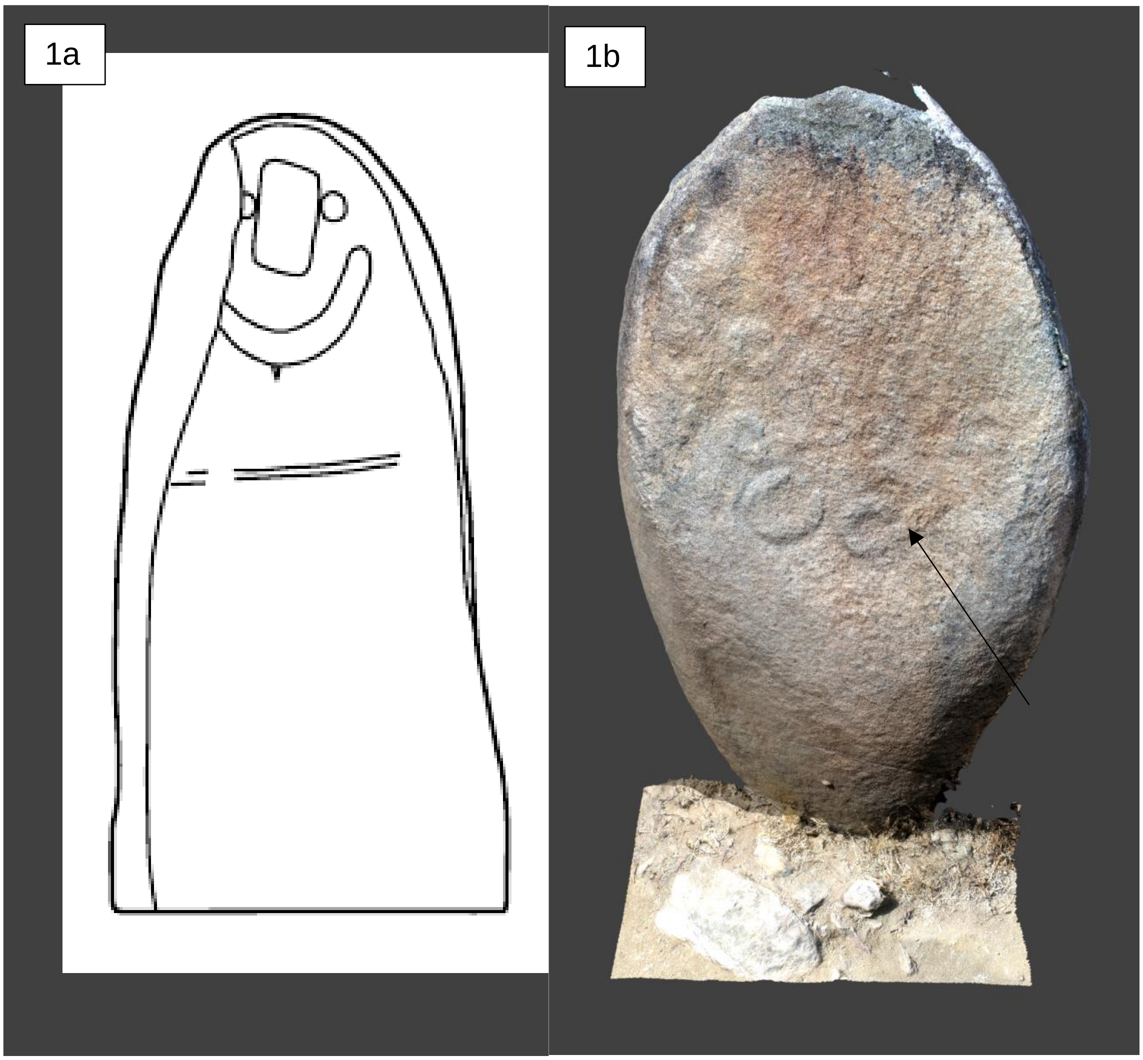

Figure 1a: From Gomes (2002). A drawing of the face seen on ALM56 at Almendres Cromlech. Features include circles, rectangle and crescent shape. Other anthropomorphic features can include a crosier or belt.
Figure 1b: Arrow indicating crosier on ALM57.

of the Neolithic people (Manca, 2002), or were filled with material that was able to be lit, acting as lanterns (Pozzi, 2014). Other interpretations suggest they represent solar shapes (Calado, 2004), or astral themes, perhaps the moon and stars. Other shapes are also suggested to represent a solar theme, such as circles and radial zigzags (Calado, 2004).

However, due to the lack of a fuller context in which to base our interpretation of petroglyphs it is difficult to suggest an explanation with any confidence. Their meaning and use may have changed over time, making our understanding of them even more difficult with the information we have. Thus, this study will focus more heavily on our ability to detect, identify and record petroglyphs and megaliths. The data collected will be useful as a reference for future researchers if additional evidence is discovered which expands our understanding of the Neolithic people, and therefore adds more weight to our interpretations of the meanings of the rock art.

Study Site

The Almendres Cromlech is the largest megalithic enclosure in the Iberian Peninsula, and is thought to be one of the most important Neolithic archaeological sites in Portugal. It is situated on one of the highest points in the Alentejo area, at the confluence of three rivers. Its geographical position and large size denotes its contemporary importance, as these rivers would have been vital to survival, travel and trade during the Neolithic period. Calado and Rocha (2006; 2007; 2008a) suggest that hydrographical ridges, the skyline and astronomical direction also contributed to the geographical location of the site. The site itself spans around 56 metres by 23 metres, and contains 95 stones. Its shape is either that of two horseshoes or a figure of 8, though it is possible the shape of the Almendres Cromlech has changed since its original construction (Figure 2) (Sarantopoulos, 1997; Díaz-Guardamino, 2010). The site is home to 13 decorated megaliths.

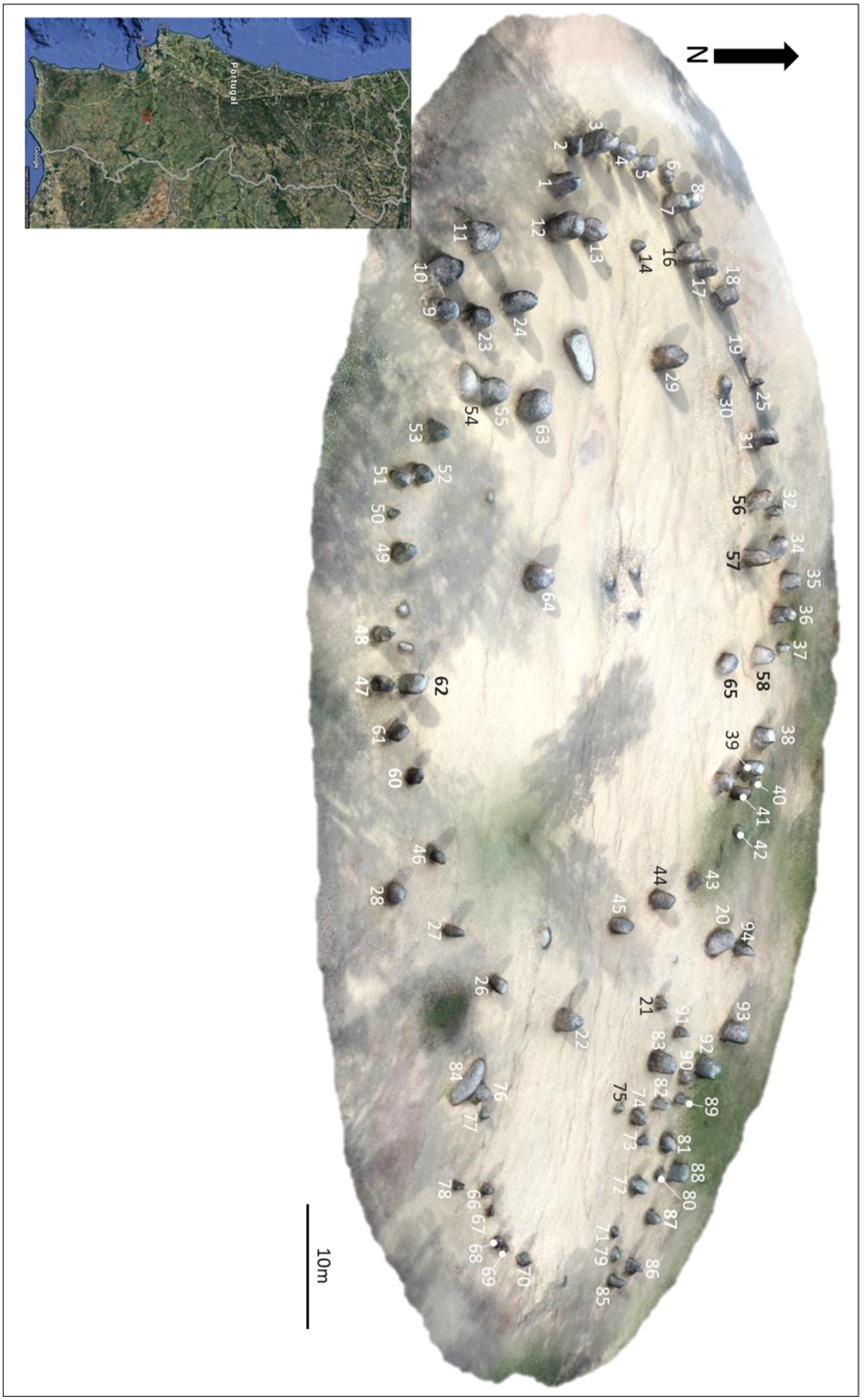

Figure 2: Birds eye view of the Almendres Cromlech with stones numbered. Insert map shows southerly location of the Cromlech in Portugal.

The Almendres Cromlech today is a popular tourist destination, at number 5 of things to do in Évora on Trip Advisor (Trip Advisor, 2018). The site is fairly accessible via car, a few companies run tours, and the site is also used by local schools for trips. It is also popular with those interested in the spiritual aspect of ancient monuments, and is sometimes used for pagan rituals. This means that the site is often busy, particularly during the tourist season in March to April and July to August. This puts a significant amount of pressure on the vegetation and soil in the area, which is known as lithosoil (Poesen and Hooke, 1997; Nunes, Seixas and Pacheco, 2008). It is very shallow, and has low fertility, putting it at high risk of rill and interill erosion (Vandaele *et. al.,* 1997). There is visible evidence of gullying and trampling at the Almendres Cromlech (Figure 3).

Figure 3a: Widespread gullying throughout the site. Figure 3b: Close up of gully. Evidence for erosion by water. Photographs taken by Sarah Mercer, June 2018.

Previous research on the Almendres Cromlech

In recent times the Almendres Cromlech was a place known only by the local population until Henrique Leonor Pina, with the help of a local farmer, rediscovered the site in the 1960s (Pina, 1976). Many of the menhirs were found fallen, and Pina endeavoured to reconstruct the site. He used excavations to identify the 'sockets' in which the base of the stones sat. This gave information as to the orientation of the stones, which is crucial information in Neolithic sites. Pina then re-erected as many menhirs as possible, and today only two are lying down.

Since its discovery, there has been a significant amount of research at the Almendres Cromlech. However, the results remain uncertain, particularly in relation to the age of the site and the meanings of the petroglyphs. There have been three in-depth surveys of the megaliths at the site. These are Gomes (2002), Calado (2004) and Ferraz (2016). The other papers that discuss the Almendres Cromlech, but have not conducted specific surveys are Gonçalves (1975), Pina (1976), Alvim (1996, 2006) and da Silva (2000). The total number of decorated megaliths identified varies between 13 (Gomes, 2002) and 14 (Ferraz, 2016). Additionally, Gomes and Ferraz do not perfectly agree with which megaliths these are. Most studies agree that there are 96 megaliths in total, but no research has yet done a detailed study about the volume, area and orientation of each individual megalith. Additionally, some of the earlier research used techniques that are now generally disapproved of, as they suffer from interpretation errors, have the potential to damage the petroglyphs and were restricted by time in the field. Thus our records of the petroglyphs of the Almendres Cromlech may be incorrect, or incomplete.

The first, in-depth archaeological recording of the petroglyphs at the Almendres Cromlech was completed by Mário Gomes (1986, 2002). His focus was on the identification of petroglyphs, using the bi-chromatic method. The bi-chromatic technique involves applying white dye to the face of the rock, and applying soot over the top (Anati, 1960). This highlights areas of relief and depression. The resulting image can then be traced or copied. Using this method, Gomes created a visual record of the petroglyphs (Figure 4). Gomes identified 13 decorated megaliths, and an additional three decorated exclusively with cup-marks.

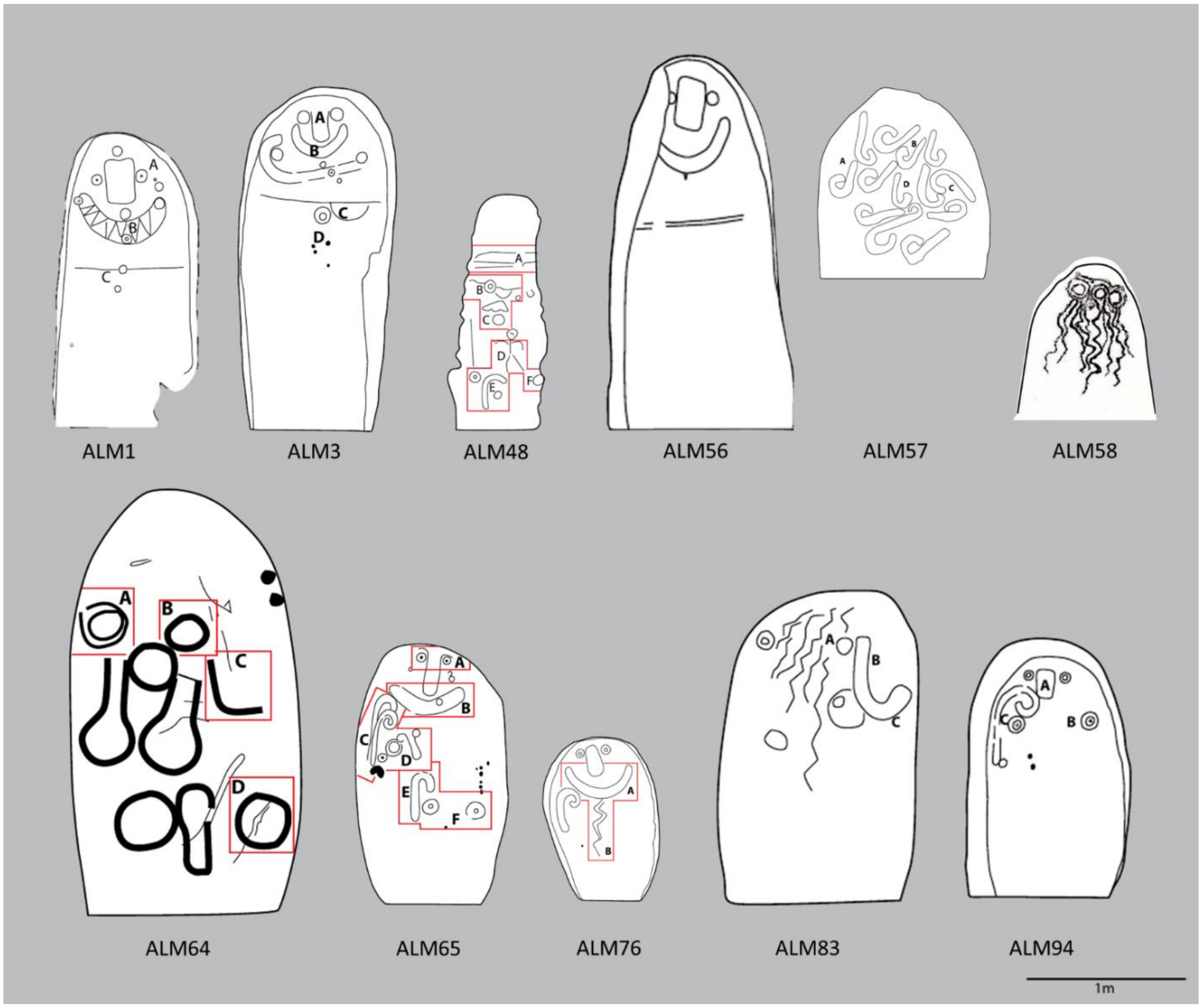

Figure 4: Remastered images of Gomes' original drawings of petroglyphs at the Almendres Cromlech. Taken from Ferraz (2016). Only eleven of the 13 decorated megaliths are presented here. The other two were simply described in the original study, without a visual reference.

Gomes theorised that the site underwent a series of changes throughout the Neolithic. He believed it was originally used as a megalithic structure during the Early Neolithic, built in the shape of a triple ringed concentric circle (Figure 5A). During the mid-Neolithic, Gomes suggested a double ringed ellipse was added, using larger megaliths. Finally, during the Late Neolithic, Gomes suggests the larger elliptical shape was used as an 'atrium', and megaliths from the eastern end of the structure were removed for another purpose, or destroyed. During the excavation of the site by Pina, the majority of the decorated megaliths were found with their decorated sides down. Gomes (2002) suggests this could indicate that some form of iconoclastic destruction had occurred since its last use. However, given that, as discussed above, there is a lack of evidence and understanding of the religious, spiritual and political ideologies of the people throughout the Neolithic age, and limited dated information, that proposal must be considered with caution. Additionally, it is difficult to precisely date stones as they cannot be radiocarbon dated due to the lack of securely associated biological material. Their ages can be estimated by studying how long the stone has been exposed, but quarrying and carving practices could affect this data, as they change the exposed surfaces of the stones.

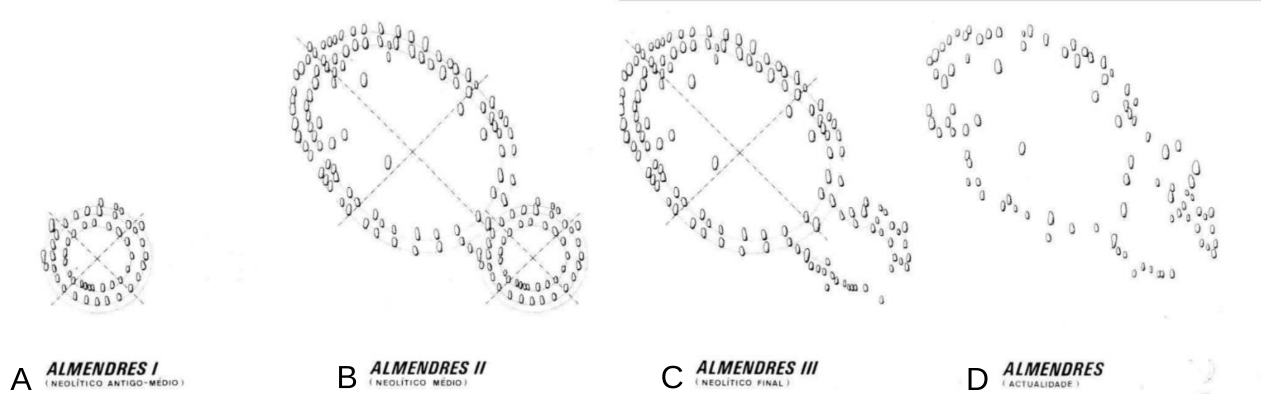

Figure 5: shows Gomes' interpretation about how the site developed throughout the Neolithic. From Gomes 2004, original drawing from Gomes 1997.
Original caption translates to: Almendres grounds. Possible reconstitution of their evolution. A) Early-Middle Neolithic; B) Middle Neolithic; C) Late Neolithic and D) Today.

Gomes also studied other megalithic sites in the Iberian Peninsula. Using these surveys Gomes found consistencies in the shapes seen. These included faces, crescents, breasts, belts, crosiers, circles, dimples, and other shapes (Table 1). Gomes discovered that petroglyphs are usually carved on larger stones, and never on the buried part, which Gomes suggests indicates that they were carved after they were erected. Gomes suggested that circle and crescent shapes (such as those seen on ALM 57, Figure 4) may represent the sun and the moon. This theory is supported by multiple researchers, including Calado (2004) and Pimenta and Tirapicos (2008). Gomes also believes that the circular shapes on ALM64 were created during the Late

Neolithic, due to the use of engraving, rather than the petroglyphs being in relief. However, because of the lack of dated information this idea is only based on the difference in carving technique. Most importantly, Gomes identified a theme of anthropomorphism, stating that eyes, noses and mouth/necklaces can be seen clearly on multiple megaliths. This idea is evidenced by several of the megaliths in the Iberian Peninsula, and both Calado (2004) and Ferraz (2016) support the idea that the megaliths somehow portray an anthropomorphic figure, or figures.

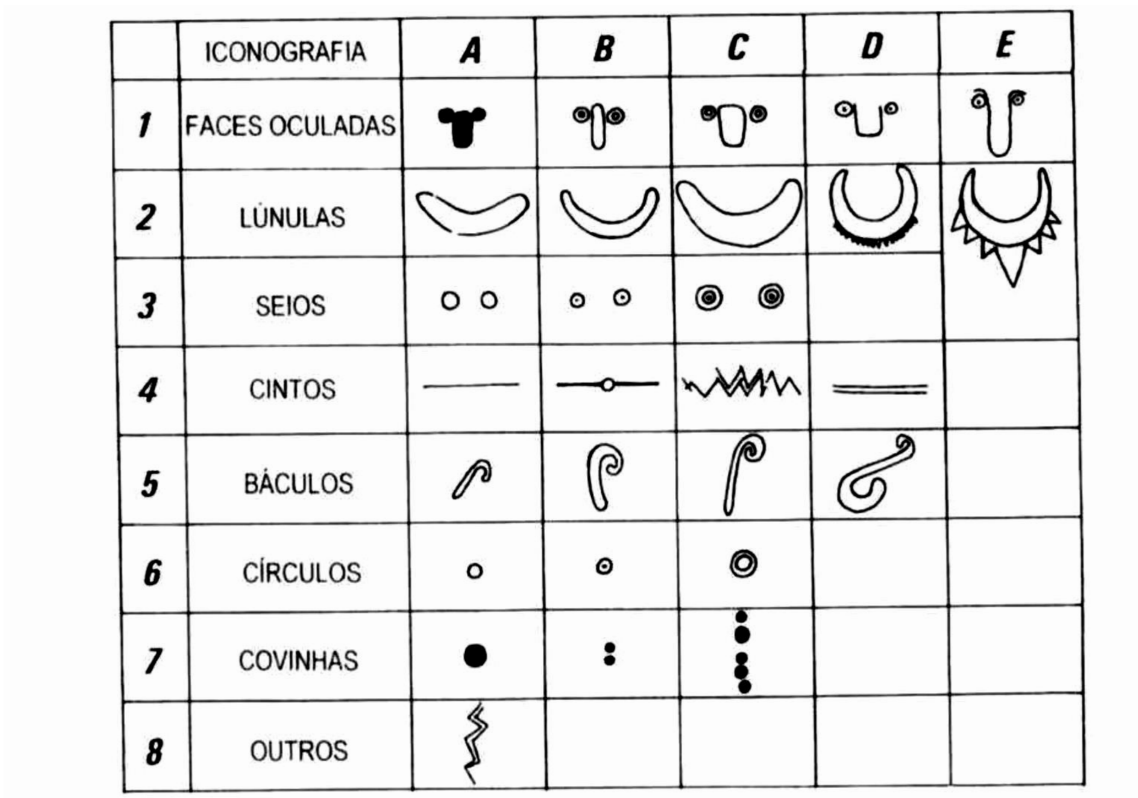

Table 1: Original caption reads "main iconography detected in the menhir statues of the Évora region". Column 2 reads: Iconography (heading), hidden faces, crescents, breasts, belts, staffs, circles, dimples and others. Taken from Gomes 2002.

However, Gomes' interpretations have been met with some criticism since its publication. The bi-chromatic technique used in this earlier work is now considered damaging, intrusive and to cause errors in the interpretation stage. Due to the covering of the stones texture when the white dye is applied, it is difficult to differentiate between natural and manmade features, resulting in misinterpretations about what is present on the stone. Although the petroglyphs at the Almendres Cromlech are usually carved on smoothed flattened faces, there is still some roughness present. As one is unable to use the texture of the stone to provide contextual information about the nature of features observed when using the bi-chromatic technique, it is likely that Gomes misclassified natural features as manmade petroglyphs.

Additionally, Gomes' work was one of the pioneering investigations since the discovery of many of these sites by Pina in the 1960s. At this time there was a very small amount of archaeological material that had been found and dated, and what was known about the people of the Neolithic in the Iberian Peninsula was even more limited than today. Gomes' work was one of the first forays into this unknown section of megalithic history. As Gomes was working almost exclusively from his own findings, there is the possibility that Gomes saw features that were not necessarily there, due to the phenomenon that what we see is often affected by pre-established knowledge or belief (Berger, 2008). As Gomes had discovered a multitude of anthropomorphic looking figures throughout Central Alentejo, perhaps this influenced what he saw at the Almendres Cromlech, thus causing him to record more features than were there. This phenomenon of seeing more than is there has been seen elsewhere (Díaz-Andre, 2006) and should caution an awareness of the subjectivity of researchers.

The second survey completed at the Almendres Cromlech was done by Calado (2004) and developed subsequently (Calado and Rocha, 2008a; Calado 2012). Calado's (2004) survey focused less on the petroglyphs than Gomes (1997, 2002), instead choosing to study the implantation sockets and rock shape (Figure 6). Calado also surveyed the rest of the menhirs in Central Alentejo, and his work focuses on the similarities and differences, and general patterns found at megalithic sites.

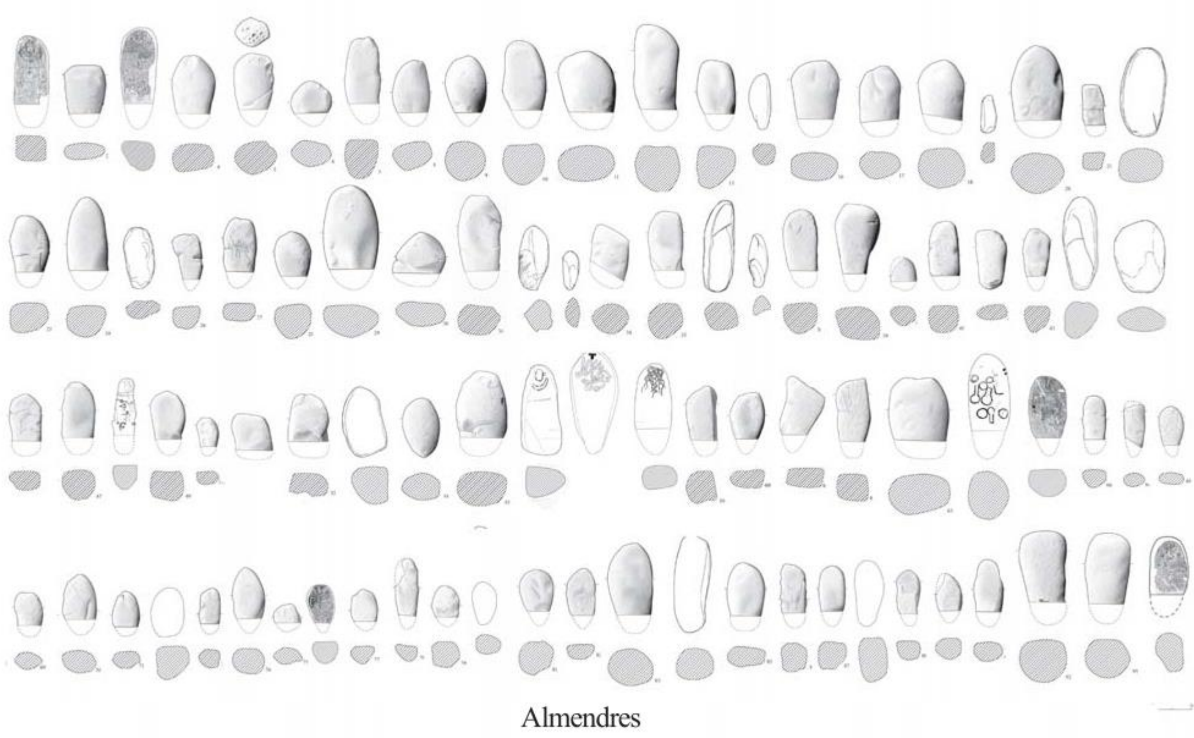

Figure 6: Original caption translates to "Menhirs of the precincts of the area of Évora". Taken from Calado 2004.

Calado and Rocha (2008a) suggest that sites such as the Almendres Cromlech were ‘the beginning of monumentality’, with their origins in the Mesolithic to Neolithic transition. Calado suggested that megalithic enclosures signify the first sacred architectural structures in Portugal (Calado, 2002). Calado (2004) theorises that the earliest Neolithic monuments could have been built by the late Mesolithic indigenous populations as a result of their progression towards the Neolithic way of life. He believed that megalithic monuments were ‘socially active’ during the expansion of the Neolithic culture in terms of territory control, and were related to economic, iconographic and social changes caused by the adoption of the Neolithic lifestyle (Calado, 2002). The idea that megalithic enclosures had territorial importance is supported by Benevolo and Albrecht (2003), though again, the lack of dated evidence hinders the verifiability of these suggestions (Valera *et. al.,* 2017).

Calado’s interpretation of the menhirs themselves was that they were ‘manifestations of proto-statuary’ or in other words, the earliest attempts to create statues. His 2004 survey focused on the shape and size of every rock rather than on the petroglyphs, reflecting his view that standing stones are still rock art even if they lack carvings. Calado did not do any new research into the iconography of the petroglyphs, instead using Gomes' drawings to base his own on. Calado suggested that each stone could represent an individual, and thus the enclosure represents a community (Calado, 2015). He also suggests that the differences in stone size and location could signify social stratification, a hierarchy present in Neolithic communities (Calado, 2015).

Though not surveying the petroglyphs himself, Calado does venture some interpretations of his own about their meanings. He supports Gomes' theory that circle and crescent shapes may represent the sun and the moon, and puts forward the suggestion that the cup marks could represent a solar theme. Calado (1997) also suggests that the crosier could portray a pastoral lifestyle, though others suggest it could represent an unequal society (Cassen and Robin, 2010; Cassen *et. al.,* 2015).

Both Calado (2004) and Gomes' (1997, 2002) work was reevaluated in Díaz-Guardamino (2010) in her review of Prehistoric megaliths in the Iberian Peninsula. This resulted in re-drawn copies of Gomes (2002) work, with the addition of the stone shape and buried segment taken from Calado (2004). The work of Díaz-Guardamino (2010) is a thorough record of the decorated megaliths of the Almendres Cromlech and all other known menhirs in the Iberian Peninsula. The catalogue included name, location, height, width, thickness, geology, description, context and an image of each decorated menhir. Though she did no direct research of her own at Almendres Cromlech, her work is not only a valuable source of information about individual megaliths, but, given the wide geographical focus, is a valuable comparative study. This enabled her to identify that megaliths at the Almendres Cromlech, Portela de Mogos and Vale Maria do Meio are naturally rounded, perhaps chosen because of this feature. She also highlights that although there are anthropomorphic figures, often represented in just two eyes and a nose, and occasionally a smile/necklace or breasts and no other features or limbs are found. The work done by Diaz-Guardamino (2010) to compile a full record of prehistoric megaliths in the Iberian Peninsula was useful in order to observe patterns that recurred at different sites throughout Portugal. It emphasises the need for comprehensive data in order to create a full picture, and as we discover more about the history of the Iberian Peninsula, and therefore better understand it.

Ferraz (2016) undertook a survey of all decorated megaliths in Central Alentejo. Ferraz used a diurnal macroscopic observation of each megalith and the grazing light technique, a non-invasive technique that highlights the contours of petroglyphs, allowing Ferraz to identify and record the shapes by combining areas of the decorations visible in each image into one digital drawing. This method requires fairly simple equipment, including a tripod, camera and light source, making it affordable and portable. The resulting photographs take up a significant amount of virtual memory, but the processing is not too intensive, therefore not requiring a specialised computer. The advantage of this technique is that the drawing of the petroglyphs can be done back in the office, reducing the amount of time needed in the field. Additionally, the photographs can be made available online, allowing a wider audience to participate and educate themselves about the megaliths of Central Alentejo. Having access to the photographs also allows other researchers to repeat or revaluate the work of Ferraz (2016), which could result in more robust observations of the petroglyphs. However, interpretations based solely on these photographs are necessarily removed from the wider frame of reference, and risk missing important contextual information that could aid the interpretation effort (Plets, 2012; De Reu, 2013; McCarthy, 2014), such as texture, nearby landscape and general geographic position. Thus, attempts should be made to one, make interpretations on site or two, record as much information as possible about the megalithic sites in order to have the best database from which to make interpretations.

Ferraz (2016) reinvestigated the petroglyphs at the Almendres Cromlech, with different results to Gomes (2002). Where Gomes (2002) discovered 13 decorated megaliths, and three with cup-marks, Ferraz (2016) found 14 decorated megaliths (and some different to Gomes'), and twelve with cup-marks (Figure 7). Ferraz found 9 new decorated megaliths, but was unable to see 4 of the stones Gomes found. This suggests that either one methodology is better than the other or that the decoration on the stones has disappeared (or reappeared) since Gomes' study. Ferraz believes that the bi-chromatic methodology used by Gomes (2002) is the reason behind the differences in their surveys. Not only is bi-chromatic technique damaging to the stone, it also obscures the texture and natural face of the rock, making it difficult to know what features are natural, and which are manmade. Ferraz, using the grazing light technique and photographs from daytime was able to use the texture of the stones to help classify features as natural and non-natural. Ferraz believes the differences in their results is that Gomes' (2002) incorporated natural features, and recorded them as manmade iconography.

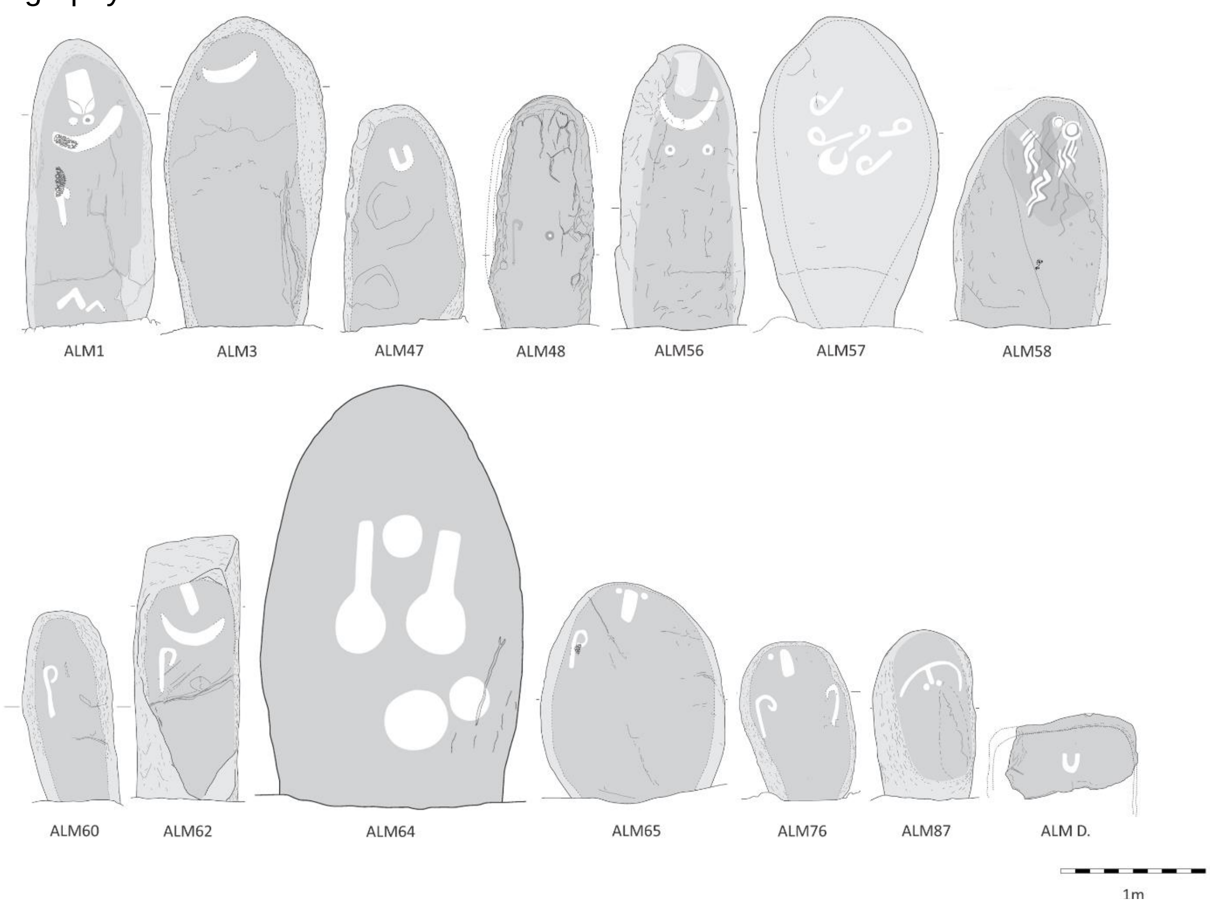

Figure 7: Ferraz (2016) petroglyph vector drawings.

However, there is also the possibility that the carvings have become less visible since Gomes' (2002) survey. To begin with, the bi-chromatic technique may have damaged the petroglyphs, contributing to the erosion and degradation of the art. Secondly, although granite is an extremely hard stone, there is some evidence of erosion, both biological and physical.

Risk to stones – are the petroglyphs disappearing?

Anything exposed to the wind and the rain is at risk of eroding, even if the timescale is over millions of years (Pope *et. al.,* 2002). Erosion comes in many forms: biological (lichens, photosynthetic microorganisms); physical (wind, precipitation, thermal) and chemical (rain, human touch, scientific surveys). The stones at the Almendres Cromlech are subject to all of these factors.

The presence of lichens is obvious at the Almendres Cromlech (Figure 8). Lichens can often hinder petroglyph identification, as they make edges more subtle, and obscure features (Hixon *et. al.,* 2017). Previous research has recorded that lichens have caused deterioration of stone in Portugal (Ascaso *et. al.*, 1985; Jones and Wilson, 1985; Jones, 1988; Romão and Rattazzi, 1996), on stones with the same geology as those at the Almendres Cromlech. There are two ways in which lichens can cause the degradation of granite. Their hyphae damage the crystalline structures, and their kyphae penetrate deeply into the rock, weakening it and causing fragmentation (Romão and Rattazzi, 1996). According to Pope, Meierding and Paradise (2002), biotic

Figure 8: Lichens are clearly visible on many of the rocks at the Almendres Cromlech. Photograph taken by Sarah Mercer, June 2018.

weathering is one of the most aggressive forms of weathering. However, removing lichen without damaging the rock underneath is very difficult due to the deep roots. This indicates that the stones at the Almendres Cromlech are undergoing biological weathering, but that the prevention or reduction of this is expensive, difficult and may lead to more damage to the rock.

The enclosure's location on an exposed hilltop also leaves the stones vulnerable to more physical forms of weathering. This includes by precipitation, thermal stress and wind. Sellier (2008) found evidence for more deterioration on the top or south/west faces of menhirs than the rest of the stone. These areas are more exposed, and their degradation indicates that Portuguese menhirs are susceptible to physical weathering. The evidence for the south facing side being more affected is supported by Pope *et. al.,* (2002) and Matias and Alves (2002). The menhirs may also be affected by wet-dry cycling (Siegesmund *et. al.,* 2002), particularly during the rainy season. This causes fragmentation of the rock. All of these factors could contribute to the degradation of petroglyphs, particularly those near the top of stones, or facing south/south west.

There is also evidence that salts contribute to the disintegration of granite stones in Portugal (Alves *et. al.,* 1996). Though Évora is some way from the ocean, salt weathering has been found to occur in temperate cities throughout Europe (Smith, 1994; Williams and Robinson, 1998). Salts can cause thermal expansion, hydration and crystallisation (Rodriguez-Navarro and Doehne, 1999; Rivas et al., 2003) and can cause chemical weathering to occur quicker (Pope *et. al.,* 2002).

Perhaps the most important erosion force to consider is that of human beings. According to Pope *et. al.,* (2002), human impact is the greatest cause of stone deterioration. Human contact, whether that be through interested tourists, or invasive, contact survey methods, can induce and exacerbate mechanical and chemical weathering processes (Paradise 2000; 2002). Due to the exposed and completely accessible nature of the Almendres Cromlech, all stones are susceptible to human contact. There are no warnings or information signs about the possible vulnerability of the stones, and so people can sit, climb and touch the rocks. This not only threatens the petroglyphs through increased weathering, but also the stability of the standing stones. Only around a fifth of the stone is buried, and due to the high levels of soil erosion, and the thin lithosoils of the area, they are at risk of collapsing. Many of the more vulnerable stones have already been concreted in place to prevent this. As the stones themselves are as important as the petroglyphs, damage to any of them would be devastating for our understanding of the history of Portugal.

It is important to note that the rates of deterioration of granite in Portugal are slow, around 40mm per millennium, and up to 48mm per millennium for the areas most prone to erosion (Sellier, 2008). However, over the last century the deterioration of buildings and monuments has significantly increased (Siegesmund *et. al.,*2002), suggesting that weathering rates could be higher. Different megaliths, and in different areas weather differently due to exposure, orientation, property of the granite, initial state of the stones, amongst many other factors (Sellier, 2008). This suggests that the weathering levels at different sites, or even on different rocks at the same site could be different. Therefore, we ask the question whether erosion is a factor in the differences between previous research and this study.

Research Problem

The Almendres Cromlech is an increasingly popular tourist destination. Increasing footfall is putting significant pressure on the vegetation in the area, which is putting the stability of the megaliths at risk. This study aims to identify discrepancies between the survey carried out for this study and previous surveys of the petroglyphs at the Almendres Cromlech, and ascertain the reasons for those differences. Due to time restraints in the field this study will focus on the Almendres Cromlech, but will lay down a foundation from which further research can be done on the surrounding enclosures and megaliths. This study also hopes to create a comprehensive, freely accessible 3D database of the site. We hope this will encourage public engagement with the site, enhance education opportunities, such as for the nearby interpretation centre, and act as a precise and accurate 3D model of the site for researchers in the future.

Aims

1) To establish and investigate discrepancies between the recordings of petroglyphs from earlier research (Gomes, 2002) compared to this photogrammetric study.

Using UAV SfM photogrammetry and feature mapping in Agisoft Photoscan, 2D images will be used to create 3D models. These will then be analysed using a virtual light/shadow technique. The resulting 3D models will be compared to the results of Gomes (2002) and Ferraz (2016).

2) To investigate the possibility of undiscovered petroglyphs.

Using SfM photogrammetry, ultra high-quality models will be created of each stone with a flat face/possible petroglyph. These will be analysed using a virtual light/shadow technique in order to identify the petroglyph shapes.

3) To create an accurate, precise 3D model of the Almendres Cromlech that can be used for both educational and research purposes in the future.

SfM photogrammetry will be used to create a high-quality model of the full site which will be made freely available online, along with the comprehensive database and analysis of the petroglyphs.

Methodology

This is one of the latest in a series of studies (Cabuk *et. al.*, 2007; Lambers *et. al.,* 2007; Sauerbier and Eisenbeiss, 2010; Eisenbeiss and Sauerbier, 2011; Verhoeven, 2011; Verhoeven *et. al.,* 2012; Rinaudo *et. al.,* 2012; Cerrillo *et. al.,* 2019) using UAV SfM photogrammetry to document archaeological sites. Cerrillo et. al. (2019) used SfM photogrammetry at the Almendres Cromlech, though used different intermediary techniques in order to highlight petroglyphs, namely their 3DMeshTracing's protocol. This study, on the other hand, will use the previously tested method of UAV photogrammetry, but will push the boundaries of the capabilities of the inbuilt GPS system on the Phantom 4 Pro in order to assess its usefulness for inaccessible sites, where ground control points are unable to be placed. This study will also be the latest paper to use 3D models as a technique for public engagement, by creating the first comprehensive 3D documentation of volumetric and petroglyph information about Almendres Cromlech. The use of open source 3D hosting platform will potentially lay down the foundation for future research to make their studies accessible to the general public by utilising similar techniques. This will begin to bridge the gap between scientific studies and accessible and interesting information about the sites they study.

The recording of archaeological monuments has always provided a challenge to archaeologists. There is always a compromise between accuracy and time, with expense often limiting the time available in the field. There are multiple techniques that have been used to document Neolithic monuments. The traditional, empirical techniques (Livieratos, 1992 in Gomes, 2011) include tracing with paper, freehand drawing, 2D photography, plaster moulding and latex and wax rubbing (Lerma, 2010). However, these methods are time consuming (Fritz *et. al.,* 2016), expensive and often damaging to the site due to their invasive, contact nature (Simpson *et. al.,* 2003; González-Aguilera *et. al.,* 2009). They also result in distortion of the final petroglyph image, due to the nature of turning a 3D object into a 2D drawing (Cassen and Robin, 2010). Additionally, these techniques only concentrate on the petroglyph design, missing factors such as stone shape, texture of stone, location of design on stone and location within the full monument (Cassen and Robin, 2010). According to Bradley (2002) and De Reu *et. al.* (2013), archaeological documentation should aim for the most comprehensive record of the site. The lack of full context, and distortion of 3D to

2D formats significantly affects our ability to understand the monuments geographical space and contemporary context (Tsiafakis et al., 2004) making the results less useful to future researchers (De Reu *et. al.,* 2013; McCarthy, 2014a).

Due to these limitations, archaeologists have been searching for more accurate, yet still affordable and efficient ways to document archaeological sites. Reflectance transmission imaging (RTI) has been used as a technique to create 3D models from 2D photographs. RTI uses photographs taken at the exact same position of a stationary object, where the light source angle is changed in order to illuminate different aspects (Manrique *et. al.,* 2013). In addition, the increased economic availability of laser scanners and good quality handheld cameras, as well as the increase in accessible feature matching technology that can produce good quality 3D models has resulted in the increased popularity of topographic methods such as laser scanning (Boehler and Marbs, 2002 in Gomes, 2011) and Structure from Motion (SfM) photogrammetry (Livieratos, 1992; Hanke and Grusenmeyer, 2002; Tsioukas and Patias, 2002). These techniques are able to record an archaeological site in 3D both quickly and with up to millimetre accuracy (depending on conditions) (De Reu *et. al.,* 2013; Koenig *et. al.,* 2017). These methods have significantly higher accuracy and precision than traditional techniques (Cassen *et. al.,* 2015; Carrero-Pazos *et. al.,* 2016).

Due to these advantages, and the comparable accuracy yet lower cost compared to laser scanners (Doneus *et. al.,* 2011; Pierrot-Deseilligny *et. al.,* 2011; Georgantas *et. al.,* 2012; Kersten and Lindstaedt, 2012; Chandler and Fryer, 2013; McCarthy, 2014a), this study has chosen to use SfM photogrammetry to document the Almendres Cromlech, with the incorporation of elements of digital RTI in the methods used to highlight petroglyphs. There was no need for separate, on-site RTI imaging, as the resulting 3D models were able to be used for virtual RTI. Virtual RTI techniques allow greater scope, as we are able to manipulate the type of light source and the colour and reflectance of the 3D models, allowing increased visibility of petroglyphs. It also removes the issue of time and financial restraints of being in the field. SfM photogrammetry is the creation of a 3D model using images captured using a moving camera (Szeliski, 2010; James and Robson, 2012; Verhoeven *et. al.,* 2012; Fonstad *et. al.,* 2013; Fisher *et. al.,* 2013). Algorithms are used to identify image feature points, and monitor their movement through multiple images (Verhoeven, 2011). SfM photogrammetry results in reliable and precise models that can record high levels of detail even over complex surfaces with varying textures (Díaz-Andreu *et. al.,* 2006; Hixon *et. al.,* 2017). Most studies agree that the accuracy of SfM models is within a few centimetres (Doneus *et. al.,* 2011; De Reu *et. al.,* 2013) and the precision within millimetres (Lerma and Muir, 2014). Petroglyphs can be of thicknesses of a few millimetres, making the precision of SfM crucial. 3D models don't suffer from the distortion found in 2D records, and don't require decisions on petroglyph location on site (which tracing and other traditional techniques do require), which is an interpretation in itself. This ensures 3D models are more objective than 2D records (Carrero-Pazos *et. al.,* 2016). SfM photogrammetry has been used in many projects previously including the Durham Rock Art Project (NADRAP), Chandler *et. al.* (2007), Koutsoudis *et. al.* (2007), Tsiafakis *et. al.* (2004), Plets *et. al.* (2012), Rinaudo *et. al.* (2012), McCarthy (2014a) and Tomášková (2015), and has had widespread success as a method for digitising archaeological sites.

Due to the size of the site, covering the entire ground using terrestrial photogrammetry would have been too time consuming. In order to overcome this obstacle, we chose to use an Unmanned Aerial Vehicle (UAV) to complete aerial surveys. This allowed us to obtain photographs of the entire site, giving spatial resolution, while the terrestrial photographic work we did provided us with the millimetre accuracy we were aiming for. The advantages of UAV SfM photogrammetry are numerous. High standard, automatable UAVs are affordable and portable, making them ideal for work in different countries on projects with limited budgets. The ability to automate and save their flight path using software such as DJI Go or Litchi allows repeat surveys to be undertaken with ease, adding reliability to temporal results. UAVs give access to sites that are inaccessible or too large to record by terrestrial photogrammetry alone (Eisenbeiss and Sauerbier, 2011; Lerma and Muir, 2014). Most UAVs also have built in GPS systems, which records the coordinates of each photograph. This can be used in feature matching software to help align the photographs and give them a geographical location, although most studies also use ground control points (GCPs) to georeference the model. Unlike laser scanners, SfM photogrammetry is not significantly affected by lighting (Johansson and Magnusson, 2004), and is best under natural light conditions, making it ideal for documentation during the day (Carrero-Pazos *et. al.,* 2016). UAVs are excellent alternatives to traditional methods (Eisenbeiss and Sauerbier, 2011).

Due to the availability of accessible, simple to use photogrammetry software anyone with a small amount of understanding of the technique can create accurate 3D models (Doneus *et. al.,* 2011; Bevan *et. al.,* 2014) . We used Agisoft Photoscan, a well-known feature matching software. It has been used with success in the past, on a variety of projects, including archaeological surveys (De Reu *et. al.,* 2013), thus making it ideal for this project. Due to the highly automated nature of the software, there is very little knowledge needed to create a good quality 3D model, making this study repeatable in the future by those not well versed in 3D photogrammetry.

The 3D model of the site was used to create a full database about the Almendres Cromlech, including number of stones, volume, area and height of each individual stone. A virtual 'grazing light' technique was used on individual 3D models of the stones in order to make the petroglyphs stand out, allowing us to also record the presence and likely shape of petroglyphs. The resulting 3D model will be made accessible to the general public, and will be used for information dissemination at the new visitor centre near the site. Digital 3D models allow a wider dissemination of information about unmovable archaeological sites to the wider scientific community and general public (González-Aguilera *et. al.,* 2009; De Reu *et. al.,* 2013; Bonacchi *et. al.,* 2014; McCarthy, 2014b; Ritsos *et. al.,* 2014; Fritz *et. al.,* 2016). It also provides an accurate and reliable model of a site that is at risk, and may not remain as it is forever (Fritz *et. al.,* 2016), allowing researchers to monitor changes in the future, and aid preservation or recovery.

Although UAV SfM photogrammetry does have some disadvantages, which we will discuss later, its overall convenience, cost and accuracy and precision levels made this the ideal method to use on a site such as the Almendres Cromlech.

SfM photogrammetry consists of 7 stages; planning, photograph acquisition, alignment, dense point cloud, mesh reconstruction, texturing and error calculation.

Planning

Using Google Earth, a flight path was pre-planned in order to cover the entire site at different spatial scales (Rinaudo *et. al.,* 2012; De Reu *et. al.,* 2013) **(**Figure 9**).** The planning had to take into account the shape and size of the site, the complexity of the site, the level of detail desired and the processing time available (Pavlidis *et. al.*, 2007), and allow the photographs to have at least an 80% overlap, which is needed for SfM photogrammetry. This path was created on Litchi, an autonomous flight app. Photographs were taken at 20m and 50m. We also created a map which numbered each megalith so that we could match the terrestrial photographs with their respective megaliths in the field.

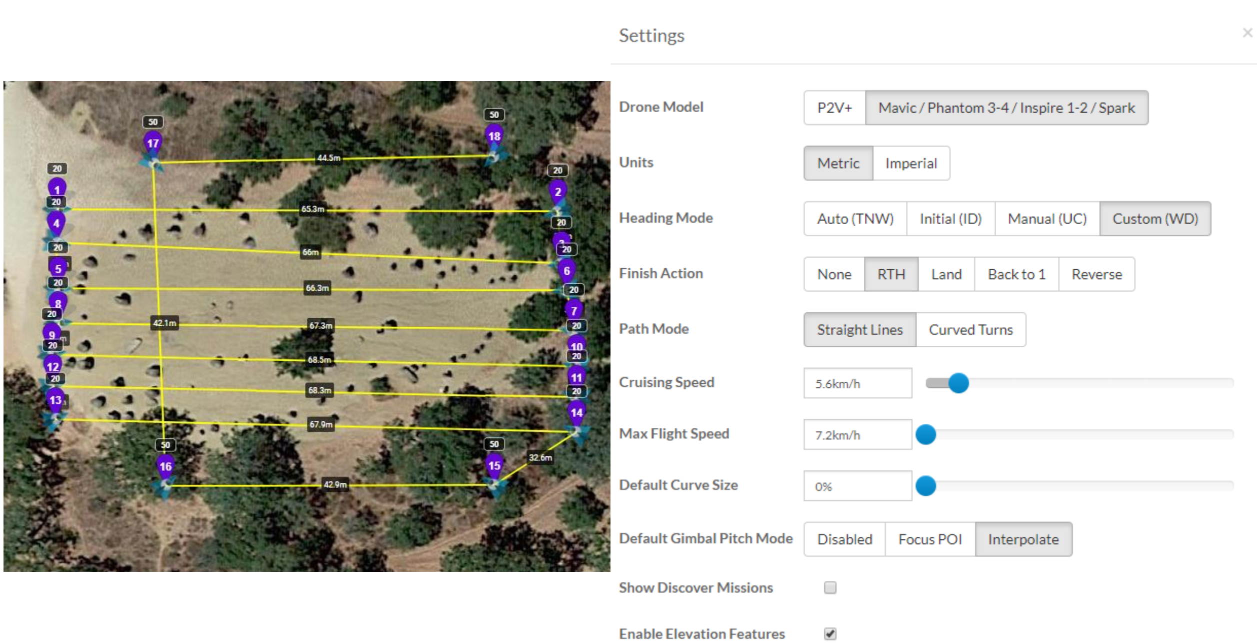

Figure 9: Map of flight path and menu from the Litchi app showing the selections made for the survey.

In order to make sure we were legally allowed to fly and record images in Portugal, we applied and were granted the two permits necessary. These were the drone permit from the National Aeronautical Authority, and formal authorisation from the DGPC (Direção Geral do Património Cultural).

<u>*Photograph acquisition – terrestrial and aerial SfM photogrammetry in the field*</u>

The UAV used was a Phantom 4 Pro, with a 1-inch 20-megapixel camera stabilised using a gimbal. The lens is a wide-angle lens with a 24mm equivalent focal length, resulting in low distortion, which is crucial when working with feature matching software. See Table 2 for the main flight parameters. We used the UAV for both the aerial and terrestrial photogrammetry, and made sure not to change any settings during the two days to ensure consistency (McCarthy, 2014a).

Area	***Height above ground (m)***	***Focal length (mm)***	***UAV velocity (ms^{-1})***	***Flight mode***	***Acquisition mode***	***Size of area***	***Image overlap***
Almendres Cromlech	20, 50 and 70.	24	1.6	Autonomous	In motion	56x23 metres	80%

Table 2: Main flight parameters of study.

The aerial survey was completed using the full automation mode of the Litchi app, including take-off and landing. The UAV was then held in the hands and walked around each stone while pictures were taken using the timer mode (Figure 10). It is best to take photographs in sequence (Koenig, Willis and Black, 2017), so this was attempted where possible. In order to reduce the time required to circle 95 stones, some were grouped into ‘families’ where neighbouring stones were photographed at the same time. The camera angle was adjusted in order to reduce the amount of sky in the photographs, which is crucial for photogrammetry, which relies on the differences in pictures, and thus finds sky difficult to place (Agisoft, 2014).

Figure 10: Holding the UAV to capture the images from multiple heights and angles. Photograph taken by Vivian Mercer, June 2018

SfM photogrammetry works best with photographs in a concave shape and around an 80% overlap (Agisoft, 2014). This allows the software to avoid using the edges of images, which reduces distortion. SfM also works better with images without strong changes in lighting, shadows, moving objects (e.g. vegetation) and blurriness (González-Aguilera *et. al.,* 2009; Koenig *et. al.,* 2017). In order to reduce these we shaded the camera from strong sun, moved vegetation out of the way as much as possible without damaging it and retook blurry photographs. In order to get the best spatial resolution while ensuring high-quality textures, photographs should be taken from a variety of distances. We aimed to take one circle around 7 metres away from the stone, and one just 1-2 metres away. For stones which we knew had carvings or flat faces that had the potential to be carved, we spent extra time taking more photographs, and from a closer distance in order to increase the spatial resolution. In order to ensure we had photos of the tops of the stones that could be matched with those taken on the ground, we manually piloted the UAV at low altitude over the majority of the Cromlech, at a height of around 4 meters. At the end of the day the data was uploaded onto a hard drive as a backup, and some preliminary models were created to ensure we had not missed anything significant. It took two days to complete the full survey of the Almendres Cromlech.

<u>Alignment – feature matching in Agisoft Photoscan</u>

The images were grouped into folders containing photos of a single stone or families. Each photograph was checked to ensure it was not blurry, too dark and didn't contain too much sky, as these affect the quality of the 3D model (González-Aguilera *et. al.,* 2009; Hixon *et. al.,* 2017). The photo folders were then uploaded into Agisoft Photoscan (henceforth referred to as Photoscan). Photoscan is a piece of software that uses a scale-invariant feature transform (SIFT) algorithm to match similar features in photographs in order to generate 3D models. This is known as feature detection and matching (Bevan *et. al.,* 2014). These points are then used to determine the shape of the subject, and the position of the image (Koenig *et. al.,* 2017).

Due to the large amount of data being processed, Photoscan's 'workflow' tool was used. This allows multiple stages in the 3D modelling process to be done with minimum manual input. These stages followed the path indicated in Figure 11.

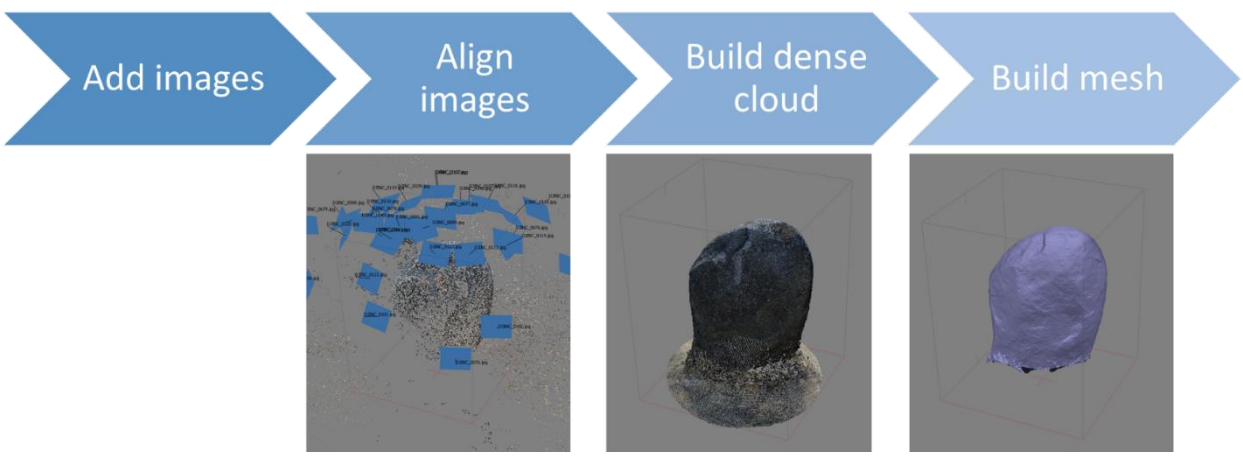

Figure 11: Flow chart of the workflow stages in Photoscan, used to create a 3D model of each megalith

For the alignment of photographs, we first removed any remaining sky using the masking tool. We then aligned the aerial images only, using pair preselection and reference preselection. This meant Photoscan used both the order in which the images were taken, and their geodata (GPS points) to align the images. This resulted in a georeferenced 3D model of the whole site, but had poor spatial resolution. We then added the terrestrial photographs, but only enabled pair preselection (order of images). This is because we discovered that the z coordinate (altitude) of the UAV's GPS while on the ground was more than a few metres out, and varied each time the UAV was turned on and off. By only enabling pair preselection, we removed the need to align by GPS point, but the feature matching technique meant the terrestrial photographs could be aligned with the aerial photographs, thus ensuring the 3D model was still georeferenced. In future studies, it would be useful to use a ground based differential GPS (D-GPS) to calibrate the low accuracy of the z-axis on the UAV GPS. The results of the D-GPS could then be imported into Photoscan to ensure the model had the correct values in order to scale it. However, this paper aimed to show the possibility of using only the onboard GPS, in order to highlight its applications in difficult to access locations, where being on site is impossible, which is why we chose not to use a D-GPS and we found that the accuracy of the x and y-axis of the onboard GPS was sufficient to create 3D models precise enough to identify petroglyphs. In order to reduce lens distortion, Photoscan takes into account the camera calibration parameters, which results in a more accurate 3D model (Verhoeven, 2011). Due to the non-linear increase in time required to align photographs as the quality is increased (in the time frame of a few days) the first model was aligned using 'low' on the quality setting. Once we were sure the images would align correctly, we aligned the images on high and left the model running for a few days.

Most UAV SfM photogrammetry is done using ground control points (GCPs) (Kersten and Lindstaedt, 2012; McCarthy, 2014a; Koenig *et. al.,* 2017). These are 'targets' on the ground with known GPS points, which can be used to georeference the 3D model in processing. However, this technique is time consuming both in the field and during processing, and requires access to the site which is not always possibly, particularly for archaeological sites. SfM photogrammetry can be done without GCP points, but lacks scale and spatial data (Koenig *et. al.,* 2017). However, this can be overcome by using a scale bar in the site (Kersten and Lindstaedt, 2012), or the inbuilt GPS onboard most UAVs (Carbonneau & Dietrich, 2017). We decided to test the latter technique. Ideally, this would reduce the impact on the site, and reduce the time required both in the field and during processing, as all georeferencing would be done automatically. If this proves successful, this technique will be extremely useful in areas where GCPs cannot be placed to due risk of damaging the site or inaccessibility.

Multi-scale alignment technique

Most UAV SfM photogrammetry surveys use images of a similar scale. For example, if one is surveying an area of shrub land, the flight path with likely consist of the same area being covered by photographs taken at 20m, 40m and 60m heights. However, for this survey, we had to combine images taken at 50m, 20m and 4m, then terrestrial images taken at between 10 and 1m from the stones. As Photoscan uses feature matching, trying to match an image taken 50m above ground to one taken 1m from the stone is difficult. To overcome this we first aligned the 50 and 20m images, removed the central block of images, and then aligned the rest of the images. As the elevation of the UAV GPS is not very accurate, we aligned the 50m and 20m images with references preselection and pair preselection, then aligned the rest of the images with only pair preselection. Having images taken on a variety of scales between high and low spatial resolution allowed features to be matched in all of these images, thus resulting in a large model which still has millimetre accuracy.

Dense point cloud creation

Once the images were aligned on high, a dense point cloud can be created. This was originally done on low to save time, but later was recreated with the quality on ‘High’. We used the Height Field algorithm, as this is the best for aerial photographs (Verhoeven, 2011). Once the dense cloud was created the ‘crop’ and ‘delete’ tools were used to remove unwanted areas. This included the forest area surrounding the cromlech and any trees on the site, and the shape of the model was cropped to an oval shape around the outside of the stones. This reduces the amount of points that the software needs to deal with in the next sections, and therefore reduces the amount of processing time.

Mesh creation

Due to the size of the area, we did not have the computing power to create a high-quality mesh from the dense cloud of the full site. To overcome this problem, we used the georeferenced dense cloud of the full site as a base from which to create georeferenced, high-quality models of each individual stone. To do this, we selected only the area of dense cloud of the megalith, and deleted the rest. We then removed unnecessary images, taking the total image count from 2646 to around 150-200 depending on the stone. This significantly reduced the amount of processing required when creating a mesh. The mesh was created on the highest setting, with the surface type left as Arbitrary. Finally, we used the close holes tool to fill in any gaps. This technique allowed us to model each stone individually at high-quality, but ensure they were still georeferenced. The 3D models were then used to collect information including volume of stones (Fritz *et. al.,* 2016), area, height and shape. Shape is crucial in archaeological contexts (Lerma *et. al.,* 2010; De Reu *et. al.,* 2013). These models were then used to identify possible flat faces and petroglyphs, which then underwent further processing.

Accuracy analysis

For multiple stones at the Almendres Cromlech we took images with 30cm rulers positioned at the base. This was to ensure we knew the exact dimensions of a feature that would be reconstructed in the model. We then measured the length of the rulers in the model, and compared those results to the actual length of the ruler. We calculated the mean, standard deviation, percentage error and the precision. Due to some unusable images, only 56 rulers out of 60 were clear enough to be measured. As we are working with millimetre differences, we made sure we consistently measured the same corner to corner distance, and zoomed in as much as possible to find exactly where the corner is. However, it is important to note that these measurements are done by humans, therefore are susceptible to human error. Though we minimised this as much as possible by following a consistent method, it is still possible that it affected our results.

Additionally, this analysis was done only on the full size model, with high alignment and high dense cloud creation. We did not measure the accuracy of the ultra high-quality models of the individual megaliths, as to speed up the processing we removed all ground points from the sparse cloud stage. Future research should look into measuring the accuracy of the ultra high models that can be created.

Petroglyph identification

On stones where previous research had identified petroglyphs (Gomes, 2011), or where there were flat faces/possible petroglyphs we recreated the models at the highest quality. This was to ensure we got the most accurate measurements possible when measuring the petroglyphs. To do this we chose the photographs that contained images of the desired stone and deleted the rest in order to keep the processing time manageable. We then realigned the images on *highest*, created dense cloud on *highest* and created the mesh on *high*. This was only done on stones likely to have petroglyphs as the processing time is very long when using high-quality settings, and thus modelling the entire area would have taken months.

Once the high-quality models were created, they were exported into Blender. Blender is a free, open-source piece of 3D computer graphics software. We used the light tools in Blender in order to recreate a virtual version of the grazing light technique. This is where a light source is directed at the stones face so that the light just touches it, throwing even small changes in surface into dark shadow (Figure 12). By moving the
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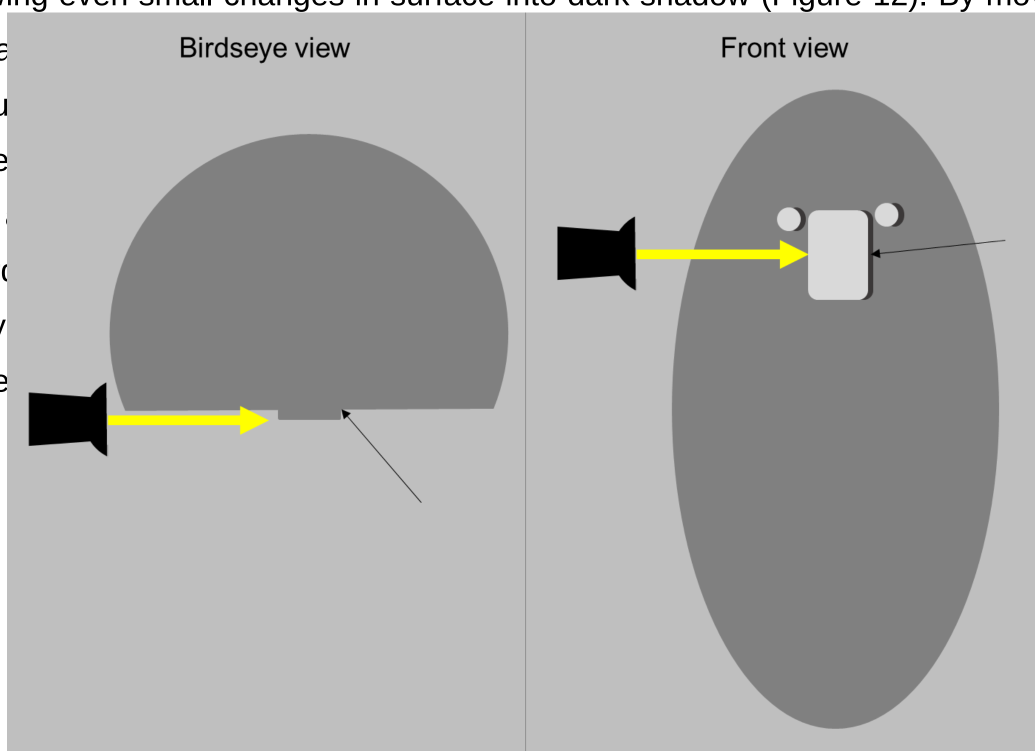


Figure 12: Graphic of the grazing light technique. Yellow arrow is direction of light. Black arrow shows where the shadow would be. By moving the light around, it lights up different areas of the petroglyph.

Investigating possible petroglyph changes

In order to investigate the possibility that the petroglyphs at the Almendres Cromlech are being eroded we needed to compare with previous research at the site. Firstly, we drew our own interpretations of where the petroglyph features were using the results of the virtual light grazing technique. We then used what we identified in these drawings to compare with those identified by Gomes (2002) and Ferraz (2016). We aligned Gomes' drawings with our 3D models, then colour coded each feature with the following categories: non-matching features (white), matching features (green), natural features (red) and new features (blue). This allowed us to compare the similarities and differences between the studies. The results of this are seen in section C of the petroglyph figures in the results chapter.

Methodological limitations

SfM photogrammetry does have some disadvantages, which this study will endeavour to minimise as much as possible. The main limitation of SfM is the quality of the images. This can be affected by light levels, sun glare, blurriness, too much sky, insufficient overlap or too much tree cover. Many of these issues can be reduced in the field. For example, in order to avoid sky as much as possible the camera on the drone was constantly adjusted to avoid it. If we spotted a blurry picture we took it again, we shaded the drone from the sun to reduce glare and moved tree cover as much as possible. However, some issues are unavoidable and therefore may lead to images that are unusable. To avoid using these images in the model every photograph was checked beforehand and removed if it was unsuitable. We also used the masking tool in Photoscan to remove sky. Unfortunately, removing images can result in holes or distortion in the model. This can be avoided by retaking the unsuitable images, but time pressures can make it impractical to do so. In this study, a few stones ended up with holes in the top. This was due to an insufficient number of low aerial images (~4m). These holes were fixed using the meshing tool, but there is some distortion, which we will highlight in the database. In the future, we will ensure to get a sufficient number of low aerial shots in order to allow the feature matching algorithm to more effectively match the aerial and terrestrial images.

Another limitation is the accuracy of the onboard GPS (Eisenbeiss and Sauerbier, 2011). The Phantom 4 Pro has a GPS accuracy of ±0.5m vertically and ±1.5m horizontally (DJI, 2018). In order to maximise the accuracy of our onboard GPS we ensured we had sufficient satellites before we flew each flight. To reduce the error caused by GPS in the model we used both pair preselection and reference preselection in Photoscan. While reference preselection uses the images geodata (derived from the UAVs onboard GPS), pair preselection uses the order in which images were taken. GPS data was used for general location of the images, but the feature matching processing is what dictates the final position of the images, and therefore the accuracy of the model.

The requirement to understand how to operate UAVs can also limit the use of this methodology. Due to the advances in the automation of UAV flight, the knowledge required is decreasing. However, you do still need to know how to set up the UAV and create a flight path, which requires specific knowledge. If working for a company or a university, there are also insurance issues to take into consideration, which often require some training before the fieldwork. As with most archaeological surveys, you are likely to need to request permission to fly and take photographs. These often take weeks to months to be authorised, which needs sufficient advanced planning. Different countries have different UAV rules, and it is crucial to check these before taking a UAV to your field site. Although Portugal does allow UAVs, there were permissions that needed to be granted before we were allowed to take photographs and fly at Almendres.

An important limitation to consider in this study is that of human error. Identifying and tracing over petroglyphs identified in the 3D models requires human interpretation, and different people may be able to see different features. Much the same as Gomes (2002), determining which are manmade features and which are natural is difficult. Additionally, having the knowledge of the drawings from the previous studies may also bias what can be seen. Therefore, we must take into consideration that any results using a technique that requires human involvement, such as the drawing of petroglyphs, even if using millimetre accurate 3D models to draw from, are susceptible to bias and must be used with that consideration in mind.

The grazing light technique also suffers from some limitations. The main issue with this technique is that the results are fragmented (Pires *et. al.,* 2015). Each photograph has different shading, thus each present a different point of view. Several photographs are needed in order to fully comprehend the rock art, which makes presenting the results difficult. It is also difficult to successfully light surfaces that are not flat. Though most of the petroglyphs are found on flat faces at the Almendres Cromlech, roughness of the surface, or rounding of edges makes lighting the models in order to show the whole carving at once is difficult. This limitation can especially be observed in the results for ALM64 (Figure 28) and ALM72 (Figure 30).Additionally, usually interpretations made using this technique have to be made with the colour and texture of the stone, including obscuring features such as lichen. However, we overcame this technique by removing colour texture from the models, and using a ‘skin’ of one colour. This skin could be changed to be more or less reflective, different colours etc., allowing us to choose the format that best showed the carvings. We made sure to also use the coloured texture to help us identify between natural and manmade features, avoiding the obscuring issue that Gomes faced. However, ultimately, the grazing light technique, even when combined with UAV SfM photogrammetry, is unlikely to be able to perfectly record petroglyphs at Almendres Cromlech.

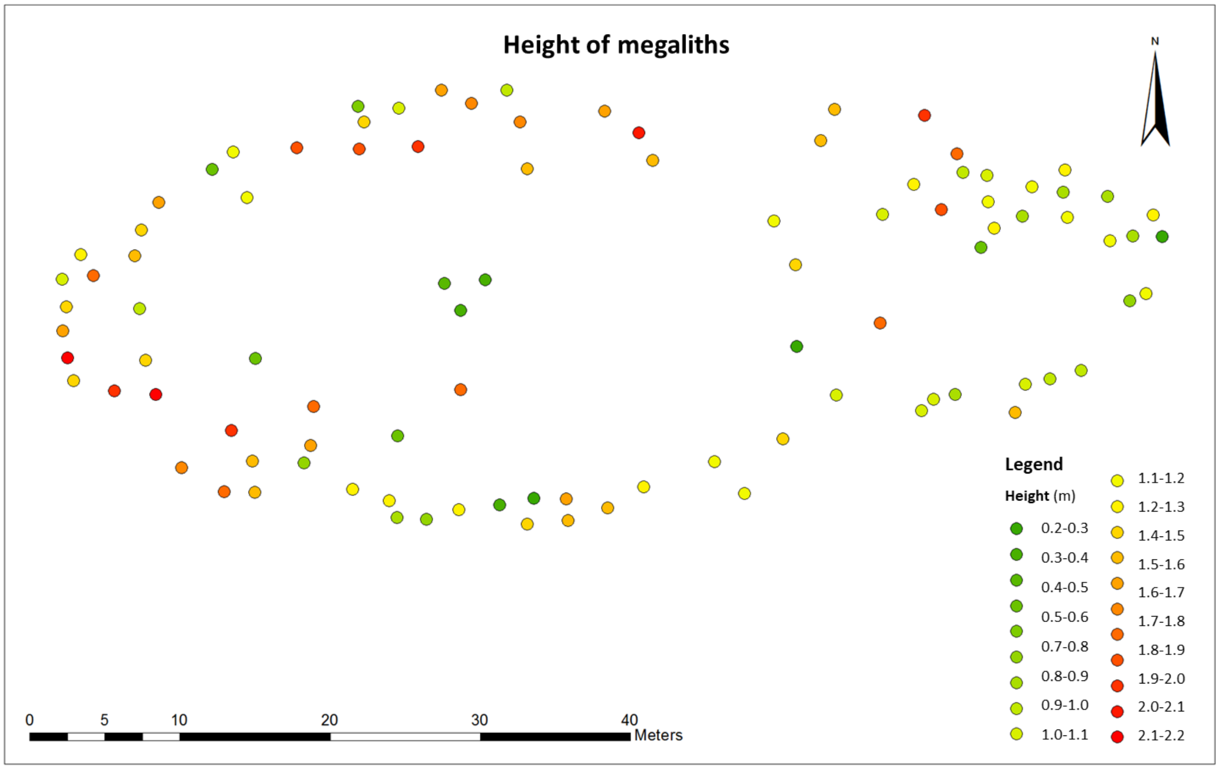
Results

This study resulted in a full site 3D model with 4.9mm accuracy (Figure 13). The total site was 56 metres long and 23 metres wide. We identified 95 stones, varying from 0.2 metres to 1.9 metres in height. We discovered 13 decorated megaliths, and 3 with cup marks. See table in Figure 13 for full information. We also produced 13 ultra high-quality models of the megaliths with confirmed or possible petroglyphs at 4.9mm accuracy.

Width (m)	*Length (m)*	*Area (m^2)*	*Quantity of megaliths*	*Average height of megalith (m)*
23.0	56.0	1377	95	1.17

Figure 13: Birdseye view of 3D model of the Almendres Cromlech

There does not seem to be a strong correlation between height or volume of megalith and position downslope (East to West) (Figure 14a & Figure 15a). The correlation between volume and distance downslope is slightly greater than that between height and distance.



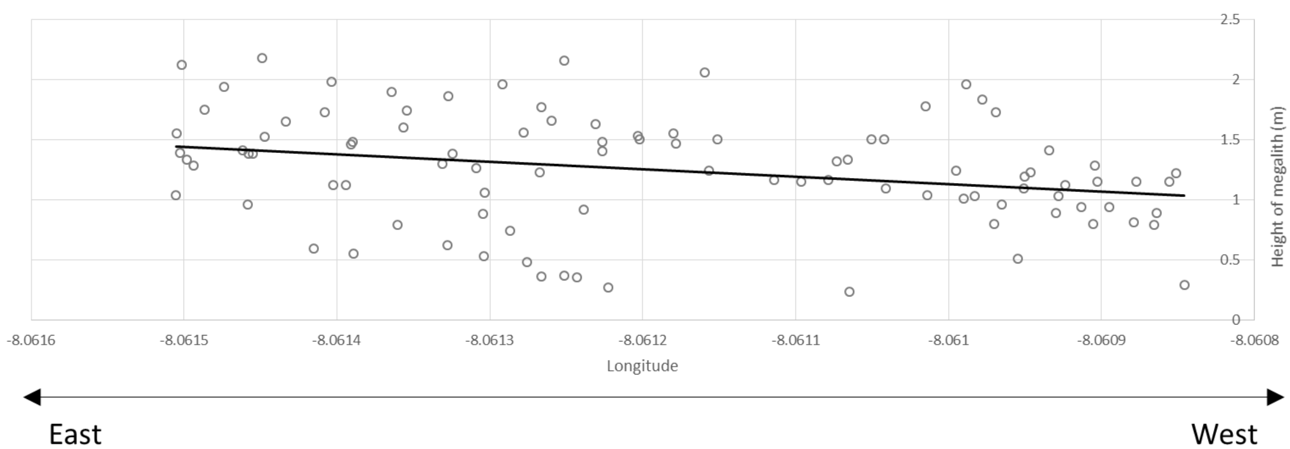


Figure 14a: Map of height of megaliths. Figure 14b: Graph of height of megaliths

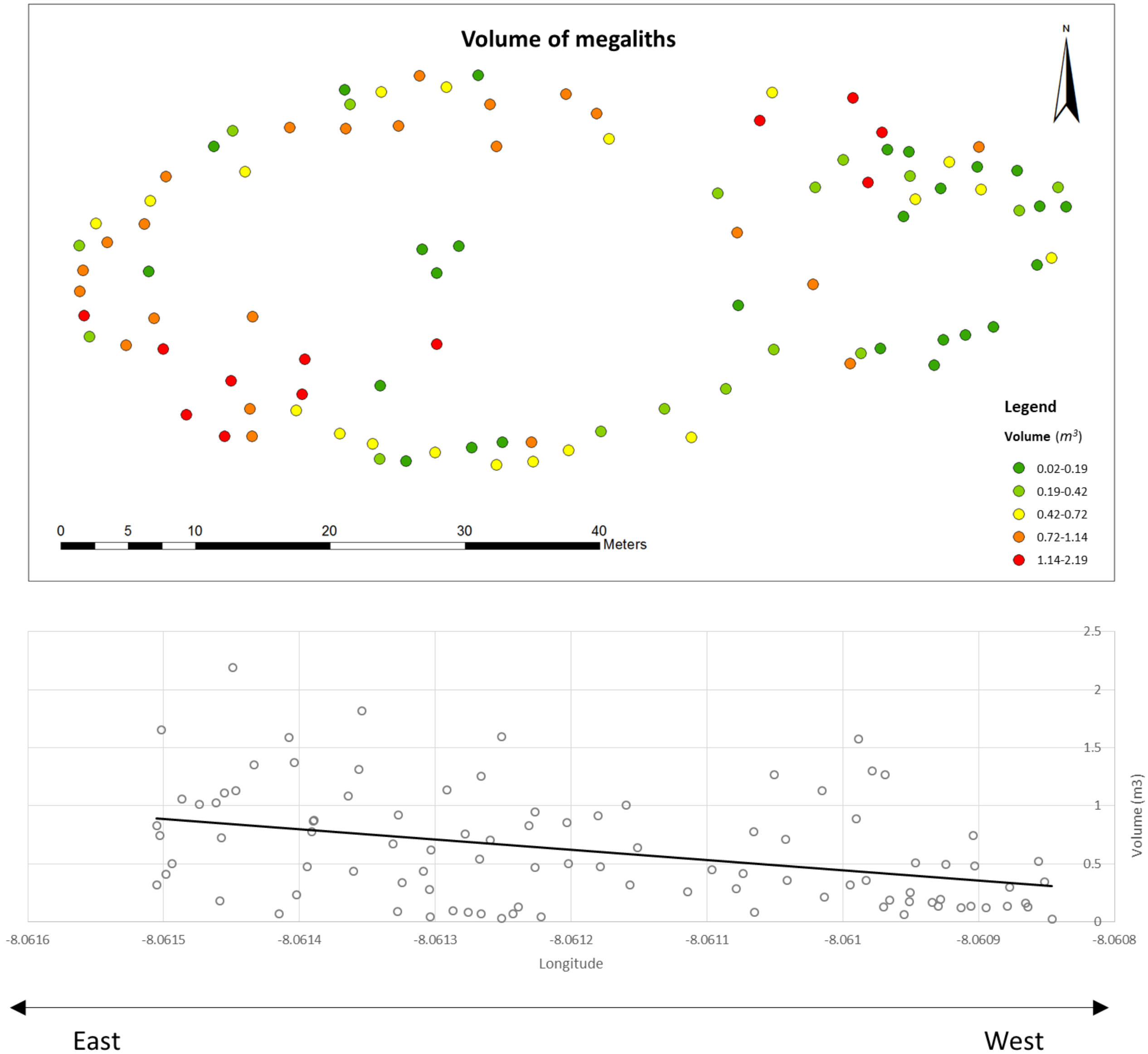


Figure 15a: Map of individual volumes of megaliths. Figure 15b: Graph of individual volumes of megaliths.

We identified possible petroglyphs on 13 of the 95 megaliths studied (Figure 16). Of the 13 decorated megaliths, 10 had flat faces. Two of these were as yet undiscovered decorated megaliths. The mean bearing of the flat faces was 94º (Figure 17). 43 of the stones, including decorated and non-decorated, had flat faces. Figure 18 shows a map of all 43 flat faces as arrows indicating the direction they point. The rose diagram in Figure 18 shows that most flat faces point east, with an average bearing of 72º.

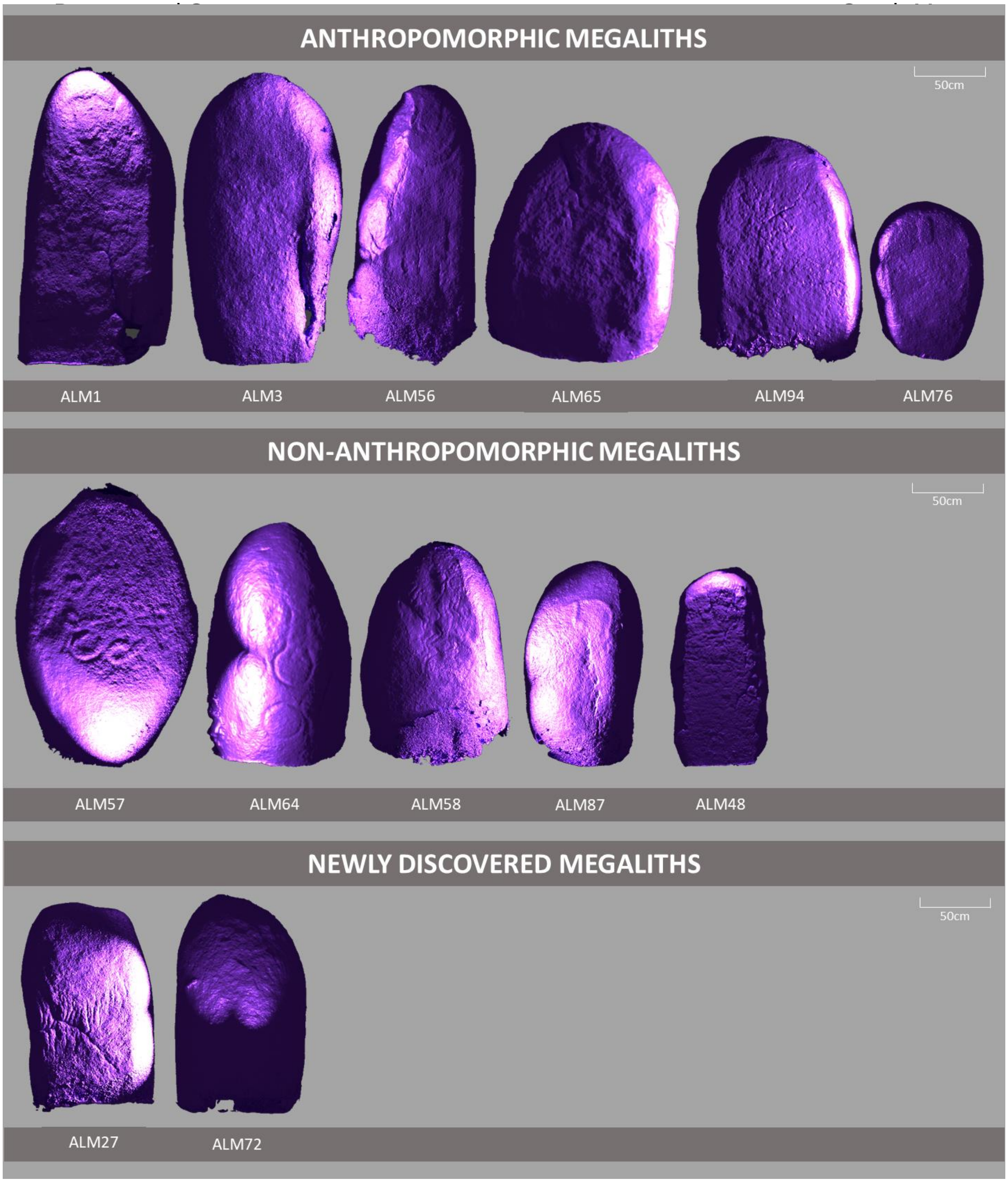
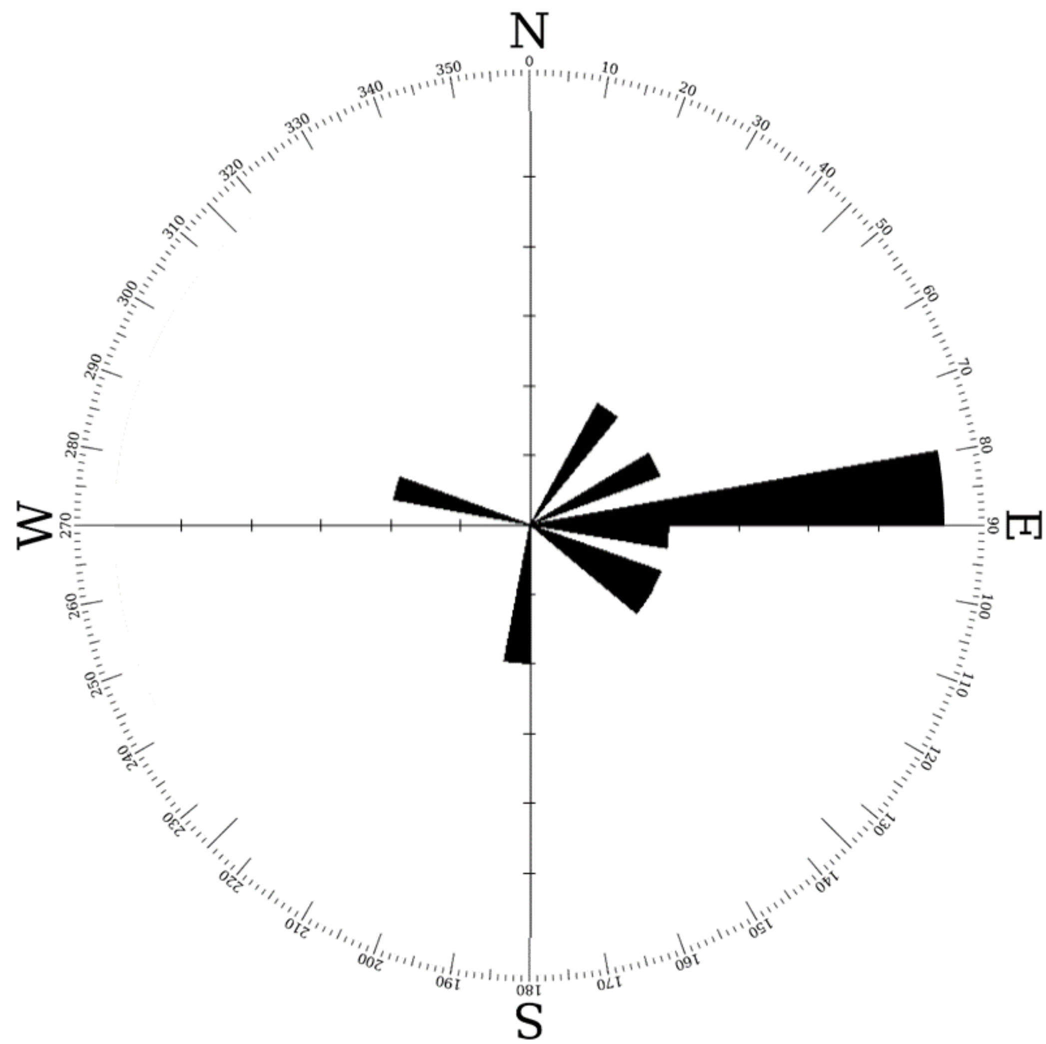
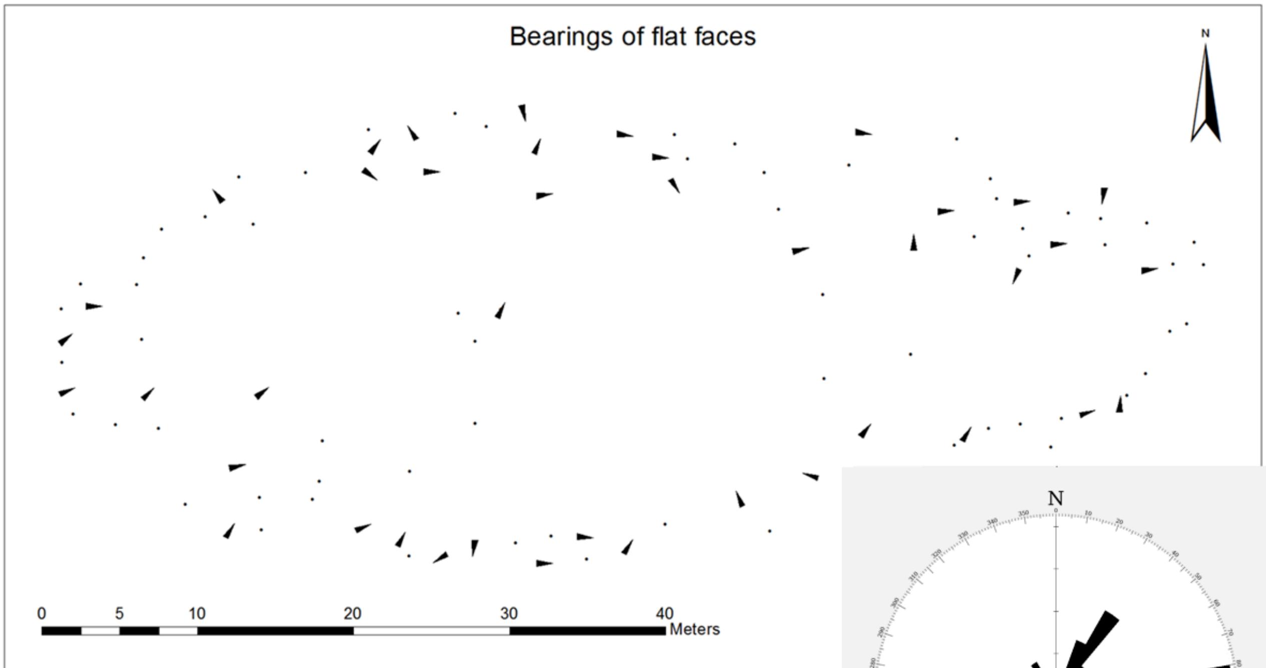


Figure 16: Best lit image of each decorated megalith this study identified. These have been split into Anthropomorphic, non-anthropomorphic and newly discovered sections.



No. of Data	Sector angle	Scale: tick interval	Maximum	Mean Resultant direction
10	10°	5% [0.5 data]	30% [3 data]	094

Figure 17: Rose diagram of the bearing of the decorated megaliths with flat faces. The average bearing of the decorated megaliths was 94°. Table contains information about the data.



No. of Data	43
Sector angle	10°
Scale: tick interval	5% [2.2 data]
Maximum	20.9% [9 data]
Mean Resultant direction	072

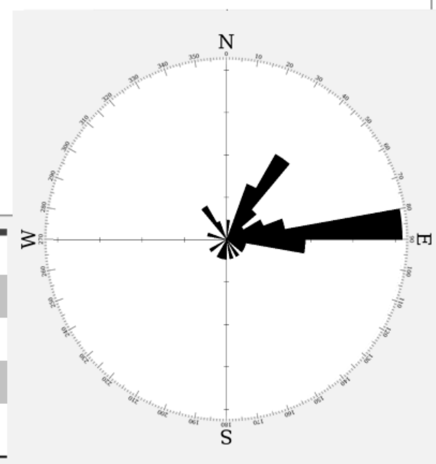


Figure 18: Map of bearing of flat faces, and rose diagram. Shows a preference for easterly facing. Table contains information about direction data.

Petroglyph results

We used Gomes' iconography table (Table 1) to identify iconography present on our studied megaliths (Gomes, 2011). We identified 13 decorated megaliths, two of which had not been discovered previously. Six of these fit into an anthropomorphic category, with features Gomes (2002) described as faces and necklaces. Five of the decorated megaliths are non-anthropomorphic, though some share features that can be seen on anthropomorphic megaliths. Of the two newly discovered decorated megaliths, ALM72 fits in the non-anthropomorphic category. ALM27 presents a feature that could be a belt, therefore placing it in the anthropomorphic category. In this section we present images using the grazing light technique, and identify the main iconography. In order to assess whether the petroglyphs this study identified are different to those observed by previous studies (Gomes, 2002; Ferraz, 2016) we identified similarities and differences. This study and Ferraz's largely agree, thus we chose to visually present only the disparities between Gomes (2002) and this study. However, this study identifies two additional stones not found in Ferraz's investigation, which will be presented after the comparisons with Gomes. Ferraz also identified an additional four petroglyphs which neither Gomes nor this study observed. These will be presented in the discussion, as Ferraz's findings are not part of the results of this investigation.

Anthropomorphically decorated megaliths

This study identified six decorated megaliths that fit into the theme of anthropomorphism, with one of the newly discovered petroglyph features also fitting this category. We considered the anthropomorphic theme as has having one or more of the following elements: a rectangle, usually interpreted as a nose; circles, interpreted as eyes or breasts (depending on location); crescent, interpreted as a mouth or necklace. Although crosiers are often found in conjunction with these features, there are also stones found exclusively with crosiers, which do not necessarily represent a human figure, thus we excluded it from this list. The following megaliths bear one or more of these features.

ALM1 is 1.88m in height and has a volume of 1.01m^3. It has a flat face on a bearing of 113.5^o. The features this study observed are a rectangle, crescent shape, a circle in the position of a left eye and two circles below the rectangle (Figure 19).

The rectangle and crescent are represented in all three surveys, though the shape identified by Ferraz (2016) is different to that identified by Gomes (2002) and this study (Figure 19A). The circle underneath the centre of the rectangle is visible in all surveys. The zigzags within the crescent are not visible in Ferraz (2016) or this study, nor are the circles above the rectangle and on the right of the rectangle. A circle at the bottom left of the rectangle is visible in Ferraz (2016) and this study. However, Ferraz identified a crosier towards the middle of the menhir, which neither Gomes (2002) nor this study observed. Overall, the results of this study agree mostly with Gomes and Ferraz about the main features (rectangle and crescent), but did not observe the details that Gomes drew (zigzags and multiple circles) (Figure 19C).

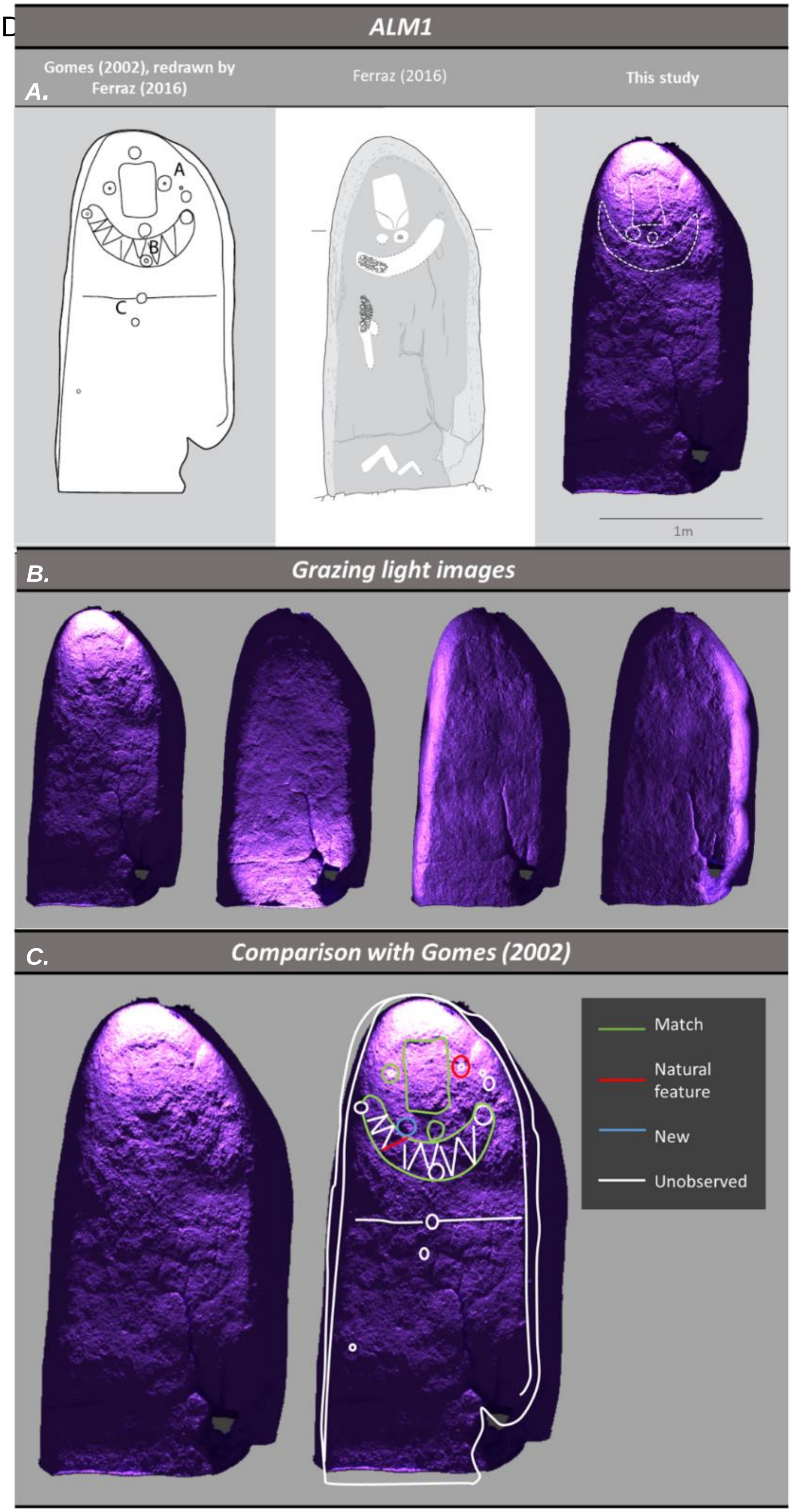


Figure 19: Sections are as follows:

A. Results of survey of ALM1 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM3 is 2.05m tall, with a volume of 1.65m^3. Is has a flat face on a bearing of 63^o with rounded edges. This study identified a small rectangle, and two crescent shapes, one smaller and one large, located near the top of the stone (Figure 20A). We also found a circle on the left side of the rectangle, and a raised double circle near the bottom of the menhir.

This study matches with Gomes for the eye, nose and smaller crescent (Figure 20C). However, this study did not observe the other circles that Gomes identified. Additionally, where Gomes identified a horizontal crosier, this study instead believes there is a second, larger crescent. On the other hand, Ferraz (2016) identifies a different crescent shape that neither Gomes nor this study observed. Finally, this study identified a possible double circle near the bottom of the stone that neither Gomes nor Ferraz identified, best seen in the lighting from the sides of the model (Figure 20B).

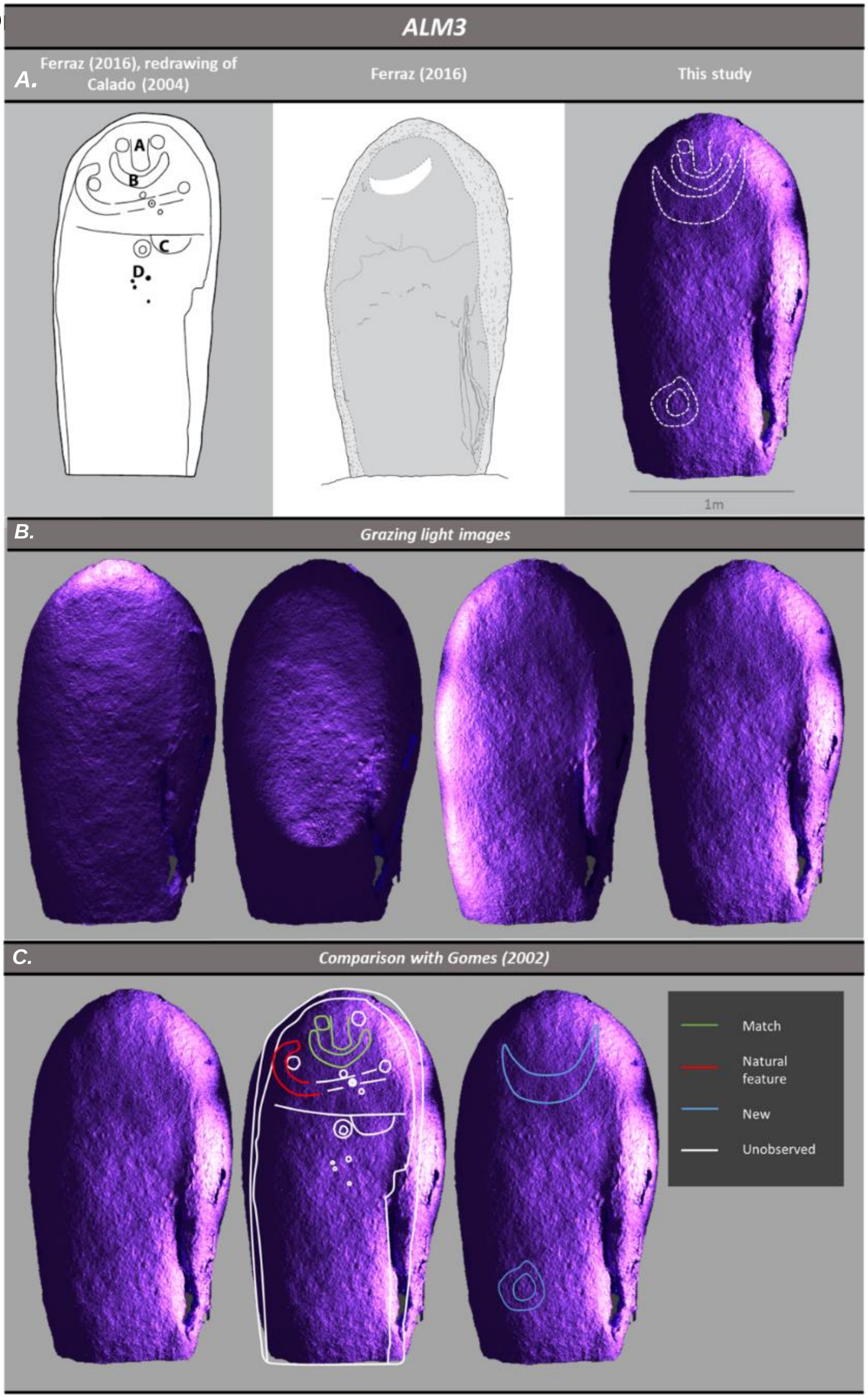


Figure 20: Sections are as follows:

A. Results of survey of ALM3 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies.

ALM56 is 1. 83m tall, with a volume of $0.92m^3$. It has a flat face on a bearing of 126^o. The features this study observed are a rectangle, circle and crescent near the top of the stone (Figure 21A). It also has a circle under the left half of the crescent, seen best in the lighting from the sides of the model (Figure 21B).

The rectangle and crescent are visible and the same shape in all three studies (Figure 21C). Ferraz (2016) identified two circles where breasts may be, but this study only observed the left circle, and in a higher position than Ferraz located it. We also identified the right eye circle which Gomes identified, best seen in the figure lit from the right-hand side (Figure 21B), which Ferraz did not observe.

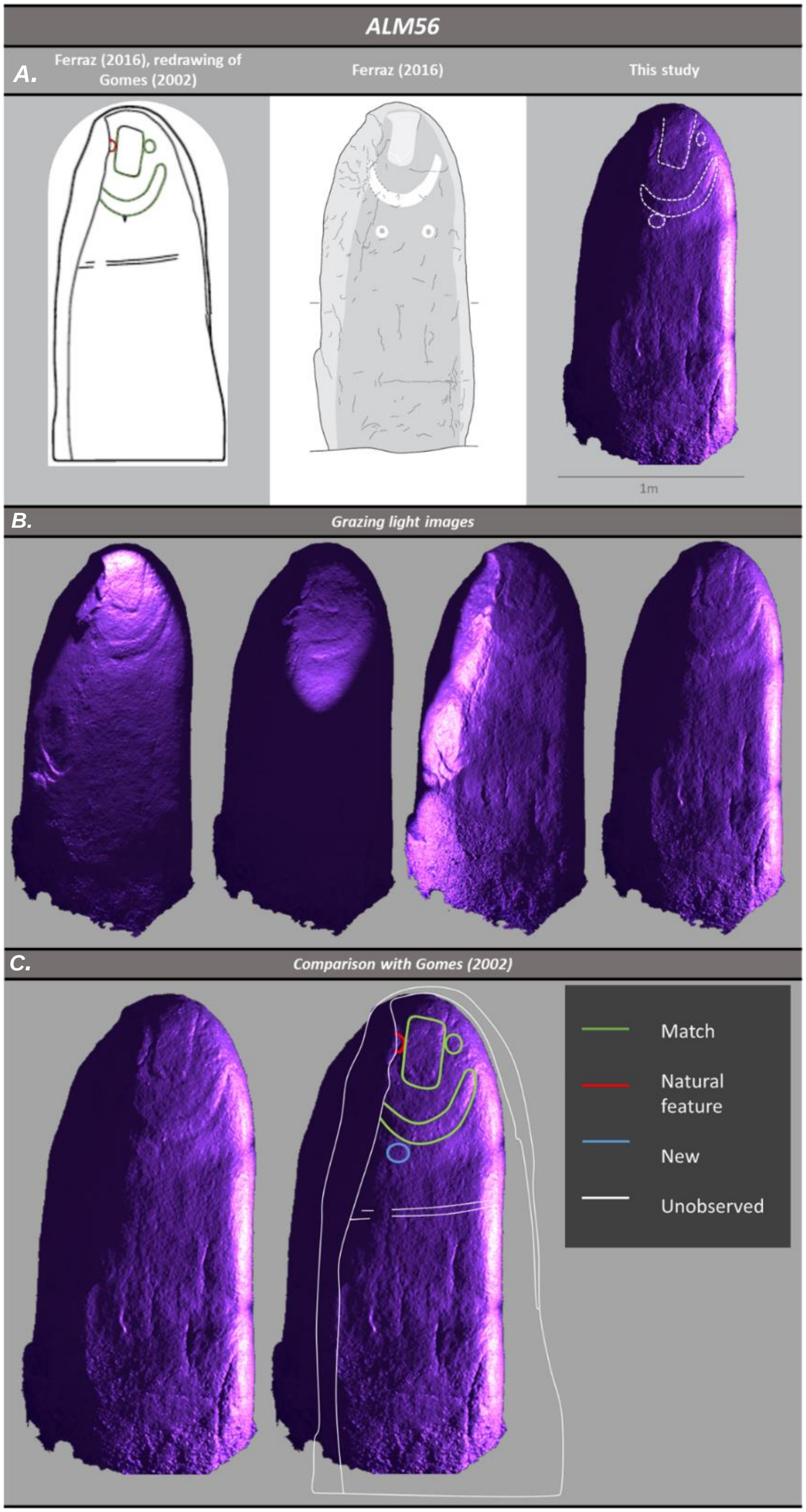


Figure 21: Sections are as follows:

A. Results of survey of ALM56 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM65 is 1.33m tall, with a volume of 0.95m^3. Is has a roughly flat face on a bearing of 83^o. This study identified a small, narrow rectangle on the righthand side of the top (Figure 22A) and two small circles either side of this rectangle and a crosier down and to the left of the rectangle. We also identified two circles, and two other shapes, though these are less clear.

Of the multiple different features identified by Gomes (2002), the only matches with this study are the rectangle and surrounding circles (Figure 22C). We did identify natural features that Gomes may have classified as crosiers and circles, but this study cannot identify a definite crosier or circle shape in these locations. Ferraz (2016) identified a crosier in a similar location to where was indicated in Gomes (2002) on the left-hand side of the stone, but we were unable to identify this. We identify 4 shapes, including a circle near the bottom of the stone, a crosier and two unclassified shapes that neither Gomes nor Ferraz identified.

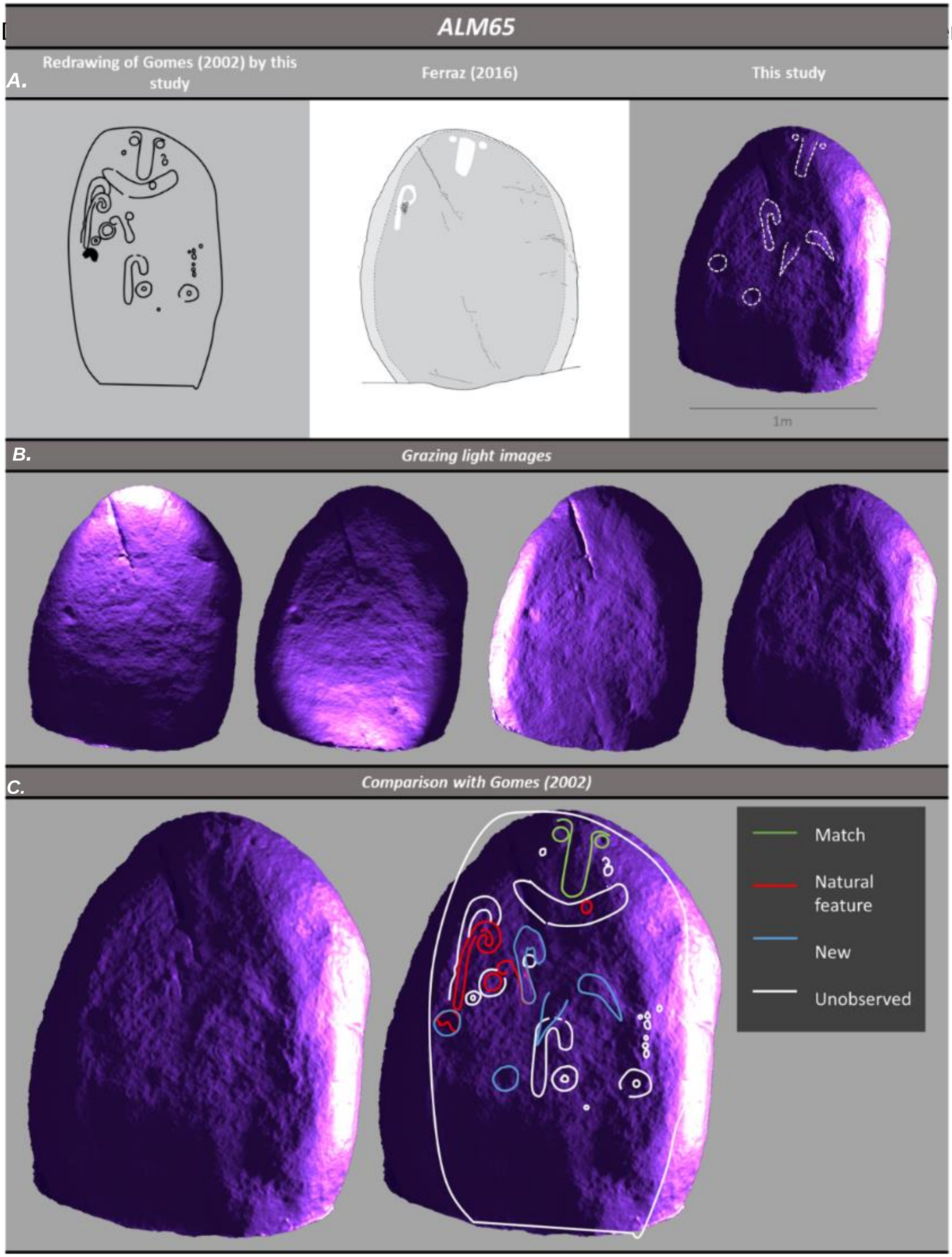


Figure 22: Sections are as follows:

A. Results of survey of ALM65 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM76 us 0.97m tall with a volume of $0.35m^3$. It has a flat face on a bearing of 32^o. This study identified a rectangle at the top of the stone, a crosier on the left-hand side, an engraved zigzag line down the centre and a possible crosier or unspecified shapes on the right-hand side (Figure 23A).

The rectangle and left-hand crosier can be seen in all studies, though only Gomes and Ferraz identified a circle on the left-hand side of the rectangle (Figure 23C). Gomes also identified a circle on the right-hand side, but neither Ferraz nor this study identified this shape. Both Gomes and this study identified a zigzag line, though the one discovered in this study was shorter than that drawn by Gomes. Additionally, both this study and Ferraz identified a shape on the right-hand side of the stone, whereas Gomes identified none. However, Ferraz identified a crosier shape, whereas the shape seen in this study was too subtle to classify as a definite crosier shape.

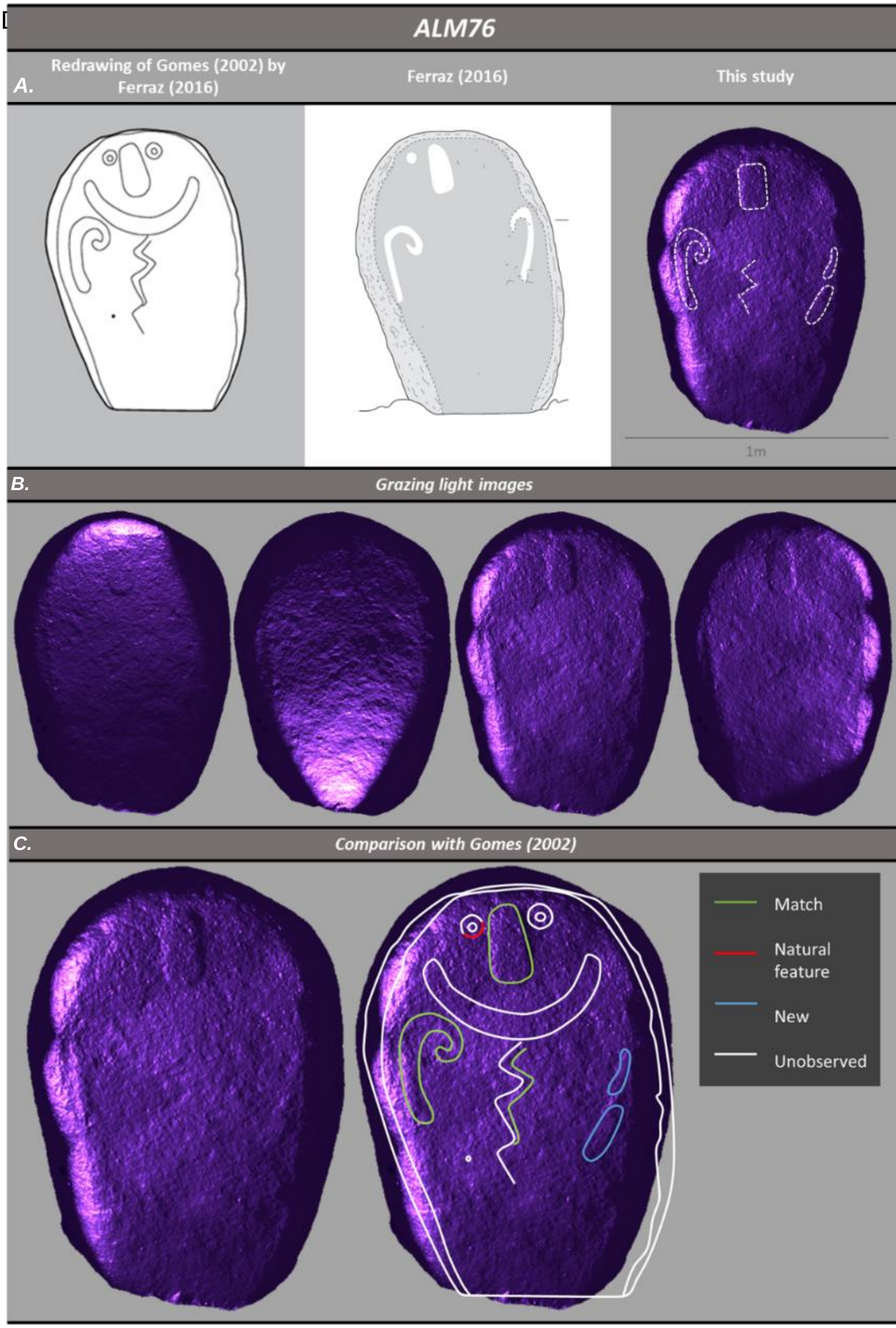


Figure 23: Sections are as follows:

A. Results of survey of ALM76 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM94 is 1.39m tall with a volume of 0.71m^3. It has a flat face on a bearing of 97º. We identified a slight line that could be the side of a rectangle, but no other features (Figure 24A).

Gomes identified a rectangle, two circles either side, a crosier, two double circles and smaller filled in circles (Figure 24C). Ferraz did not identify any features on this menhir. We did identify some natural features/roughness that Gomes could have taken to be petroglyphs, as can been seen in Figure 24C.

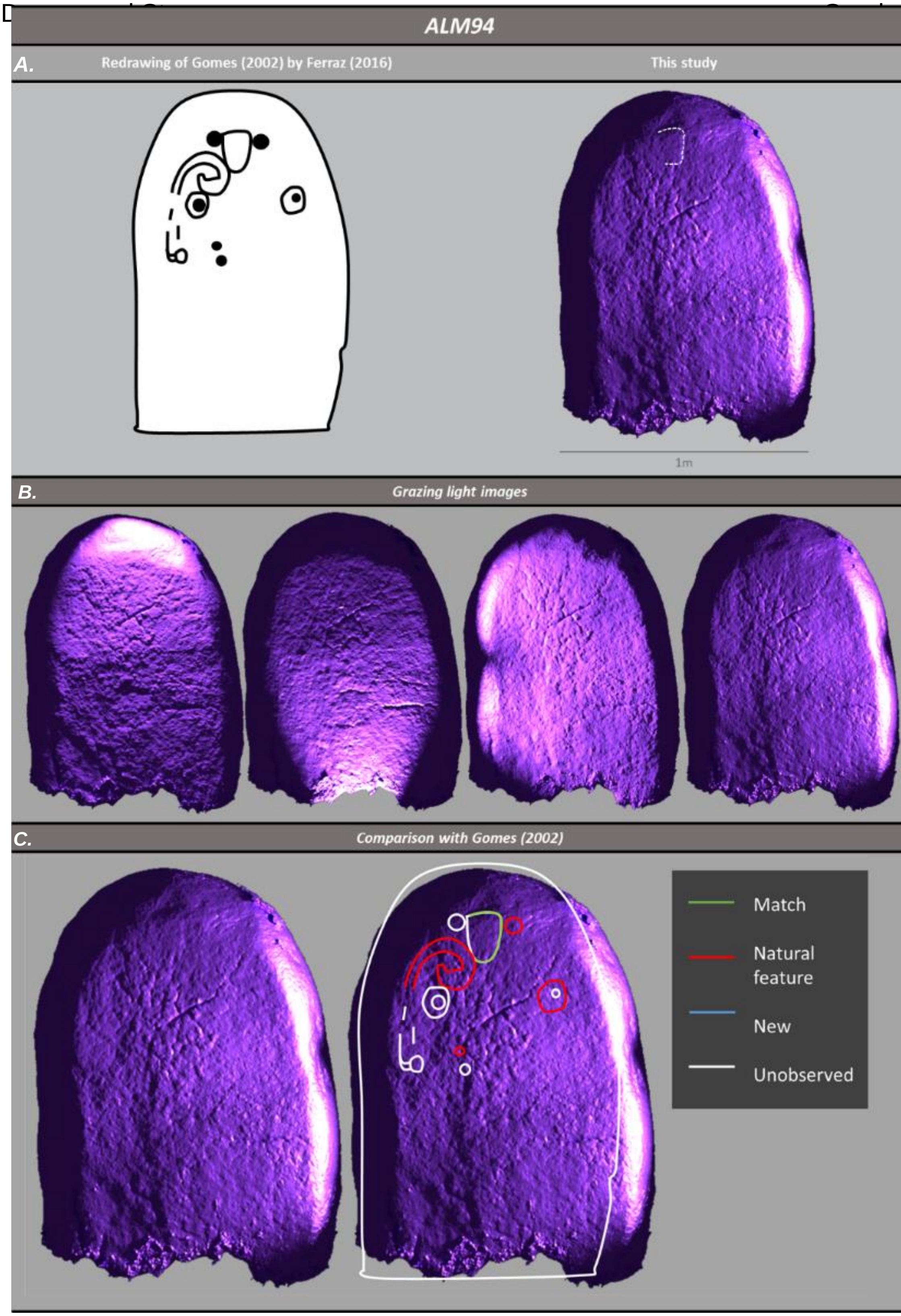


Figure 24: Sections are as follows:

A. Results of survey of ALM94 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

Other forms of decorated megaliths

Though anthropomorphic megaliths are commonly found, they are not the only themes that appear in rock art throughout the Iberian Peninsula. This section covers those stones that don't necessarily fit strictly within the anthropomorphic theme. They may share features, but there are also some that do not appear to represent anthropomorphic figures at all. This study identified six decorated megaliths that did not directly fit into the theme of anthropomorphism, including one of the newly identified decorated menhirs, though this will be discussed in a later section.

ALM48 is 1.37m tall with a volume of 0.47m^3 with a flat face on a bearing of exactly 90^o. This study identified only one double circle (Figure 25A). ALM48 has a rough surface making petroglyphs difficult to identify. Gomes identified multiple lines, circles, a crosier and other shapes, but Ferraz identified only the double circle and a crosier not seen by Gomes nor this study (Figure 25C). This study identified a natural feature that could be the line of the crosier, but did not observe the curved top.

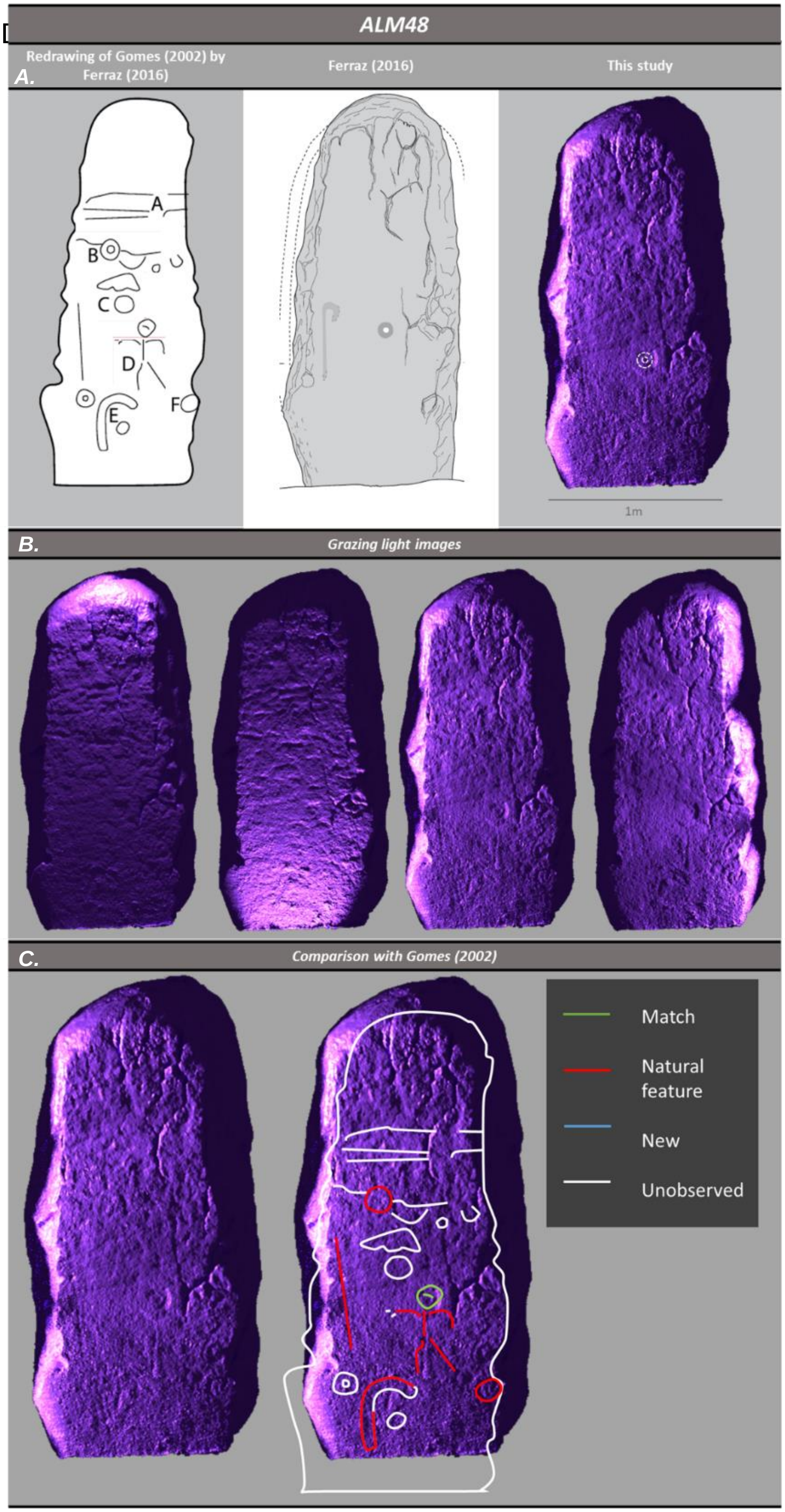


Figure 25: Sections are as follows:

A. Results of survey of ALM48 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM57 is 1.94m tall, with a volume of 1.14m^3. It has a flat face on a bearing of 90^o. This study identified seven crosiers and one crescent shape (Figure 26A).

Gomes identified 13 crosiers. Ferraz identified only 5 crosiers and one crescent. Figure 26C shows that though the crosiers this study identified mostly match the location and shape of those found by Gomes, there are a few differences in shape. Additionally, we found one crosier not identified by Gomes or Ferraz, best seen in the models list from the bottom or right-hand side in Figure 26B. Additionally, we suggest the double sided crosier identified by Gomes is instead a large crescent, with the other end in fact being linked to the crosier above the crescent shape. Though the crescent shape agrees with Ferraz, our positioning of the two crosiers above it differ slightly.

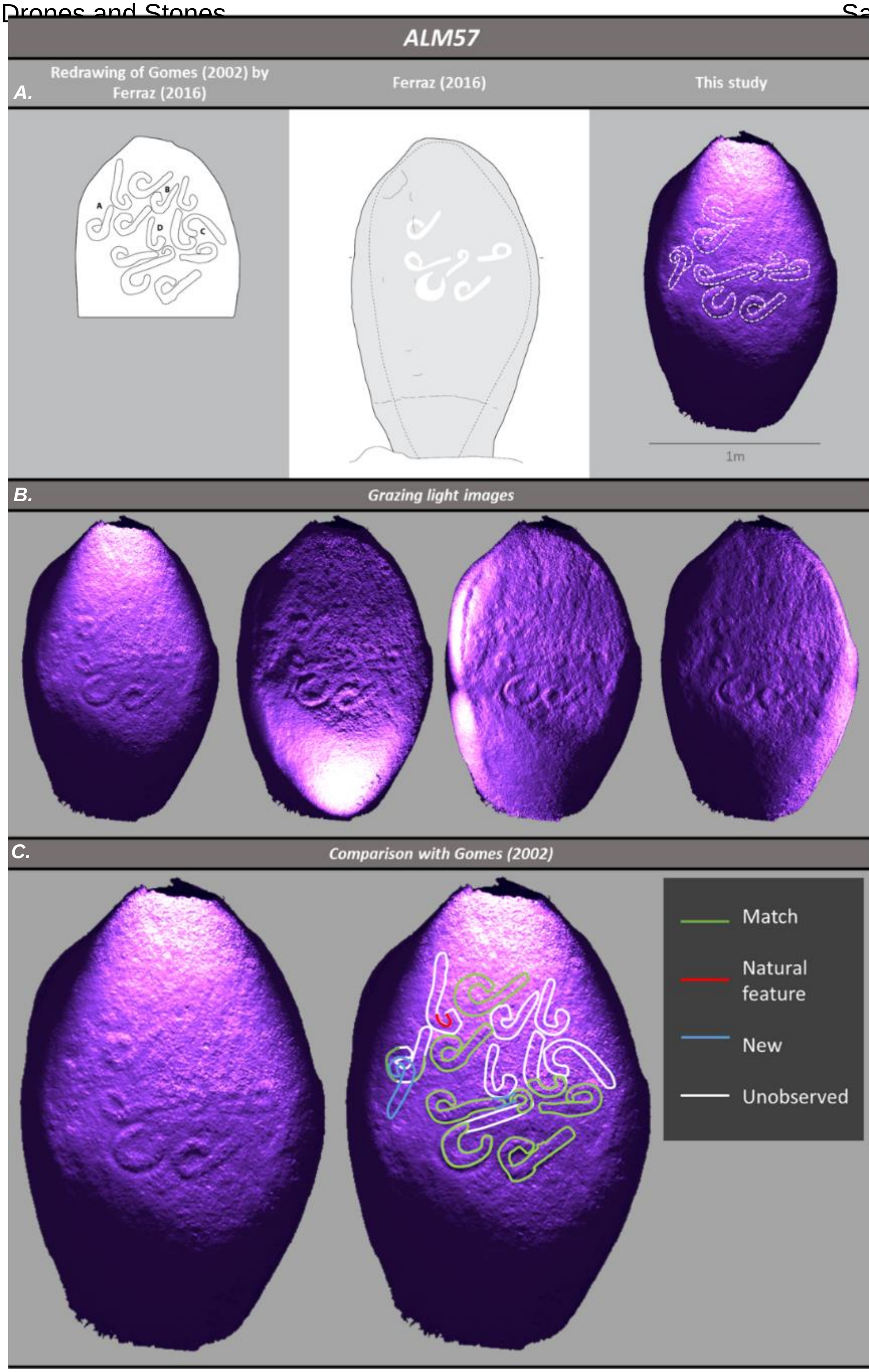


Figure 26: Sections are as follows:

A. Results of survey of ALM57 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM58 is 1.59m tall, with a volume of 0.83m^3. It does not have a perfectly flat face; instead the petroglyphs appears to have been engraved into the natural, or barely modified shape of the stone. The direction of the face the petroglyphs are engraved into is 183º. This study identified three double circles, with multiple zigzag/wavy lines extending down from these (Figure 27A). These are engraved, rather than protruding from the surface.

The original drawing by Gomes (2002) fairly closely matches the model created from this study (Figure 27C). The main differences are significantly less vertical lines on the left and right side of the stone, though there is the possibility of lines that have not been drawn on by this study. The left side of the model from this study more closely matches Ferraz (2016), with three short lines. However, Ferraz (2016) only identified two double circles, whereas Gomes (2002) and this study found three.

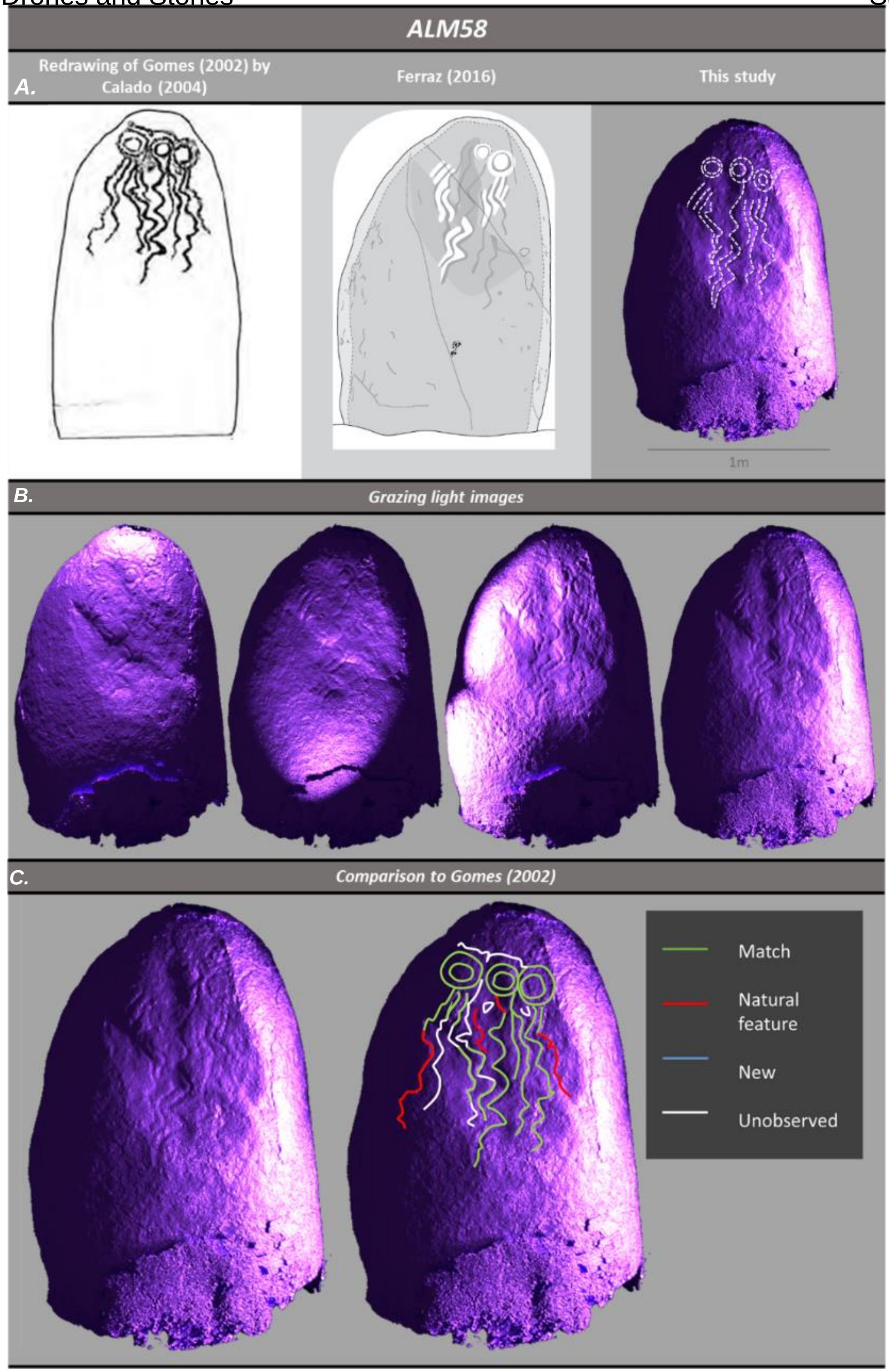


Figure 27: Sections are as follows:

A. Results of survey of ALM58 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

ALM64 is 1.62m tall with a volume of 1.25m^3. It does not have a flat face, and its carvings face west. This study identified that one double circle that protrudes from the surface, but the other features were created using the technique of engraving. There are three vase like shapes, two pointing upwards, and one pointing down (Figure 28A). There is also an engraved circle at the bottom of the stone.

The results of this study almost exactly match those of Ferraz (2016). The only feature that differs is the vase shape that points downwards. Ferraz drew this as only a circle, whereas we identified two vertical lines connected to the circle (Figure 28). Gomes (2002) identified an additional double circle, two engraved circles, a curved line and two smaller filled in circles, possibly cup marks, nearer the top of the stone, but these were unable to be seen (Figure 28C). We saw possible evidence for half of the higher single circle, but could not confirm its presence.

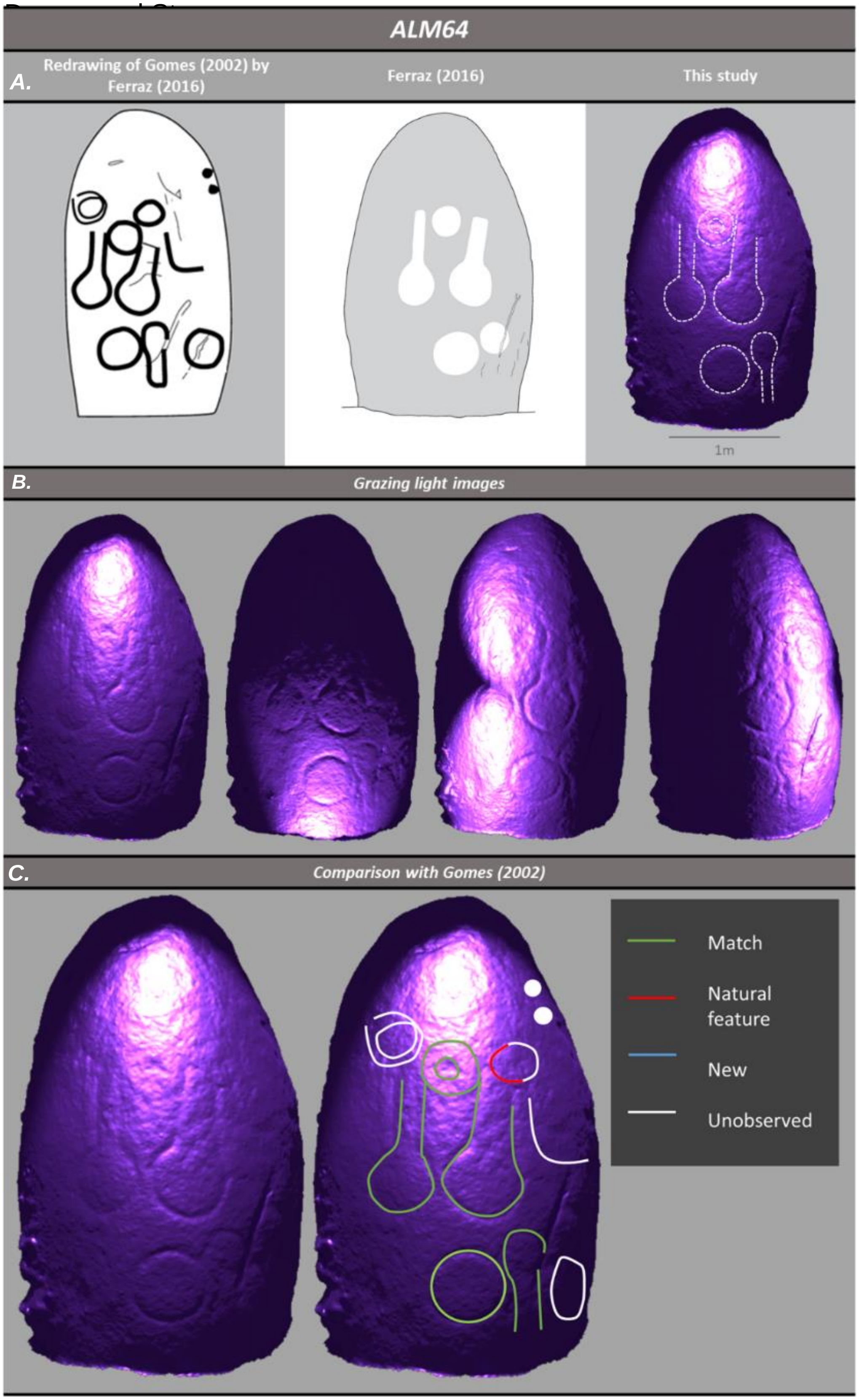


Figure 28: Sections are as follows:

A. Results of survey of ALM64 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies.

ALM87 is 0.7m tall, with a volume of 0.13m^3. It does not have a flat face, with the petroglyph having been carved into the natural, or barely modified shape of the stone. This study identified the shape of a crosier, with a straight short verticle line/thin rectangle connected at the top and extending down vertically (Figure 29).

Gomes did not identify any carvings on this megalith, but the shape agrees mostly with Ferraz. The only difference is that we see a shorter 'tail' to the crosier.

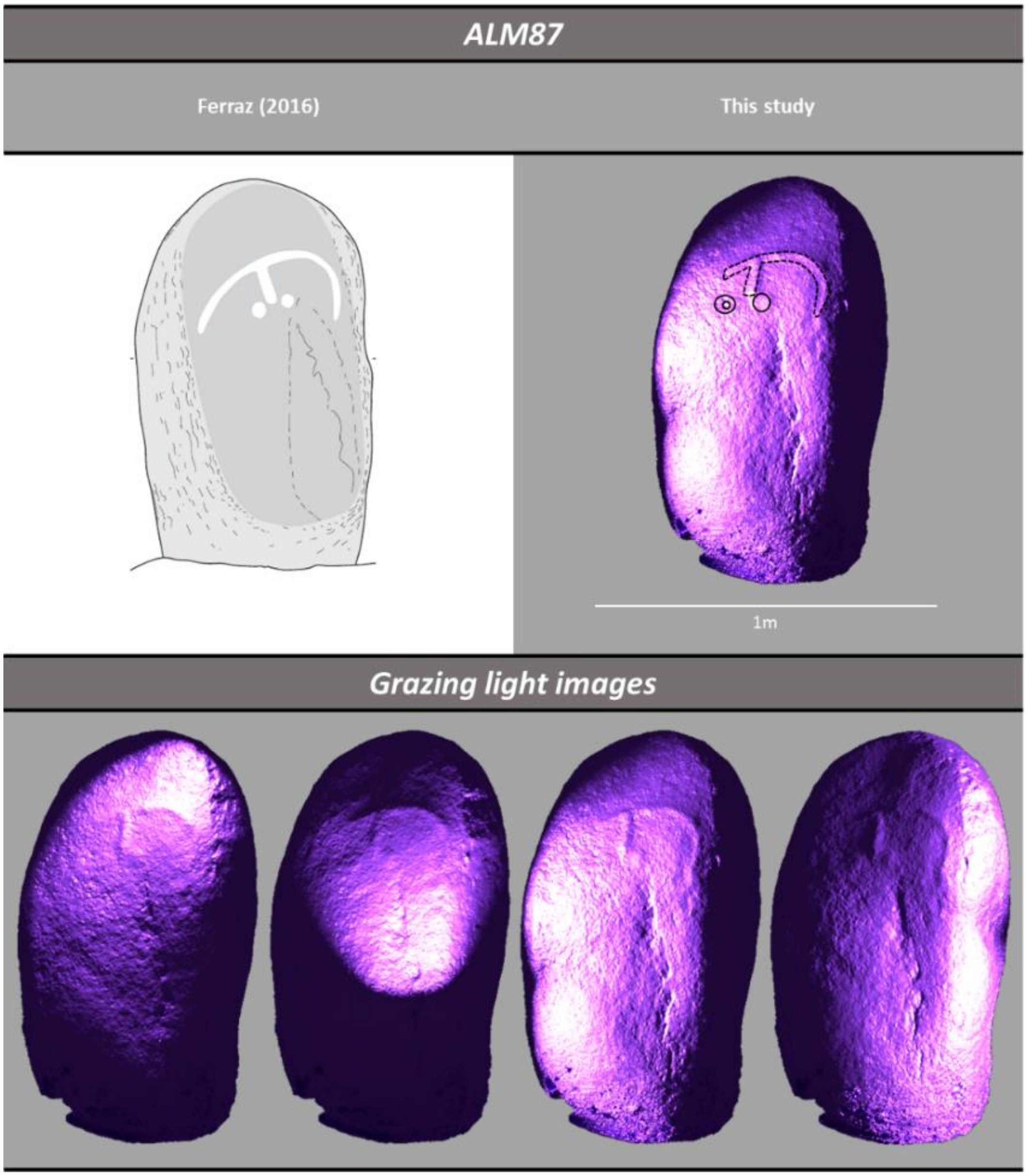


Figure 29: Sections are as follows:

A. Results of survey of ALM87 by Gomes (2002), Ferraz (2016) and this study.

B. The four best light angles to highlight the petroglyph on the 3D model.

C. Comparison with Gomes (2002), using colour coding to identify discrepancies

Possible newly discovered petroglyphs

The following two megaliths in this section are the ones that have not previously been discovered or recorded.

ALM27 is 1.28m tall with a volume of 0.42m^3. It has a flat face on a bearing of 290^o. This study identified a zigzag, or multiple vertical lines in the centre of the stone (Figure 30).

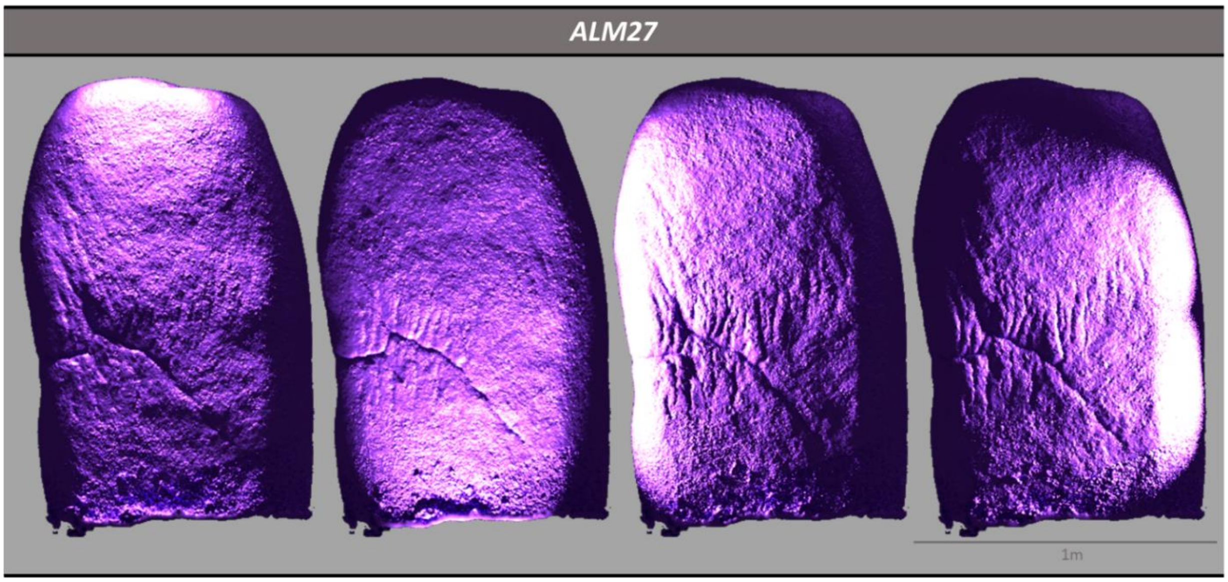


Figure 30: The four best light angles to highlight the zigzag line across the centre of the stone.

ALM72 is 1.1m tall with a volume of 0.48m^3. It has no flat face. In the middle left-hand side of the stone, this study identified a small protruding rectangle or line (Figure 31).

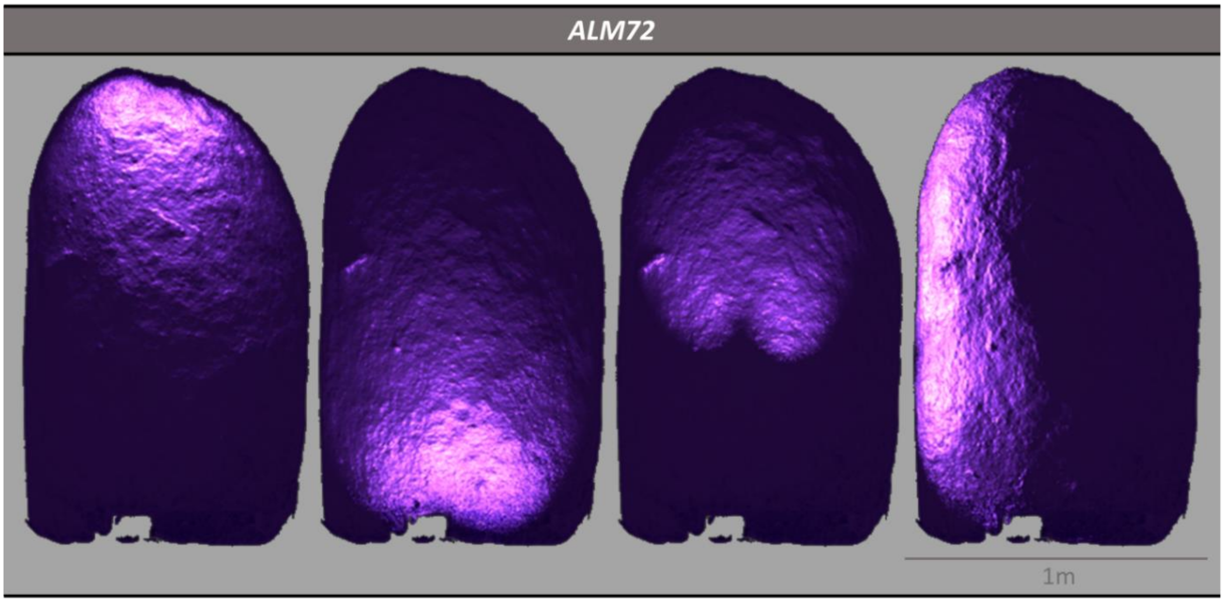


Figure 31: The four best light angles to highlight the petroglyph on this menhir.

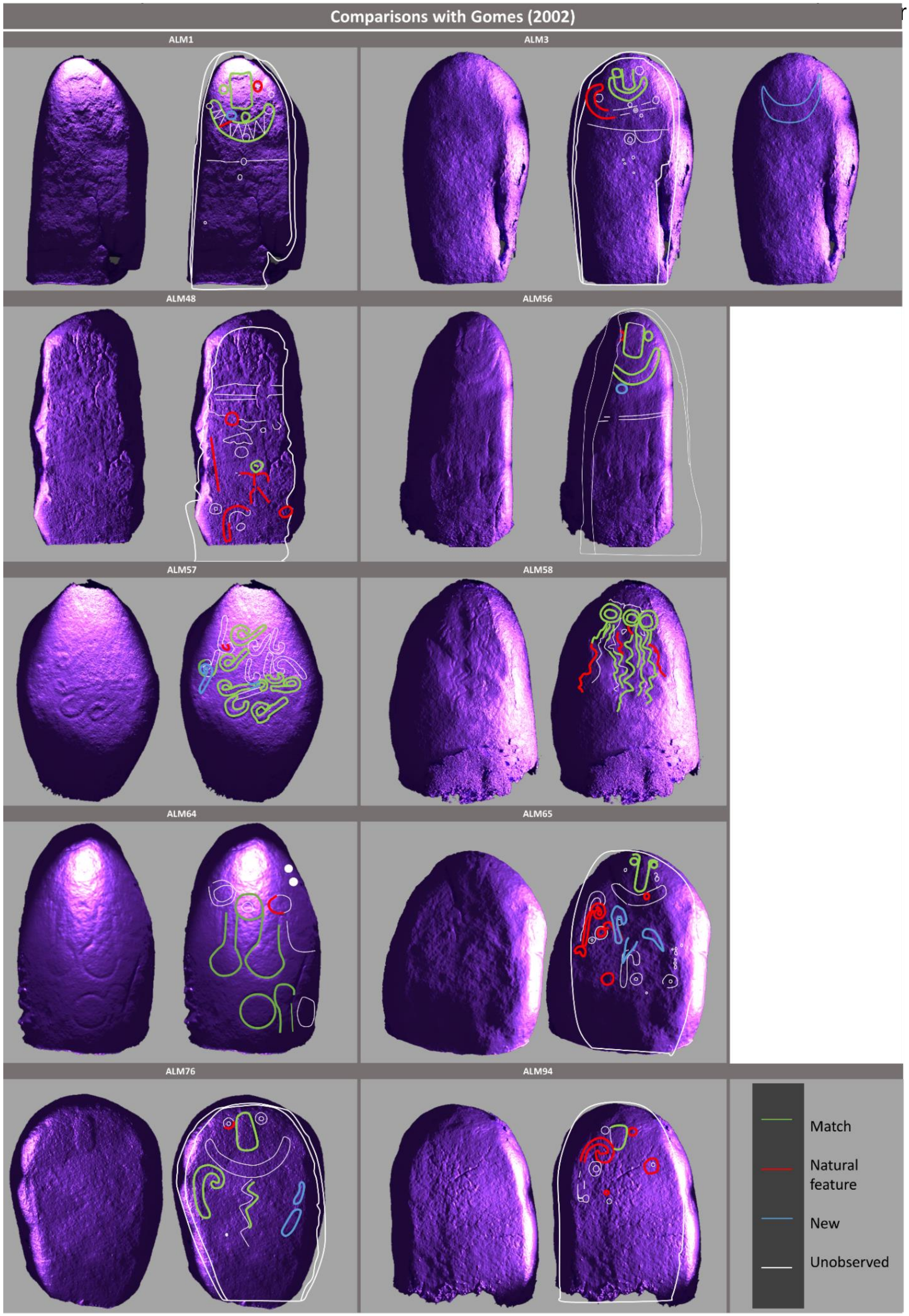


Figure 32: The comparisons between this study and Gomes (2002) for easy viewing.

Accuracy analysis results

We calculated the virtual length of 56 individual rulers. The mean length was 29.8cm ±0.25, whereas the actual length of the rulers was 30cm. The standard deviation of the difference was 4.9mm. Please note that these accuracy results apply only to the database created using information taken from the full model, not the individual models, which were created using ultra high settings, and therefore have a higher accuracy.

Discussion

This study found that the petroglyphs identifiable at the Almendres Cromlech in 2018 present various discrepancies with research done previously (Gomes, 2002; Ferraz, 2016). On the whole, this study identified fewer petroglyph features than Gomes (2002), but matched almost completely with Ferraz (2016). We also found two previously undiscovered decorated megaliths. Overall, UAV SfM photogrammetry proved to be an efficient and accurate way of investigating petroglyphs, without causing damage to the stones, and resulted in a freely accessible 3D model for future research and public outreach purposes. We propose that there are multiple explanations for why the results in this study differed from previous research. These include possible limitations of SfM photogrammetry, damage caused by and limitations of the bi-chromatic technique used by Gomes (2002), differences in classification of natural and manmade features, human error, and natural erosion. This thesis will discuss each of these possibilities, but it is difficult to draw a definitive conclusion as Gomes (2002) is the only record of the stones in the 1960s, and without contemporary comparison studies it is hard to move beyond conjecture.

Though traditionally placed at the end of the discussion, this thesis will discuss the limitations of UAV SfM photogrammetry first, before continuing onto evaluating the possible limitations of Gomes (2002), as it is useful to discuss these in tandem. Though UAV SfM photogrammetry has significant advantages over traditional techniques such as tracing or rubbing, both in accuracy and objectivity, there is the possibility that UAV SfM photogrammetry may capture fewer features than the bi-chromatic technique used by Gomes (2002) was able to. The accuracy of photogrammetry can vary depending on the quality and comprehensiveness of the original survey, and processing power of the PC dictates what resolution can be achieved. While it is generally understood that more photographs, distributed effectively, results in a more accurate model, time restraints in the field meant we were unable to take photographs of each megalith individually. Instead, we grouped them. This cut back on the amount of time needed, but resulted in some of the megaliths to be only partially modelled. As the shape of the stones themselves are part of the rock art, it is crucial to successfully model the entire megalith, not just flat faces. Fortunately, we were able to return to the site at a later date and resurvey the megaliths that we knew had errors. We also resurveyed the stones which Gomes (2002) reported to have petroglyphs on, taking roughly 100-200 photographs per megalith. This allowed us to complete our earlier survey and create ultra high-quality models of the known decorated megaliths without gaps and with less surface roughness, resulting in a more successful outcome from the grazing light technique, thus better portraying the petroglyph features. The high quantity of photographs, and thoroughness of the survey of the individual megaliths during the return visit means that the resulting models should be of a very high accuracy, which is reflected in the accuracy results of this study.

An issue we faced which could have affected the accuracy of the full size model (though not the ultra high-quality individual models) was that of the alignment of the aerial with the terrestrial images. Though we took surveys at 50m, 20m, 4m and ground level, there was difficulty in getting these to align correctly in Photoscan. Multiple alignment attempts resulted in double models, which aligned on the x and y, but not the z axis. This error meant there were many overlaps in the model, making it impossible to identify petroglyphs accurately. It also resulted in inaccurate measurements. We discovered this was due to the 50m and 20m images not aligning correctly with the ground photographs, likely due to the inaccurate z values from the on-board GPS. The altitude recording of handheld GPS's is known to be fairly inaccurate, and is often not used in research. We believe the GPS on-board the Phantom 4 Pro also suffers from this inaccuracy. Additionally, we found that each time the UAV was turned on and off the z value varied wildly.

In order to overcome this, we aligned all the aerial photographs using reference and pair preselection, then removed the 20m images over the centre of the model (Figure 33). We then used the alignment of the aerial photographs to help align the ground photos, using only pair preselection. This meant the z values that were different to the aerial photographs were not used, thus resulting in a complete model. However, removing some of the aerial photographs resulted in gaps in the top of some of the megaliths. Gaps in the megaliths affects both our observation of the complete shape of the megalith, and may have resulted in us being unable to observe petroglyphs at the top of the model. In our results, we found that ALM57 has a small gap at the top, and ALM58 has a slight error. Fortunately, Gomes recorded no carvings at these locations, and petroglyphs are rarely found on the top of stones. The only megalith with carvings in the top of the stone at Almendres Cromlech is ALM5, the cup marked menhir. This means we believe that the errors on these two menhirs did not affect our ability to observe petroglyphs, though future research should endeavour to have more images bridging the gap between the high aerial images and terrestrial images, perhaps by doing a more thorough survey at lower heights (e.g. 4m, 10m).

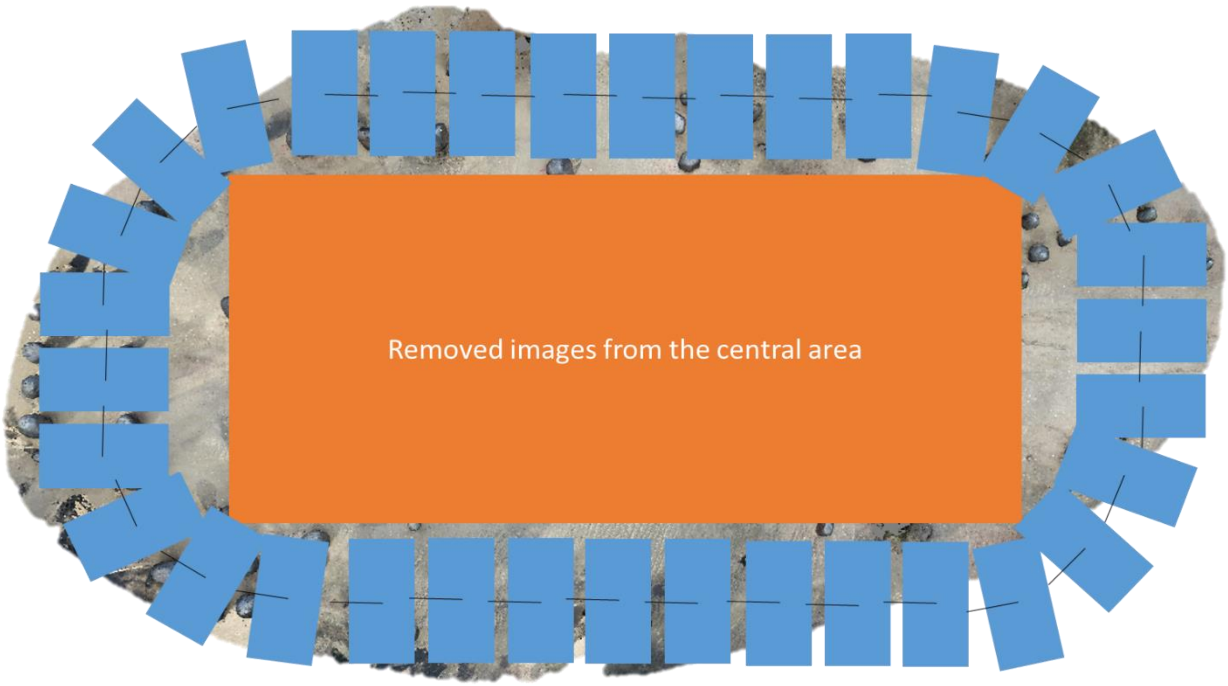


Figure 33: In order to get the aerial photographs to align with the terrestrial photographs, we removed the central block of images.

Vegetation also had a role to play in causing potential errors in the model. Moving objects confuse SfM photogrammetry, and though we tried to avoid this issue by gently moving vegetation out of the way, we were not able to avoid it entirely. This issue can be seen at the bottom of ALM58 and 94, and the bottom right-hand side of ALM64. Fortunately, these errors do not obscure any areas where there were petroglyphs, so did not affect our observations. However, in future, a more concerted effort to temporarily suppress the vegetation without damaging it, or conducting the survey in winter when vegetation is too low to impact the photogrammetry, would result in a model without obscured sections.

UAV SfM-photogrammetric resolution is affected by processing power. Data storage and processing time can be a significant limitation when using thousands of images and creating ultra high-quality models. Our survey collected over 2000 photographs in JPG and RAW format. This took up over 100GB of space. Combined with the additional surveys completed in January and June 2018, this resulted in a total storage requirement of over 120GB. Computers have limited storage capacity, and without other storage mechanisms such as hard drives, this project would be unable to be completed. The high storage requirement results in multiple problems. Hard drives are expensive, meaning if working on a limited budget, projects may not have the capacity to store enough information to result in a full model. Additionally, even using High-speed USB ports, data had to be transferred to the PC before it could be processed, then the final result exported back onto multiple hard drives to save space and act as a backup. Unfortunately, transferring Photoscan and Blender projects takes time and can corrupt the data. We experienced this with a few of the projects, resulting in no texture information. Although this was an easy fix, it is important to consider the storage capability of the machines used for the task before beginning a project of this size. It is also crucial to have enough space for a backup. Fortunately, we had the ability and hardware to overcome the data storage problem, meaning we were able to incorporate all the data into our models instead of selecting only the highest quality images, which may have resulted in gaps or inaccuracies due to a more limited number of photographs, ensuring the accuracy of the model remained high and the petroglyphs were as clear as possible.

Additionally, Photoscan projects are processing intensive, and use a lot of RAM. Processing time goes up by 8 with each quality increase (Verhoeven, 2011). The PC we used could only align and create the dense cloud of the full model on high (rather than Ultra High), and was unable to process a mesh at all. This meant in order to create ultra high-quality meshes of each megalith, we had to align, create a point cloud and create a mesh for each stone individually. While this worked for our needs, a mesh of the full site would be useful for both research and public outreach. The actual processing time is also significant, ranging from a few hours to a couple of weeks depending on the quality level and amount of data. Studies looking to use SfM photogrammetry over fairly large sites should consider the processing capability of their PC. Due to the processing power of the PC we used, we were able to create ultra high-quality models for the megaliths we thought were decorated, which means the accuracy of the petroglyph results was as high as we could achieve with the methodology used.

Though the full model has an accuracy of 4.9mm, as calculated using the rulers within the model, the ultra high-quality individual models of each megalith would have been more accurate yet. The expected error of SfM photogrammetry is 0.1% of the distance between the camera and the object (Harwin & Lucieer, 2012; James & Robson, 2012; Stumpf *et. al.,* 2015; Carbonneau & Dietrich, 2017). As the images for the ultra high-quality models were taken at between 1-2 metres from the stones, the estimated accuracy is between 1 to 2 millimetres. Though this is comparable with the accuracy of laser scanners, we are surveying petroglyphs that are less than a centimetre thick, meaning even with an accuracy of 1-2mm, we may have missed more subtle features and edges. Additionally, due to restricted time in the field on the second visit, we were unable to undertake the new survey with rulers by the stones, and therefore cannot give a precise figure for how accurate the ultra high models are. Future investigations should ensure to complete all surveys while rulers are in place, in order to be able to calculate the accuracy. However, this is almost the highest accuracy one can achieve with commercial equipment, and we did everything possible in order to ensure the highest accuracy. This raises the question that with current methods, even the best 3D model may not yet be accurate enough to model features that are less than 5 millimetres thick.

However, due to the millimetre accuracy of UAV SfM photogrammetry, we argue that the resulting 3D models are the best representation of the stones as they are today. It is unlikely that the bi-chromatic technique would have allowed Gomes to see the petroglyphs more clearly suggesting that the possible limitations of SfM photogrammetry is not a likely explanation for the discrepancies between this study and Gomes (2002).

The bi-chromatic technique has been criticised for its potential to damage the stones, and for likely inaccuracies in the recording techniques used, raising the possibility that the bi-chromatic method itself may explain the discrepancies between the studies. The invasive nature of the method, due to the rubbing of charcoal on the stone (Pires *et. al.,* 2015), could have resulted in the degradation of petroglyphs. As the petroglyphs protrude just a few millimetres to centimetres from the surface, this rubbing could have resulted in the loss of some of the subtler shapes. These smaller shapes are the features that this study and Gomes most differed on (white lines in Figure 32). This could be because the smaller size and protrusion made those features more vulnerable to damage than the larger features. This would explain why they were visible during Gomes' survey, but unable to be seen today. The primary indicator for where this is likely to have happened is where a stone exhibits concurrence between the two studies regarding larger features, but not smaller features. The best examples of this are ALM1, 3, 48, 64, 65 and 94.

On ALM1, Gomes identified a series of zigzag lines on the crescent shape. This study observed one matching line, but suggests this is just a natural feature, not part of a purposefully carved zigzag. The zigzag lines Gomes identified would likely have been thinner than the crescent, and so may have worn away quicker, exacerbated by the possible damage caused by the bi-chromatic method, so although we could identify the crescent, we could not observe the lines. Gomes' drawing of ALM1 also displays multiple other shapes, including circles and a horizontal line in the middle of the stone. This study could not identify any of these features, suggesting they may have disappeared since Gomes' investigation. However, the roughness of the stone may also have contributed to the discrepancies between the studies, which will be discussed in further detail later.

Gomes' drawing of ALM3 indicates multiple smaller circles and three horizontal lines but none of these could be seen in this investigation. However, it was difficult to identify any features on ALM3, as even the nose and crescent shape are subtle, suggesting the entire megalith has undergone erosion, either natural or contributed to by the bi-chromatic method, or the features were more shallow than on other megaliths to begin with. Its smooth surface would have left features more vulnerable to erosion or damage as they would have been the only features at a different plane, not protected by the various protrusions and dents found in a rougher surface, such as ALM1.

Gomes' drawing of ALM48 also has discrepancies with the results of this study. We identified one circle, and believe some of the other vertical lines and circles identified by Gomes draw on the natural features of the stone. However, we were not able to identify any horizontal lines. The circle that was observed was fairly small, shallow and engraved into the rock, rather than protruding from the surface. Gomes' drawing suggests that the other features were similarly sized and it is likely they were carved the same way. Therefore it is unexpected to see one, where we cannot see the others. Though the small size and shallow depth may mean the shapes were more vulnerable to damage than larger shapes, the engraved nature of the features would have somewhat protected them from the rubbing. However, the rubbing may have blurred the edge of the shapes, making them too difficult to identify in this study. Additionally, the surface of ALM48 is very rough, making it difficult to identify features with confidence. Therefore, though methodological damage may have contributed to the degradation of some of the edges of the features on ALM48, it is more likely that the discrepancies are due to interpretation differences caused by the roughness of the stone.

Although the results from this study and Gomes (2002) match fairly well for ALM64, Gomes identified three additional circles, and L shape. The depth of the engravings of the central circle and two vase shapes were fairly similar, but the upside down vase shape on the right-hand side of the stone and the upper circle between the vase shapes were shallower. This suggests that some of the engravings on this megalith were more subtle, and perhaps the circles around the edges were carved less deeply into the rock, making them more vulnerable to being lost through damage. The feature that would be most at risk to methodological damage is the double circle Gomes identified in the top left side, as it is likely this protruded from the surface like the one in the centre. It is also likely that this feature would have been of a similar width to the double circle in the centre of the stone, resulting in similar degradation rates. As we can just see the very bottom of the circle on the left, and the bottom half of the circle in the middle, this supports the theory that they have both been affected by the same form of degradation. However, we argue that their current state of being less visible nearer the top of the circles, and the less visible circle on the left being higher up suggests that they are also susceptible to natural weathering. This is supported by the circle at the bottom of the stone being the clearest feature, with the majority of discrepancies occurring near the top of the stone. This will be discussed in more detail later.

Other than ALM48, the comparison of the results for ALM65 had the most discrepancies. Though we were clearly able to identify the nose and eye shapes, we could not identify with confidence any of the other features Gomes identified, though there were some natural features on the left-hand side that could have been interpreted as rock art. Again, the surface of this megalith is fairly rough, making it difficult to distinguish between natural and manmade features. The new interpretations (in blue) this study made are just possibilities as it is difficult to say with confidence that these shapes were designed to be part of the rock art or not. However, the other shapes Gomes identified (in white) could not be matched even with natural features. As even the nose and eyes on this megalith are subtle, we propose that if these features did exist during Gomes' study, they too would have been subtle, and therefore vulnerable to damage by the bi-chromatic method, explaining why we are unable to see them today. However, due to the roughness of the stone, it is also possible that the discrepancies between the studies are caused by human error, which will be discussed in more detail later.

Finally, ALM94 also has features that support this theory. All the features on ALM94 are extremely subtle and difficult to see even in different lighting conditions, so any that may have been there during Gomes' study may well have been damaged enough to make them unable to be seen in this studies results. As a nose can just be seen, it is likely that these features would have been more pronounced when they were first created, similar to the other megaliths with nose shapes (ALM1, 3, 56, 65 and 76), and have either weathered due to natural erosion, or been damaged by the bi-chromatic technique.

However, while damage done by the bi-chromatic technique could explain the absence of less prominent features, such as the lines, circles and shapes seen on ALM1, 3, 48, 64, 65 and 94, it is unlikely to explain the missing crescents (necklaces or mouths) on ALM65 and ALM76. This is because the 'face' shape (consisting of two circles, a rectangle nose and a crescent) is usually more prominent and well defined, thus protruding slightly further from the surface of the stone, so less vulnerable to the invasive nature of the bi-chromatic technique. Therefore, there must be other factors at play that explain the discrepancies between Gomes (2002) and this study. One of those factors is the issue of distortion when translating a 3D shape into a 2D image. This affects the accuracy of Gomes' results. While we were mostly able to overcome these differences by slightly stretching Gomes' drawings, it could explain the discrepancies of the locations of individual features. However, this would not explain why this study saw fewer features than Gomes.

Instead, the discrepancies could be caused by the error introduced in the interpretation stage by the bi-chromatic technique (Pires *et. al.,* 2015). This is because the method hides the texture of the stone, making it more difficult to distinguish between the roughness of the stone surface, natural features, and features designed to be part of the rock art. We must consider the idea that rock art ranges from using the natural features and shapes as part of the art, to obscuring the natural features in order to overlay manmade creations over the top, like a canvas (Bradley, 1991). For example, this goat motif (Figure 34) in Penascosa incorporates a natural fracture in the drawing (Baptista, 1999).

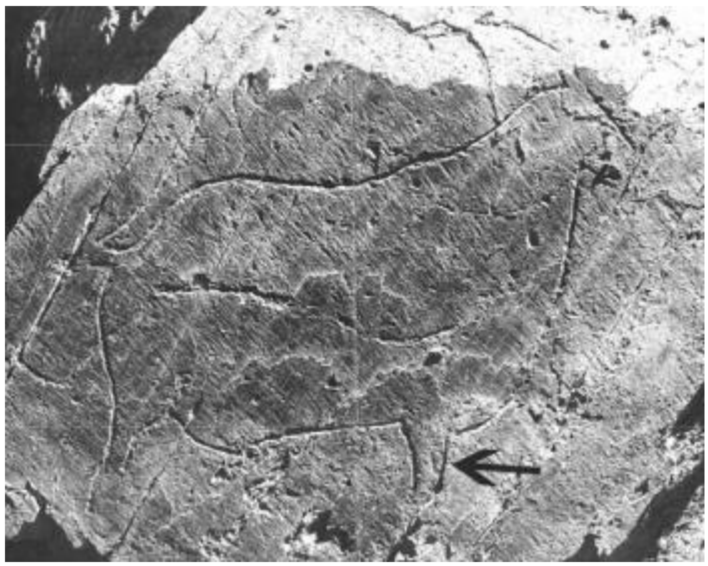


Figure 34: Goat motif in Penascosa Rock 5C. The arrow indicates the pre-existing fracture that was used to complete the shape of the animal’s front leg. (Photo and reference: Baptista, 1999: 106-7).

We have no way of knowing where on the scale of using to obscuring natural features the petroglyphs at Almendres Cromlech lie, as although there has been an effort to flatten the stone face on most decorated megaliths, they have also used the natural shape of the rock as part of the overall statue. This makes distinguishing what was intended to be part of the rock art by the original creators difficult, thus resulting in different interpretations. However, we attempted to overcome this issue, by trying to match the shapes found by Gomes, either in agreement that they are part of the rock art, or as a natural feature. This does not mean we claim the natural feature is not part of the art, we just wanted to record manmade and natural features separately, allowing different interpretations by other researchers in the future. However, we do argue that the features this study identifies as 'natural' features, are often less pronounced than the manmade carvings. This could suggest that although natural features could have played a role in the art, the creators wanted attention to be focused on the more obvious nose, eye and mouth shapes at the top of the stones. Ultimately, it is impossible to know what the original creators intended, or indeed what petroglyphs were present during the Neolithic, so any drawings or interpretations made now, no matter what method used, are at best a guess of what may have been there.

ALM3, 48, 65 and 94 have the most features identified as natural features, where Gomes interpreted them as part of the art. ALM48 and 65 have the roughest surfaces, and this supports the hypothesis that the bi-chromatic technique made it difficult to classify features, particularly on rougher stones. On ALM48 and ALM65, there are many features that could be explained by the roughness, particularly the circles shapes and vertical lines. Gomes' drawing of ALM65 also includes three crosiers. Two of these cannot be seen at all, but we suggest that the third one is not a crosier, but instead a natural feature from which Gomes extrapolated the shape of a crosier. It is possible that this error in interpretation was exacerbated by the obscuring of texture by the bi-chromatic method. We argue that this is seen on multiple other stones, including ALM3 and ALM94. The crosier in ALM3 somewhat matches a faint line on the stone, but from our results, that faint line does not map into the shape of a crosier. Instead, we suggest it may be part of a crescent that was not observed by Gomes. Additionally, the crosiers on ALM94 do not map onto the shape of a crosier on our models. This suggests that Gomes may have seen natural features as more than they were, perhaps due to the obscuring of the stone by the bi-chromatic technique.

This is also likely to explain the differences seen on ALM58. The petroglyphs on ALM58 are engraved, and often difficult to see. The covering of the stone by the white dye may have made it more difficult to identify the paths the zigzags took, thus leading to the discrepancies seen between Gomes (2002) and this study. Additionally, Gomes may have included some natural features as part of the zigzag lines, as shown by the red lines in Figure 27. The subtlety of the features may have made them susceptible to erosion, and we will discuss this further later.

However, some of the features observed by Gomes on ALM48 and ALM65 could not be observed at all, such as the horizontal lines on ALM48, or multiple crosiers and circles on ALM65, suggesting there are other explanations for the discrepancies between the studies. Additionally, despite the roughness of ALM1, the features identified match fairly well, and it is only the zigzags on the crescent, and the line across the middle that are unable to be observed in this study, which could be explained by the potential damage done by the bi-chromatic technique or weathering. ALM3, which has a fairly smooth surface, has many features that cannot be seen at all, meaning those differences cannot be explained by the surface roughness and obfuscation of the bi-chromatic technique. The lack of correspondence between discrepancies of observations and roughness of stones in some cases indicates that additional factors are likely to be responsible.

One of these explanations is the possibility of human error and bias. As mentioned, the classification of features on the rock (natural/manmade), is dependent on the researcher, but there are other factors that could explain the differences. Human perception is subjective, meaning the results are not perfectly objective, leaving room for different interpretations by different people. We are also susceptible to biases. A common bias is that humans have a tendency to see anthropomorphic faces where there are none. This is known as pareidolia (Liu *et. al.,* 2014). What we see is also affected by our knowledge base and beliefs (Berger, 1972).

In this study, the drawings created using the images from the grazing light technique were the largest source of subjectivity and human bias. Petroglyphs are difficult to categorise, as we do not know what the original creators intended to show. Therefore, the researcher must make those decisions, placing their own biases onto the research. We were more conservative than Gomes (2002) at categorising shapes as petroglyphs. We categorised only the most obvious shapes as ‘manmade’ features, leaving the majority of the other shapes on the stones as natural features (though still possibly part of the rock art). However, due to the roughness of many of the stones surface, and the subtlety of many of the shapes, it was difficult to decide what were features, and what was stone roughness. This can particularly be identified in our introduction of three new

possible features on ALM65 (Figure 22, blue lines). It is difficult to say for certain whether these shapes were intentional, or whether they were just part of the stones surface. The possible new shape identified on ALM3 (**Error! Reference source not found.**, blue line) is very subtle, and other researchers may establish that it does not qualify to be an actual feature. We may be susceptible to the issue of both pareidolia and that our knowledge of petroglyphs is likely to affect what we see, as a crescent shape is a common feature, making it more likely that we saw one where none were present. This is why we present the drawings as one interpretation only, and would encourage other researchers to use the unannotated models to draw your own conclusions as to what petroglyphs are present.
In a number of cases, discrepancies suggested some degree of error and potential observer bias within the results of Gomes' survey. The clearest example of this bias is the observation of the rectangles, circles and crescents that are said to make up a face. Although the circles, rectangle and crescent were found in both studies on ALM1, 3 and 56, this study was unable to observe the crescents on ALM65 and ALM76. As the protrusion of the crescents was similar to the thickness of the rectangles in ALM1, 3 and 56, it is likely that the nose and crescents of ALM65 and 76 would also have had similar thicknesses. Additionally, the crescents are still clearly visible on ALM1, 3 and 56, and show no signs of being eroded or damaged faster than the nose. As the stones are all made of the same granite, the features will have eroded at roughly the same rate, both between stones and on the same stone. It is unlikely that if there had been crescents on ALM65 and 76 they would have eroded at such a different rate to the noses, and the crescents on surrounding stones. This suggests that lack of crescents in ALM65 and 76 is not due to the disappearance of the crescents since Gomes' study, but rather that they were not visible to begin with. Gomes saw a significant number of 'faces' (rectangles, circles and crescents) throughout his research of megaliths in Central Alentejo. We suggest that this pattern of common shapes led to Gomes having a subconscious bias towards seeing the pattern repeat itself, resulting in him being more likely to report a full face where there were missing sections. We suggest this subconscious bias was compounded by the human tendency to see faces, which would have meant Gomes was more likely to see the shapes as connected features, rather than individual features to be recorded. However, pareidolia only applies to seeing

faces, and does not apply to general shapes. Therefore, it cannot explain many of the discrepancies of the other types of petroglyph, indicating there are other factors involved.

One of these factors is the possibility of erosion. The menhirs of the Almendres Cromlech have been subjected to erosion since they were quarried in the Neolithic period. There is considerable evidence for erosion at the Almendres Cromlech including prolific lichen colonisation, presence of weathered granite and more recently, its popularity for visitors. Erosion in the Central Alentejo area on granite stone occurs at a rate of around 40mm per millenia (Sellier *et. al.,* 2008). Weathering also occurs episodically, suggesting that at times this rate may be quicker or slower, depending on the stage of weathering (Phillips, 1999; Pope *et. al.,* 2002). Sellier *et. al.* (2008) highlighted that erosion occurs mostly at the top and west/south faces of the menhirs, reaching rates of around 4.8mm per century. Average erosion rates put the rate at around 2.4-2.9 millimetres since Gomes' study in the 1960s. This could possibly be higher if the stone is going through the exfoliation stage of granitic weathering, where a hardened 'crust' is shed, leaving the softer interior vulnerable to rapid weathering (Pope *et. al.,* 2002). Though 2.4-2.9 mm does not appear to be a significant amount, the petroglyphs at Almendres are only a few millimetres to centimetres thick. There is the possibility that features that protruded less than 3 millimetres from the surface during Gomes' survey have been eroded, making them invisible today.

This could explain the differences between Gomes' drawings and this studies results of ALM57. Though the crescents and crosiers observed towards the bottom of the stone match, they get less clear towards the top of the menhir. As the top would have been disproportionately affected by erosion it supports the theory that the petroglyphs of ALM57 have degraded due to natural weathering. It is also likely that the definition at the top of the nose on ALM65 may have deteriorated since Gomes' study, explaining why we did not identify a top line.

ALM3 and ALM94 may also have been affected by natural weathering. ALM3 has a very smooth surface, reducing the risk of misidentifying features, so it is unlikely the discrepancies are caused by differences in interpretation. The nose and crescent at the top of the shape protrude less than those on ALM1, ALM56 and the nose of ALM76, suggesting they were either carved more shallowly to begin with, or that they have been more susceptible to weathering. The shape of ALM3 may have made it more susceptible to weathering. While the faces on ALM1, 56 and 76 are carved on the vertical flat face of the stones, the faces of ALM3 and ALM65 are carved into the rounded and slightly upward facing top of the stone. This would have made the carvings more vulnerable to direct rainfall, and weathering from multiple directions, rather than just the direction of the flat face. Though we can still just about see the rectangle and crescent on ALM3, and the nose on ALM94, if the other features on the stone had been carved at the same or protruded slightly less, this erosion may have resulted in them vanishing from view. This is also a possible explanation for why the nose on ALM94 is so subtle in comparison to other anthropomorphic stones.

Erosion may also explain some of the discrepancies on ALM58. The zigzag lines are very shallow, making them susceptible to erosion. It is possible that since Gomes' survey in the 1960s, some of the shallower lines have become too degraded to see clearly. However, as mentioned earlier, there are multiple other explanations for the discrepancies, including interpretation differences and human error.

Overall, we argue that most discrepancies between Gomes (2002) and this study are explained due to differences in classification of natural and manmade features. Ferraz (2016) agrees with this theory. The discrepancies caused by differing classification is an issue that is faced by all researchers in this field, and also explains some of the differences between this study and Ferraz (2016), as discussed in the next section. However, there were still many discrepancies and features in Gomes investigation that this study could not observe. We suggest that this is most likely due to methodological limitations of the bi-chromatic technique obscuring the menhirs surface, combined with human error and bias, and the probability that some features have naturally eroded since Gomes' study, particularly those near the top of the menhirs, such as ALM3 and ALM57. Finally, we suggest that there is the slight possibility that for the subtler features, the bi-chromatic technique damaged them, resulting in their partial or total disappearance.

Differences to Ferraz (2016)

Although the results of this study and Ferraz (2016) mostly agreed, there were some discrepancies. Due to the close time period between the studies, it is unlikely that factors such as natural weathering would have contributed to the differences. Additionally, Ferraz used an in-situ version of the grazing light technique, which is non-contact, meaning it is unlikely that the stones have been damaged due to the methods used. This leaves three options. Firstly, that there were methodological differences. Secondly, there could have been human error or bias, and finally, there is the possibility that erosion/damage rates are faster than expected due to increasing human contact.

On ALM1, Ferraz identified a shorter crescent, a crosier and two triangle lines at the bottom of the stone. Using Ferraz's own images, we suggest that the lighting positions failed to observe the full width of the crescent, which can be best seen in our model the top lit image in Figure 19B. However, we identify no crosier or triangles, and suggest that these may be natural features that Ferraz saw as carvings with specific shapes.

On ALM3, Ferraz identified a crescent, but suggested a different shape to that suggested by this study. Looking at Ferraz's images (Figure 35), we argue that the full width crescent is visible, and matches the shape observed on the models created by this study. Therefore we argue that this discrepancy is due to differences in human interpretation. Additionally, Ferraz did not identify the rectangle or eyes that this study and Gomes observed. We argue that this is because the methodology used did not highlight the presence of those shapes, perhaps due to the position of the carvings on the rounded top edge of the stone. However, our model shows both crescents and a possible eye, particularly in the images with the lights coming from the side.

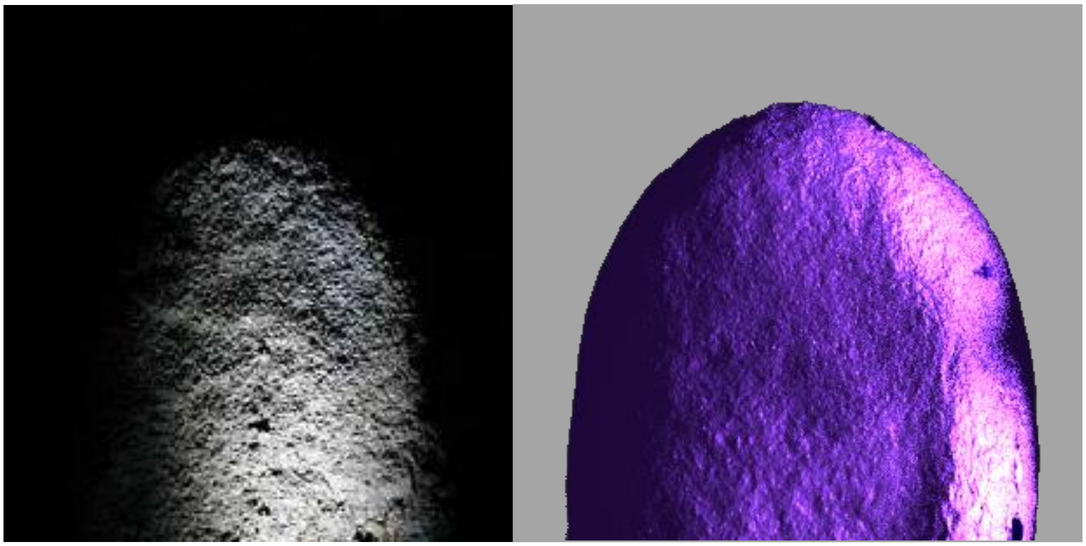


Figure 35: (A) One of the images taken by Ferraz (2016) of ALM3 using the grazing light technique. Shows a crescent shape. Taken from Ferraz (2016). (B) Still from 3D model from this study for comparison.

For ALM48, the results of this study agree mostly with Ferraz, though we argue that the crosier she identified is just a straight line in the stone. Additionally, we identified many more natural features, which can better explain the discrepancies with Gomes (2002).

The only differences for ALM56 were Ferraz's lack of an eye, and inclusion of two circles underneath the crescent (Figure 36). Though we did identify one circle below the crescent, we argue that it is higher up than where Ferraz believes, and we could not see a second circle. Using Ferraz's images, we can identify the circle observed in this study, and can observe two possible dimples where she places the two circles horizontal from each other. Our models do not show these dimples. This suggests that human interpretation differences were likely responsible for the lack of identification of the circle just below the crescent, and methodological differences for the two circles below that.

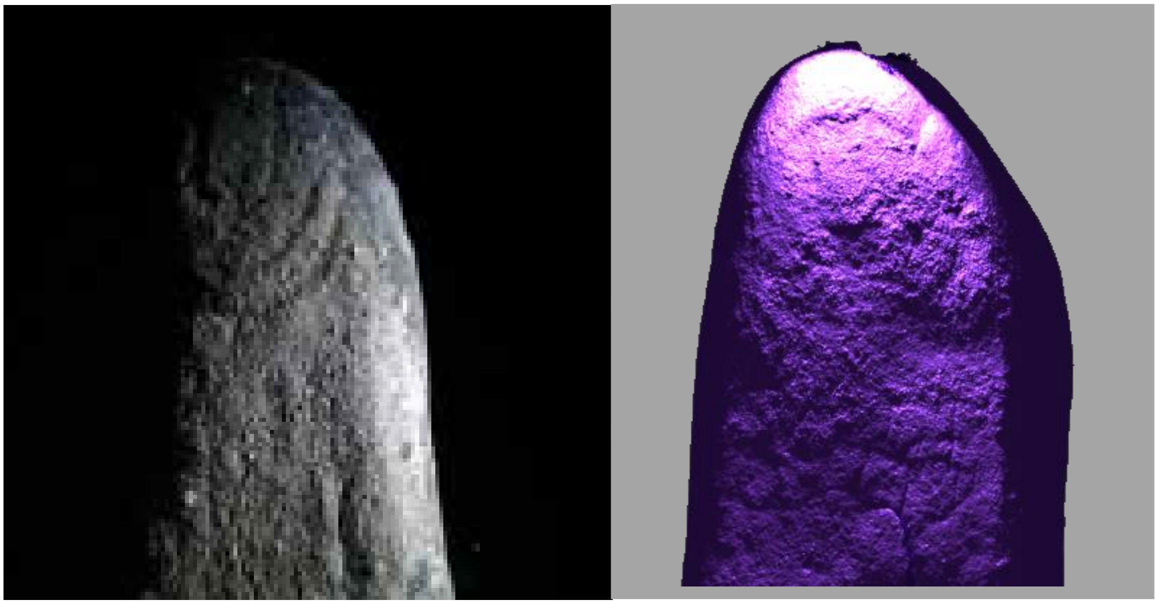


Figure 36: (A) Photograph of ALM56 taken by Ferraz (2016) using the grazing light technique. Shows a rectangle, crescent, circle and two possible dimples. (B) Still from 3D model from this study for comparison.

Both this study and Ferraz (2016) identified fewer crosiers than Gomes (2002) on ALM57. Though many are the same between Ferraz and this study, she identified five crosiers, where we saw seven. Additionally, the shapes of some differ. Though the crescent and the crosier at the bottom of the stone agree, the two crosiers above the crescent are shaped differently in the two studies (Figure 26A). We argue that the crosiers are connected by their tails, whereas Ferraz draws them separately. Again, we argue that this is due to the different results by the different methods. We argue that being able to observe the stones in a virtual setting, and manipulate their colour and the lighting as much as we needed, we were able to see more features than Ferraz. The colour and sharp contrast seen in Ferraz's images may have hindered the identification process. However, there is also the possibility that we have seen more than is there. The crosiers we identified on the far left-hand side and very top are very faint, and seen only in the image with the light coming from below. Therefore, we encourage other researchers to use their own interpretations, rather than relying on those of one person, as the identification of petroglyphs is too subjective with current methodology.

The difference between the results of Ferraz (2016) and this study for ALM58 and ALM64 are likely due to methodological differences. This is because Ferraz's photographs do not show the left circle on ALM58, or the lines from the bottom right circle on ALM64, both of which can be clearly seen in the 3D models in this study. ALM65 has multiple differences between the studies. Though both identify the rectangle and circles making up the eyes, Ferraz did not identify the three shapes in the centre, and the two larger circles further down the stone. This is likely due to interpretation differences, where the classification of petroglyphs differed between the studies. The shapes are visible in both studies, but Ferraz did not class them as shapes, whereas we propose there is the possibility they are petroglyphs. However, the surface of this stone is rough, making it difficult to tell with certainty. Ferraz did not identify the zigzag in the centre of ALM76. Looking at Ferraz's images, the zigzag cannot be seen. However, it is clear, if subtle in our 3D model, suggesting this discrepancy was caused by a limitation in the in-situ grazing light methodology used by Ferraz. The only difference between this study and Ferraz for ALM87 is the length of the crosiers tail. Ferraz's images show a longer tail, suggesting it is a possible limitation with the 3D methodology. Either the stone was reconstructed with errors, or we were not thorough enough when deciding positions for the lighting. For ALM94, Ferraz identified no features. This study could only identify a possible half a rectangle, but it is likely that Ferraz did not class this as a shape during her study.

Ferraz also identified four stones that had petroglyphs that had not yet been discovered (Figure 37). Unfortunately, we did not have time to return to the site to take photographs of these stones individually. This means that the models we have for these stones are of a lower quality than those we have for the stone Gomes identified, meaning we are unable to assess whether there are petroglyphs present as they are not accurate enough. In future, ultra high-quality models of these stones should be constructed in order to assess whether the 3D SfM photogrammetry method can identify the same shapes that Ferraz did.

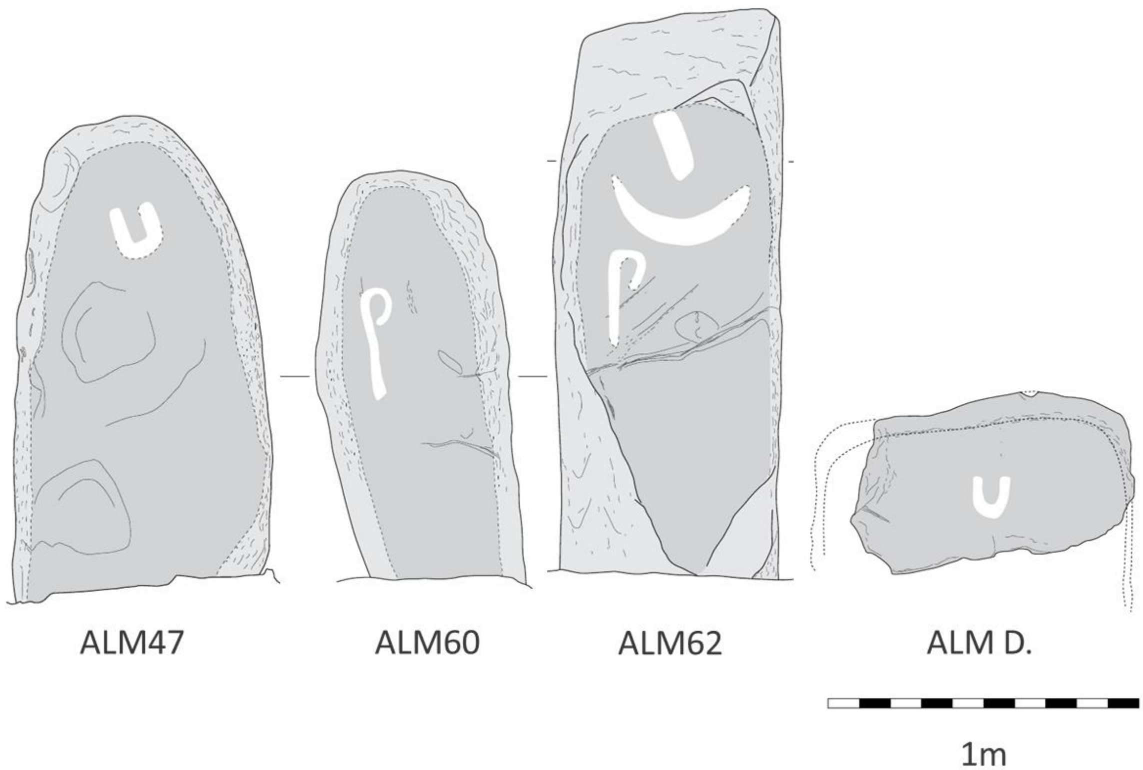


Figure 37: The four new decorated megaliths found by Ferraz (2016). Taken from Ferraz (2016)

Overall, the main reasons for the discrepancies between Ferraz (2016) and this study are methodological and interpretation differences. We believe the in-situ grazing light technique was unable to highlight some shapes, but the 3D grazing light also was not able to identify some features. As with the discrepancies between this study and Gomes, the decision to include or exclude shapes is fairly subjective, resulting in differences. This is particularly seen with ALM65. Overall, the virtual grazing light technique was able to identify more shapes than the in-situ version, as it allowed more manipulation of lights and textures to find the best angles to highlight shapes. However, the comparisons show that both techniques have flaws, and we do not yet have a perfect technique for identifying petroglyphs. Additionally, the subjectivity of the researcher resulted in discrepancies, showing that we cannot yet have objective petroglyph recording with current techniques, as they require human involvement.

Newly discovered petroglyphs

Though this study is not delving into an interpretation of the petroglyphs found at the Almendres Cromlech, it is worth discussing the two petroglyphs discovered in this study.

ALM27 has a zigzag line across the middle of the stone. We argue that this could possibly represent a belt. Belts are commonly found in Neolithic carvings (Gomes, 2002). Figure 38 shows some of the types of belt shapes that Gomes (2002) found in Central Alentejo. The belt in the third box is similar in shape and style to the belt on ALM27. However, it is important to note that the shape on ALM27 is engraved, rather than protruding from the surface like the majority of Neolithic petroglyphs (though not exclusively). Additionally, in its current position, the rock art is on a bearing of 290º. This is almost facing exactly the opposite direction to most Neolithic carvings, adding doubt to its validity as a Neolithic petroglyph. However, this is just in its current position, and it may have been re-erected wrongly by Pina in the 1960s, causing the petroglyph to face in the opposite direction, like the nearby megalith further down the hill to the Almendres Cromlech. Additionally, there are other carvings at the Almendres Cromlech that face west rather than east, such as on ALM64.

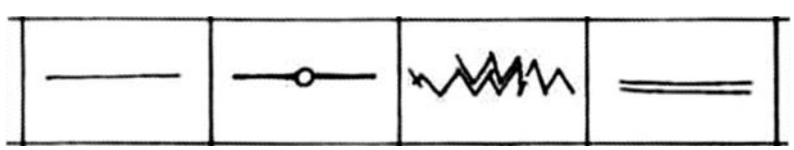


Figure 38: Belt shapes identified by Gomes (2002).

The shape discovered on ALM72 is very small, and does not seem to fit into any of the categories presented by Gomes in Table 1. It is also not carved into a flat face. The clarity of the shape suggests it is not a result of error in the model, so we suggest that this may be an incomplete petroglyph, or was perhaps used as practice.

Conclusions

Overall, we found that the main cause of discrepancies between all three studies was differences in human interpretation, whether that be the inclusion or exclusion of a feature, or a different classification (manmade or natural). This highlights the highly subjective nature of petroglyph identification, even when using 'objective' methodologies to record the images of the stones. This raises the question of the difficulty of presenting the results of petroglyph research to the public, and to other researchers. Information should be presented as objectively as possible, but if the results themselves are subjective, this is difficult to achieve. In the arena of petroglyph identification, the methods have not yet developed enough, and we do not know enough about the original intentions, for us to guarantee objective observations. In the meantime, so long as we are aware of the human bias present at the interpretation stage, we can avoid placing too much weight on any one annotation, and allow the general public and other researchers to discover the art for themselves by presenting them with unannotated, millimetre accurate, 3D models.

The results of this study also indicate that the petroglyphs may be vulnerable to erosion rates on the decadal scale. If the increasing rate of erosion seen elsewhere in Portugal is occurring here, we may begin to see significant degradation over the next few decades which could be exacerbated further by open access to the site and lack of protection from human contact. There is the need to consider whether protective measures should be implemented at the site. By postponing the question, we risk waiting until we have lost invaluable art. It is worth preventing damage in the first place, rather than bandaging up the destruction in the future. Additionally, the structural stability of the stones is at risk. The thin soils, lack of protection and rainy season have already resulted in some megaliths becoming unstable, leading the Portuguese government to cement them in place. They also add new soil to the area every year after the rainy season. Introducing foreign material to an archaeological site makes further research difficult, as they cannot confirm what was original and what is new, and it is a short-term solution to a longer-term problem. A more effective solution would be to prevent the erosion in the first place. This would require restricting where humans are allowed to walk. This would allow the natural vegetation to regrow, or native vegetation could be replanted and protected, which would reduce surface run off and soil erosion. The Almendres Cromlech is the largest megalithic enclosure in Portugal, and holds a wealth of information about the people who built it. Its vulnerability to erosion is worrying, and we hope this study can highlight the importance of putting in place protection measures as soon as possible.

Future research should look to reanalyse erosion rates at the Almendres Cromlech, and establish whether human contact is having an impact on the petroglyphs in the area. It would also be useful to conduct an extended project to look at soil erosion rates and causes in the area, and offer affordable but effective solutions. Additionally, researchers should look to expand the geographical focus of the methodology used in this study to the wider Central Alentejo area, and develop a comprehensive, millimetre accurate 3D database of all the megalithic monuments. This would allow researchers to have an updated record of the petroglyphs, and more accurate records of monument size and exact geographical locations. If any of these monuments are damaged in the future, having an accurate reference will enable better analysis of the damage, and will assist in reparation to the site. Researchers should also consider extending the research done on these sites temporally, and use the 3D models to investigate any changes to the petroglyphs, adding evidence to the analysis of erosion in the area. Although the technology may not be here yet, it would be interesting to see whether 3D modelling can be used to objectively identify petroglyphs, perhaps by using sharp changes in stone face elevation to identify edges of shapes. While this would only work on flat faces, it is an interesting avenue to consider exploring.

The work done in this study will extend past this thesis. The database created from the 3D model of the site, the model itself and the individual megalith models will be made freely available online, allowing researchers that do not have access to the site to conduct their own investigations of the site. High-quality images that highlight the petroglyphs will be used in the new interpretation centre being built in the nearby village, Nossa Senhora de Guadalupe, as well as 3D printed models of the decorated megaliths. Combined with detailed information about the research and the petroglyphs themselves, we hope that these models make viewing the petroglyphs more accessible to the general public, and promote engagement with the area. Additionally, by highlighting the possible erosion occurring at the site, we hope to encourage compassionate and sustainable use of the site, reducing the impact caused by humans. We hope that this studies' research of the erosion at the site, combined with the new visitor centre, will contribute to the pressure for the Évora municipality to consider protective measures for the Almendres Cromlech. The 3D models created will act as a reference to analyse possible petroglyph degradation, and in the worst case scenario, as an archive for what the petroglyphs looked like in 2018.

On the wider scale, this study adds to the growing number of research using UAV SfM photogrammetry in archaeological surveys, and we hope that it will encourage more researchers to use this efficient, affordable, yet millimetre accurate recording technique. This study highlights the numerous advantages of UAV SfM photogrammetry, including its geographical range, the removal of the restrictions of in-situ research, the improvement of precise 3D measurements, the ease of methodological repetition due to customisable and saveable survey patterns, its lack of impact on the site, and the major advantage of being able to manipulate the models in virtual reality, allowing completely customisable forms of methods such as the grazing light technique, unrestricted by site access or time restraints. UAV SfM photogrammetry is fast becoming a standard 3D surveying method, and rightly so.

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