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Use of Zanzibar copal (*Hymenaea verrucosa* Gaertn.) as incense at Unguja Ukuu, Tanzania in the 7–8th century CE: chemical insights into trade and Indian Ocean interactions

Alison Crowther [a, *], Margaret-Ashley Veall [b, c], Nicole Boivin [b], Mark Horton [d], Anna Kotarba-Morley [b, e], Dorian Q. Fuller [f], Thomas Fenn [g], Othman Haji [h], Carney D. Matheson [a, c, i]

[a] School of Social Science, The University of Queensland, St Lucia 4072, Australia
[b] School of Archaeology, University of Oxford, 28 Little Clarendon Street, Oxford OX1 2HU, United Kingdom
[c] Department of Anthropology, Lakehead University, 955 Oliver Road, Thunder Bay P7B 5E1, Ontario, Canada
[d] Department of Archaeology and Anthropology, University of Bristol, 43 Woodland Road, Bristol BS8 1UU, United Kingdom
[e] Centre for Archaeological Science, School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW 2522, Australia
[f] Institute of Archaeology, University College of London, 31–34 Gordon Square, London WC1H 0PY, United Kingdom
[g] Yale Center for the Study of Ancient Pyro-Technology, The Council on Archaeological Studies, Department of Anthropology, Yale University, 10 Sachem Street, PO Box 208277, New Haven, CT 06520, USA
[h] Department of Museums and Antiquities, PO Box 4267, Zanzibar, Tanzania
[i] Department of Biology, Lakehead University, 955 Oliver Road, Thunder Bay P7B 5E1, Ontario, Canada

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ABSTRACT

This study presents the chemical analysis of an amorphous organic residue extracted from a 7th–early 8th century CE brass artefact from the trading port of Unguja Ukuu, Zanzibar, Tanzania, hypothesised to be an incense burner. The artefact is a very rare and highly significant find in East Africa, with only one other example being found previously (also at the same site), and likely represents early contact between coastal East Africa and the Indian Ocean world. Chemical analysis of the residue adhering to this artefact was undertaken to confirm its use to burn incense, and to determine whether the resin used was local or exotic to East Africa and thus likely acquired through long-distance trade. The residue extract was analysed by gas chromatography–mass spectroscopy (GC–MS) and identified as Zanzibar copal (*Hymenaea verrucosa* Gaertn.), a local species that rose to major importance in colonial period trade. The results obtained from this study provide the first direct archaeological evidence for the ancient use of this East African species as an aromatic, suggesting that it might have had a much earlier role in long-distance incense trade than previously demonstrated. This finding also provides insights into local East African engagement with the material culture of the Indian Ocean world.

1. Introduction

The archaeological site of Unguja Ukuu, located on the south-west coast of Zanzibar, Tanzania (Fig. 1) is one of the earliest known trading ports in coastal East Africa. It is therefore a key location for studying early interactions between East Africa's Swahili communities and the wider Indian Ocean world. This paper focuses on the chemical analysis of an organic residue extracted from a metal artefact resembling an incense burner lid (Fig. 2) recovered from a 7th–early 8th century CE deposit at the site. The artefact was excavated by the University of Oxford's Sealinks Project, which has been investigating a number of Later Stone Age and Iron Age sites on East Africa's islands (Zanzibar, Pemba and Mafia), coast, and coastal hinterland in order to better understand early Indian Ocean trade and interaction in the region (e.g., Boivin et al., 2013; Crowther et al., 2014, forthcoming; Helm et al., 2012; Mitchell, 2012; Shipton et al., 2013; see also Boivin et al., 2012; Boivin et al., in press; Fuller and Boivin, 2009; Fuller et al., 2011).

* Corresponding author. Tel.: +61 7 33653236.
E-mail addresses: a.crowther@uq.edu.au (A. Crowther), margaret-ashley.veall@arch.ox.ac.uk (M.-A. Veall), nicole.boivin@rlaha.ox.ac.uk (N. Boivin), mark.horton@bristol.ac.uk (M. Horton), anna.kotarba-morley@arch.ox.ac.uk (A. Kotarba-Morley), d.fuller@ucl.ac.uk (D.Q. Fuller), thomas.fenn@yale.edu (T. Fenn), hajiothman@ymail.com (O. Haji), cmatheso@lakeheadu.ca (C.D. Matheson).

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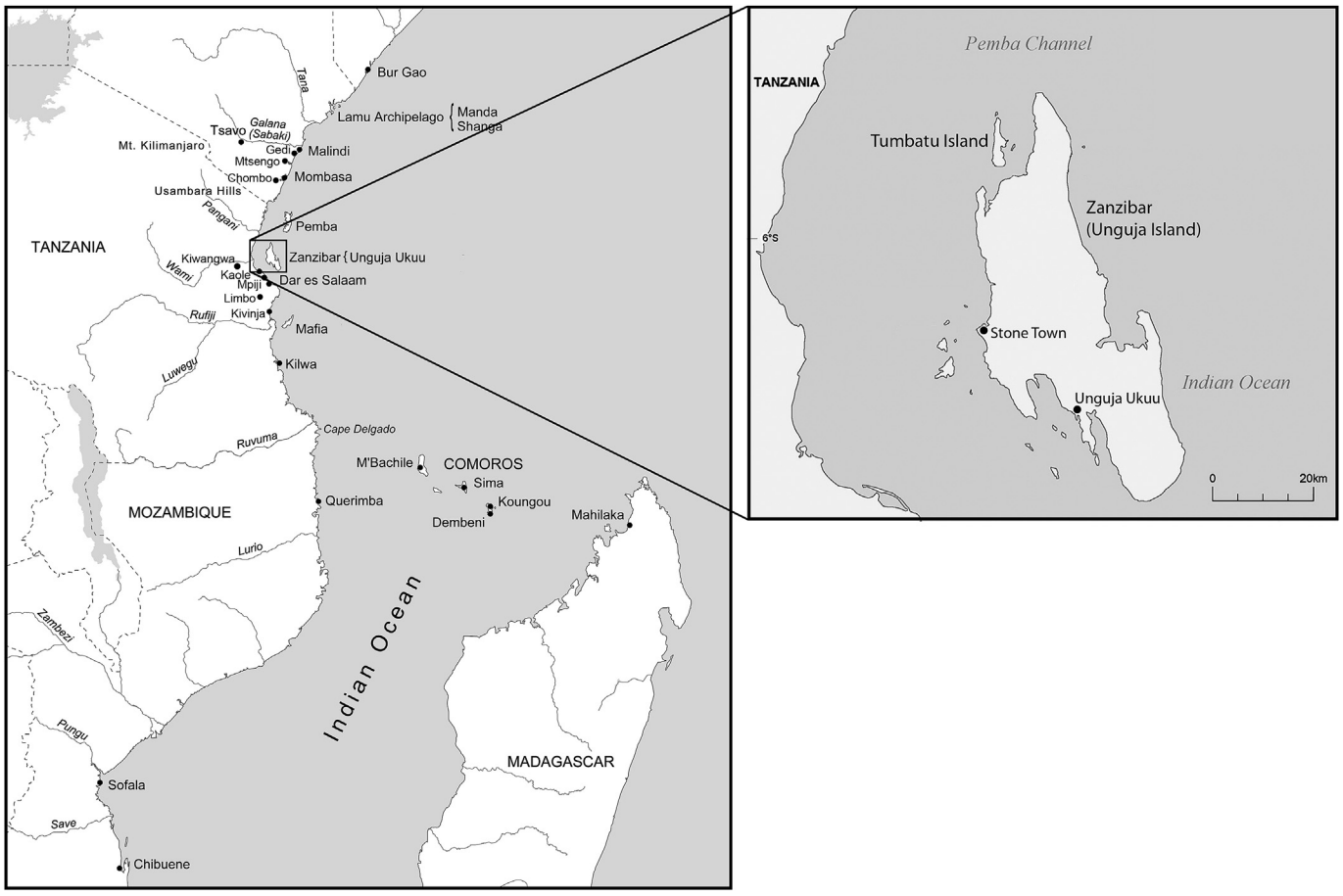

Fig. 1. Map of East Africa showing sites mentioned in text and the location of Unguja Ukuu on the southwest coast of Zanzibar.

Coastal East Africa has a long history of Indian Ocean trade dating back to at least the early first millennium CE, as described in such Classical period texts as the *Periplus of the Erythraean Sea* (Casson, 1989: 75, 191, PME 39) and Ptolemy's *Geography* (Berggren and Jones, 2000: 68–70). The main trade period, however, began in the Islamic era, with an apparent boom seen during the Abbasid phase (c. mid-8th to 10th century CE) when the Arab Caliphate shifted to Baghdad and took control of the maritime and overland trade routes that linked distant regions around the Indian Ocean rim (Horton and Middleton, 2000; Sheriff, 2010). Among the most important trade sites to emerge in East Africa during this period were Shanga and Manda in the Lamu Archipelago (Chittick, 1984; Horton, 1996), Kilwa off the central coast of Tanzania (Chittick, 1974), and Unguja Ukuu on Zanzibar (Chittick, 1966; Horton and Clark, 1985; Juma, 1996, 2004) (Fig. 1). While settlement and trade activities at Unguja Ukuu are argued to date from the late 5th or early 6th century CE (Juma, 1996, 2004), our excavations suggest that the main trading phase was between the 7th and 9th centuries. During this time, the Islamic religion and its associated material culture also began to be adopted on the East African coast, a process that was undoubtedly encouraged by the interactions and exchanges that took place at its Indian Ocean ports (Horton, 1996; Horton and Middleton, 2000; Insoll, 2003).

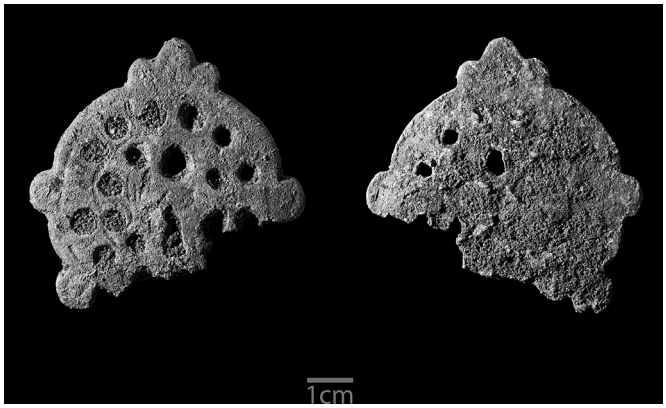

Fig. 2. Decorated brass artefact from Unguja Ukuu, Zanzibar (Photo: Ian Cartwright, University of Oxford).

Studies of East Africa's participation in early long-distance trade usually focus on artefactual evidence such as ceramics, beads and metal (e.g., Horton and Blurton, 1988; Juma, 1996; Kusimba et al., 1994; Wood, 2011), which are both highly visible and durable, and often very abundant in the archaeological record. While less visible organic goods such as resins, textiles, perfumes and oils, wood (mangrove and hardwood), ivory, tortoise shell, animal skins, and exotic foods and spices are recognised as being major commodities of East Africa's trade (as both imports and exports), their role is rarely studied directly owing to issues of preservation and detection (Boivin et al., 2013; Helm et al., 2012). The recovery of a probable incense burner grate from Unguja Ukuu during excavations by the Sealinks Project thus provides a rare opportunity to increase our knowledge of East Africa's trade in natural products such as resins during the early Islamic period. Old World incense trade at this time was centred, as it had been for centuries, on the

Ḥaḍramawt coast (Yemen), as well as the Dhofar coast, on the island of Socotra off Yemen and the Somali coast (Casson, 1989: 162–167; Gupta, 2007: 112–113). It primarily involved the important resinous species frankincense (*Boswellia* spp.) and myrrh (*Commiphora myrra*), which were derived from trees and shrubs growing in the Horn of Africa and southern Arabia (e.g., Artzy, 1994; Boivin and Fuller, 2009; Casson, 1989: 124–25; Groom, 1981; Peacock and Williams, 2007; Regert et al., 2008; Rougeulle and Benoist, 2001). Closely related species in India also provided lesser incense resins (Asouti and Fuller, 2008; Boivin and Fuller, 2009). Our study therefore sought to identify whether the artefact from Unguja Ukuu had in fact been used to burn incense, and if so, to identify the taxonomic origin of the resin in order to ascertain whether it was acquired locally or from farther afield, with the broader aim of shedding light on East Africa's place in the burgeoning early Medieval incense trade.

2. Archaeological context and artefact description

The archaeological site of Unguja Ukuu was first discovered by Chittick in the 1960s (Chittick, 1966) and subsequently excavated by Horton and Clark (1985) and Juma (2004) in the 1980s and 1990s, and by the Sealinks Project in 2011 and 2012 (Crowther et al., 2013a, 2013b, forthcoming). It is located on a narrow coral-rag peninsula on the southwest coast of Zanzibar, between the mangrove-lined Uzi Creek to the east and the marine resource-rich Menai Bay to the west, which also provided a relatively sheltered natural harbour. Occupied during the mid-late 1st millennium CE, Unguja Ukuu was a major trading port with a wattle-and-daub settlement spread across some 17 ha (Juma, 2004). Its importance as an early trading site is indicated by the presence of large quantities of imported goods in its deposits, including Chinese and Near Eastern ceramics (e.g., Changsha painted stoneware, Yue Green ware and Dusun stoneware from China; turquoise-glazed and white-glazed wares from Iraq and/or Iran), glass beads, and glass vessel fragments. Despite their broad geographical origins, many of these goods were probably acquired through trade with merchants from Arabia and the Persian Gulf (Horton and Middleton, 2000), although direct contacts with South and Southeast Asia have been proposed (see Boivin et al., 2013 for a review).

The brass artefact of interest here was recovered during Sealinks excavations at the site in July 2011. It was excavated from Trench UU11 (WGS84 Zone 37M 541332E 9301601N) (Fig. 3), a 2 × 2 m excavation located on a raised beach immediately adjacent to the western shoreline, about 10 m from the current high-water mark and 2–3 m above sea level. The archaeological deposits were just over 3 m deep, and comprised a sequence of highly organic, culturally rich layers alternating with beach sand layers. This sequence most likely reflects fluctuations in the intensity of use of this area of the site over time, possibly relative to changes in sea level and/or beach transgression and regression events. The artefact was deposited in a shell midden-like layer (Context 012, c. 75–110 cm below surface) composed of very organic and blackish sandy sediments, and very dense quantities of shell and other cultural material. It was associated with local Early Tana Tradition/Triangular Incised Ware (TT/TIW) pottery that dates regionally to the 7th–10th centuries CE (Fleisher and Wynne-Jones, 2011), as well as imports dating mainly from the 7th–9th centuries CE, including relatively large quantities of turquoise-glazed Sasanian-Islamic sherds. A radiocarbon date on a charred pearl millet (*Pennisetum glaucum* (L.) R. Br.) grain recovered from the same context as the incense burner indicates that the artefact most likely dates to between the early 7th and early 8th centuries CE (OxA-A2507-17: 1403 ± 28 BP, or cal CE 634–765 [OxCal, 95% probability using the southern hemisphere calibration curve]).

The artefact comprises a fragment of a flat, round metal disk with four preserved lobes/clusters of lobes around its margin. It is 59 mm long × 60 mm wide, although originally it would have been longer as it is now broken at one end (Fig. 2). It has nineteen preserved round/sub-round perforations (ranging from 3.6 to 7.2 mm in diameter) arranged in two concentric circles around its centre. It is minimally decorated, bearing only shallow lines around the perforation zones and on the lobes. Juma (2004: 137–38, 141) recovered a similar perforated metal grate with decorative lobes and a metal pan during excavations at Unguja Ukuu in the 1990s, which he also identified as fragments of an incense burner. These are the only examples of this type of

Fig. 3. Trench UU11 at Unguja Ukuu, where the artefact was found.

perforated metal artefact known from any archaeological site on the East African coast.

Macroscopic examination of the artefact indicates it was made by casting in a mould, and preliminary elemental analysis with portable X-ray fluorescence (pXRF) indicates that the metal is a copper–zinc alloy containing appreciable quantities of lead and iron, which classifies it as brass. Although brass objects are relatively common in Swahili sites, there is no clear evidence to support the local production of brass or the casting and manufacture of brass objects. There are no known copper, zinc or lead deposits anywhere on the East African coast, and no finds of copper ore, copper slag or metallic zinc have been reported from any archaeological contexts on any Swahili sites to suggest that brass was locally produced prior to at least the mid-second millennium CE (Killick, 2009: 203; Kusimba et al., 1994: 64). While it is possible that imported brass ingots or recycled brass objects were melted and the artefact was cast locally, the lack of evidence for these activities in the form of crucibles with brass residues or casting moulds at Unguja Ukuu or anywhere else on the Swahili coast makes it difficult to support this scenario. On present evidence, therefore, it seems most likely that the object was imported to the site through Indian Ocean trade. It is widely recognised that brass (including leaded brass) was the main copper alloy used for Islamic period non-ferrous metallurgy, and objects made from it were traded widely throughout the Islamic world (Al-Saa'd, 2000; Craddock et al., 1990). Chemical and lead isotopic analysis of another copper object from Unguja Ukuu, recovered from previous excavations (Juma, 2004), linked that object with copper likely originating from Iran, an observation that is also consistent with a number of other analysed copper-based Swahili objects (Fenn, unpublished data). Further compositional studies, including elemental composition and lead isotope analyses, are being undertaken to determine more precisely the likely origin of the metals used in the artefact's manufacture. The main copper sources during this period would have included Iran, India, and central and southern Africa, while metallic zinc was most likely sourced from the Near/Middle East or India (Killick, 2009; Kusimba et al., 1994).

Stylistic comparison with incense burners from neighbouring Indian Ocean regions sheds little additional light on the artefact's function or origin. The main incense burner types found at Islamic period sites in Arabia are ceramic or soft stone (steatite) (Le Maguer, 2011), and while metal burners are also known to occur, their range of forms are not well documented in the literature (cf. Aga-Oglu, 1945, 1950; Baer, 1983; Rahmani, 1980). The brass artefact from Unguja Ukuu is stylistically unlike the highly ornate Islamic-era Coptic burners from Egypt, which often have elaborately-decorated domed lids and three-dimensional zoomorphic ornamentation (Aga-Oglu, 1945). Given the extreme rarity of this type of artefact at sites on the East African coast though, it seems likely that the object was a prestigious item associated with a person of wealth and/or high status, potentially either a visiting foreign merchant at Unguja Ukuu, or a member of the local trading or ruling elite.

3. Archaeological resin residue analysis

As discussed above, plant resins are one of the main types of raw materials that were used as incense during the Islamic period. They have also been used for a variety of other non-aromatic purposes throughout history, including as natural binders, pigments and sealants, and as a raw material for personal ornaments (Langenheim, 2003; Mills and White, 1977). They are therefore relatively well understood archaeologically in terms of their botanical sources, physical properties, and chemical compositions. Resins are obtained primarily from woody conifers and flowering trees and shrubs belonging to a range of plant families found worldwide, the most important being the Angiosperms: Burseraceae (e.g., frankincense/olibanum – *Boswellia*, myrrh/bdellium – *Commiphora*), Dipterocarpaceae (dammars such as *Shorea*, *Anisoptera*), Fabaceae (copals such as *Hymenaea*), and Anacardiaceae (e.g., *Pistacia*); and the conifers: Pinaceae (e.g., *Pinus*), and Araucariaceae (e.g., New Zealand kauri – *Agathis)* (Langenheim, 2003: 24). The exudates consist of combinations of chemical compounds derived from the plant of origin dissolved in terpene or terpenoid oils that, once the volatile oily component has evaporated, preserve well in the archaeological record. The non-volatile component is composed primarily of diterpenoids and triterpenoids, which are the main compounds used in taxonomic identification.

Resins have been recovered archaeologically as raw lumps (e.g., Burger et al., 2010; Regert et al., 2008), coatings on pottery vessels (e.g., Lampert et al., 2003; Serpico and White, 2000; Stern et al., 2003), hafting residues on stone tools (e.g., Boot, 1993; Lombard, 2005, 2008; Robertson et al., 2009), and components of rock art pigments (Pyatt et al., 2005). The analysis of resin micro-residues on artefacts using chemical techniques is also becoming more common (e.g., Charrié-Duhaut et al., 2013). Although a range of analytical techniques can be used to characterise and identify resins, including Fourier-transform Raman (FT-Raman) and Fourier-transform infrared (FTIR) spectroscopy (Brody et al., 2001; Edwards and Falk, 1997; Meyer et al., 1991), thin layer chromatography (TLC) (Matuszewska and John, 2004), and paper chromatography (Boot, 1993; Duewell, 1977), the most commonly used technique is gas chromatography (GC) coupled with mass spectroscopy (GC–MS). GC–MS separates the residue into its organic components based on their molecular weight, and then identifies each individual component by the fingerprint (ion spectrum) produced by the characteristic fragmentation ions of the molecules on ionisation. Plant resins can be identified to family, genus or potentially even species level based on the presence of unique chemical compounds or combinations of these compounds. For example, frankincense has a number of chemical compounds from the lupane, oleanane, tirucallane and ursane triterpenoids (Table 1). Some of these like the oleanane triterpenoid, α-boswellic acid ((3α,4β)-3-Hydroxyolean-12-en-23-oic acid) and the ursane triterpenoid, β-boswellic acid ((3α,4β)-3-Hydroxyurs-12-en-23-oic Acid), as well as their *O*-acetyl derivatives can be used to identify the presence of frankincense (Evershed et al., 1997a). A range of archaeological plant resins has been identified using this technique, including frankincense (Evershed et al., 1997a; Mathe et al., 2004; van Bergen et al., 1997), *Pistacia* (Charrié-Duhaut et al., 2007; Stern et al., 2003), copal (Regert et al., 2008; Stacey et al., 2006), pine (Eerkens, 2002) and dammar (Burger et al., 2010).

4. Methods

4.1. Artefact excavation and curation

The artefact was exposed *in situ* during the excavation and removed by hand without wet or dry sieving. After retrieval, it was wrapped in tissue and stored in a clean sample bag. It was not washed or treated at any point after excavation, and handling was minimal.

4.2. Microscopy and residue extraction

Initial examination of the brass artefact by low-powered stereomicroscopy (Amscope) identified the presence of small plant fibres and possible resinous residues on its surface. The latter comprised an amorphous, glossy material that was observed within the crevices of a white residue with brown edges overlying the

Table 1
List of known resin-producing plant genera from Africa and neighbouring regions (e.g., Arabia, Middle East, Mediterranean, South and Southeast Asia) that could be used as incense, and their diterpenoid and triterpenoid composition.

Family	Common name	Genus	No. species[a]	Distribution[b]	Diterpenoids	Triterpenoids
Altingiaceae	Styrax, Copalm Balsam, Storax	*Liquidambar*	4 (7)	Middle East to East Asia	Abietanes[1], Pimaranes[1]	Lupanes[2], Oleananes[2,3], Ursanes[1]
Anacardiaceae	Mastic of Chios, Mastic	*Pistacia*	10 (29)	Mediterranean to South Asia		Dammaranes[4], Malabaricanes[5], Oleananes[4,6], Polypodanes[5], Tirucallane[4], Euphanes[7]
Apiaceae	Asafoetida, Galbanum	*Ferula*	208 (52)	Mediterranean to East Asia	Abietanes[8], Podocarpanes[9]	
	Sweet Myrrh, Balm of Mecca	*Opopanax*	3 (9)	Mediterranean, northeast Africa	Peucelinanes (Amimajanes)[10]	
Arecaceae	Dragon's Blood	*Daemonorops*	101 (3)	Southeast Asia	Abietanes[11], Isopimaranes[11], Pimaranes[11]	
Asparagaceae	Dragon's Blood	*Dracaena*	121 (23)	Northeast Africa, western Arabia		Cycloartanes[11]
Burseraceae	Frankincense	*Boswellia*	30 (3)	East Africa to South Asia		Lupanes[12], Oleananes[12], Ursanes[12], Tirucallanes[12]
	Myrrh, Bdellium	*Commiphora*	222 (17)	Northeastern Africa, Arabia, South Asia		Dammarane[13], Octanordammarane[13], Oleananes[13], Polypodane[13]
	African Elemi, Elemi	*Canarium*	94 (10)	West Africa		Oleananes[6], Euphanes[7]
		Dacryodes	62 (3)	Africa, tropical South America		Amyranes[14]
		Santiria	1 (69)	Southeast Asia		Friedelanes[15], Lanostanes[15], Lupanes[15]
Cannabaceae	Hashish	*Cannabis*	1	Central Asia, South Asia	Phytanes[16]	Friedelanes[16]
Cistaceae	Labdanum, Ladanum, Ladan	*Cistus*	55 (157)	Mediterranean, Transcaucasia, northern Africa	Clerodanes[17], Labdanes[18]	
Clusiaceae	Crost balsam, Tacamahac	*Calophyllum*	192 (37)	Global		Friedelanes[19]
		Garcinia	425 (49)	Australasia, Africa, Asia		Friedelanes[20]
Cupressaceae		*Widdringtonia*	4	Southern Africa	Abietanes[21], Labdanes[21]	
		Cunninghamia	3	Southeast Asia	Abietanes[22], Labdanes[9,22,23], Pimaranes[9]	
		Calocedrus	4	Asia, America	Abietanes[9], Isopimaranes[9], Labdanes[9], Pimaranes[6], Phenolic Abietanes[9], Phyllocladanes[24], Totaranes[6]	
		Cupressus	29 (20)	Northwest America, Central America, northwest Africa, Middle East, South Asia	Abietanes[25], Beyeranes[9], Isopimaranes[9], Kauranes[9], Labdanes[9], Pimaranes[9], Phenolic Abietanes[9], Phyllocladanes[9], Totaranes[9]	
		Fokienia	1	Southeast Asia	Abietanes[26], Icetexanes[26], Isopimaranes[26], Labdanes[26], Pimaranes[26]	
	Sandaraca Germanica, Kedria	*Juniperus*	106 (10)	Africa, Asia, America, Mediterranean, Middle East	Abietanes[9], Isopimaranes[9], Labdanes[9], Pimaranes[9], Phenolic Abietanes[9], Totaranes[9]	
	Sandarac	*Tetraclinis*	1	Northwestern Africa, western Mediterranean	Abietanes[27], Isopimaranes[9], Labdanes[9], Pimaranes[27], Phenolic Abietanes[9], Totaranes[9,27]	
Dipterocarpaceae	Dammar	*Anisoptera*	11 (1)	Southeast Asia		Dammaranes[7]
	Balau, Minyak Keruing	*Dipterocarpus*	68 (3)	South Asia		Dammaranes[7], Ursanes[28]
	Piney Resin, White Dammar	*Vateria*	1 (33)	South Asia		Dammaranes[7], Ursanes[29]
	Dammar	*Vatica*	3 (154)	South Asia		Dammaranes[7], Ursanes[29]
	Dammar	*Hopea*	4 (178)	South Asia		Dammaranes[7], Ursanes[29]
	Dammar, Yellow Meranti	*Parashorea*	1 (16)	South Asia		Dammaranes[7]

Table 1 (*continued*)

Family	Common name	Genus	No. species[a]	Distribution[b]	Diterpenoids	Triterpenoids
	Dammar	*Shorea*	7 (284)	South Asia		Dammaranes[7], Ursane[30]
Euphorbiaceae	Dragon's Blood	*Croton*	1226 (86)	Tropical Africa, Asia	Clerodanes[11], Kauranes[11], Labdanes[31], Pimaranes[31]	
		Euphorbia	2220 (93)	Tropical Africa, tropical America, Oceania	Ingenanes[32], Lathyranes[33], Tiglianes[32]	Cycloartane[34], Hopanes[35], Lanostanes[35], Lupanes[35], Oleananes[35], Tirucallanes[36]
Fabaceae		*Colophospermum*	1	South Africa	Labdanes[37]	
	Congo Copal	*Copaifera*	47 (5)	Tropical Africa, Asia, America	Clerodane[38], Kauranes[38], Labdanes[38]	
	Ogea Copal, Accra Copal	*Daniellia*	8 (2)	Tropical West Africa	Labdanes[39]	
	Congo Copal	*Gossweilerodendron*	2	Tropical West Africa	Labdanes[40], Clerodanes[40]	
	Congo Copal	*Guibourtia*	18 (1)	Tropical West Africa, tropical America	Labdanes[41]	
	Zanzibar/East African Copal	*Hymenaea*	24 (12)	East Africa	Labdanes[6], Trachylobanes[42]	
	Congo copal	*Oxystigma*	5	Tropical West Africa	Eperuanes[43], Labdanes[43]	
	Dragon's Blood, Rosewood	*Pterocarpus*	53 (57)	South Asia		Friedelanes[44], Lupanes[44], Oleananes[45]
		Sindora	21 (2)	Southeast Asia	Clerodanes[46], Eperuanes[46]	
	Congo copal	*Tessmannia*	12 (2)	Tropical West Africa	Clerodanes[47], Halimanes[48]	
Lauraceae	Camphor	*Cinnamomum*	370 (89)	East Asia	Cinnacasanes[49]	
Pinaceae	Hungarian balsam, Galipot	*Pinus*	169 (66)	Northern hemisphere	Abietanes[9], Cembranes[9], Isopimaranes[9], Labdanes[9], Phenolic Abietanes[9], Pimaranes[9], Podocarpanes[9], Strobanes[9]	Cycloartanes[9], Lanostanes[9], Serratanes[9]
		Picea	58 (6)	Asia, Europe, America	Abietanes[9], Cembranes[9], Isopimaranes[9], Labdanes[9], Phyllocladanes[9], Pimaranes[9]	Serratanes[9]
		Pseudotsuga	6	Asia, Africa	Abietanes[9], Cembranes[9], Isopimaranes[9], Labdanes[50], Pimaranes[50]	Cycloartanes[9]
		Abies	87 (9)	North America, Central America, Europe, Asia, North Africa	Abietanes[9], Cembranes[9], Isopimaranes[9], Labdanes[9]	Gammaceranes[9], Hopanes[9], Lanostanes[9]
	Cedar	*Cedrus*	5 (1)	Mediterranean, Middle East, West Asia	Abietanes[9], Isopimaranes[9], Labdanes[9], Phenolic Abietanes[9], Totaranes[9]	
		Keteleeria	4 (1)	Southeast Asia	Abietanes[51], Labdanes[51]	
Plumbaginaceae		*Plumbago*	9 (36)	Tropical Africa, America, Asia		Friedelanes[52], Lupanes[52], Ursanes[52]
Podocarpaceae		*Afrocarpus*	6	Africa	Phenolic Abietanes[9], Phenolic diterpenes[53], Podocarpanes[54], Totaranes[9]	
		Podocarpus	113 (15)	South America, Africa, Australia, South Asia, Oceania	Isopimaranes[9], Kauranes[9], Phenolic Abietanes[9], Phyllocladanes[9], Podocarpanes[9], Totaranes[9]	
Styracaceae	Benzoin	*Styrax*	95 (104)	Southeast Asia		Oleananes[55]
Thymelaeaceae	Agarwood	*Aquilaria*	21 (4)	Southeast Asia	Abietanes[56]	Tirucallanes[57]
Valerianaceae	Spikenard, Nard, Nardin	*Nardostachys*	2 (1)	South Asia	Unnamed skeleton[58]	
Zingiberaceae	Costus root	*Costus*	110 (6)	Africa, South Asia		Cholestanes[59]

[1] Shang et al., 2014, [2] Fukuda et al., 2006, [3] Chien et al., 2013, [4] Assimopoulou and Papageorgiou, 2005, [5] Marner et al., 1991, [6] Regert et al., 2008, [7] Mills and White, 1977, [8] Lee et al., 2009, [9] Otto and Wilde, 2001, [10] Muckensturm et al., 2005, [11] Gupta et al., 2008, [12] Mathe et al., 2007, [13] Hanus et al., 2005, [14] Ajibesin 2011, [15] Da Silva et al., 1990, [16] Turner et al., 1980, [17] Kalpoutzakis et al., 2003, [18] De Pascual et al., 1982, [19] Laure et al., 2005, [20] Mawa and Said, 2012, [21] All Cupressaceae have Labdanes and Abietanes (Otto and Wilde, 2001), [22] Li and Kuo, 1998, [23] He et al., 1997, [24] Chiang et al., 2003, [25] Liu et al., 2010;, [26] Wu et al., 2013, [27] Barrero et al., 2003, [28] Bandaranayake et al., 1975, [29] Geevananda et al., 1980, [30] Misra and Ahmad, 1997, [31] Sutthivaiyakit et al., 2001, [32] Fürstenberger and Hecker, 1986, [33] Khan and Malik, 1990, [34] Ferreira et al., 2001, [35] Rizk, 1987, [36] Akihisa et al., 2002, [37] Ferreira et al., 2003, [38] Leandro et al., 2012, [39] Bevan et al., 1968a, [40] Fujita, 1970, [41] Plazzotta et al., 2006, [42] Hugel et al., 1965, [43] Bevan et al., 1968b, [44] Maruthupandian and Mohan, 2011, [45] Kumar et al., 1974, [46] Aoki et al., 2007, [47] Kihampa et al., 2010, [48] Kihampa et al., 2009, [49] Ngoe et al., 2009, [50] Hsieh et al., 1998, [51] All Pinaceae have Labdanes and Abietanes (Otto and Wilde, 2001), [52] Kishore et al., 2012, [53] Cambie et al., 1983, [54] Faiella et al., 2012, [55] Wang et al., 2006, [56] Yang et al., 2013, [57] Cheng et al., 2013, [58] Zhang et al., 2005, [59] Böhme et al., 1997.

[a] Number of accepted species and subspecies worldwide according to The Plant List (2010); number of unresolved species in brackets.

[b] Modern geographical distribution, compiled from Mills and White (1977), Langenheim (2003), Regert et al., (2008), Mabberley (2008), Hepper (1969), Zohary (1973), Vollesen (1989), Radcliffe-Smith (1992), Thulin (1999), The Plant List (2010), African Plants Database (2012) and the International Plant Names Index, (IPNI).

surface of the artefact. Macroscopically visible sections of this dry, white/brown residue, weighing <0.5 mg in total, were removed with forceps and placed in sterile 1.5 ml vials. The subsequent chemical preparation method used for the dry residue is described in Section 4.3 below. After removal of the dry residue, the artefact was placed in a polyethylene sample bag, to which 1.5 ml of a solvent mixture of sterile (distilled, UV irradiated, filtered and deionised) water, acetonitrile (LCMS grade, Sigma–Aldrich), and ethanol (Sigma–Aldrich) was added to partially immerse one edge of the brass burner fragment. The edge of the artefact was left in the solvent for 30 min to dissolve the residue, after which time the solvent-residue extract was transferred to two 2 ml glass autosampler vials (referred to as residue samples 1 and 2) and the artefact was allowed to air dry.

The solvent mixture (acetonitrile:ethanol:water, 1:1:1) used for this analysis was chosen for its capacity to dissolve a broad range of organic compounds from the unknown mixture that potentially comprised the archaeological residue. Water was included to increase the polarity of the solvent mixture, thus ensuring that more polar compounds like carbohydrates and some amino and nucleic acids could be solubilised along with oxidised organic molecules. To ensure fatty acids, resin acids and alkaloids were solublised, less polar solvents were also required. Ethanol was chosen for its efficacy at dissolving resin acids and alkaloids (Alqasoumi and Abdel-Kader, 2012; Conforti et al., 2006; Popova et al., 2010; Zhang et al., 2005), while acetonitrile was selected for its ability to dissolve fatty acids, resin acids, as well as some amino acids (Barnard et al., 2007; Shen et al., 2006; Sobolevsky et al., 2003). Importantly, unlike other solvents such as dichloromethane, chloroform, butanol and diethyl ether, some of which are more commonly used for resin and fatty acid analysis in archaeological residue studies (Charrié-Duhaut et al., 2007, 2013; Evershed et al., 1997b; Malainey et al., 1999; Regert et al., 2008; Stern et al., 2003; van Bergen et al., 1997), both ethanol and acetonitrile are miscible with water. It is important that the solvent mixture behaves as a solution rather than as a suspension or emulsion so that all of the organic components of the residue are solubilised and thus available for analysis. Other organic solvents that are miscible with water like methanol and acetone were not chosen due to their low boiling point. The evaporation of these solvents would have made the sampling more difficult because the residue extraction step was performed by briefly soaking the metal artefact in the solvent solution.

We also note that, while it is preferable to perform the residue extraction in solvent-washed glass receptacles, such apparatus were not available when the extraction was performed. Given that this study was targeting botanical compounds such as di- and triterpenoids, alkaloids, sterols, waxes and carbohydrates, we were confident that any contaminants released from the plastic receptacles such as phthalates and other types of plasticizers, could be identified and excluded from the analysis (discussed further in Section 4.4 below).

4.3. Gas chromatography–mass spectroscopy (GC–MS) analysis

The dry residue sample was prepared using two different solvents. First it was placed into 1 ml hexane (Sigma–Aldrich) in a sterile glass autosampler vial. Hexane was used to remove any hydrocarbons, which may be found in waxes and oils. The supernatant was transferred to a 2 ml glass autosampler vial (residue sample 3) ready to be analysed by GC–MS. The dry-removed residue sample was dried after the hexane treatment and dissolved in 1 ml of acetonitrile and mixed by vortexing before heating at 70 °C for 8 h. Once dissolved, the acetonitrile solution was centrifuged and two aliquots of 500 μl were transferred to two 2 ml glass autosampler vials (residue samples 4 and 5). The solvent-extracted residue samples (residue samples 1 and 2) and one of the two acetonitrile-dissolved dry-removed samples (residue sample 4) were then freeze-dried under vacuum (Labconco Freezone 12) for 8 h or until dry. An additional 500 μl of acetonitrile was added to residue sample 5 to bring it to a final volume to 1 ml solution for GC–MS analysis.

Residue samples 1, 2 and 4 were then derivatised with 0.1 ml solution of BSTFA (bis(trimethylsilyl)trifluoroacetamide) with 1% TMS (trimethylchlorosilane) (Sigma–Aldrich), and 0.9 ml of cold acetonitrile (Sigma–Aldrich). The vials were purged with nitrogen, sealed with teflon-coated septa, and incubated on a Baxter Scientific Multi-Block at 120 °C for 30 min. The samples were mixed lightly by vortexing and analysed immediately using GC–MS.

The underivatised samples (residue samples 3 and 5) and derivatised samples (residue samples 1, 2 and 4) were analysed by a Varian model 450 gas chromatograph coupled with a Varian model 300-MS quadrupole mass spectrometer equipped with Factor-Four™ capillary column (VF-5ms, 30 m × 0.25 mm ID, DF = 0.25 μm). Helium was used as the carrier gas at a flow rate of 1.0 ml/min. Samples were introduced via splitless mode in an autosampler with the injection port at a temperature of 270 °C. The column temperature was initially held at 50 °C for 2 min then increased to 155 °C at a rate of 8 °C/min and then to 275 °C at a rate of 40 °C/min and held at that temperature for 9 min. The ionisation energy was 70 eV and the ion source was set at 200 °C under electron ionisation (EI) conditions. The scan range was from 40 to 500 *m/z*. The GC–MS interface temperature was set at 266 °C. Both reagent and procedural negative controls were run with all of the samples in this analysis.

4.4. Data analysis

The individual chemical compounds recovered from the residue were identified based on their ion spectra and the ionisation peaks (e.g., the molecular ion, M+ peak, M+1 peak and the various ionisation peaks M−15 peaks), using Varian MS workstation version 6 and the NIST98 Mass Spectral Database (National Institute of Standards and Technology). All compounds identified in the residue that could be derived from plastics, plasticizers, antioxidants, retardants, antistatic compounds, stabilisers, emulsifiers, extrusion compounds, lubricants, and pigment compounds, as well as those that are used in modern applications but could have come from natural sources (e.g., pelargonic acid as a single compound can be found in many plant species and is also extracted for use in herbicides, lacquers, and plastics) were excluded from the data analysis. Any fatty acids that could potentially derive from handling contamination or that occur as general soil constituents (e.g., stearic acid, palmitic acid) were also omitted (Croxton et al., 2010; Michalski et al., 2013). While the presence of a broad suite of compound types was considered in the final data analysis, our identification of the resin component of the residue focused on the presence of terpenoids, which are much less likely to be due to contamination.

All remaining chemical compounds identified in the residue were then cross-referenced against published data on the chemical compositions of resins from 55 genera native to the regions from South Africa to Southeast Asia, which were considered as possible botanical sources (Table 1, Fig. 4). These species represent key taxa of known importance in the ancient incense trade (e.g., various species of *Boswellia* and *Commiphora*), as well as local East African species (*Hymenaea verrucosa*) (Williams, 1949; Schlüter and von Gnielinski, 1987) and several important genera from West/Central Africa (e.g., *Canarium*, *Gossweilerodendron*, *Guibourtia*, *Copaifera*, *Daniellia*, *Oxystigma* and *Tessmannia*) (Langenheim, 2003; Meyer et al., 1991). Some of these West/Central African genera are also

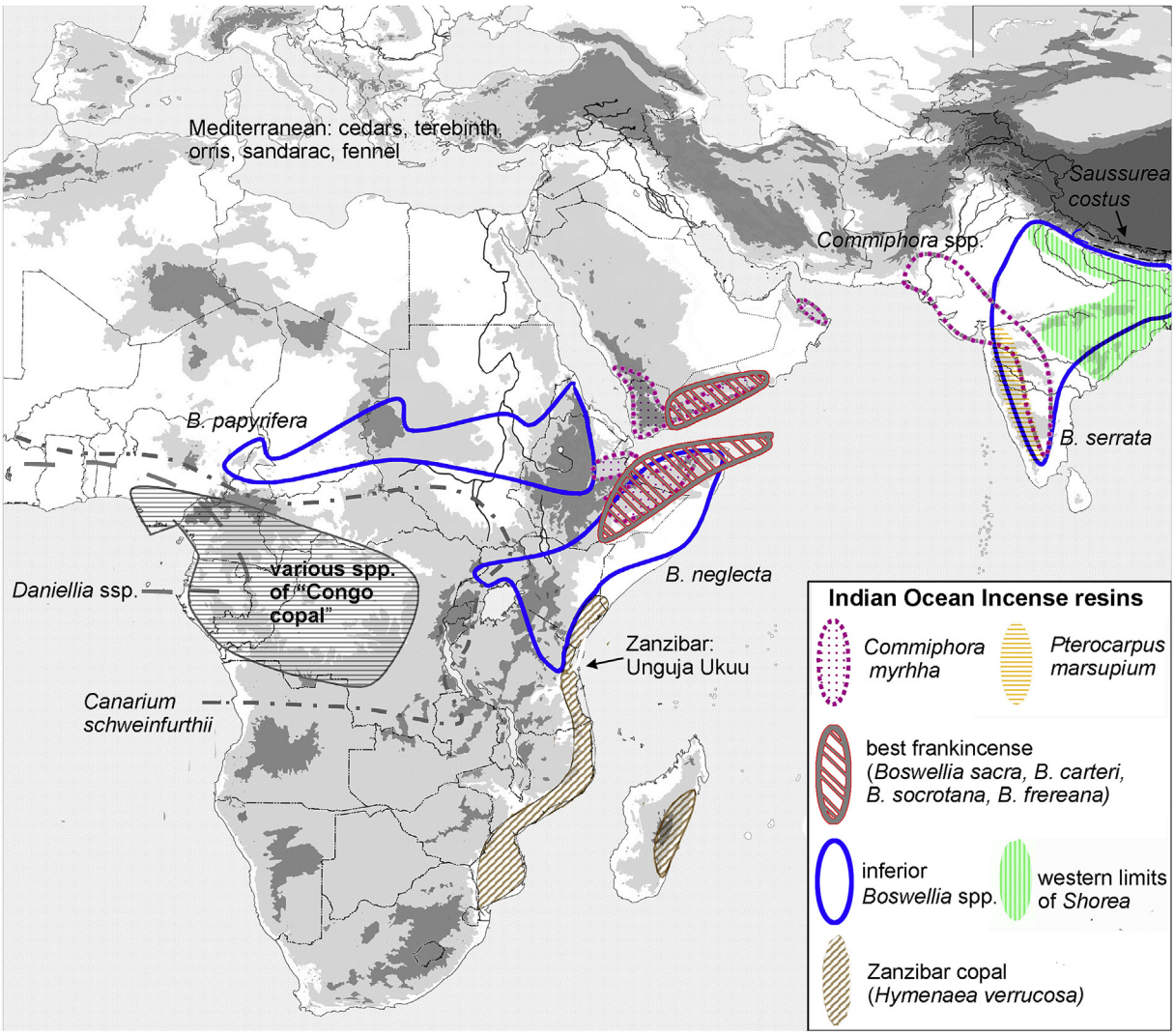

Fig. 4. Distribution map of the main resinous incense-producing species in Africa, Arabia and South Asia.

known to occur as outliers in coastal East Africa (*Guibourtia*, *Oxystigma* and *Tessmannia*) and in the Sudanian and Zambezian savannahs (*Daniellia*) (Langenheim, 2003: 78), while *Boswellia* species that produce 'inferior' frankincense also grow locally in Kenya and Tanzania (Maundu et al., 1999). Species from the Mediterranean and South and Southeast Asia were also considered given these regions' early Indian Ocean trade links.

5. Results

The GC–MS analysis of the residue revealed the presence of a range of chemical compounds including terpenoids (resin acids) in the samples, confirming that resinous residues were preserved on the surface of the artefact. Initial examination of the chromatographs (see Fig. 5 for example) and mass spectra identified the presence of a number of distinctive chemical compounds in the analysed samples (Table 2), including the following labdane diterpenoids: pinifolic acid (enantio-labd-8(20)-en-15, 18-dioic acid), guamic acid (enantio-labd-8(20),13-dien-15, 18-dioic acid), copalic acid (enantio labd-8(20), 13-diene-I 5-oic acid), zanzibaric acid ((*E*)-6-Hydroxy-8(17),12,14-labdatriene-19-oic acid) and ozic acid ((1,8β)-Decahydro-1,4α-dimethyl-6-methylene-5α-((*E*)-3-methylpenta-2,4-dienyl)-1-naphthalenecarboxylic acid). Analysis of the mass spectra of each chromatographic peak was performed to verify the identity of each of these compounds (e.g., Fig. 6 for zanzibaric acid). The mass spectrum for each compound is very unique owing to the way the compound fragments. The finding of labdane diterpenoids immediately suggests that the resin is unlikely to be any of the main species known to have been traded during the Classical and Medieval periods, such as frankincense or myrrh, which are composed primarily of triterpenoid (oleananes, lupanes, ursanes and tirucallanes) compounds (see Table 1; also Langenheim, 2003; Mills and White, 1977).

Labdane diterpenoids in general occur in the resins produced by a number of different genera in the broader study region (Table 1). While the specific compounds detected in the archaeological residue are found individually in several of these genera (Table 2), the full suite is only known to occur in the leguminous species, *H. verrucosa* Gaertn. (Zanzibar copal, syn. *Trachylobium verrucosum* (Gaertn.) Oliv.) (Table 2; Cunningham et al., 1973; Imamura et al., 2004; Regert et al., 2008; Vandenabeele et al., 2003). Two other compounds, 13-epimanool and 18-hydroxy-13-epimanool (both of which are diterpene alcohols) are also reported as present in the resin of this species (Hugel et al., 1966), but were not detected in the residue; however these occur in relatively small quantities in Zanzibar copal and therefore may have been present in

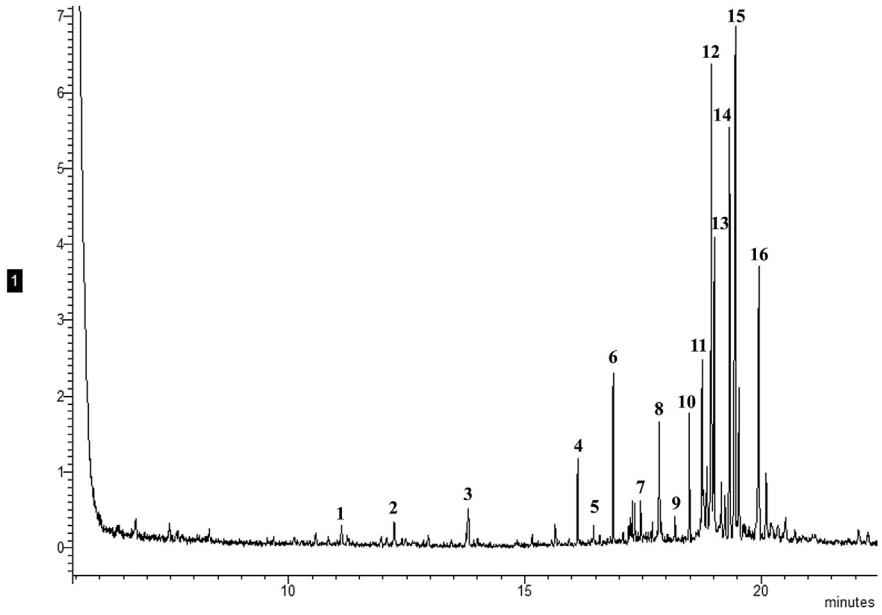

Fig. 5. The chromatograms obtained from analysis of the dry-removed sample that was derivatised and analysed in acetonitrile (sample 4). Peaks for the following chemical compounds have been labelled: 1 = nonanoic acid; 2 = hexadecane-1,2-diol; 3 = butyl 2-methylpropyl phthalate; 4 = 2,5-ditertbutyl phenol; 5 = dodecanol; 6 = labdan-8-ol; 7 = trachyloban-18-ol; 8 = hexadecanoic acid; 9 = methyl labd-8(20)-en-15-oate; 10 = octadecanoic acid; 11 = diisoctyl phthalate; 12 = ozic acid; 13 = copalic acid; 14 = zanzibaric acid; 15 = 3α hydroxyl trachyloban-18-oic acid; 16 = pinifolic acid.

concentrations too low for detection in the small sample of aged archaeological material that we analysed. In sum, therefore, we detected twelve of a compiled suite of fourteen chemical compounds known to occur in the resin of *H. verrucosa* in the archaeological residue; six of these compounds are currently known to be unique to this taxon (Table 2). Overall, these data provide strong evidence that the resinous residue is derived from this local East African species.

All reagent and procedural negative controls showed no evidence of contamination by any compounds. Acetamide, a breakdown product of acetonitrile, was found in some of the samples that were analysed with acetonitrile. Artefacts of the derivatisation process like trimethylsilyl complexes and oxidised trimethylsilyl compounds were detected in some of the negative controls that were derivatised. These compounds were excluded from the analysis and are not listed in Table 2. We also consider it unlikely that the resinous residues on the artefact are contaminants from the burial environment, since resins are water insoluble and therefore not likely to be mobile in solution in depositional sediments. No copal fragments were recovered from any of the archaeological deposits during the excavation. Organic residues on other artefacts from Trench UU11 have also been analysed by GC–MS, and none of these have indicated the presence of this suite of resinous compounds (C. Matheson and M-A Veall, unpublished data).

6. Discussion

The detection of labdane diterpenoid resin acids in the residue extract from the Unguja Ukuu brass artefact confirms its likely function as an incense burner, as was hypothesised based on its style and morphology. What was more unexpected from our results was that, despite the artefact's probable foreign origin and the importance of exotic resins such as frankincense and myrrh to the long-distance incense trade of this period, the resin was identified as a local species, *H. verrucosa* Gaertn., more commonly known as Zanzibar copal. This species is native not only to Zanzibar but much of the wider East African coastal region where it is dominant in the now largely depleted coastal forests that stretch from southern Somalia to Mozambique, including the islands of Zanzibar, Pemba, Mafia, Madagascar, the Seychelles and Mauritius (Clarke, 2000; Cunningham et al., 1973; Langenheim, 2003: 396) (Fig. 5). These dry lowland and upland forests form a distinct biota that is highly specific to the coastal region, generally occurring no more than 200 km inland from the coast (Clarke, 2000; Sunseri, 2007). *Hymenaea* resin occurs either in semi-fossilised form, often found in pockets in the coral bedrock, or as fresh copal, which is collected from incisions on the tree trunk or from recent drippings onto the ground (Langenheim, 2003: 396; Sunseri, 2007). Resin is also produced in the tree's seed pods and leaf pockets, but it is harder to extract from these sources. On Zanzibar island itself, copal most commonly occurs in terrestrial reef formations, into which it was incorporated after being washed out from the coastal forests. It was dug out in pits from the coral in the 19th century, and over 400 tons were exported annually (Horton, in press).

No other diterpenoid or triterpenoid compounds were detected in the residue extract to suggest that the artefact had also been used to burn other resins, although if the burner had been used multiple times prior to being discarded, those resins from the first use(s) may not have been present in high enough quantity to be detected. Likewise, if the burner was used with other non-resinous aromatics, which contain more volatile compounds, such as sesquiterpenoids, sterols and monoterpenoids, these also might not have preserved. Many of the chemical compounds found in plant resins, on the other hand, polymerise over time, making them highly resistant to degradation, hence their occurrence in semi-fossilised and fossilised (i.e. amber) form in sediments potentially as old as the Tertiary (Langenheim, 2003: 81, 183). Nonetheless, we cannot rule out the possibility that the incense burner from Unguja Ukuu was not also used to burn other non-local aromatics whose residues have not survived.

While the potential range of aromatics used in the incense burner may therefore not be fully apparent, the results clearly provide the first direct archaeological evidence of the use of Zanzibar copal as an aromatic in antiquity. While our evidence for copal

use at Unguja Ukuu is only a single occurrence, and does not necessarily show that this raw material was being exported at this time, its presence at a major Indian Ocean trading site in direct association with a rare and potentially exotic item of material culture is highly suggestive in this regard. We explore this possibility further in the following discussion and also briefly outline the potential implications of this study for understanding early incense use and local engagement with Indian Ocean material culture on the East African coast.

Table 2
List of all chemical compounds identified in each archaeological residue sample and their source (for resinous compounds, the source is restricted to genera known from our broader study area, see Table 1).

Compounds	Residue sample	Source
Enantio-labda-8(20)-en-15, 18-dioic acid (pinifolic acid)	1,2,4	Resin: *Hymenaea*[1], *Pinus*[2]
Enantio-labda-8(20),13-dien-15, 18-dioic acid (guamaic acid)	1,2,4	Resin: *Hymenaea*[1,3]
Enantio-13-epilabdanolic acid	1,4	Resin: *Hymenaea*[1]
Methyl labd-8(20)-en-15-oate	1,4	Resin: *Hymenaea*[3], *Moldenhawera*[4]
Trachyloban-18-ol	1,4	Resin: *Hymenaea*[5], *Xylopia*[6]
Trachyloban-18-oic acid	1,4	Resin: *Croton*[7], *Hymenaea*[5], *Mastigophora*[8], *Mitrephora*[9]
3α-Hydroxy-trachyloban-18-oic acid	1,4	Resin: *Hymenaea*[10]
Enantio-6-acetyl labda-8(17),12, 14-triene-19-oic acid (zanzibaric acid)	1,2,4	Resin: *Hymenaea*[5]
Enantio-labda-8(20)-en-15-oic acid	1,4	Resin: *Hymenaea*[5]
Enantio-labda-8(17),12,14-triene-19-oic acid (ozic acid)	1,2,4	Resin: *Daniellia*[11,12], *Helianthus*[13], *Hermas*[14], *Hymenaea*[15], *Mikania*[16], *Orthosiphon*[17], *Pycnanthus*[18]
Enantio-labda-8(20), 13-diene-15-oic acid (copalic acid)	1,2,4	Resin: *Aristolochza*[19], *Copaifera*[20], *Detarium*[21], *Eperua*[22], *Hymenaea*[3], *Oxystigma*[12]
Labdan-8-ol	1,4	Resin: *Hymenaea*[3]
Serverogenin acetate	1,2,4,5	Plant, e.g,. leaves of *Trichilia*[23]
Hexadecanoic acid (palmitic acid)	4	Plant[24]; animal[24]; beeswax[25,26,27]; human handling[28,29]
octadecanoic acid (stearic acid)	4	Plant[24]; animal[24]; beeswax[25]; human handling[28,29]
Nonanoic acid (Pelargonic acid)	1,2	Plant[30,31]; contamination[31]
(1E)-1-(phenylmethylidene)indene	1,2	Burnt organic material[32]; contamination[33]
2,5-Ditert-butylphenol	1,2	Burnt organic material[32]; contamination[34]
2,4,6-Tritert-butylphenol	1,2	Burnt organic material[32]; contamination[34]
Heneicosanes (21 Carbons)	3	Burnt organic material[35]; beeswax[26,27]
Tridecanes (13 Carbons)	3	Burnt organic material[32,35]
Tetradecanes (14 carbons)	3	Burnt organic material[32,35]
Hexadecanes (16 Carbons)	3	Burnt organic material[35]
Oxanilic acid	4	Environmental contamination[36]
Hexadecan-1,2-diol	4	Contaminant
Dodecanol	4	Contaminant
Octadecanol	4	Contaminant
Butyl, 2-methylpropyl, phthalate	1,2	Plastic[37,38]
Diisooctyl phthalate	1,2	Plastic[23,37]

[1] Cunningham et al., 1973, [2] Enzell and Theander, 1962, [3] Hugel et al., 1966, [4] David et al., 2007, [5] Hugel et al., 1965, [6] Elhassan et al., 2010, [7] Kapingu et al., 2000, [8] Leong and Harrison, 1997, [9] Li et al., 2005, [10] Fraga, 1994, [11] Bevan et al., 1966, [12] Bevan et al., 1958, [13] Stipanovic et al., 1979, [14] Hanson, 1975, [15] Mills and White, 1994, [16] Mendes et al., 2005, [17] Hussein et al., 2007, [18] Ramalhete et al. 2007, [19] Lopes and Bolzani, 1988, [20] Pinto et al., 2000, [21] Cavin et al., 2006, [22] Avila and Medina, 1993, [23] Senthilkumar et al., 2012, [24] Malainey et al., 1999, [25] Regert et al., 2001, [26] Maia and Nunes, 2013, [27] Lakshmi et al., 2012, [28] Croxton et al., 2010, [29] Michalski et al., 2013, [30] Knudsen et al., 1993, [31] Vannozzi 2006, [32] Kaal et al., 2009, [33] Aracil et al., 2005, [34] Fujita, 1974, [35] Kaal et al., 2008, [36] Kolpin et al., 1998, [37] Zhang et al., 2012, [38] Huang et al., 2013.

6.1. East Africa's copal trade in historical and archaeological context

Known to the Swahili as *msandarusi* (from the Arabic *san'dar-oussi*, meaning 'fossil hard copals') (Regert et al., 2008: 674) and the Bantu-speaking farmers of the coastal hinterland as *mnangu* (Sunseri, 2007), copal was one of the key commodities traded out of East Africa and Madagascar in the late 18th and 19th centuries. Like many leguminous resins dominated by labdane diterpenoid resin acids, *Hymenaea* produces a very hard copal that was in particular demand by traders from North America and Europe for its toughness and durability for varnishes (Langenheim, 2003; Sunseri, 2007). It was during the late second millennium CE that this resin acquired the name 'Zanzibar copal', owing to the island's monopoly on the copal trade, which saw most international copal exports shipped from its ports (Langenheim, 2003: 305). Large quantities of the semi-fossilised resin were dug from subterranean deposits by local villagers along the east coast hinterland and on the islands, and shipped via Zanzibar to foreign markets (see descriptions in Burton, 1872; Elton, 1874; Fitzgerald, 1898; Kirk, 1869). It was one of the main ingredients in varnish. According to Sunseri (2007), the 19th century copal economy not only provided a further means of connecting coastal and inland East African communities, but also allowed for the accumulation of material wealth, and relative political security among territorial leaders in the coastal hinterland. East Africans were also active agents in controlling and influencing the copal trade, and the global economy to which it was tied, through their consumer desires for foreign goods, particularly American cloth (Prestholdt, 2008:73–75). The copal trade began an inevitable decline by the late 19th century with the arrival of German colonial influence and an increased need for the more lucrative trade item, wild rubber (Sunseri, 2007). On Zanzibar, however, copal was still an export item until the 20th century, when the rise of New Zealand *kauri* resin saw the collapse of the world market for copal (Juma, 2004).

The early stages of East Africa's copal trade are much less clear. A pendant found in a third millennium BCE Mesopotamian grave from Eshnunna (Tell Asmar, near modern Baghdad) has been identified as being made from East African *Hymenaea* resin (Meyer et al., 1991), suggesting that the trade in this raw material has deep roots. The identification of the Eshnunna pendant resin should be viewed with caution, however, owing to the use of FTIR

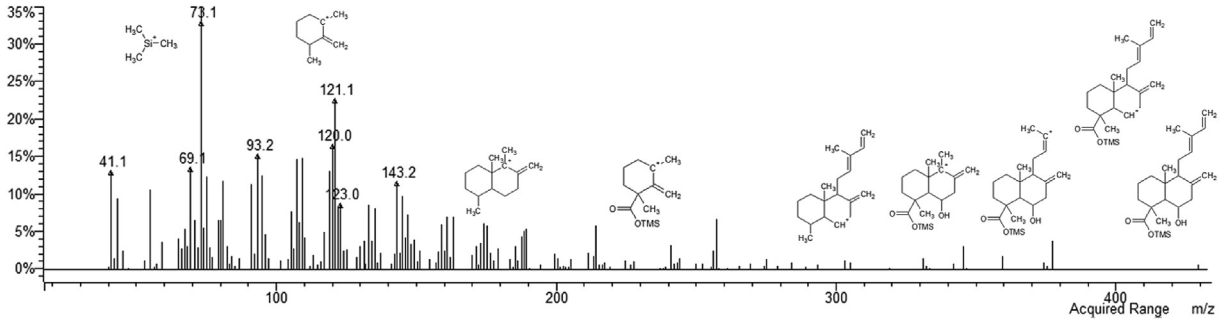

Fig. 6. The mass spectrum of the derivatised compound, zanzibaric acid trimethylsilyl (TMS) ester obtained from the GC–MS analysis of the archaeological residue sample, showing its characteristic fragment ions (inset).

to identify the source of the resin. This technique lacks the sensitivity and specificity of GC–MS when applied to chemical mixtures, being able to provide only a fingerprint (chemical bond resonant frequencies) of major chemical constituents common to a particular family or genus, rather than species (Langenheim, 2003: 154). Indeed, the absorption bands in the Eshnunna pendant analysis are only characteristic of labdane diterpenoids in general (Meyer et al., 1991: 296), which could include a number of leguminous West/Central African species as well as several from the Middle East, and West and Central Asia (see Table 1). The date of the Eshnunna pendant is also significantly earlier than any other evidence of long-distance trade involving coastal East Africa (Boivin et al., 2013; Sinclair, 2007), which raises further doubts regarding its authenticity (see also Phillips, 1997: 437). Alternatively, if the resin used to manufacture the Eshnunna pendant is indeed *Hymenaea*, then it might have been acquired from the coastal forests growing in Somalia or northern Kenya by early traders located in the Horn of Africa (Sinclair, 2007). In either case, re-analysis of the pendant using a more discriminating technique such as GC–MS would be highly desirable in order to authenticate its identification.

Aside from the Mesopotamian pendant, the earliest archaeological evidence for Zanzibar copal comprises small fragments of resin, presumed to be from *Hymenaea*, found at sites along the East African coast dating to the Early Iron Age (c. 2nd–6th century CE) (Fig. 7) and the Mid-Late Iron Age (c. 7th–15th century CE) (see Table 3) (Chami, 1992, 1994, 2003; Chittick, 1974; Crowther et al., 2012; Helm, 2000; Horton, 1996; LaViolette et al., 1989; Pollard, 2008; Pradines, 2001). These sites include the major Swahili trading harbours of Shanga and Kilwa. Based on these findings, it has been widely suggested that copal was one of the local natural products traded by early Swahili communities from around the 8th century onwards (e.g., Horton, 1996; Pradines, 2003; Regert et al., 2008; Spear, 2000; Sunseri, 2007). However, the presence of copal fragments in Early Iron Age (pre-Swahili) contexts indicates that this trade may trace back to the early first millennium CE (perhaps even to the time of the 1st century CE *Periplus*), when it is suggested to have formed a component of local exchange between coastal and hinterland communities (e.g., Fawcett and LaViolette, 1990; LaViolette et al., 1989). It cannot be said with certainty, however, that any of these copal fragments are direct evidence of trade, as after all, the semi-fossilised resin can occur naturally in

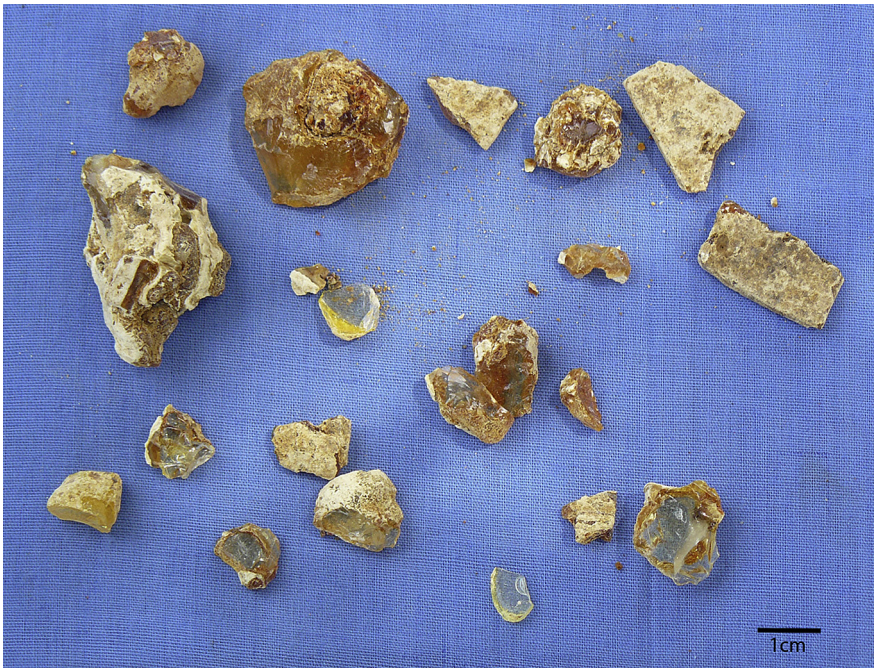

Fig. 7. Examples of copal fragments recovered from the Early Iron Age site of Limbo (c. 2nd–3rd century CE; Chami, 1992), coastal hinterland, central Tanzania.

Table 3
Archaeological sites in coastal East Africa with finds of copal fragments.

Site name	Location	Date	Period	Reference
Limbo	Central coastal hinterland, Tanzania	2nd–3rd century CE	Early Iron Age	Chami, 1992; Crowther et al., 2012; LaViolette et al., 1989
Kivinja	Central coast, Tanzania	3rd–4th century CE	Early Iron Age	Chami, 2003
Misasa	Central coastal hinterland, Tanzania	4th–6th century CE	Early to Middle Iron Age	Chami, 1994; LaViolette et al., 1989
Kaole Village	Northern coast, Tanzania	6th–8th century CE	Middle Iron Age	Pollard, 2008
Mpiji	Northern coast, Tanzania	7th century CE	Middle Iron Age	Chami, 1994: 46
Kiwangwa	Northern coastal hinterland, Tanzania	7th century CE	Middle Iron Age	Chami, 1994
Chombo	Southern coast, Kenya	Late 8th–10th century CE	Middle Iron Age	Helm, 2000
Shanga	Lamu Archipelago, Kenya	8th century CE (most copal occurred 11th–13th century CE)	Middle Iron Age	Horton, 1996: 251
Gedi	Central coast, Kenya	12th–16th centuryCE	Late Iron Age	Pradines, 2001: 359
Kilwa	Central coast, Tanzania	13th century CE	Late Iron Age	Chittick, 1974: 438
Mtsengo	Southern coast, Kenya	14–15th century CE	Late Iron Age	Helm, 2000

local soils from where it can also wash out and be re-worked into new contexts (Langenheim, 2003: 183–184; Sunseri, 2007). However, the apparently common occurrence of copal fragments at these sites as well as their broad date range would seem to suggest longstanding use and trade of this natural resource. The finding of Zanzibar copal incense residues in a 7th–early 8th century deposit at Unguja Ukuu adds further weight to this hypothesis.

The first concrete evidence of East Africa's foreign copal trade comes from the 11th century CE site of Sharma on the Ḥaḍramawt coast of Yemen (Regert et al., 2008). A number of archaeological resin fragments recovered from this site have been identified as *Hymenaea* using a range of analytical techniques, including GC–MS (Regert et al., 2008). These fragments were apparently recovered from a range of contexts, and although it is not clear if they were used in mainly ritual or domestic settings, their use for incense is considered highly likely (Regert et al., 2008). Perhaps even more significant was the finding that, even though the Ḥaḍramawt coast was a major centre for frankincense production throughout antiquity, 42 of the 50 resin lumps analysed from Sharma were found to derive from East African *Hymenaea*, while only two samples proved to be from *Boswellia* (Regert et al., 2008). Although this pattern could be the result of differential preservation (Zanzibar copal fragments will be more durable than frankincense in depositional settings owing to the abundance of highly substituted diterpenoids, which polymerize over time) (Regert et al., 2008: 692), this finding nonetheless suggests that by the 11th century, East African copal had become a major export and potentially a key contributor to the Medieval incense trade, perhaps even eclipsing the Ḥaḍramawt coast as a primary producer. Sherds of East African TT/TIW pottery found at Sharma also attest to trade and/or exchange contacts between southwest Arabia and East Africa (e.g., Rougeulle, 2005; Rougeulle and Benoist, 2001).

Support for the hypothesis that copal may have been an early East African export is found in analyses of Arabian poetry, which demonstrate that despite the global renown of Arabian incense, non-Arabian incenses were more highly valued in early Arab culture than local frankincense and myrrh. In Arabia itself, non-Arabian incenses were viewed as rare and exotic, and accordingly conferred status on those who could acquire and use them (King, 2008: 188–189). The importance of distance to the value of early incenses can also be seen further east. During the 5–7th centuries CE in China, Middle Eastern incenses began to be joined or replaced by those of Indonesian origin. These were, however, initially traded as "Persian" goods, since Persia, unlike Southeast Asia, was a very distant and wondrously exotic locale for the Chinese (Wolters, 2008). Clearly incense had a range of origins, and the Yemeni findings highlight the possibility that the Ḥaḍramawt's dominance of the earlier "Incense Road" decreased in the late first millennium CE, with other sources such as East African copal and Southeast Asian resins becoming available — and possibly even more highly desired — during the Middle Ages. According to Sunseri (2007), East African copal was sought after for burning as incense during religious ceremonies in Jerusalem and Mecca in the Middle Ages, and was mixed with oils to coat paintings in Medieval Europe.

When integrated into its broader historical and archaeological context, the finding of copal residue on the brass incense burner from Unguja Ukuu thus adds a new temporal dimension to our understanding of the prehistory of East Africa's 'landscapes of extraction' (Sunseri, 2007: 202). Like other natural resources such as ivory, gold, tortoise shell, and wood, the historically documented exploitation and trade of copal may have a long history in East Africa. Although the earliest concrete evidence of its long-distance trade dates from only the 11th century CE (Regert et al., 2008), our study demonstrates that the aromatic properties of this resource were recognised from at least the 7th–early 8th century CE. It seems plausible, given the widespread finding of copal fragments at various Iron Age sites along the East African coast, that copal came to be incorporated into a widespread and enduring trade in resins, alongside the more commonly recognised frankincense and myrrh, that spanned many of the regions surrounding the Indian Ocean from this time. Additionally, this long-distance trade may have been based on earlier local networks that moved copal between hinterland and coastal sites during East Africa's Early Iron Age, potentially as early as the Classical period (Fawcett and LaViolette, 1990; LaViolette et al., 1989). It seems likely therefore that the limited evidence for copal outside of East Africa during these early time periods is the result of the lack of systematic and targeted chemical analyses (cf. Meyer et al., 1991; Regert et al., 2008) rather than its unimportance to regional and long-distance trade and exchange. Further studies along the lines that we report are critical for testing this hypothesis.

6.2. Incense in local East African practices

Our study findings also raise interesting questions about the possible social uses of incense on the East African coast, and the role of external Indian Ocean influences in these practices. A major outcome of East Africa's long-distance trade with Arab regions from the Iron Age onwards was the gradual adoption of elements of Near Eastern culture, and eventually the conversion of much of its coastal population to Islam (Horton and Middleton, 2000; Insoll, 2003; LaViolette, 2008). The earliest direct evidence for this process comes in the form of wooden mosques at the site of Shanga in the Lamu Archipelago, Kenya, dating to the late 8th century CE (Horton, 1996). A key feature of the spread of Islam in sub-Saharan Africa was its indigenisation by local communities, who

incorporated their own beliefs and practices into the new religion, and made local innovations such as new forms of mosque architecture (Horton and Middleton, 2000; Insoll, 2003; see also Faki et al., 2010). As Horton (1986: 211) observed, the first phase of this long-term process, as attested archaeologically, involved the adoption of an Islamic material culture, while architecture and institutionalised religion appear to follow. The burning of incense was common in a range of Islamic settings, including political, social and religious; and the production of a wide range of brass and bronze incense burners was a major industry during this time (Aga-Oglu, 1945). While the only other example of a metal incense burner known from the East African coast also comes from Unguja Ukuu (and is roughly contemporaneous with our find), several ceramic examples have been recovered from later contexts at the sites of Shanga (15th century CE or later; Horton, 1996) and Manda (mid 9th–early 11th century CE and later; Chittick, 1984) in the Lamu Archipelgo, Vumba Kuu on the southern Kenyan coast (14th–15th centuries CE; Wynne-Jones, 2010), and Kilwa off the central Tanzanian coast (late 12th–15th centuries CE; Chittick, 1974). Interestingly, the earliest of these — a rare cuboid type found only at Manda — resembles those manufactured in the Middle East (O'Dwyer Shea, 1983), suggesting to Chittick (1984) that they might be imported. Later types on the other hand all appear to be locally made in East Africa, suggesting that, as a class of material culture, incense burners underwent a gradual process of local adoption and adaptation following their initial introduction to East Africa as foreign imports. The burners from Shanga and Vumba Kuu were also found in or near mosques, indicating that their use was possibly closely linked to Islamic religious practice (Horton, 1996; Wynne Jones, 2010). In the absence of similar contextual evidence for our find from Unguja Ukuu, it is unfortunately impossible to draw a similar link to Islamic religious practice with any certainty. As mentioned above, thurification was also important in social transactions in the Islamic world (Aga-Oglu, 1950). An alternative, and perhaps more plausible hypothesis, then is that this early phase of incense burner use on the East African coast, as represented by our find at Unguja Ukuu, took place in more mundane social settings, perhaps related to trade rather than religion. Indeed, it may have been such social uses that facilitated the subsequent adoption of Islamic material culture and practice into religious life, and eventually the wholesale conversion of the East African coast to Islam.

It is worth noting that incense is also thought to have a long history of use in local religious rituals in East Africa. It is still widespread practice today to offer incense to indigenous spirits at sacred sites, such as stone tombs, caves, rock shelters, abandoned mosques and settlements (Abungu, 1994; see also Dale, 1920; Faki et al., 2010). Juma (2004: 63) observed one such sacred site in the vicinity of Unguja Ukuu in the 1990s, where fragments of pots were found in association with ritual incense burning. Although there is no definitive evidence that such practices also occurred on the coast prior to or during our study period, and likewise, we cannot be certain from its recovery context how the incense burner was actually used at Unguja Ukuu, one possibility is that it could have been used in the performance of similar, deeply embedded local rituals as those practiced across the region today. Indeed, the use of local resin for incense in the Iron Age suggests that its aromatic properties might already have been well known to the local inhabitants of the coast, where the *Hymenaea* trees were so common. In this scenario, the imported burner may simply have provided a new material cultural medium for these local practices. Again, while we cannot be clear on context, we are certain that this blending of these two elements — local resin and foreign, possibly Islamic, material culture — into a single use at Unguja Ukuu, quite likely reflects the very early stages of these complementary processes of indigenisation and Islamisation (or perhaps more broadly put, *Indian Oceanisation*) that later came to define the local cultures of the East African coast.

7. Conclusion

Chemical analysis has been applied to a rare ornate brass artefact recovered from a 7th–early 8th century deposit at the site of Unguja Ukuu on Zanzibar, one of the main ports to have operated on the East African coast during the early Islamic trading period. We have shown that the artefact retains traces of resin from the local species *H. verrucosa* on its surface, confirming the artefact's function as an incense burner and demonstrating for the first time the prehistoric use of resin from this local tree species as an aromatic. In light of findings suggesting that Zanzibar copal may have been a dominant commodity in the 11th century incense trade in southern Arabia (Regert et al., 2008), we propose that this role might have already begun some three to four centuries earlier, when copal was already in use as incense at Unguja Ukuu. Our study is therefore part of an emerging recognition of the role of non-Arabian resin sources in the ancient terrestrial and maritime incense trade. The methods of modern archaeological science are key to examining these other sources, which are often masked in historical documents. The latter reflect ancient notions about where incense was obtained from, rather than real origins and routes, and in a world where distance gave value to goods (as discussed in Helms, 1988), and where middlemen were keen to prevent competition, understandings of origins were often wildly inaccurate. The potential for archaeological science to contribute to our understanding of ancient trade is therefore important, particularly given that many of the most significant goods that travelled the ancient Silk Road and spice routes were organic and archaeologically accessible primarily through the application of advanced chemical and biological techniques.

Although our evidence for the use of Zanzibar copal is only a singular example, it also provides an important link between the historically documented colonial exploitation of East Africa's natural resources for global markets, and the integration of these resources in increasingly intensifying local, regional and long-distance trade networks during the Early and Middle Iron Ages. This is a key finding in terms of reconstructing the long-term historical ecology of East Africa's 'landscapes of extraction', which, as noted by Håkansson (2004: 561; see also Lane, 2010), "cannot be understood apart from the regional exchange systems in which they were embedded, and the world systems with which they were connected". Even though East Africa's role as a key provider of raw materials for Indian Ocean trade is attested to as early as the 1st century CE by texts such as the *Periplus of the Erythraean Sea*, archaeological evidence of such commodities has been extremely limited until now. Here, the recovery of well-preserved organic residues from a brass artefact that lay buried in tropical beach sands for some thirteen centuries or so, gives hope that further studies along these lines will continue to shed new light on this important aspect of East Africa's past.

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