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Artículo

The Historical Quarries of Jabal Fuwairit (North Qatar): Preliminary Studies for its Enhancement, Conservation, and Musealisation

Las canteras históricas de Jabal Fuwairit (norte de Qatar): Estudios previos para su puesta en valor, conservación y musealización

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Abstract: The historical quarries of Jabal Fuwairit are in the north of Qatar. Approximately 1 km NW of the archaeological site of Fuwairit (N 26° 2′ 28.457′′ E 51° 21′ 57.418′′). Jabal Fuwairit fossil dunes are pseudo-parallel to the coastline and have an NW-SE orientation. They are approximately 1.3 km long and 0.2 km wide at their widest. Throughout the hills, there are numerous vestiges of historic stonework. Traditionally quarried building stone at Jabal Fuwairit is an ooidal limestone characterised by medium-scale crossbedding and a vuggy fabric with ophiomorpha burrows and cemented roots. Ooid grains are well sorted and medium- to coarse-grained, with sparse fossil debris. The quarrying was facilitated by the cross-bedded strata set in pseudo-horizontal planes, along with the desiccation cracks filled with muddy material (pseudo-vertical planes), which made possible the extraction of individual blocks in the historical quarry. The homogeneity of the grain size and high porosity of this stone allows it to be easily carved. Jabal Fuwairit historical quarries are in a privileged geological environment. They have numerous engravings, especially cup-marks, and possibly a ground-plan of a house with an inscription, attesting to the place where the stone was extracted for the building of a shaikhly residence around 1900 by the headman of Fuwairit, Nasr bin Shahin Al Tuwar. Jabal Fuwairit historical quarries can be reused generating economic profitability with cultural actions. They have numerous geological and archaeological elements to become an open-air museum.

Keywords: Fossil dunes; limestone; Nasr bin Shahin Al Tuwar; archaeology.

Key points:

The historical quarries of Jabal Fuwairit contain important geological, archaeological, historical, and environmental elements for its musealisation.

There are different rock engravings from prehistoric times to the present day in the historical quarries of Jabal Fuwairit.

Other historical quarries in Qatar need to be studied and catalogued.

Resumen: Las canteras históricas de Jabal Fuwairit se encuentran en el norte de Qatar, aproximadamente a 1 km al NO del sitio arqueológico de Fuwairit (N 26° 2' 28.457'' E 51° 21' 57.418''). Las dunas fósiles de Jabal Fuwairit son pseudoparalelas a la costa con una orientación NW-SE. Tienen aproximadamente 1,3 km de largo y 0,2 km de ancho en su parte más ancha. A lo largo de las colinas se encuentran numerosos vestigios de cantería histórica. La piedra de construcción tradicionalmente extraída en Jabal Fuwairit es una caliza oolítica caracterizada por estratificación cruzada de escala media y una red de bioturbación con madrigueras de ophiomorpha y raíces cementadas. Los ooides están bien clasificados y son de grano medio a grueso, con escasos restos fósiles. La estratificación cruzada está dispuesta en planos pseudohorizontales, que junto con las grietas de desecación, llenas de material fangoso (planos pseudoverticales), facilitaron la extracción de bloques individuales en la cantera histórica. Lo que permitió individualizar bloques sin necesidad de herramientas sofisticadas. La homogeneidad, el tamaño de grano y la alta porosidad de esta piedra permiten que sea fácilmente tallada. Las canteras históricas de Jabal Fuwairit se encuentran en un entorno geológico privilegiado y tienen numerosos grabados rupestres, especialmente marcas de copa, e incluso un plano de una casa con una inscripción, que da fe del lugar donde se extrajo la piedra para la construcción de una residencia del jeque Nasr bin Shahin Al Tuwar, jefe de Fuwairit, alrededor de 1900. Las canteras históricas de Jabal Fuwairit pueden reutilizarse generando rentabilidad económica con acciones culturales. Cuentan con numerosos elementos geológicos y arqueológicos para convertirse en un museo al aire libre.

Palabras clave: Dunas fósiles; calizas; Nasr bin Shahin Al Tuwar; arqueología.

Puntos clave:

Las canteras históricas de Jabal Fuwairit contienen importantes elementos geológicos, arqueológicos, históricos y medioambientales para su musealización.

En las canteras históricas de Jabal Fuwairit existen diferentes grabados rupestres de edades desde la prehistoria hasta la actualidad.

Existen otras canteras históricas en Qatar que deben ser estudiadas y catalogadas.

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Supplementary information ↓

1. INTRODUCTION

Quarries have been the subject of analysis since humans have searched for the best building stones to build huts and megaliths that would last over time. Thanks to this interest in finding the best quality stones, prehistoric quarries have prevailed to the present day (Garcia-Moreno, 2010; Pizzo, 2011). Some quarries provide stones that have been transported over long distances because of their specific characteristics (Harrell, 1992; Frumkin *et al.*, 2014; De Laet *et al.*, 2015; Cech & Harrell, 2024).

Large-scale quarrying of stone has an ancient history in the Middle East region. Large public buildings with stone foundations were built in southern Iraq, at Uruk (Warka), as early as the 4th millennium BC, quarried from limestone outcrops 60 km away (Potts, 1997). During the 3rd and 2nd millennia BC other varieties of stone were brought to that region from the Persian Gulf, including hard dark stone for monumental sculpture. Within the Persian Gulf itself, systematic quarrying of limestone for monumental architecture and tombs took place in the Bahrain archipelago during the first half of the 2nd millennium

BC, the most notable evidence coming from the island of Jiddah, where oolitic limestone has been matched with masonry used at the Barbar Temple (Højlund, 2013). The Jiddah quarry was later used to provide building stone for the Portuguese-Hormuzi fort at Qala'at Al Bahrain, according to a dated inscription of 1561 AD. At least two other sources of quarried limestone were used in Bahrain to provide massive ashlar masonry for the palaces and royal tombs of Dilmun, though the immense royal tomb "Mound P" used oolitic limestone, and therefore probably the Jiddah Island source (Laursen, 2017). The immense amount of stone used in ordinary Early Dilmun burials would also have required quarrying.

Building stone in ancient times reached its maximum splendour in Greek culture and under the Roman Empire, especially during the rule of Augustus. The social elites, not only in Rome but in all the provinces, decorated their palaces with ornamental stones, which led to stones from conquered areas being used around the large cities. Marble was a symbol of luxury and power and the exploitation of the great oriental quarries of ornamental rock was under imperial control. The main trade routes were linked to the sea routes that linked the port of Ostia with the different extraction points scattered throughout the empire and particularly concentrated in Asia Minor and the Greek islands (Brilli *et al.*, 2015; Lapuente Mercadal, 2019). Detailed descriptions of quarries were made by the Greek philosopher Theophrastus (ca. 372-287 BC) in the work "*Peri Lithon*" (Carrasco *et al.*, 2013), where stones used in classical Greece for the construction of their buildings were described. "*Peri Lithon*" is a set of lecture notes that the author would have delivered in the gardens of the Lyceum almost two millennia ago. Incredibly, the text of the treatise appears to have come down to the present little changed from what it was in the beginning. All surviving ancient works have made their way through time through a tradition of manuscript copying. Invariably, as scribes copied manuscripts, mistakes were unwittingly introduced. The fact that this work exists in a relatively few manuscripts that when compared show few differences, suggests that "*Peri Lithon*" is probably very close to what Theophrastus originally wrote. The Roman architect Marco Vitruvio Pollione (ca. 80-15 BC) describes quarries and building materials, addressing their use in his work entitled "*Ten Books on Architecture*" as a guide for building projects. As the only treatise on architecture to survive from antiquity, it has been regarded since the Renaissance as the first known book on architectural theory (Oliver Domingo, 1997; Freire-Lista, 2021). Later, Gaius Pliny Second (ca. 23-79 BC) wrote "*Natural History*" in thirty-seven books. In part, based on knowledge inherited from ancient Egypt (Coli *et al.*, 2011; Marčiš & Fraštia, 2023).

Historical quarries have an important aesthetic, cultural, and heritage value, and they must be studied, conserved, and valued since relevant information can be extracted from them. That is, they tell the history of the construction of villages and cities. Traditionally, building raw materials for vernacular architecture came from the vicinity of the building in which they would be used (Barroso *et al.*, 2018). Proximity, ease of extraction, and quality of building stones are some essential traits when selecting quarries. The study of historical quarries is essential for geology, archaeology, architecture, and restoration purposes. In addition, the petrographic and petrophysical properties of the extracted stones are fundamental for the maintenance, restoration, and reconstruction of heritage buildings to be effective (Fort *et al.*, 2013; Castro *et al.*, 2022). For the conservation and enhancement of historical quarries to go hand in hand with development, appropriate strategies must be defined as interdisciplinary. Geologists, archaeologists, historians, architects, and museologists have a fundamental role in these aspects (Brilli *et al.*, 2015; Cultrone *et al.*, 2001; Álvarez Areces *et al.*, 2017; Lapuente Mercadal, 2019; Martín Duque *et al.*, 2021). The archaeological, geological, and structural analysis of buildings and archaeological sites and their quarries allows us to deepen our knowledge of their construction process, the technology they use, the technological transfer they reflect, and the productive context to which they belong (Álvarez Areces & Utrero Acute, 2019).

Quaternary stones of coastal origin have been used throughout history for the construction of civil buildings and fortifications (Freire-Lista *et al.*, 2019; Hird & Al Kindi, 2023). For a quarry to be suitable, it had to have fractures or planes of weakness that facilitated the extraction of blocks. Fractures and planes of weakness have therefore been of paramount importance in historical quarries. (Freire-Lista & Fort, 2017; Riquelme *et al.*, 2022).

The aim of this work is the collect a bibliography related to the historical quarries of Jabal Fuwairit and its area for enhancement, conservation, and musealisation. The historical quarries of Jabal Fuwairit are located on a hill of fossil dunes on the north coast of Qatar, in the municipality of Ash Shamal, approximately 90 km North of Doha. (Figure 1). It is approximately 500 m North of the Fuwairit archaeological site, a coastal town a little over a kilometer long, with the main area of ruined architecture measuring approximately 750 m long by 160 m wide, with an orientation NNW-SSE broadly parallel to the actual coast. In addition to the geological and archaeological value, Fuwairit has a shallow (< 3 m) nearshore coralline fringing community at less than 600 m from the shore (Burt *et al.*, 2026), the mangroves of Fuwairit contain biodiversity of macrofauna (Al Khayat & Jones, 1999) and hawksbill sea turtles (Eretmochelys imbricata) nest annually at Fuwairit (SCENR, 2006; Pilcher *et al.*, 2014). All these aspects make Fuwairit a unique scenario for its preservation and enhancement.

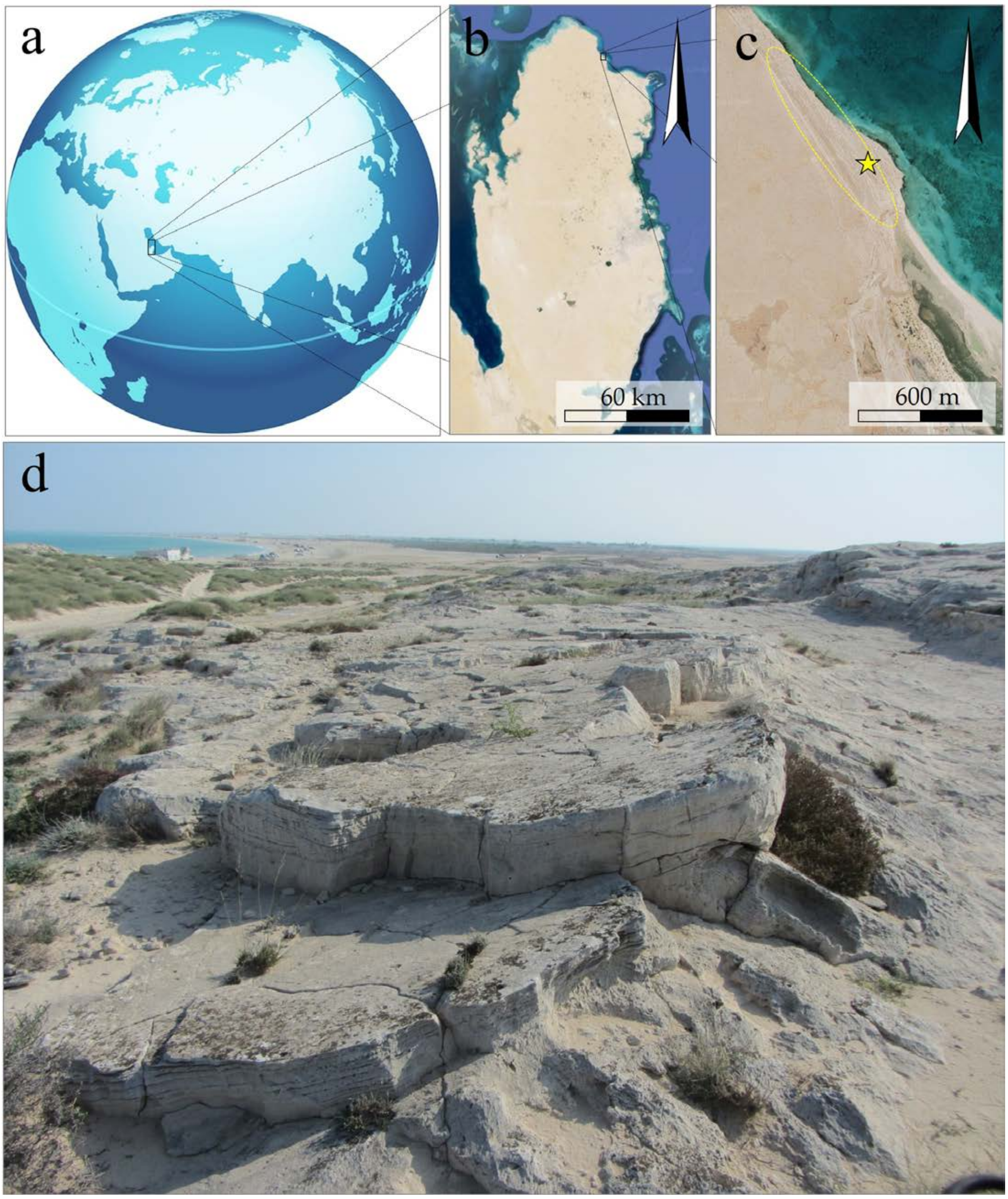

Figure 1. Location of the historic Jabal Fuwairit quarry. a: Location map; b: Map of Qatar; c: Adjacent area to Fuwairit. Jabal Fuwairit is marked in yellow; d: View of a part of the historical quarries. The location from which the photograph was taken is indicated with a yellow star in Figure 1c.

Figura 1. Localización de la cantera histórica de Jabal Fuwairit. a: Mapa de localización; b: Mapa de Qatar; c: Área adyacente a Fuwairit. Jabal Fuwairit está marcado en amarillo; d: Vista de una parte de las canteras históricas. El lugar desde donde se tomó la fotografía está indicado con una estrella amarilla en la Figura 1c.

2. GEOLOGICAL SETTINGS

Regional geology determines the location of quarries, both historical and current. Qatari Quaternary was characterised by glacial and interglacial periods. At the beginning of the Pleistocene epoch, the climate was dry with strong monsoonal winds. Extensive dunes were deposited. During the glacial periods of the Pleistocene, global sea levels dropped by at least 100 m, and the coast regressed from the present shore by hundreds of meters (Glennie & Singhvi, 2002; Hird & Al Kindi, 2023). The winds eroded the exposed carbonate beds of the seafloor and re-deposited the carbonate fragments as huge sand dunes. The Pleistocene epoch ended with another glacial period, the last one in the Quaternary. Throughout most of the upper Pleistocene and early Holocene, a considerable amount of runoff in southwest Asia was funneled into the Gulf basin via submarine aquifers flowing beneath Arabia. In the Rub’ al Khali, shallow lakes and sabkha deposits resulted from these past periods of elevated groundwater and higher humidity (Matter *et al.*, 2015; Hird & Al Kindi, 2023).

The archaeological site of Fuwairit is on a Holocene fossil chenier plain, between aligned Pleistocene fossil dunes, the main outcrop of which is called Jabal Fuwairit, where there are historical quarries. These consolidated coastal oolitic ridges were deposited on the Upper Dammam Formation. The fossil dunes are close and pseudo-parallel to the shoreline. On the landward side, this oolitic ridge gives way to supratidal flats, sabkhas, and the rocky desert (hamada), which presents on its surface fractured stones of the Umm Bab Member of the Dammam Formation (middle Eocene carbonate deposits).

The lower part of Jabal Fuwairit is made up of marine carbonate-sand bars, the upper part shows a change toward wind-blown dune deposits of ooids. They were deposited as coastal dunes adjacent to beaches where abundant calcareous sand was available. The accumulation of these sediments is related to climatic changes and fluctuations in sea level. Wind sediments were deposited during a high stand of sea level in the Sangamonian (75,000 - 125,000 BP) (Williams & Walkden, 2002). The oolites are characterised by medium-scale cross-bedding. Sets of cross-beds vary in thickness from meters to centimeters and generally pinch out over lateral distances of tens of meters. Their strata show rhizocretions (Fossil root systems that have been encased in mineral matter), burrows (Fossil holes or tunnels excavated by an animal), and desiccation cracks filled with mud, suggesting an alternation of flooding and dry periods (Figure 2), although the water that has percolated through the dunes has not been enough to dissolve all the aragonite. The dunes were stabilised by the cementation of ooidal grainstones and vegetation.

Pleistocene pluvial events and eustatic sea-level changes have played an essential role in the evolution of the Fuwairit area. A river system, possibly a wadi (seasonal watercourse) with approximate SW-NE direction cut and eroded part of the dunes ridge, where the archaeological site would later be established. Changes in sea level produced throughout the Holocene configure the current geomorphology of the area. This period began approximately 11,700 years ago when aridity ameliorated, and there was more rainfall, especially in the early to middle Holocene, as the sea level rose (Macumber, 2011).

In early Holocene times, coastal embayments containing little sediment and with wide entrances that were open to the ocean, and cliffs of Eocene limestones and dolomites, drew a tortuous coastline on the east side of Qatar. After stabilisation of the present sea level, fine-grained, carbonate sediment and dolomite out-wash from the land began to fill and regularise the coastal embayments (Cavalcante *et al.*, 2016). Concurrent longshore transport of recent coarse-grained carbonates from the North created “chenier” beaches with hook-shaped spits at their southern ends, which gave added protection to these pre-recent embayments. Contemporaneously, additional cheniers and spits were forming seawards of the older one creating quiet water embayments. During this five to six-thousand-year period, a tidal channel system developed on the flats behind and between successive cheniers and spits that straightened the coast of Fuwairit.

Currently, the surface of the fossil dunes where the historical quarries are is dominated by shamal winds during winter and early summer (Aboobacker *et al.*, 2021). These winds generate wind abrasion marks with a marked directionality (Figure 2a). Aeolian abrasion is the process whereby rocks and landforms are eroded by saltating particles, contributing to the formation of ventifacts, yardangs, deflation basins, and inverted relief. Sand is the predominant abrasive agent. Abrasion is sensitive to the highest velocity winds in a region, which controls the directionality of ventifact features. Many decades, centuries, or even millennia may be required for ventifact formation, depending on the frequency of the winds (Bridges & Laity, 2013). Jabel Fuwairit is also affected by hygroscopic salts from the sea, which at high temperatures crystallise in the porosity of the limestone and break the bonds of the ooids, which accelerates the erosive action of the wind.

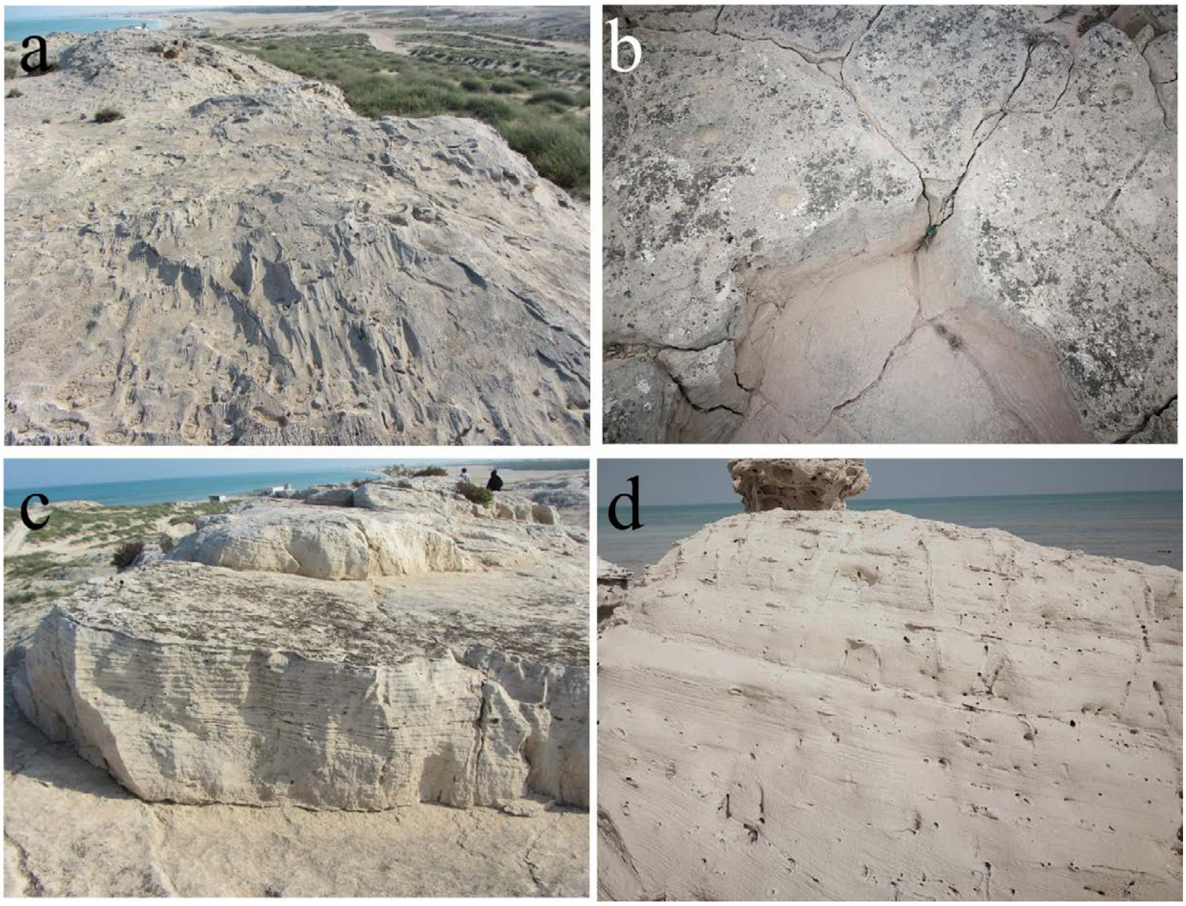

Figure 2. Geological aspects of Jabal Fuwairit historical quarries. a: General view with superficial wind abrasion marks; b: Desiccation cracks that individualize blocks facilitating extraction; c: Planar cross-stratification; d: View of a stratum with bioturbation (Rhizocretions).

Figura 2. Aspectos geológicos de las canteras históricas de Jabal Fuwairit. a: Vista general con marcas superficiales de abrasión por el viento; b: Grietas de desecación que individualizan los bloques facilitando su extracción; c: Estratificación cruzada planar; d: Vista de un estrato con bioturbación (Rizocreciones).

3. PETROGRAPHY OF BUILDING STONES FROM THE HISTORICAL QUARRIES OF JABAL FUWAIRIT

The building stones extracted from the historical quarries of Jabal Fuwairit are ooidal limestones characterised by medium-scale crossbedding and a vuggy fabric with *ophiomorpha* burrows and cemented roots. They are classified as an oosparite (Folk, 1962) and as a grainstone (Dunham, 1962) (Figure 3). They show uniform granulometry. Ooid grains are well sorted and medium- to coarse-grained, with sparse fossil debris as echinoid spines. The limestones are cross-bedded, almost devoid of skeletal components, and consist almost exclusively of ooids and coated grains. Ooids display concentric laminae. The nuclei of ooids are mostly carbonates, but there are also quartz nuclei in smaller quantities. The ooid cortices consist of alternating clear thick lamellae and dark thin micritic laminae (Freire-Lista *et al.*, 2021). Cortices and/or the nuclei of many ooids have been dissolved leaving oo-moldic porosity. The molds are sharply defined, commonly surrounded by micrite rims, and in some cases partially filled by calcite cements. The interparticle porosity is occluded by calcite cements. The equant spar of calcite is the volumetrically most important cement. These types of cement were precipitated as isopachous rims, filling interparticle, intraparticle, and oo-moldic porosity. The calcite cements surround the ooid grains and reduce more substantially the primary as well as the secondary porosity (Zhang *et al.*, 2023). Interparticle macropores between ooids are filled by isopachous calcite and late equant meteoric cement.

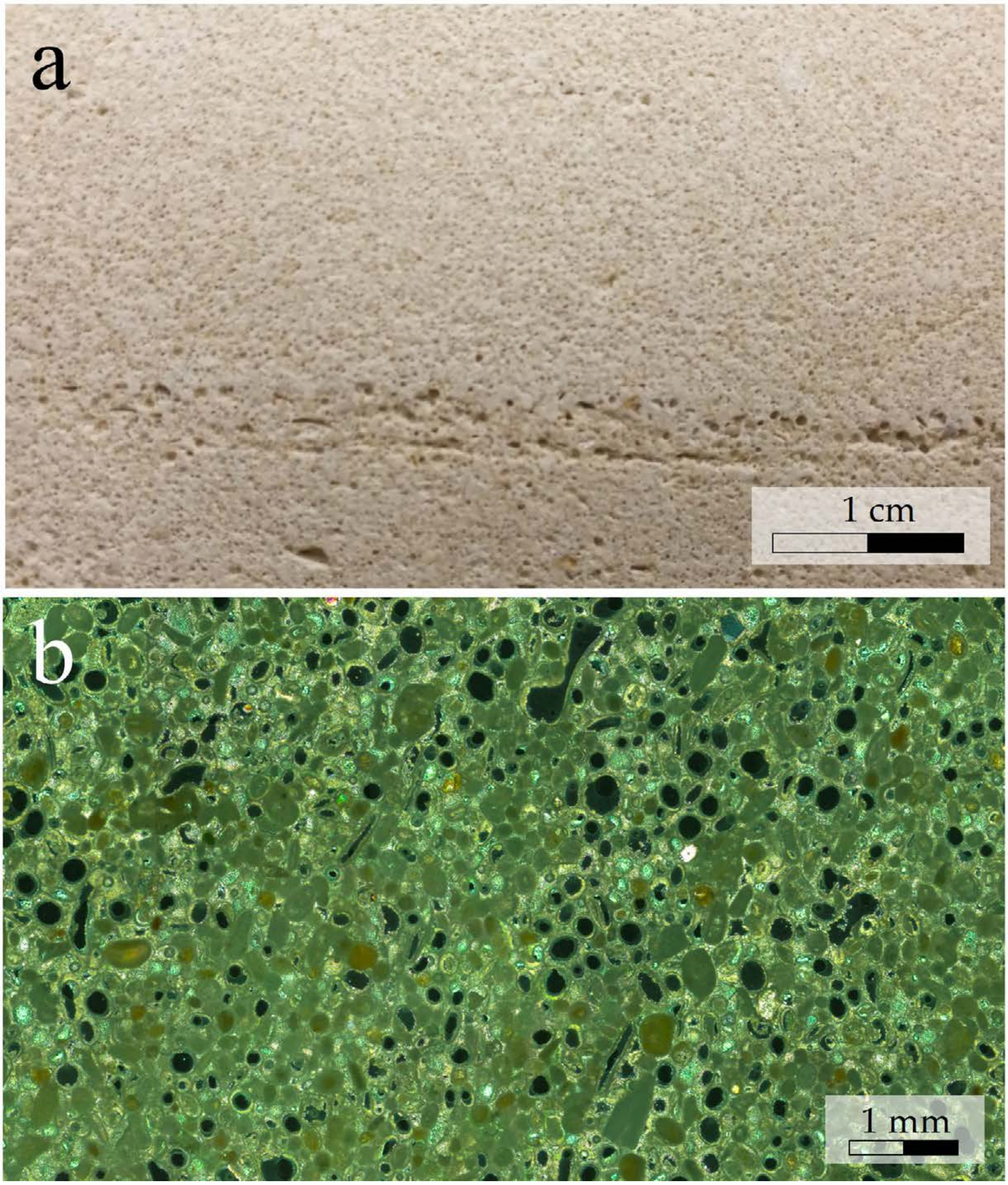

Figure 3. Grainstone extracted from the historical quarry of Jabal Fuwairit. a: Macroscopic view. b: Microscopic view.
Figura 3. Caliza extraída de la cantera histórica de Jabal Fuwairit. a: Vista macroscópica. b: Vista microscópica.

4. ARCHAEOLOGICAL AND HISTORICAL NOTES

The inhabitants of the Fuwairit area discovered the properties of the surrounding stones and quarried them for their buildings, also engraving rock outcrops on Jabal Fuwairit with petroglyphs and inscriptions. These are difficult to date, but the evidence presented below shows that some were created during the recent historical era, contemporary with or soon after quarrying events relating to the 18th-20th town of Fuwairit. Similar petroglyphs at Jabal Jassasiya (northeast Qatar) are from the last three centuries. Representations of more recent boats also exist at this site. But also, evidence for dates earlier in the Islamic period, namely Lombard's evidence from Qala'at Al Bahrain for a "game board" earlier than the 16th century AD.

The most abundant petroglyphs type in Jabal Fuwairit are cup-marks, roughly hemispherical depressions of about 2-10 cm diameter and up to 3 cm depth, often appearing in groups on the surface of many rocky outcrops.

The rock carvings of Qatar were first recorded by P. V. Glob in 1957 and there are currently nineteen rock carving sites confirmed throughout the country. A further five were reported by the Danish archaeologist in the 1960s but are not yet localised. The groups of cup-marks generally have two shapes (Pelling, 2014): A double row of cups, generally seven per row, and a circular configuration of cups surrounding a central cup, called "rosettes" (Figure 4). They have traditionally been attributed to being "board games" as they resemble a traditional board game commonly known as mancala, which is often found along trade routes from Africa to Southeast Asia. This is known locally as Al Haloosah (Pelling, 2014). However, this theory has been questioned in recent decades due to their large numbers in small areas and, in some cases, they are carved into steep slopes and locations not suitable for use as game. The Rosettes were also interpreted as game boards, a variation of the same mancala game known in Arabia as Al Ailah. A Fuwairit engraving shows a large, shallow cup with radiating channels ascending the slope on which they are located. These are shaped like a comet (Pelling, 2014) (Figure 4d). It is interesting to observe that all the cup carvings are connected by channels downhill from the Jabal in which they are carved, and all of them advance towards the sea, which may indicate that they are related to liquid runoff or watercatcher.

Other rock carvings comprise a series of cups larger and deeper than the aforementioned cup-marks. Their average diameters are approximately 15 cm and their depths are usually greater than 10 cm. These cups are often connected by channels and they are located a few hundred meters from the fossil dune, east of Jabal Fuwairit. The outcrop in which these cups are found is stratigraphically below Jabal Fuwairit and presents boulders, remains of bivalves, and centimeter-sized gastropods. The utility of these cups is also unknown (Figure 5). There are anthropogenic abrasion marks on the inside of the cups, which may indicate that their function was most likely related to the need to grind, crush, macerate, pulverise, or soften certain elements, both organic and inorganic. Mortars similar to those found at Fuwairit have been reported with some frequency (Gutiérrez Calvache *et al.*, 2014), and some researchers have proposed considering mortars used in the elaboration of dyes from iron oxides and gastropods. Neolithic sites of the Arabian Gulf are mostly concentrated close to high biodiversity and biomass 'hot spots' such as estuaries, mangroves, seagrass meadows, and coral reefs where marine life abounds in the form of shellfish, crustaceans, marine mammals, and fish (Lidour, 2023). Notably, Al Khor Island (Purple Island), approximately 40 km from Fuwairit, was a centre for the extraction of purple dye from gastropods in Bronze Age (Carter, 2010).

Regarding the dating of the petroglyphs at other sites, evidence Jabal Al Jassasiya has provided chronological evidence from carvings of boats, and from scientific dating. Jabal Al Jassasiya petroglyphs include overhead views of oared boats, and side view of boats that allow identification of the boat type. Identifiable boat types are strongly associated with the 18th-20th centuries AD, though a date range back to the 11th century AD is theoretically possible (Facey, 1987). A relatively late date for some of the petroglyphs was confirmed, however, by radiocarbon dating of the calcium oxalate patina on the surface of several cup-marks, a large round basin, and two boat depictions (Hassiba *et al.*, 2012). Most returned dates listed as "modern", indicating the mid-20th century AD or later, but one from a rosette and two from unspecified cup-marks gave dates falling within the last 300 years, with the calibrated probability range of the oldest falling mostly in the 17th and 18th centuries AD. However, a longer range of age for certain types of petroglyph is indicated by “mancala boards” from Bahrain that were built into (and therefore predate) a 16th century structure at Qala’at Al Bahrain (Lombard, 2018). Similar mancala-like rows of cup-marks, with grooves leading off some of them, were carved into a gypsum feature at the early 9th century AD site of Ain Mohammed North B, in northwest Qatar. These closely resemble some of the Jassasiya petroglyphs and imply that the tradition was at least as old as the Early Islamic period.

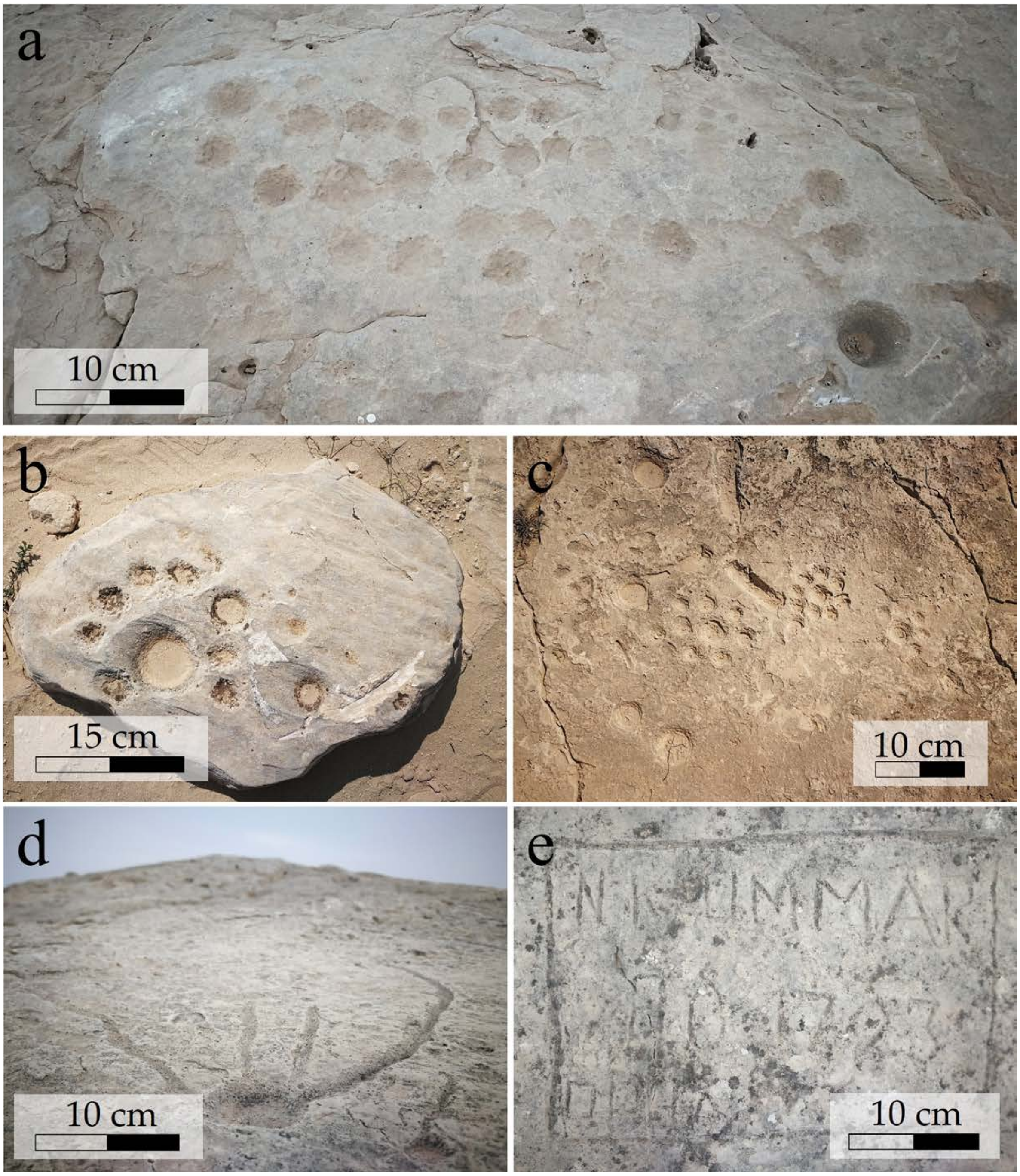

Figure 4. Rock carvings at Jabal Fuwairit. a: Grouped (left) and isolated (right) cup-marks; b: Cup-marks located on a circle with a cup-mark inside (Rosette) and two isolated cup mark with wind abrasion (right); c: Four isolated cups marks (right) and three rosettes (left); d: Cup-mark with four upslope channels; e: Recent inscription on the top of Jabal Fuwairit.

Figura 4. Grabados rupestres en Jabal Fuwairit. a: Marcas de copa agrupadas (izquierda) y aisladas (derecha); b: Marcas de copa ubicadas en un círculo con una marca de copa en su interior (Rosette) y dos marcas de copa aisladas con abrasión por el viento (derecha); c: Cuatro marcas de copas aisladas (derecha) y tres rosetas (izquierda); d: Marca de copa con cuatro canales ascendentes; e: Inscripción reciente en Jabal Fuwairit.

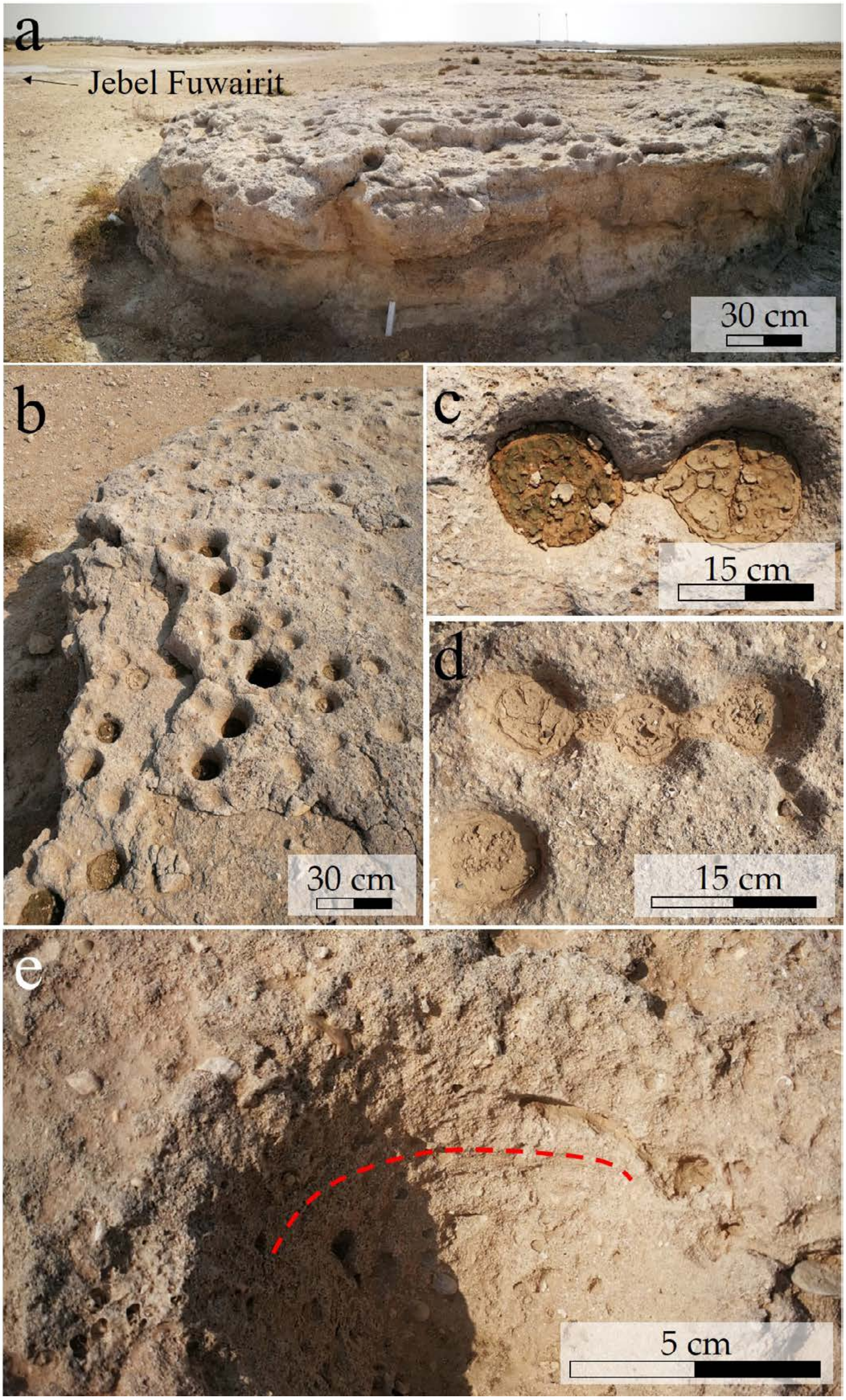

Figure 5. A set of individual cup-marks, sometimes connected by channels. a: General view of the outcrop with mortars; b: View of the area with the greatest number of mortars; c and d: Detail of mortars connected by channels; e: Interior of a mortar with anthropogenic abrasion marks.

Figura 5. Conjunto de marcas de copa individuales, algunas veces conectados por canales. a: Vista general del afloramiento con morteros; b: Vista del área con mayor número de morteros; c and d: Detalle de morteros conectados por canales; e: Interior de un mortero con estrías de abrasión antrópicas.

Archaeological investigations by the *"Origins of Doha"* and *"Qatar Project"* indicate that the archaeological site of Fuwairit was first significantly occupied in the 18th century, probably before the middle of the century. This coastal town saw several abandonments and reoccupations during the 19th century, also supported by the historical data, and at one stage it was the hometown of the Al Thani dynasty, who transferred residence to Doha in the mid-19th century. During the late 19th and very early 20th century it was walled, and major buildings included an unusually large congregational mosque. Most other buildings consisted of simple stone-built residential family compounds, with small neighborhood mosques, and a large shaikhly compound found close to the center of the site, dating to the early 20th century (older shaikhly compounds and forts were likely present but remain undiscovered) (Carter & Eddisford, 2017; Freire-Lista *et al.*, 2020). Its final occupation, by members of the Bu Kuwara tribe, took place in the early 20th century, ending in the early 1930s. This occupation provided the core of collapsed buildings in the center of the site. Frequent episodes of rebuilding and stone-robbing have heavily disturbed the building remains of earlier occupations beneath and surrounding the final occupation phase. A small resettlement later took place to the south of the site, which from the 1950s onwards expanded into today's village of Fuwairit. Throughout its occupation from the 18th to the early 20th century it can be characterised as a small pearl-fishing town. The pearl oyster banks of Qatar were once an extremely productive economic resource within the Arabian Gulf (Smyth *et al.*, 2016). The pearl oyster *Pinctada imbricata radiata* is an iconic species in Qatar, representing an integral part of the nation's cultural heritage and one of the main economic foundations upon which the nation developed. During the early part of the 20th century, nearly half the Qatar population was involved in the pearl oyster industry (Bean *et al.*, 2020).

5. HISTORICAL QUARRIES OF JABAL FUWAIRIT

In the last years the attention to historical quarries developed in three main directions: to find and to apply innovative solutions to protect the stone historically used for monuments and buildings (Martínez-Martínez *et al.*, 2017; Chelazzi *et al.*, 2018, Rosewitz & Rahbar, 2018; Toniolo & Gherardi, 2018; Croce, 2021; Merico *et al.*, 2022; Ksinopoulou *et al.*, 2022), to recognize and protect the heritage stone widely employed in a territory qualifying through physical and mechanical properties and referring to the historical and current quarries (Kaur *et al.*, 2021; Cárdenes *et al.*, 2021a; Castro *et al.*, 2021; Freire-Lista *et al.*, 2022a; Salvini *et al.*, 2023; Çetintaş *et al.*, 2023; Shaeri *et al.*, 2022), and highlight areas with potential for geotourism (Lahmidi *et al.*, 2022; Freire-Lista *et al.*, 2022b).

Quarrying in the historic Jabal Fuwairit is determined by stratification and desiccation cracks. Naturally occurring desiccation cracks form in sediments that were once saturated with water and subsequently dried and contracted. The bedding is pseudo-horizontal and the desiccation cracks are pseudo-perpendicular to the bedding (figures 2b and 6).

The quarry area of Jabal Fuwairit has an inscription that shows two lines of Arabic above a complex geometric petroglyph (figures 6c and d). Along with the inscription "mancala" cup-marks are found on the surface exposed by the quarrying, indicating that the petroglyphs and inscription were carved after the quarrying had taken place. The inscription is interpreted as a celebration of the building of a new shaikhly residence soon after 1890 AD by the headman of Fuwairit, Nasr bin Shahin Al Tuwar, using stones quarried from the location of the inscription. It is one of two Arabic inscriptions in the area by shaikhs of the Tuwar family, a leading branch of the Bu Kuwara tribe, the last residents of the site. Arabic inscriptions of any date are exceptionally rare in the region (leaving aside graffiti of the second half of the 20th century and later). Nasr bin Shahin had led his section of the Bu Kuwara to Fuwairit to resettle their ancestral town in the last decade of the 19th or first decade of the 20th century AD. They had been there previously in the 19th century but had briefly resettled in Doha in 1890, before moving back to Fuwairit soon afterwards. The wording of the inscription of Nasr, ḥadath āwal lil Būkūwāra, Nāṣr bin Shāhīn Ṭūwār translates as "a foremost event for the Bu Kuwara, Nasr Bin Shahin Tuwar", and the geometric rock engraving below it resembles a house plan. The petroglyph's outlines and proportions bear a striking resemblance to the wall outlines of a very large compound in the centre of the site, perhaps the compound of Nasr bin Shahin (clearly visible in a 1948 aerial image).

Other inscriptions are found around the southern foot of the Jabal, including one that translates as "Isa bin Nasr Bu Kuwara, born in the year 1301" (1883/4 CE). Nasr bin Shahin Al Tuwar is known to have a son named 'Isa, and this could commemorate his birth a few years after an earlier migration to Fuwairit from Doha in 1879 (Lorimer, 1915). The Bu Kuwara had an epigraphic habit, rare in the region, as a further inscription is known in the Bu Kuwara village of Al Ghariyah, not far to the north. This cannot be easily read but bears the date 1303 (1885/6 CE).

It is notable that several other stone outcrops in Qatar show similar signs of quarrying and are associated with the same kinds of cup-marks and other petroglyphs, all adjacent to 18^{th}-20^{th} settlements, for example at Bida (Doha), Fraiha, Ghariya, and Al Khor. From this, we infer that, despite the earlier evidence for earlier petroglyphs and "mancala" carvings in the region, many were likely to have been carved during and after the building of Qatari coastal towns in the 18^{th}-20^{th} centuries CE, perhaps by the individuals who were quarrying the stone.

Industrialization, transport development, and new materials led to the abandonment of traditional historical quarries (Gutiérrez Claverol *et al.*, 2012; Careddu *et al.*, 2018). The use of traditional heritage stones for construction declined in Qatar in recent decades. However, today historical quarries gain heritage and historical value that strengthen the identity aspects of a nation and they are essential for conserving built heritage (Šťastná *et al.*, 2009; Taelman *et al.*, 2013; Freire-Lista & Fort, 2016; Germinario *et al.*, 2017). The Heritage Stone Sub-commission (HSS), under the auspices of the International Commission on Geoheritage (ICG) of the International Union of Geological Sciences (IUGS), works to raise awareness of the heritage importance of natural stones (Careddu & Grillo, 2015; Lopes & Martins, 2015; Garg *et al.*, 2019; Hannibal & Schnabel, 2020; Cárdenes *et al.*, 2021b; González-León *et al.*, 2024), as well as to preserve their historical quarries, emphasizing the importance of stones in the preservation of historical buildings and the cultural legacy of a region (Ehling, 2018; Wyse Jackson *et al.*, 2019; Cetean *et al.*, 2022).

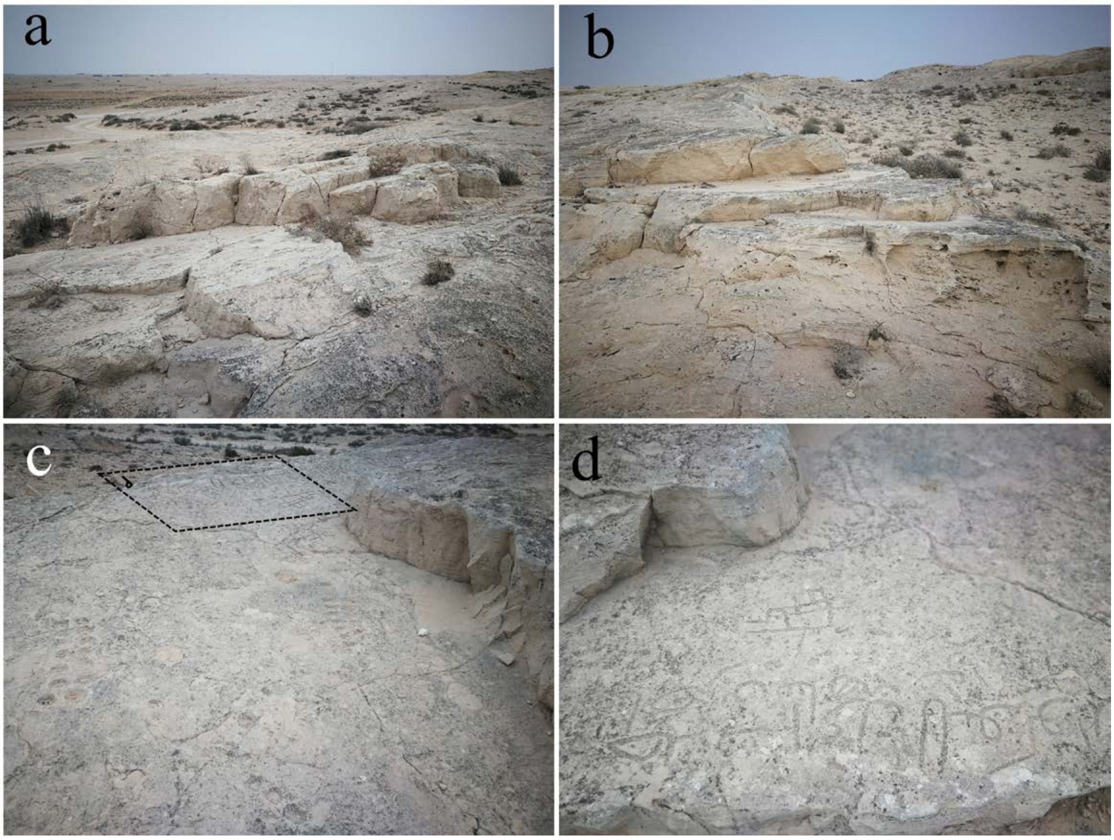

Figure 6. Jabal Fuwairit historic quarry extraction fronts. a and b: General view of taking advantage of the stratification of the fossil dunes; c: Base with rock carvings (grouped cup marks) and house plan with an inscription. d: Detail of the house plan with an inscription.

Figura 6. Frentes de extracción de la cantera histórica de Jabal Fuwairit. a y b: Vista general del aprovechamiento de la estratificación de las dunas fósiles; c: Base con grabados rupestres (marcas de copas agrupadas) plano de una casa con inscripción. d: Detalle del plano de una casa con inscripción

6. CONCLUSIONS

Historical quarries can be reused generating economic profitability with cultural actions. Jabal Fuwairit historical quarries have enough geological, archaeological, and environmental elements to become an open-air museum.

By understanding the origin of the materials, a relationship can be established with the historic structures and monuments in the area. This allows for better conservation and restoration of heritage assets.

Jabal Fuwairit reveals the level of knowledge that historic stonemasons had about geology and the properties of materials, and they present pieces of evidence for understanding the use of quarries throughout the human occupation of Qatar.

The building stones extracted from the historical quarries of Jabal Fuwairit are ooidal limestones characterised by medium-scale crossbedding and a vuggy fabric with *ophiomorpha* burrows and cemented roots.

Stratification together with desiccation fractures are the main fracture surfaces that allow easy extraction of blocks in the historical quarries of Jabal Fuwairit.

Jabal Fuwairit has numerous engravings, especially cup-marks, and possibly a ground-plan of a house with an inscription, attesting to the place where the stone was extracted for the building of a shaikhly residence around 1900 by the headman of Fuwairit.

Other historical quarries in Qatar need to be studied and catalogued. Future studies may reveal the extraction techniques used and the trade of building materials in the past, offering a window into technological advances and relationships between different regions.

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D. M. Freire-Lista: Conceptualization, formal analysis, investigation, methodology, writing – original draft, writing – review & editing.

Robert Carter: Funding acquisition, project administration, investigation, writing – review & editing.

Faisal Abdulla Al-Naimi: Funding acquisition, project administration, investigation, writing – review & editing.

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Statement on the use of Artificial Intelligence

Not applicable.

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