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Neolithic long-distance exchanges in Southern Arabia: A supposed road for the 'Jade' axes

Mohammed Al Kindi [a,*], Vincent Charpentier [b], Maria Pia Maiorano [c], Maya Musa [d], Alexia Pavan [e], Alan Heward [f], Jérémie Vosges [g], Grégor Marchand [h], Martin Pickford [i]

[a] *Earth Sciences Consultancy Centre, P.O. Box: 979, P.C.: 611, Muscat, Oman*
[b] *Inrap, UMR 7041 ArScAn, Paris, France*
[c] *Department of Asian African and Mediterranean Studies, University of Naples "L'Orientale", Italy*
[d] *Gulf Institute of Gemology, Bait Al Reem, Thaqafah St, Al Khuwair 133, Muscat, Oman*
[e] *Ministry of Heritage and Tourism, Salalah, Oman*
[f] *23 Croftdown Court, Malvern WR14 3HZ, UK*
[g] *Archéorient, UMR 5133, Maison de l'Orient et de la Méditerranée, Lyon, France*
[h] *CREAAH, Laboratoire Archéosciences, UMR 6566 CNRS, University of Rennes 1, France*
[i] *Muséum national d'Histoire naturelle, UMR 7207 CR2P, MNHN-CNRS-SU, Paris, France*

A R T I C L E I N F O

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A B S T R A C T

This paper discusses the results of a new geo-archaeological study on the nephrite (jade) axes discovered in southern Oman (Dhofar Governorate). The research presents a first account of the geological composition and the morphological structure of such tools and it outlines a preliminary distribution network of jade axe-heads across Southern Arabia. After the discovery of the first analysed sample at Shaqat Jadailah SQJ-3, in the Rub' al-Khali Desert (Dhofar), four other archaeological axe-adze samples collected from southern Oman, were analysed using micro-Raman Spectroscopy and Energy Dispersive X-Ray Fluorescence (ED-XRF). We compared the analysed samples to other nephrite axes collected in the first pioneering exploration of Gertrude Caton-Thompson (Yemen) and Wilfred Thesiger (South Oman). These objects were then correlated with nephrite raw material from the basement exposures in Yemen. Available data show that the raw material originating in Yemen reached the Neolithic groups of Southern Rub' al-Khali and coastal Dhofar most likely during the 6th-5th millennium BC, following a similar path to the obsidian route. The colour, texture and composition, together with the presence of other classes of lithic artefacts such as the trihedral projectile points, indicate that during this period Southern Oman was fully integrated into long-distance exchange networks. The analysis of the collected samples show that they are made exclusively from nephrite, and not from other general "green stones". Considering the high hardness and toughness of the nephrite, this fact allows the hypothesis of a deliberate choice in the selection of raw material for its durability or prestige value.

1. Introduction

The discovery of a remarkable jade axe-adze in the Omani Southern Rub' al-Khali during a joint geological and archaeological survey in the area in 2019 provided a new stimulus to the studies of long-distance exchange across the Arabian Peninsula. Following this discovery, other specimens were located in South Oman. In addition, specimens collected by the prehistorian Gertrude Caton-Thompson from Yemen and the explorer Wilfred Thesiger from South Oman were also examined, which are currently kept in museums in the U.K.

As early as the Neolithic, Jade artefacts (jadeite, nephrite, etc.) spread to diverse communities in the framework of a complex exchange network over considerable distances across Europe (Smith, 1965; Pétrequin et al., 2012) and Southeastern Asia, and similar widespread dispersion has been reported from remarkable sites in China where it is related to the trade of ornaments (Hung et al, 2007; Wen and Jing, 1992). Jade axes from the Italian Alps (Viso and Beigua mountains) circulated at a supra- and transcultural scale, from the shores of the Atlantic (Brittany, France) to those of the Black Sea (Bulgaria) (Pétrequin et al., 2012, 2017), testifying that an intense long-distance

* Corresponding author.
E-mail addresses: malkindi@omanescc.com, kindi@gmail.com (M. Al Kindi).

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exchange network occurred for these semi-precious stones since the second half of the 6th millennium BC.

In Southeastern Arabian, Neolithic axes and polished tools are, indeed, rare. Only a few specimens have been collected in Oman. The first at Ra's al-Hamra RH-6, where an axe made in conglomerate can be dated to the first two centuries of the 5th millennium BC (it lies between two layers dated 5750 ± 60 and 5970 ± 80 BP[1], Biagi, 1994, 1999), but also at Ra's al-Hadd HD-6 (Charpentier et al., 2013), together with six specimens recovered at different archaeological sites along the coast of Masirah Island (Charpentier et al., 2013). In total, about ten specimens have been found in Oman, and a few more in the UAE at Buhais, Shobeka UAQ2, Tel Abraq (Charpentier, 2020; Jasim et al., 2005; Méry, 2015). Also, in Yemen stone axes and azdes are extremely rare and infrequently reported in the literature (Crassard, 2008).

Around the second half of the 7th millennium BC (7184 – 7082 BP[2], Martin et al., 2009) a major socio-economic change took place in Arabia during the appearance of the first Neolithic pastoral societies (Charpentier, 2008; Crassard and Drechsler, 2013; Maiorano et al., 2020a; McCorriston, 2013). Arabian groups of hunter-gatherers developed alternative subsistence strategies focused on fishing and the herding of a few domestic species (Borgi et al., 2012; Uerpmann and Uerpmann, 2003; McCorriston, 2013; Munoz, 2019). In Southern Arabia, agriculture did not appear until the Early Bronze Age, from 3200 cal. BC (4538 ± 30 – 4464 ± 24 BP[3], Döpper and Schmidt, 2019) together with copper metallurgy that long preceded ceramic production. As the main indicator of novel transregional social connections, the creation of exchange networks, sometimes over long distances, is the most characteristic aspect of Southern and Southeastern Arabian acculturation processes from the end of the Early Holocene to the first part of the Late Neolithic from the 9th to the 6th millennium BC (Beech, 2006; Charpentier, 2008; Crassard, 2008; Inizan, 1997a; Maiorano et al., 2020a). In addition to the spread and exchange of fine and elaborate knapping technologies from the beginnings of the 6th millennium BC (7270 ± 120 – 6931 ± 48 BP[4], Crassard, 2008), or even earlier, the exploitation and circulation of new raw materials emerged.

In this landscape, where mobile herders most likely coexisted with hunter gatherer groups (McCorriston, 2013; Maiorano et al., 2020a, 2020b; Uerpmann et al., 2013), the circulation both as naturally derived clasts (obsidian: cobbles eroded from volcanic sources) or soft rocks (chloritite steatite, serpentinite), together with marine shells and, later, artificial products (bitumen, plaster, pottery), became of central importance in the Arabian Peninsula maritime and terrestrial exchanges. All these items provide evidence for a Neolithic and Bronze Age complex diffusion network, involving not only the entire Peninsula but also faraway lands such as the Horn of Africa and Mesopotamia (Carter, 2018; Khalidi, 2010).

In this paper we focus on the exchange of nephrite jade involved in the production of rare and "prestige" objects. The first discoveries were reported in southern Arabia as early as the 1930s (Warner, 1931), later being the subject of a short communication by Marie-Louise Inizan who reported that ≪a green rock (a variety of nephrite) is intended for the manufacture of small axes≫ (Inizan, 1997a: 4–5).

After a summary and revision of the state of the art and a brief introduction on the archaeological sites where the samples were collected, this paper will focus on the adopted methodology and techniques selected to study the material and the possible nephrite sources, on which basis the exchange routes that may have characterised Southern Arabia during the Neolithic are tentatively reconstructed.

2. The Neolithic period in Southern and South-Eastern Arabia

During the past two decades, the archaeological and theoretical concept of the "Arabian Neolithic" has undergone several revisions (Zarins, 2002; Cleuziou and Tosi, 2007; Charpentier, 2008; Drechsler, 2009; Uerpmann et al., 2013; Charpentier and Crassard, 2013; Crassard and Drechsler, 2013; Méry and Charpentier, 2013). Most of the preliminary studies tended to associate the increase in human presence in Southeastern Arabia with the amelioration of weather conditions that occurred in the middle Holocene (occurred ca. 6500–4000 BCE according to Preston et al., 2015; Lézine et al., 2017; Maiorano et al., 2020a), but the absence of any typical feature related to the spread of the Neolithic in the Fertile Crescent–livestock, agriculture, sedentary settlements – and the contiguous regions, supported its denomination as "Late Stone Age" (Uerpmann, 1992).

The spread of domesticated livestock and specific manufacture technologies related to the so-called "Neolithic package" seems to follow two main routes, one being the inland path following the fringes of the Rub' al Khali and the other being the coastal path from Yemen to the Gulf (Kallweit et al., 2005; Charpentier, 2008; Charpentier et al., 2012; Maiorano et al., 2020a, 2018; Crassard, 2008; McCorriston, 2013; etc.). This expansion also concerned the islands, especially Masirah, the largest, but also smaller ones such as the Hallaniyah Archipelago, Farasan Islands, Marawah, Dalma, and Akab.

In parallel, continental Arabia had several palaeo-lakes, although less extensive than those of the Pleistocene, which were favoured places for the establishment of human communities along their shores (Crassard et al., 2013a, 2013b; Maiorano et al., 2020a). At the same time, the plains beyond the foothills were selected by Neolithic communities of mobile herders as represented by Jebel Buhais 18 in UAE (Uerpmann et al., 2013, 2009).

In the Yemeni highlands, Neolithic pastoral groups settled in the main valleys, exploiting small rock shelters, such as Manayzah in Hadramawt (Crassard, 2008; Crassard et al., 2006). The Early Neolithic seems to implicate only a small part of the Arabian Peninsula: the northern fringes of Saudi Arabia, (PPNA) (Crassard et al., 2013b), and the Qatar Peninsula (PPNB) (Kapel, 1967; Inizan, 1988; Pelegrin and Inizan, 2013). From Yemen to the U.A.E, passing through Oman, only traces related to the Middle Neolithic emerge (around 6500 BCE). This was characterised by the development of new technological strategy involved in the production of stone weapons made by pressure. This new step in the manufacture of projectile weapons characterises the Middle Neolithic facies represented by trihedral and Concorde projectile points (Crassard, 2008; Maiorano et al., 2018). The production of these sophisticated artefacts spread across Southern Arabia and can be associated with the period ranging from 6500 to 5000 BCE as reported from HDOR 419 (dated between 7270 ± 120 and 6931 ± 48 BP[5], Crassard 2008) and Suwayh SWY-1 (7245 ± 55–6050 ± 40 BP[6], Charpentier, 2008; Berger et al., 2013).

During the Middle Neolithic, human groups used sophisticated techniques, including parallel-covering retouch by pressure and heat treatment that modifies the texture of raw material (Charpentier et al., 2002; Crassard, 2008; Maiorano et al., 2018). The advent of the Late Neolithic at the beginning of the 4th millennium BC (Charpentier, 2004; Zarins, 2013; Maiorano, et al., 2020a) was marked by social competition for the conquest of the most suitable lands. This period saw strong regionalisation of lithic industries (Maiorano, et al., 2020a) with the

[1] Laboratory numbers: Bln-3636/1 and Bln-4315. The first date was extracted from a sample of *Terebralia palustris* mangrove shell, while the second from a charcoal sample of *Avicennia marina*.

[2] Laboratory number: AA66685. Sample of charcoal collected at Manayzah, K9.

[3] Laboratory numbers: MAMS27886 and MAMS24458. Both dates were obtained from charcoal samples collected at Building V in Al Khashbah.

[4] Laboratory numbers: AA64361 and AA64360. Both dates were calculated analysing two charcoal samples collected at HDOR 419.

[5] See footnote number 4.

[6] Laboratory numbers: Pa2140 and Pa2131. These dates were obtained from marine shell samples.

progressive disappearance of bifacial artefacts and the appearance in Eastern Oman of cutting tools made on rough blade blanks, and a peculiar type of point made on thick flakes and backed retouched stem and edge in Dhofar (Charpentier, 2008; Maiorano et al., 2018).

The climatic history of the South-Eastern Arabian region (and the entire Peninsula) has always been utilised as a cardinal base. An important, moist phase began in the early Holocene (8th millennium BC) and persisted through the middle Holocene with short periods of instability, ending around the beginning of the 4th millennium BC, when the climate became more arid (Preston, et al., 2015; Lézine et al., 2017).

3. Nephrite axes in Arabia: The state of research

In South-Eastern Arabia, Neolithic axes, adzes and polished tools are particularly rare. The known adzes and axes were generally produced in hard, siliceous stones, and one of these was shaped from haematite (Charpentier, 2020). However, the recent (2019) discovery of a jade axe in the Neolithic site of SQJ-3 in the area of Maitan (Rub' al-Khali, Maiorano et al., 2020b; Al Kindi et al., 2020) opened a new research path. This paper presents a first attempt to provide a first analysed collection of all the axes made in jade and nephrite from the literature (Caton-Thompson, 1944; Crassard, 2008; Inizan, 1997a, 1997b; Inizan and Rachad, 2007; Thesiger, 1946) together with the collection of small nephrite axes in the Rub' al-Khali made by amateurs mentioned in social networks, (cf. megalithic.co.uk), comprehending the in-depth analysis of the five artefacts available for micro-Raman Spectroscopy and Energy Dispersive X-Ray Fluorescence (ED-XRF). Our inventory covers Yemen and the Sultanate of Oman because no jade items have been so far recorded in the Emirates and only one is known from Saudi Arabian archaeological literature (Sordinas, 1978).

In 1931, William H. Lee Warner reported "a piece of jade shaped like a small axe head", found in the Wadi Du'an (Do'an, Dawan) in Hadramawt (Eastern Yemen) (Warner, 1931). The research undertaken in Yemen from the late 1980s onwards revealed a great number of such items, particularly during the survey expedition carried out by Marie-Louise Inizan, who reported the discovery of an axe from the edge of Ramlat as-Sab'atayn (Inizan, 1997a; Inizan et al., 1997), and a petrographic analysis of one of them, from site 17 at Al-Hawa, showed that it had been made in nephrite (tremolite) (Inizan, 1997b; Inizan: 66, 2007, Fig. 4). Subsequently, only at Manayzah (Hadramawt) the distal half of an extremely small axe was recovered (Crassard et al., 2006: Fig. 12; Fig. 4/e). Moreover, near Radā' A Amasān, a fragment of a polished 'green stone' axe and a hatchet suggested the presence of nephrite objects, as well as in the region of Sa'ada, where several Neolithic sites are characterised by the presence of such axes, as in Wādī Rūbay' (Inizan, 2007: 63-70, Fig 35n°11, Fig 33n°13). But the most exceptional object comes from another Neolithic site in the same region at Jebel al-Makhruq (Inizan and Rachad, 2007: Fig. 101), reported in Fig. 4, because its discovery demonstrates that 'jades' were exploited not only for the production of axes and adzes but also for other purposes.

In January 2019, the "Arabian Seashores" team joined a team of geologists and palaeontologists with the aim of exploring, through a systematic survey, the area north of the desert village of Maitan (Shaqat Jadailah and Shaq Shuayt). The area lies close to the borders that separate Oman, Yemen and Saudi Arabia and is characterised by sand dunes alternating with flat inter-dunal plains of gypsum and gravel. These hardened and flat inter-dunal surfaces have periodically hosted temporary lakes (Al Kindi et al., 2020). The linear sand dunes overlie Eocene shallow marine carbonates, and thin layers of Mio-Pliocene deposits, aeolianite and playa-like deposits. All the surveyed sites have undergone significant deflation. Shaqat Jadailah consists of a number of archaeological sites characterized by a high inter-assemblage diversity and thousands of well-preserved lithic artefacts. Concentrations of artefacts occur on evaporite and aeolianite beds on which Late Palaeolithic and Neolithic assemblages are numerous and seem to cover the entire period between the early and the middle Holocene. SQJ-3 (Fig. 2), in particular, is an extensive workshop for bifacial tools, projectile points, scrapers, ostrich eggshell beads and macro-tool production which might be safely dated to the Middle Neolithic on the basis of the technological study of the flint artefacts and the presence of trihedral and Concorde points dated to the 6th millennium BC (Crassard, 2008; Maiorano et al., 2020a). This extended site was a settled area characterised by hundreds of debitage flakes and bifacial thinning flakes, numerous bifaces abandoned at different stages of knapping, together with grinding and polishing stones. A nephrite axe specimen (Specimen 1, Fig. 3) was collected during the geological and archaeological survey in the Maitan area (Figs. 1 and 2). This finding triggered further research on the distribution of these tools and their uses. In the following months, the collection was enriched by three specimens (Specimens 2 to 4, Fig. 3) of nephrite axes stored in the warehouse of the Museum of the Frankincense Land, Salalah. These were found in Sumhuram and in the area of Khor Rori. Another specimen (Specimen 5, Fig. 3) was collected by a Dhofari man and is believed to come from Jebel Samhan. In addition, the samples presented here include two artefacts (Specimens 6 and 8, Fig. 4) collected by Wilfred Thesiger during his 1945–46 expedition and one of the axes (Specimen 7, Fig. 4) collected by Gertrude Caton-Thompson from Hureidha in Yemen. Despite (but also due to) their ancient origins, all these axes are considered in the traditional Omani society (and still today) to be magical objects, favouring their preservation and transmission over time and generations (Guba, 1995). Specimen 9 (Fig. 3) is a sample of raw nephrite material collected from outcrop in Yemen.

4. Overview of the collected nephrite axe heads

4.1. Specimen 1

Specimen 1 is a nephrite axe head, which was discovered at the margins of the main site SQJ-3 (Fig. 2). The adze-gouge has the shape of a drop. The cutting edge is rectilinear, asymmetrical, and convex in cross-section. The two edges converge toward a partially deteriorated pointed extremity. The overall cross-section of the body of the adze-gouge is lenticular. Surfaces are extremely smooth suggesting a high degree of polish which eliminated traces of possible picking or abrasion facets (Fig. 3, Specimen 1). However, the long exposure on the surface has modified the surface, giving it a desert-weathered aspect. Specimen 1 does not show any visible evidence of hafting. However, the accuracy in its shaping, the symmetry, as well as the treatment of the convex cutting edge might indicate a functional potential.

4.2. Specimen 2

Other samples come from the Salalah area where they are stored in the Museum of the Frankincense Land. The first, Specimen 2, (Fig. 3) is a miniature axe (S1055) discovered in the city of Sumhuram[7] outside the perimeter wall (namely A7). The area was covered by an accumulation of debris discarded from older excavations (Cleveland, 1960; Albright, 1982). A large number of different materials was collected during the removal of this mixed-up layer, including metal objects, coins, stone objects, pottery sherds and this axe (S1055). The specimen is almost complete except for a small break in the cutting edge. There is no evidence that the axe had been used and the minor wear may be a taphonomic effect.

[7] Sumhuram is a fortified settlement founded in the 2nd century BCE as the easternmost outpost of the caravan kingdom of Hadramawt and it was definitively abandoned, after a couple of centuries of crisis, in the 5th century CE (Avenzini 2008).

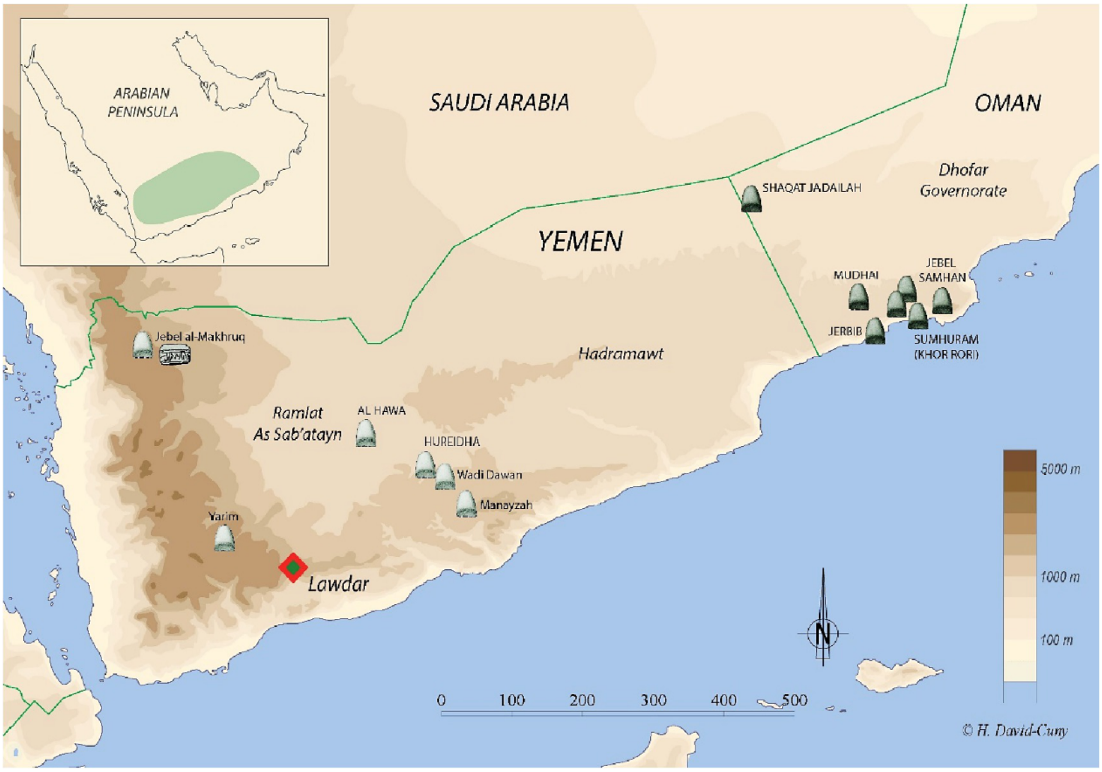

Fig. 1. Map showing the location of the nephrite axes presented in this paper (dark green), the specimens cited in literature (light green), and the possible source of raw material (in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

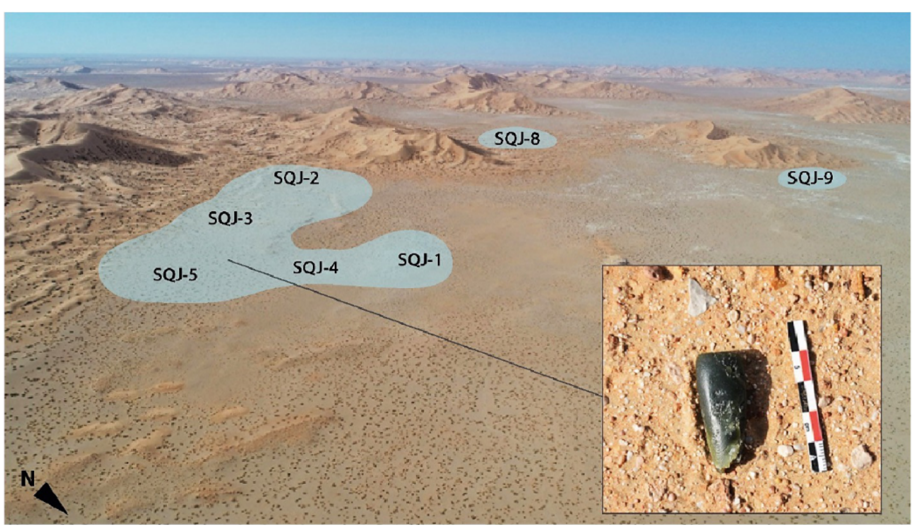

Fig. 2. Aerial photo of the sand dunes and flat interdunal surfaces (often with evaporite and lake deposits) at Shaqat Jadailah (SQJ-3), where the nephrite axe was found during a geo-archaeological survey in January 2019. Detail: Deflated surface at the flat interdunal areas where the nephrite axe was found in Shaqat Jadailah.

4.3. Specimen 3

The third miniature axe (Fig. 3) was found during a geo-archaeological survey conducted in 2006 by Mauro Cremaschi and Alessandro Perego at Khor Rori (Cremaschi and Perego, 2008). The Neolithic axe was discovered in the pre-Islamic graveyard KR55-KR56 (TA95: 255), located about 2 km northwest of the city of Sumhuram. The small axe presents two close detachments along the active edge, probably traces of re-sharpening, although it was not polished afterwards. The butt presents traces of percussion (picking or hammering). Due to weathering, it is not possible to identify evidence of use.

4.4. Specimen 4

Another axe (Fig. 3) was discovered at Sumhuram in 2010. The axe was found during consolidation works of the buttresses on the south-eastern perimeter of the city wall. Walls in Sumhuram were built with the rubble masonry technique with internal filling. The objects with apotropaic/votive function were found inside the infilling of the walls (database of the Italian Mission to Oman, S2493 (M25, SUM14A)). This axe is relatively large with a symmetrical biconvex section with a well-polished distal edge, while the proximal part (the haft-end) is missing. Another possibly nephrite axe was discovered at Sumhuram during the

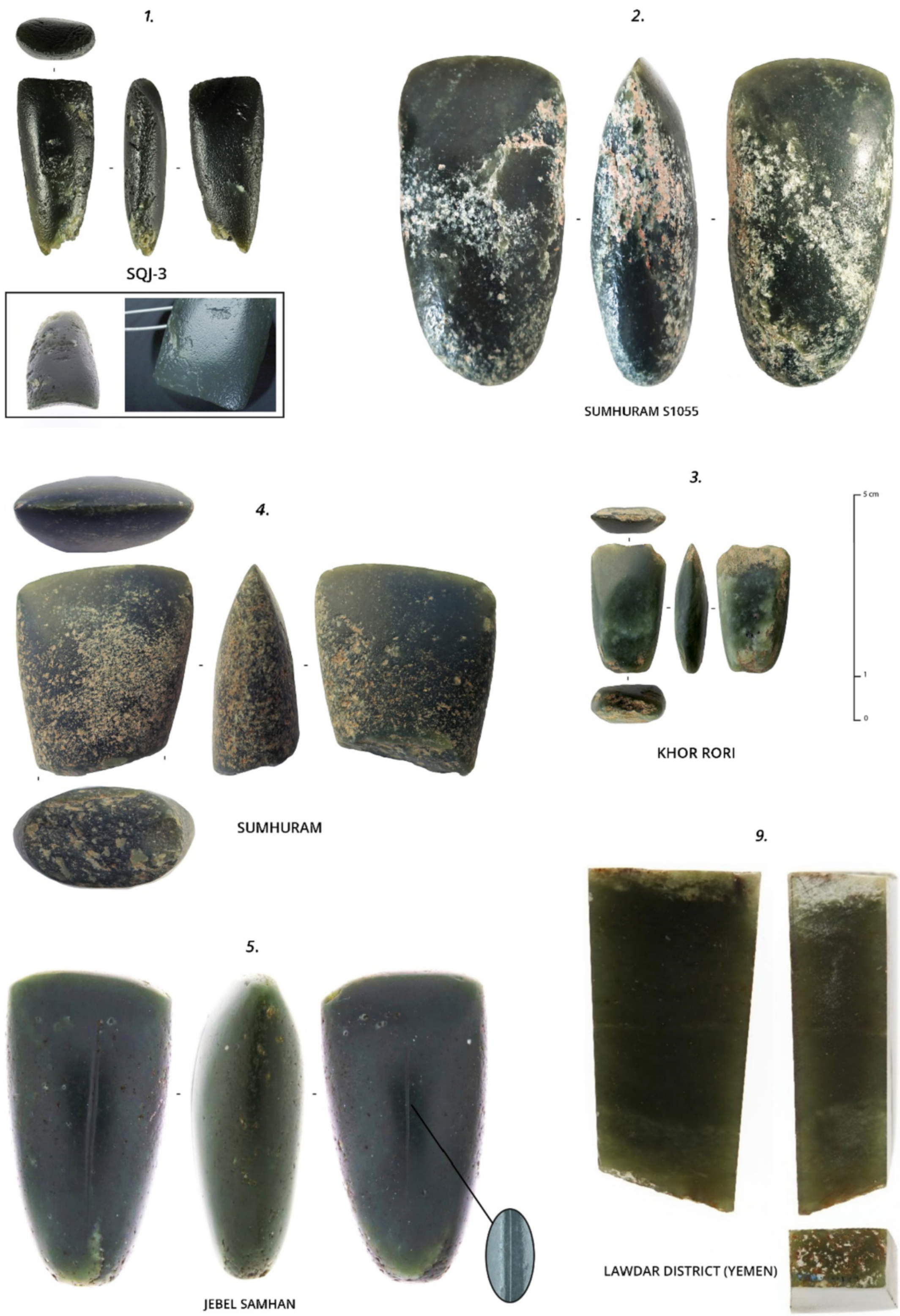

Fig. 3. Analysed axes from Dhofar (Oman): specimen from Shaqat Jadailah SQJ-3 (1) with a detailed view of the gouge, S1055 (2), Khor Rori (3), Sumhuram (4), Jebel Samhan (5) with the detail of the engraving, and a raw material block from a nephrite outcrop in Yemen (9). All the pictures were scaled according to the reported reference (5 cm).

excavations in 2000, but it is currently not available for examination by the authors.

4.5. Specimen 5

While seeking additional nephrite axe heads from Oman, we were contacted by a man from Jebel Samhan. He inherited a nephrite axe (Specimen 5, Fig. 3) from his grandmother. She found the axe lying in

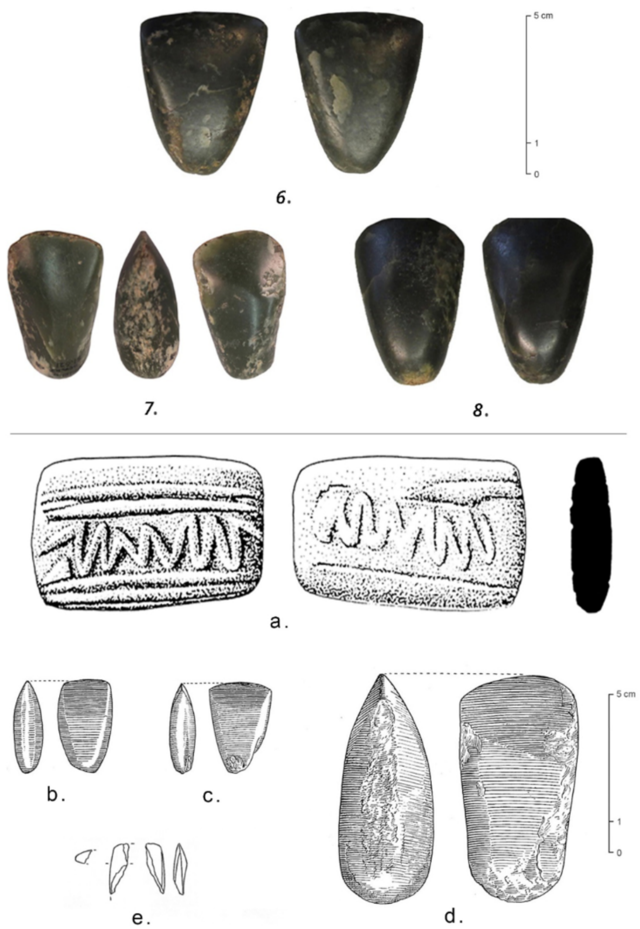

Fig. 4. Photos of the axe heads collected by Wilfred Thesiger (6, 8) and a polished jade axe bought at Hureidha by Gertrude Caton-Thompson (7). In the lower part of the plate are reported the drawing of a nephrite artefact characterised by snake-shaped decorations on both sides coming from Jebel al-Makhruq in Yemen (*a*, after Inizan and Rachad, 2007), the jade axe heads from Hureidha (*b*, *c*, *d*; after Caton-Thompson, 1944), and the green stone axe fragment from Manayzah (after Crassard et al., 2006). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

one of the wadis in the jebel. It has neat engraved grooves on the middle of its faces, parallel to its long axis (Fig. 3). As in the other specimens, its shaping is balanced, the symmetry between the two faces respected and the edge extremely sharp, although due to the weathering it has undergone, it is not possible to detect use-wear traces.

4.6. Specimens 6 and 8 (Museum numbers: BM 1947 10.3.1 and BM 1947 10.3.2)

During his 1945–46 expedition, Wilfred Thesiger collected the first nephrite axe (Specimen 6, Fig. 4) from under an overhang by a wadi near Mudhai. He acquired a second one from a local Dhofari (Specimen 8, Fig. 4) who had found it near Jerbib (10 km northwest of Salalah) (Thesiger, 1946). These two specimens are shown in Fig. 4 (specimens 6 and 8 respectively). The properties of the specimens collected by Thesiger are shown in Table 4. There is some damage to the haft end of both heads as though they may have been used for pounding. Minor chipping of other edges and the cutting edge being due to taphonomic damage.

4.7. Specimen 7 (Museum Number: MAA 1951.621)

In 1938, the archaeologist Gertrude Caton-Thompson collected three jade axes at Hureidha in Hadramawt (Caton-Thompson, 1944; Stark, 1940). In 1944, she wrote a research report titled "The Tombs and Moon Temple of Hureidha (Hadramawt). She described the axes, as follows:

1. Polished Jade Axe (Fig. 4.d). Bought at Hureidha. Length 7 cm. Section, a thick oval with rounded butt and sides. The cutting-edge is blunt and slightly battered. The butt and both lateral edges, also, have been bruised. The colour is dark jade green.
2. Miniature Polished Jade Axe. Bought at Hureidha. Length 2.9 cm. The section is pointed oval. The wide cutting-edge has angular corners; the sides are bevelled. The conical butt is shattered and may have been fitted into an amuletic pendant. The colour is jade green, paler than the last (Fig. 4.b).
3. Miniature Polished Jade Axe. Bought at Hureidha and stated to be a local find. Length 3 cm. The specimen is oblong with a thin oval section. The sharp narrow cutting-edge is straight, with slightly bevelled corners. The butt is tapered and may have been rubbed in an amulet mount. The colour is jade green, slightly bluer than the proceeding (Fig. 4.c).

The first specimen is currently held by the Museum of Archaeology and Anthropology in Cambridge (MAA) and is shown in Fig. 4.d while the other two smaller axes (Fig. 4.b, c) have been missing from the MAA's collections for the past 20 years.

4.8. Specimen 9

During this study, a raw sample of the nephrite veins (Fig. 3, Specimen 9) that are found in Lawdar District in the Governorate of Abyan in Yemen was delivered to us in Oman. The exact location of this specimen in Lawdar is unknown and the current conflicts in Yemen do not allow visits to the area so the nephrite veins could not be directly examined on the field. The specimen was analysed using the same non-destructive techniques to compare with the nephrite axe heads.

5. Archaeometric analysis

5.1. Materials and methods

All the specimens, available in Oman, have been analysed without preparation or alteration using non-destructive techniques: Optical Microscopy (OM), micro-Raman Spectroscopy and Energy Dispersive X-Ray Fluorescence (ED-XRF) (Smith and Gendron, 1997; Di Martino et al., 2019; Edwards and Chalmers, 2005), coupled with the standard gemological tests and archaeological tests. The optical microscopy images were obtained using a Leica S9i digital stereo microscope, that has a zoom range of .61x – 5.5x (total magnification of 6.1x – 55x) with 10x eyepieces and an integrated HD camera.

The chemical analyses were performed by ThermoFisher Scientific ED-XRF, Arl QuantX model, equipped by Silicon Drift Detector (SDD) and Rhodium (Rh) Xray Tube generating 50 W, as maximum output power and working in vacuum chamber conditions. The micro-Raman instrument used for the present work is a Renishaw In-Via Reflex μ-spectrometer. The Raman spectral region between 1200 and 200 cm^{-1}, useful for distinguishing silicate mineral phases, such as amphiboles and pyroxenes, was investigated.

To check homogeneity in the mineral composition, several bi-dimensional grid Raman maps have been carried out on the samples.

5.2. Results

Table 1 shows the characteristics of specimens 1 to 5 based on classical gemological observations; the measurements are width × length × total depth in millimetres. The colour refers to the body colour of the samples and it is expressed as a dominant Hue (Green) plus its modifying hue (brownish).

Table 1
Description of specimens 1 to 5 and the raw material block specimen 9.

	Specimen 1	2	3	4	5	9
Species	Nephrite	Nephrite	Nephrite	Nephrite	Nephrite	Nephrite
Weight	9.48 g	79.78 g	6.21 g	54.43 g	58.38 g	39.78 g
Measurements	16.44 × 39.52 × 8.95 mm	33.77 × 66.33 × 22.00 mm	16.92 × 29.29 × 12.27 mm	39.60 × 44.46 × 19.24 mm	30.41 × 56.99 × 20.43 mm	23.66 × 56.65x 14.04 mm
SG	2.92	2.95	2.94	2.95	2.97	2.98
Colour	brownish Green, mottled	brownish Green, mottled	brownish Green, mottled	brownish Green, mottled	brownish Green	brownish Green
Transparency	Opaque, Translucent along the edges	Opaque	Opaque, Translucent along the edges	Opaque	Opaque	Opaque
Surface characteristics	Polished, with weathered surface	Polished, with weathered surface	Polished, with weathered surface	Polished, with weathered surface	Polished with weathered surface	Polished
Texture	Medium to coarse grade texture, with grains associated to elongated crystals, oriented in different directions.					

It must be noted that the Specific Gravity is in the nephrite range (Gunther, 2008), but in the lower numbers, especially for Specimen 1, while the value of SG for specimen 9 is slightly higher than other samples. This is probably due to the presence of other mineral phases associated with surface weathering (Fig. 3). For all the specimens, the texture, as observed by the OM, is associated with elongated crystals, oriented in different directions and the quality grade of the texture can be defined as medium to coarse.

5.2.1. ED-XRF analysis

In Table 2 the chemical compositions for each specimen by ED-XRF are provided. The relative intensities correspond well to the actinolite-tremolite series chemical composition (Zussman, 1955, 1959; Deer et al., 1992). To compare the relative intensities of the elements with the Yemen reference sample (specimen 9), some ratios were determined. In particular, the ratios between silicon (Si) and calcium (Ca); silicon and iron (Fe) plus magnesium (Mg), and iron versus calcium were calculated. These represent the main occupancy of the tetrahedral (Si), octahedral (Fe and Mg) and cubic (Ca) crystal lattice sites, respectively, in the actinolite-tremolite series. The congruent results between the different specimens and the Yemen reference sample are clearly notable; nevertheless, small differences can be highlighted, especially regarding the Al and Fe trends. For this last one, the element concentration shows small shifts between the different specimens. This can be correlated with the substitutions Mg-Fe, typical of amphiboles of the tremolite/actinolite series, as attested also by the Si/(Fe + Mg) calculated ratio, which show quite constant values between the different specimens. On the other hand, Al is an element that is able to substitute in more sites: not only the tetrahedral but also the octahedral, making its interpretation more difficult (Deer et al., 1992). In any case it is a fact that the Aluminium concentration is lower in specimens 5 and 9, which is corresponds to the samples without mottled colours. This is correlated with associated minerals on the surface due to weathering.

It should be noted that the ED-XRF analyses have been carried out without any sample preparation, and, due to the morphologies (not perfectly flat) and surfaces characteristics of the specimens, the chemical data have been considered as indicative of the chemistry of the specimens. Nevertheless, evident analogies are observed between the archaeological artefacts and the geological specimen (both in the major and trace elements).

Table 2
Chemical composition carried out by ED-XRF. The values are normalised to 100%. Cl, P, S, and Zr are not consistent with the nephrite chemical composition, but in consideration of the low relative intensity, could correlated with associated trace minerals.

Element Ox%	Specimen 1	2	3	4	5	9
SiO_2	58.28	56.06	58.01	57.22	57.90	58.23
MgO	21.17	26.12	22.25	22.72	24.28	24.70
CaO	13.32	12.97	13.60	13.78	12.71	13.94
Al_2O_3	3.06	2.06	3.64	2.36	1.65	1.15
Fe_2O_3	2.95	1.67	1.28	2.23	2.26	1.18
Na_2O	0.609	0.47	0.63	0.92	0.59	0.45
TiO_2	0.0385	0.229	0.0555	0.08	0.0425	0.028
K_2O	0.202	0.111	0.275	0.314	0.238	0.0734
SO_3	–	0.099	–	–	–	–
MnO	0.21	0.0815	0.111	0.108	0.153	0.123
Cl	0.0686	0.0623	0.063	0.131	0.0506	0.0198
P_2O_5	0.075	0.0437	0.058	0.107	0.106	0.075
ZnO	0.015	0.0083	0.0190	0.0145	0.0176	0.017
ZrO_2	–	–	–	0.0063	–	–
Ratios						
Si/Ca	4.38	4.32	4.27	4.15	4.56	4.18
Si/(Fe + Mg)	2.42	2.02	2.47	2.29	2.18	2.25
Fe/Ca	0.22	0.13	0.09	0.16	0.18	0.08

5.2.2. Micro-Raman analysis

The micro-Raman spectra obtained for the six specimens are illustrated in Fig. 5. Based on their Raman features, all the specimens were identified as nephrite. Particularly, the vibrational modes of symmetric and antisymmetric stretching of the Si-O-Si bonds have been considered as diagnostic for phase' identification (Rinaudo et al., 2004). For the nephrite, the literature reports 674 cm^{-1} for the symmetric and the doublet 1032–1061 cm^{-1} for the antisymmetric modes, respectively (Schubnel, 1992). Discrepancies in the band intensities may be related to the orientation of the grains/crystals with respect to the incident Raman beam source (Rinaudo et al., 2004).

Regarding the Spectrum carried out for Specimen 4, it is also interesting to note that it presents an additional band at 464 cm^{-1}, ascribable to the phase quartz (Schubnel, 1992). This second phase has been detected in correspondence to the mottled areas of the specimens.

Considering the reference bands reported for the pure terms (tremolite and actinolite) and the nephrite (Table 3), it should be noted that the last one occupies an intermediate position of the main Raman bands, generally at slightly lower wavenumbers than tremolite but at slightly higher wavenumbers than actinolite. This is expected for microcrystalline material composed of both phases, as nephrite is defined (Deer et al., 1992). Moreover, the higher hardness and toughness typical of this material than the pure terms (tremolite and actinolite), are correlated with the texture, mixing grains and elongated crystals in random orientations and they represent a good balance between the distribution of the two minerals (Dorling and Zussman, 1985). In order to compare the five Specimens plus the sample from Yemen (9) in this way, more attention has been focused on the relative balance between the actinolite-tremolite mineral phases. This investigation was performed by the micro-Raman mapping tool.

The map image in Fig. 6, carried out for specimen 2, reports the spatial distribution of the band at 674 cm^{-1}, calculated as signal to baseline. The map shows a very homogeneous distribution of the band,

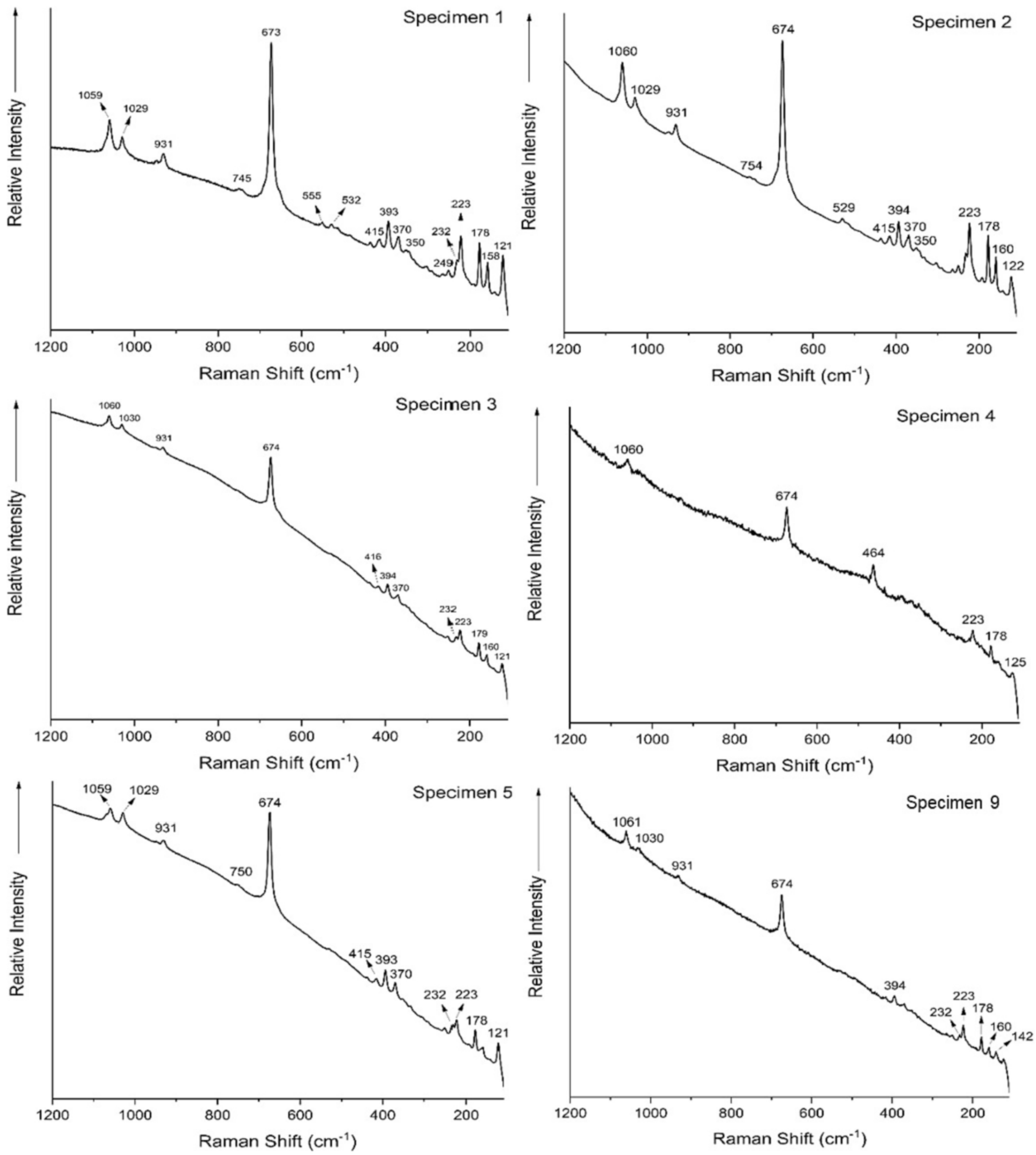

Fig. 5. The micro-Raman spectra characterizing the six specimens (1 to 5, and 9). Note that the peak (band) at 674 cm^{-1} represents the dominant Raman features in all specimens, as expected for nephrite phase. The spectrum corresponding to Specimen 4 presented more fluorescence and it appears slightly more noisy, in respect to the others. Moreover, a band at 464 cm^{-1} ascribable to quartz microcrystals associated to the surface has been observed.

while neither at 676 cm^{-1} (tremolite), nor at 669 cm^{-1} (actinolite) were highlighted. The same results were obtained by analysing the other four specimens by the same methodology.

Finally, the micro-Raman results and the chemical considerations were confirmed by optical microscopy observations, where the samples showed compact texture (Table 1), as expected for nephrite, without any column-like *habitus*, typical of actinolite and tremolite pure terms. In other words, by the combination of the chemical analysis, Raman features and optical microscopy observation, the very high quality of the material used to create the axes, made by homogenic nephrite, in a very compact texture, without any other minerals in veins or as associated crystallisations has been demonstrated.

The homogeneity of nephrite represents an interesting observation regarding the material chosen to fabricate the artifacts. In fact, also in the modern gemstone trade, the nephrite quality can be lower, due to the presence in the same object of other minerals associated with it, or to the presence of dominant pure terms, reducing its hardness. The hardness of the tremolite and actinolite mineral phase is relatively lower (5–6 in Mohs scale) (Deer et al., 1992) than that of nephrite (6 to 6.5) (Gunther, 2008), thanks to its peculiar texture (Dorling and Zussman, 1985). It is important to note that the samples discovered are only of well-formed nephrite which represents the hardest possible material of this rock type. Finally, it must be noted that the sample from Yemen presents the same high quality of nephrite characteristics.

Table 4 presents the properties of the nephrite axe specimens collected by Wilfred Thesiger and Gertrude Caton-Thompson. We managed to examine these specimens in the British Museum (BM) and the Museum of Archaeology and Anthropology (MAA) in Cambridge.

6. Discussion: The road of jades

Lawdar District, in the Governorate of Abyan (Al-Arakabi and Um

Table 3
Raman bands and relative intensity of the 6 specimens compared with the Raman bands reported by Schubnel (1992) for the nephrite mineral phase. It must be noted that all the bands reported by Schubnel correspond well in all the 6 specimens analysed in the present work. Moreover, the reference Raman bands (Rinaudo et al., 2004, 2010) characterising the standard tremolite and actinolite mineral phases were reported. For the abbreviations: vs = Very Strong, s = Strong, m = Medium, w = Weak, vw = Very Weak, b = broad.

Specimen	References							
1	2	3	4	5	9	Schubnel 1992 Nephrite	Rinaudo et al 2004 Tremolite	Rinaudo et al. 2010 Actinolite
1059 *m*	1060 *m*	1060 *m*	1060 w	1059 *m*	1061 *m*	1061 *m*	1062 *m*	1062 *m*
1029 *m*	1029 *m*	1030 *m*	1030 w	1029 *m*	1030 *m*	1032 *m*	1031 *m*	1027 *m*
945 vw	948 vw						950 w	
931 w	931 w	931 w	931 vw	931 w	931 w	931 *m*	932 *m*	929 w
745 w	754 vw			750 vw,b			751 w	741 w
							676 vs	
673 vs	674 vs	674 vs	674 s	674 vs	674 vs	674 vs		
								669 vs
555 vw								
532 vw	529vw,b						531 w	535 w,b
514 vw							516 w	
			464 m s					
436 w	437 w			437 w			438 w	
415 *m*	415 *m*	416 w		415 *m*			418 *m*	
393 s	394 s	394 s	397 w	393 s	394 *m*	393 s	396 s	
								384 s
370 s	370 s	370 s	370 w	370 s	370 w	372 s	373 *m*	
								367 *m*
350 w,b	350 w,b			350 vw		352 w	355 vw	
302 vw	303 vw						306 vw	
264 vw	264 vw						290 w	
							254 *m*	
249 w	250 w	250 vw		250 w				
232 *m*	232 *m*	232 *m*		232 *m*	232 *m*		234 s	
223 s	223 s	223 s	223 *m*	223 s	223 s	224 s	225 s	
								219 s
	193 vw							
178 s	178 s	179 s	178 *m*	178 s	178 s	179 s	180 s	
158 s	160 s	160 s		160 *m*	160 *m*	160 *m*	162 s	
	143 vw				142 *m*			
121 *m*	122 *m*	121 *m*	125 *m*	121 *m*	123 w	123 *m*		
–	–	–	–	–	–	105 w	–	–

Table 4
Description of the nephrite axe specimens collected by Wilfred Thesiger and Gertrude Caton-Thompson illustrated in Fig. 4.

	Specimen		
	6	7	8
Location	Mudhai	Hureidha, Yemen	Salalah
Museum Reference Number	BM 1947 10.3.1	MAA 1951.621	BM 1947 10.3.2
Weight	56.2 g	118.3 g	40.8 g
Measurements	57 × 43 × 21 mm	70 × 35 × 29.5 mm	51 × 32 × 21 mm
SG	2.99	2.980	2.981
Colour	Dark Green	Dark Green	Dark Green
RI	1.632	–	1.63
Extinction Angle °	14.5	–	16
Comments	Found by Thesiger in Nov 1945 under the ledge near the spring of Wadi Ghara (tributary of Wadi Ghudun)	Bought by Caton-Thompson in 1938 and said to be a local find. Asymmetrical, chipped blade.	Acquired by Thesiger from a local inhabitant who found it on the coastal plain about two years previously

Sallamiah deposits, 13° 48′ N, 45° 57′ E) near the town of Jawf al Maqbābah (Le Bas et al., 2004), could be identified as the most probable source of the nephrite based on our present knowledge. The area includes Precambrian (Late Archaean–Late Proterozoic) mylonites, ortho- and paragneisses, diatexite and metatexite migmatites, and amphibolites that are well recognized in the southeastern exposures (Heikal et al., 2014). It has been selectively mined by the local people for various gemstones, including pure nephrite. However, this district has been barely investigated (Arbach and Crassard, 2007), and the surrounding area, extending several tens of km around the deposit, as highlighted before, still needs to be surveyed. Unfortunately, the current conflicts and instabilities in Yemen do not allow visits to the area for further examination of the nephrite veins. In addition to the Yemeni origin, it is important to note that the collected samples are made exclusively of homogeneous nephrite which is the hardest and most durable of these rocks. This suggests deliberate specific selection of the raw material which can only be verified after further surveys in the region.

Once produced in Lawdar District, the nephrite axes could have been carried northwards (Saada) and eastwards, through Ramlat as-Sab'a-tayn, then the Hadramawt Plateau and, finally, to Dhofar (Rub' al-Khali and the Salalah Plain). The distance covered is considerable: 880 km to Shaqat Jadailah and 950 km to the Salalah Plain.

Considering the Lawdar region as the source of nephrite exploitation and axe production, these objects circulated from east to west, apparently only in Southern Arabia. Such objects have been reported once in Saudi Arabia at Esh Shuqqan (Sordinas, 1978; Nayeem, 1990: Fig XXXI), but never in the UAE. This main Southern Arabian distribution path seems to follow the same direction as the diffusion of trihedral points (Charpentier, 2008, 2004; Maiorano et al., 2020a, 2020b) but the vastness of the unexplored areas in the Rub' al-Khali renders such inferences hypothetical.

However, the accurate study of obsidian exchange networks represents a valid tool for an initial definition and identification of the long-distance exchange networks in Southern Arabia. We know that only the Tihama obsidian assemblage is of African origin, testifying to existing links between the two shores of the Red Sea (Inizan and Francaviglia, 2002; Khalidi et al, 2013). Obsidian objects are particularly frequent in Yemeni Neolithic assemblages and the "Yafa" deposits in the plains of the western highlands of Yemen yielded most of them (Khalidi et al.,

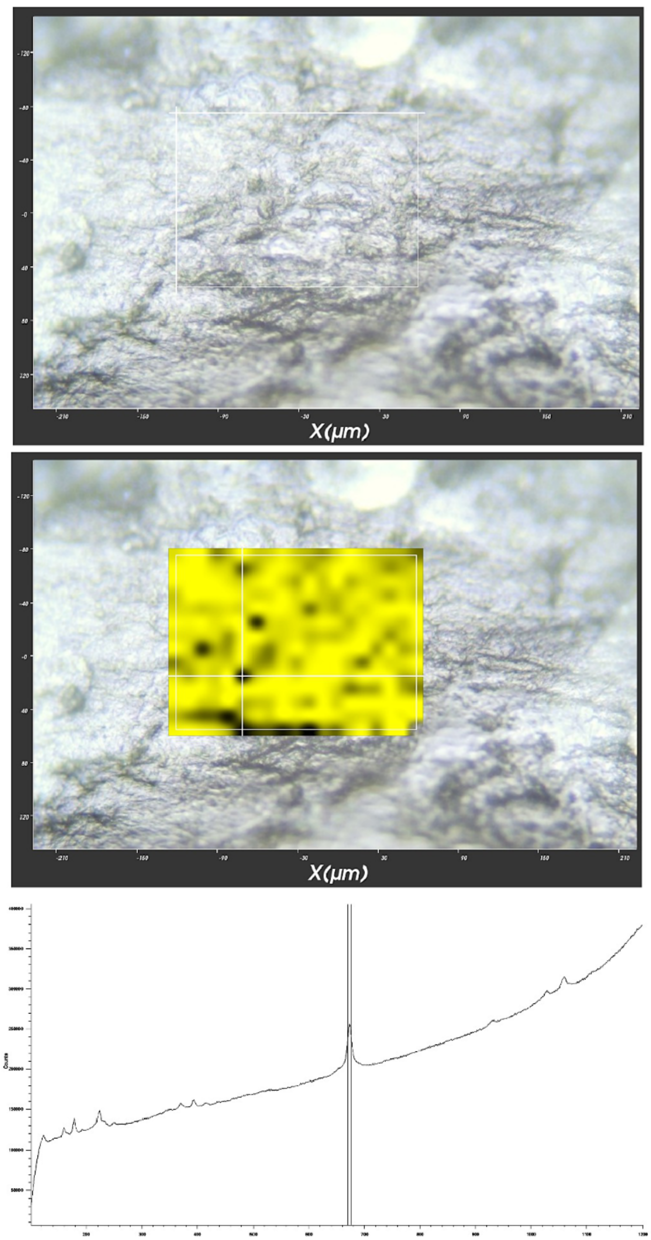

Fig. 6. Micro-Raman mapping carried out on Specimen 2. The square on the microscopy image (top) shows the area of the map (magnification 50x- reflected light) and the map results are shown in the middle image, where the relative spatial distribution of the Raman band at 674 cm^{-1}, calculated as signal to baseline, has been reported in yellow. In the dark areas the same band was detected, as shown in the spectra (bottom), but with lower relative intensity. Neither the 676 cm^{-1} (tremolite) nor the 669 cm^{-1} (actinolite) signals were highlighted by the map, as well as no other mineral phases. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2013). Artefacts from this main source, less than 200 km northwest of the tremolite deposits, has occasionally been reported from Ramlat as-Sab'atayn (site of ABR-1 and 2), the Rub' al-Khali (Mundafan, Saudi Arabia), the Hadramawt, and Dhofar (Matafah site, Wadi Ghudun, Dhofar) (Khalidi et al., 2013; Zarins, 2002; Zarins, 2013). Wadi Matafah is currently the furthest known occurrence from the original source, being 1050 km from the deposit and extraction workshops. It is possible that during the Neolithic period, jade and obsidian were diffused along the same routes. Nowadays, the desert depression of Ramlat as-Sab'atayn separates Wadi al-Jawf from Wadi Hadramawt, but it was not the same during the early and middle Holocene because a vast and unique hydrographic system, called "Jawf-Hadramawt" constituted a formidable axis for circulation and material exchange from west to east (Marcolongo and Palmieri, 1992). It is therefore not surprising that obsidian artefacts and nephrite axes are associated in some archaeological sites such as Manayzah (Crassard, 2008).

7. Conclusion

The morphological and archaeometrical study carried out on the Dhofari axe-adzes at macroscopic and microscopic levels yields a first glimpse into a new unexplored field of Southern Arabian lithic assemblages. These mineralogical and petrographic results show a feasible compositional consistency between most of the artefacts and the sole raw material reference sample from the Lawdar region in Yemen.

The discovery of a number of jade axe heads in Oman is of significant interest, not only because of the rarity of polished hard stone artifacts, but also because of the novelty and rarity of the semi-precious materials used.

The analysed samples were unfortunately found only on surface contexts. Half of them in - exclusively - Neolithic assemblages, without traces of co-occurrence with later artefacts (as in Maitan, Mudhai, and Al-Amsan; Maiorano et al., 2020b; Inizan and Rachad, 2007). Others come from more recent context where they occur only in mixed up deposits together with Iron Age, Pre-Islamic (as in Sumhuram) and Islamic (Khor Rori) artefacts. This leads us to suppose that these objects, given the rarity and uniqueness of the raw material, continued to hold a strong intrinsic value for the population, that handed them down through the generations. Moreover, as Thesiger reported (1964), in Bedouin traditions dark rocks were often associated with medicinal properties, such as for removing snake venom. But such objects may have been also used as amulets or for barter (as currency) in trade (Thesiger, 1946).

The great similarity of the collected axes in terms of technology, raw material and morphology lead us suppose that the entire collection could date back to the same period of production. These explanations open new avenues in our understanding of the South-Arabian Neolithic communities of mobile herders (and hunters), showing the possible existence of inter-regional exchanges of precious material, which partly fits with the routes reconstructed for the diffusion of obsidian (Khalidi et al, 2013).

The relationships between western Yemen and the coastal and interior Dhofar suggest two possible routes for exchanges of precious artefacts over hundreds of kilometres, most likely during the Middle Neolithic.

This research on Neolithic jades from the Arabian Peninsula represents a seminal study in the framework of long-distance exchanges in the area. The function of these axes remains to be investigated: are they goods of cultic (or religious) value, or prestigious objects indicating social relevance? Or are they just functional tools?

In Arabia, the study of jade axes and "prestige" artefacts in Neolithic societies of the 6th-5th millennium BC is only at its beginning. Additional surveys in the raw material procurement area could solve the issues related to the context of acquisition and production, and thus attempt to correlate nephrite artefacts with human groups and related assemblages. The analysis of the composition of these precious stone artefacts and a preliminary reconstruction of possible exchange networks represents the only possible way to start approaching such a challenging subject, in order to provide the foundation for a preliminary understanding of the role of nephrite artefacts and their diffusion in Arabia.

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