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# Phoenician Cedar Oil from Amphoriskoi at Tel Kedesh: Implications Concerning Its Production, Use, and Export during the Hellenistic Age

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*Archaeologists and historians have routinely attributed “branded” goods to particular regions and cultural groups, often without rigorous analysis. Phoenician cedar oil is perhaps one of the best-known examples from antiquity. Hellenistic Tel Kedesh in the Upper Galilee region of the Levant is particularly relevant for these discussions by virtue of its strategic role as a border settlement in Phoenicia during one of the most dynamic periods in ancient history. As a concise contribution to these discussions, we present here an interdisciplinary analysis of amphoriskoi found with ca. 2,000 impressed sealings from the archive complex of the Persian-Hellenistic Administrative Building. While the building was constructed under the Achaemenids and occupied in both the Ptolemaic and Seleucid eras, the archive was in use only under the Seleucids in the first half of the of the 2nd century B.C.E. Blending organic residue analysis with archaeological and textual data has allowed us to identify with certainty one of the value-added goods most closely attached to ancient Phoenicia, true cedar oil from Cedrus libani. This discovery not only empirically verifies this well-known association for the first time, but also provides a rich context in which to test our assumptions about culturally-branded goods, the role they played in participant societies, and the mechanisms and systems in place that facilitated their production, use, and export.*

**Keywords:** Hellenistic period; semi-fine amphoriskos; organic residue analysis (ORA); archaeochemistry; phytochemistry; ethnobotany; ethnohistory; palaeoenvironment; paleoecology; Open-ARCHEM

The site of Tel Kedesh, strategically situated at the end of a mountainous plateau extending 35 km east from the coastal city of Tyre before it abruptly drops 400 m into the Hula basin, was traditionally the far-

thest inland point of incursion by the Phoenicians (Berlin and Frankel 2012; **Fig. 1**). After the fall of Babylon in 538 B.C.E., it was developed by the Achaemenid Persians and/or their Tyrian clients to use as a regional administrative center. It also served this purpose under the Ptolemies and Seleucids in rapid succession as they fought to define the boundaries between their kingdoms after the time of Alexander (Herbert and Berlin 2003; Berlin and Herbert 2013). The fortuitous result of this volatile political situation is the rich deposition of pottery from the Bronze Age down to the Hellenistic period, often with a strong international flavor. In the same vein as earlier Bronze Age ceramic vessels that were clearly containers for precious liquid goods, such as Aegean stirrup jars (Koh and Birney 2017), Cypriote Base Ring juglets (Koschel 1996; Chovanec, Bunimovitz, and Lederman 2015), and

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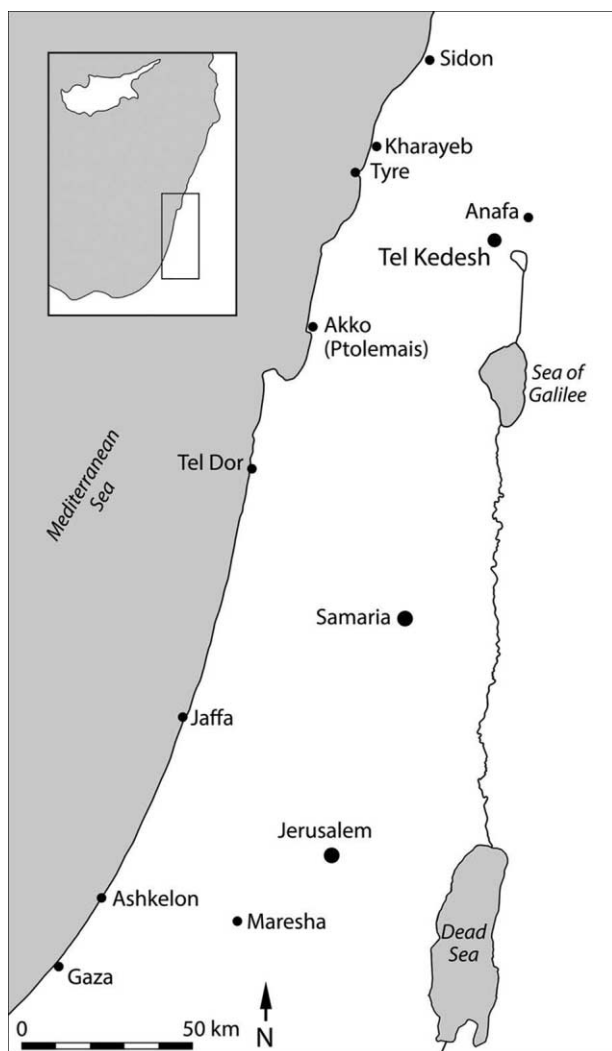


Fig. 1. Map showing the location of Tel Kedesh. (Map by A. Regiv-Gisis)

Egyptian/Levantine Tell el-Yehudiyeh juglets (Kaplan 1980), Phoenician analogues such as amphoriskoi, which are likewise found throughout the eastern Mediterranean, have great potential to illuminate the historic production, use, and export of culturally-branded goods, and, therefore, their larger socio-cultural significance. This ambitious goal is attainable if their valuable organic contents can be accurately characterized and contextualized, which is the central purpose of the ARCHEM project and the OpenARCHEM database.<sup>1</sup>

<sup>1</sup> The OpenARCHEM database (<http://openarchem.com>) is a new open-access repository, resource, and publication outlet for organic data—a natural outgrowth of the nearly two decades-old ARCHEM Project, an initiative that has collected thousands of residue samples throughout the eastern Mediterranean to encourage accessibility of ORA.

In July of 2008, at the invitation of Kedesh project co-directors Andrea Berlin and Sharon Herbert, ARCHEM project director Andrew Koh visited the site of Tel Kedesh to assess the potential for an organic residue analysis (ORA) pilot study. In an unplanned moment encouraged by the rich research opportunities presented by the site, Koh, with the support of the aforementioned co-directors, extracted sixteen ORA samples from an assortment of carefully excavated vessels (Fig. 2), after the team resourcefully procured a hotplate, sterilized jamming jars, aluminum foil, and analytical grade ethanol, which was only on hand due to the timely presence of conservator Claudia Chemello.<sup>2</sup>

Three extraction samples are the focus of the initial intensive ORA study presented here, obtained from two nearly-intact small amphoriskoi (Fig. 3a–c) of Phoenician semi-fine fabric. Although these two vessels were not found in the deep archive itself (see below), they are well representative of the corpus of 108 such vessels found at the site overall, in that they are identical in terms of fabric, shape, size, and type. Perhaps their most important attribute for this present study is the fact that they produced the best-preserved and most-representative ORA “fingerprints,” which were consistently reflected in all the amphoriskoi, indicating they all held the same fundamental commodity, allowing these particular amphoriskoi to serve as ideal reference samples that can best help us characterize and understand their standardized contents now and into the future. Particularly pertinent for understanding their biographies on site is that 40 of these amphoriskoi comprised the bulk of a remarkable assemblage of 52 largely restorable vessels (Fig. 4) found in 1999 and 2000, clustered towards the southeast corner of the northernmost room of the archive (i.e., the deep archive) located in a large administrative complex dubbed the Persian and Hellenistic Administration Building, or PHAB (Fig. 5a–b). Immediately north in the same room, 1,958 sealings were found clumped in the center of the room’s northeast quadrant (Herbert and Berlin 2003).

As is typically the case, no extant residues were visible within these vessels except for some faint discoloration alluding to their presence. Given that some mineral tempers in clay (e.g., calcites) are lipophilic, preferentially adsorbing certain fatty organic residues, the introduction of

<sup>2</sup> Methodological studies have demonstrated that field extractions that are fundamentally sound minimize the window for environmental degradation and anthropogenic contamination, which can by themselves outweigh the advantages of extractions conducted in the comfort of laboratories, but months, if not years, after discovery and exposure. Additional factors to consider on a case-by-case basis while on site include practical variables such as access to consumables (e.g., solvents) and the restrictive nature of archaeological permits (cf. Koh and Birney 2019; Koh in press).



Fig. 2. Tel Kedesh vessels pre-extraction. (Photo by A. Koh)



Fig. 3. (a) T865 amphoriskos base pre-extraction (ARCHEM 3202); (b) T864 amphoriskos shoulder pre-extraction (ARCHEM 3206); (c) T864 amphoriskos base pre-extraction (ARCHEM 3207). (Photos by A. Koh)



Fig. 4. Vessels from the deep archive. (Photo by H. Smithline)

heated solvents induces dissolution of organics from the ceramic matrix (Koh and Birney 2019; Goldenberg, Neumann, and Weiner 2014). After this initial pilot study showed promise, 80 more extractions were taken the following summer, which can now be selectively interpreted as a part of the Kedesh project's ongoing research and publication plan. The initial ORA results that are the focus of this short study empirically reveal for the first time that Phoenician amphoriskoi, at least of the type delineated here, contained true cedar oil from *Cedrus libani*, rather than from *Juniperus* (Zohary 1982; Zohary, Hopf, and Weiss 2012), the common source for "cedar oil" today that some have unequivocally claimed to be the ancient source as well (Lucas and Harris 2011: 309). This study confirms ethnohistorical accounts of cedar oil and expands beyond them to detail its day-to-day use as a preservative for papyrus (and repellent of pests and odors) in the Hellenistic period,<sup>3</sup> just as oils from both *Cedrus* and *Juniperus* are

<sup>3</sup> The recent discovery of a late Iron I structure at Tel Kabri in the Western Galilee in conjunction with a program of ARCHEM extrac-

used today to protect textiles from moths, beetles, and termites (Singh and Agarwal 1988). The conclusions presented here are not only based on the study's robust analytical results, but also on the complete archaeological picture presented by the site, which includes the fact that the amphoriskoi were discovered in situ in the heart of an indisputable Hellenistic administrative archive.

### Materials and Methods

Utilizing the ARCHEM project's proven ORA protocol, which prioritizes non-destructive extractions in the field (Koh 2006; Koh and Betancourt 2010; Koh, Yasur-Landau, and Cline 2014; Koh et al. 2015; Koh and Birney 2017; Yasur-Landau et al. 2018; Koh and Birney 2019), potential organic residues are targeted from ceramic objects carefully chosen on site in close collaboration with resident archaeologists in accordance with the overarching

tions on site invites the possibility of discerning earlier Phoenician parallels from around five centuries prior (Yasur-Landau et al. 2018).

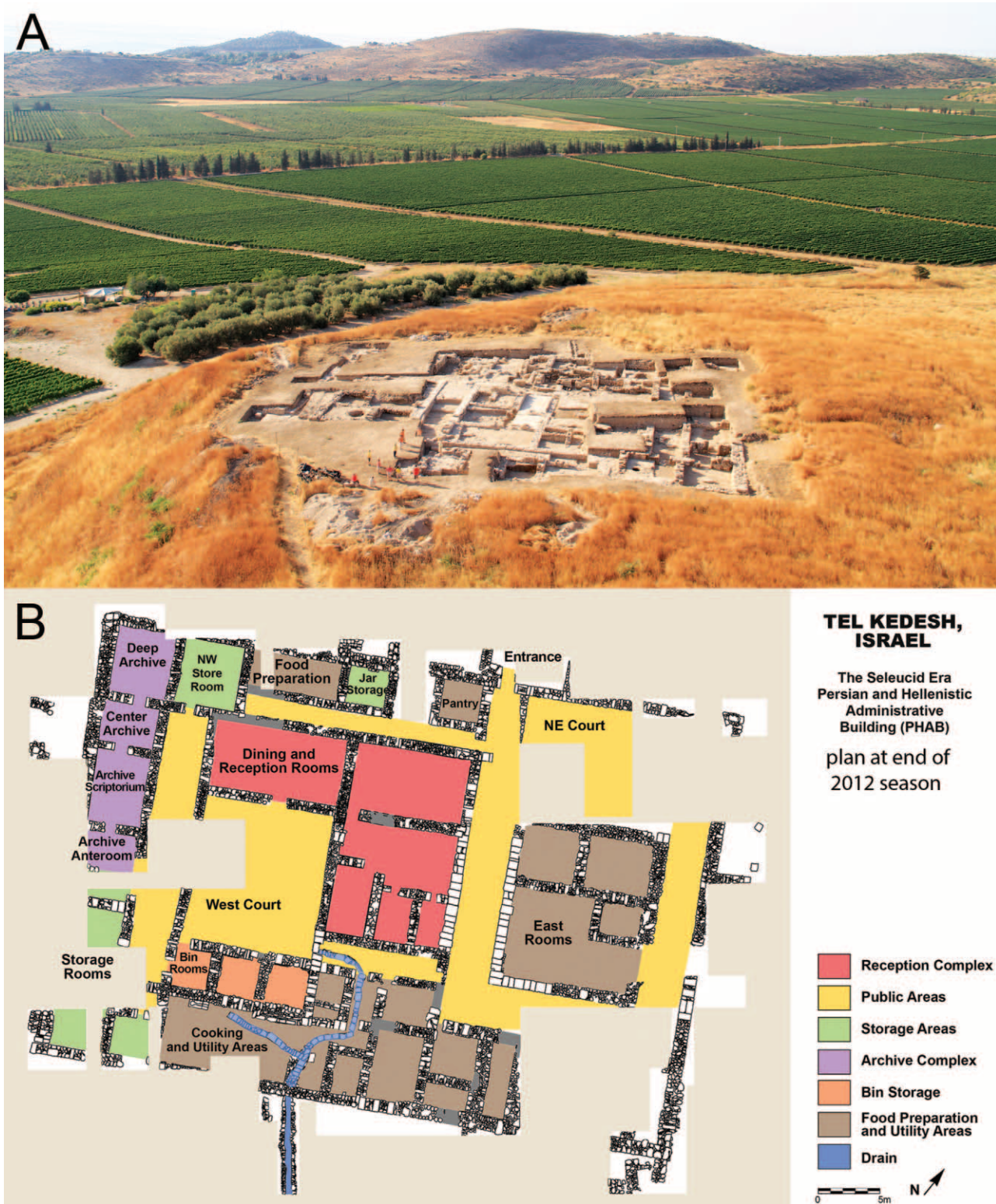


Fig. 5. (a) Aerial view of Tel Kedesh with Persian-Hellenistic Administrative Building looking southeast (Photo by Sky View Ltd); (b) The Persian-Hellenistic Administrative Building during the Seleucid period. (Plan by L. Lindorfer)

research goals of the excavations at hand. After field extractions, the resulting samples are shepherded to an analytical lab for instrumentation and subsequent interpretation, which is also executed in continuous dialogue with site archaeologists. This process helps to ensure that all external factors (e.g., contamination events, natural soil conditions) are considered from the start along with the more routinely considered internal factors inherent to each analyzed vessel (e.g., object biography, fabric). This unbroken “trowel-to-instrument” approach allows individual researchers to keep track of an object’s chain of custody and proactively screen for any suspected contaminants (e.g., plasticizers) or consider additional conditions that can affect the final ORA results and their interpretation. All the ORA samples from Tel Kedesh, once extracted into filtered solution, were stored in 20 ml scintillation vials in preparation for subsequent instrumentation. After extractions were completed, the solution samples were taken straight to the scientific labs at the Museum of Cretan Ethnology Research Centre in Vori, Crete to be analyzed by gas chromatography-mass spectrometry (GC-MS).

For GC-MS analysis at Vori, once additional sample preparations were completed (e.g., methylation), subsamples were taken from the master samples by measuring 300  $\mu$ l of solution into glass inserts placed into 2 ml vials, which were then centrifugally evaporated and refilled with dichloromethane for auto injection into a Shimadzu 5050A GC-MS in 2  $\mu$ l increments. The splitless injector and interface on the GC were both set to 250°C with a one-minute interface time. The carrier gas (helium) had a column inlet pressure of 60 kPa with a linear velocity of 53.8 cm/sec. The initial oven temperature was set to 130°C and held for 2 minutes before reaching 250°C at a rate of 5°C/min, at which time it was held for an additional 19 minutes, giving a total program time of 45 min/sample. A fused silica SPB-5 GC capillary column (30 m  $\times$  0.32 mm, 0.50  $\mu$ m) was used in the GC and directly inserted into a methane chemical ionization source set at 0.85 kV with a 50–450 m/z scan. Solvent blanks were intermittently utilized to verify that no contaminants existed from previous runs and that no components were lost in the column.

## Results

**Table 1** presents the comparative results and quantities of the diagnostic compounds recovered from the three extractions of the two amphoriskoi, T864 and T865 (**Figs. 6–8**).  $\beta$ -pinene, camphene,  $\alpha$ -pinene,  $\beta$ -myrene,  $\alpha$ -atlantone, himachalene, himachalol, cinnamic acid, cinnamate, oleonic acid, vanillin, and vanillate were identified after initial peak assignment using the NIST Mass Spectral Database, NIST 02, and confirmed with chemical reference samples

prepared and analyzed utilizing the same protocols. Note that compounds ubiquitous in nature, such as palmitic and stearic acid, have been omitted from the list of compounds, as they are so common as to be undiagnostic.

All diagnostic compounds can be phytochemically connected to a high degree of certainty with known botanical sources in the Levant and southern Anatolia through their chemical profiles, which were confirmed through comparisons with published data (e.g., Başer and Demirçakmak 1995) and our own extensive ethnobotanical (**Fig. 9a–b**) and ethnographic (**Fig. 10**) references from the OpenARCHEM library, including samples sourced from *Cedrus*, *Liquidambar*, *Styrax*, *Pistacia*, *Juniperus*, etc. The slate of detected ingredients confirms that the Kedesh amphoriskoi contained true cedar oil from *Cedrus libani*, but not without additives. It is clear that storax resin was added for purposes that can range from enhanced antimicrobial and aromatic qualities to changes in product viscosity that would aid in the oil’s application. Perhaps the most interesting lesson from the addition of storax, based on what we know about storax and the Kedesh context, is how ORA can inform object biography (Oras et al. 2017; Koh and Birney 2019), and in this case potentially provide evidence for ancient reuse through refills that would otherwise be invisible to us (see below).

### Oil from *Cedrus Libani* (*Cedar of Lebanon*)

$\beta$ -pinene (C <sub>10</sub> H <sub>16</sub> , 136 MW, 7.0 min in ARCHEM 3202, 3207)
Camphene (C <sub>10</sub> H <sub>16</sub> , 136 MW, 11.1 min in ARCHEM 3202, 3207)
$\alpha$ -pinene (C <sub>10</sub> H <sub>16</sub> , 136 MW, 11.3 min in ARCHEM 3202, 3207)
$\beta$ -myrcene (C <sub>10</sub> H <sub>16</sub> , 136 MW, 11.5 min in ARCHEM 3202, 3207)
$\alpha$ -atlantone (C <sub>15</sub> H <sub>22</sub> O, 218 MW, 17.9 min in ARCHEM 3202, 3207)
Himachalene (C <sub>15</sub> H <sub>24</sub> , 204 MW, 27.6 min in ARCHEM 3202, 3206, 3207)
Himachalol (C <sub>15</sub> H <sub>26</sub> O, 222 MW, 33.0 min in ARCHEM 3202, 3206, 3207)

Himachalol and himachalene, sesquiterpenes that serve as excellent diagnostic biomarkers for *Cedrus* (Boudarene et al. 2004; Paoli et al. 2011), were found in large quantities in all three samples. In addition to himachalol and himachalene, a third identified sesquiterpene of great importance is  $\alpha$ -atlantone. At least one study singles it out as the most distinctive diagnostic biomarker for *C. libani* (Shu and Lawrence 1997: 147). Combined with the absence of notable diagnostic biomarkers for *Juniperus* such as thujopsene (Zhang and Yao 2018), the presence of these three sesquiterpenes

TABLE 1. Gas Chromatography-Mass Spectrometry Data from Tel Kedesh Amphoriskoi (trace = 0.5–2%)

Vessel	Figure	Sample ID§	Maximum Peak Height	Maximum Peak AA*	Maximum Peak Concentration (%)†	$\beta$ -pinene RA (%)‡	Camphene RA (%)‡	$\alpha$ -pinene RA (%)‡	$\beta$ -myrcene RA (%)‡	$\alpha$ -atlantone RA (%)‡	Himachalene RA (%)‡	Himachalol RA (%)‡	Cinnamic				
													Acid RA (%)‡	Cinnamate RA (%)‡	Vanillin RA (%)‡	Vanillate RA (%)‡	Oleanolic RA (%)‡
T865 base	3a	ARCHEM 3202	2702934	33845306	32.67	trace	trace	trace	trace	3.095	29.391	3.086	trace	100	trace	15.071	5.826
T864 shou-lder	3b	ARCHEM 3206	346043	9416179	18.93	0	0	0	0	0	20.304	19.698	0	4.283	0	6.717	trace
T864 base	3c	ARCHEM 3207	2906911	48619814	36.70	trace	trace	trace	trace	3.83	11.608	2.829	trace	100	trace	14.547	5.958

§Standard ARCHEM #

\*Absolute Abundance, or peak area determined by integration in chromatograms

†Percentage of the sum of all peaks in a chromatogram

‡Relative Abundance, or peak area as a percentage relative to the maximum peak



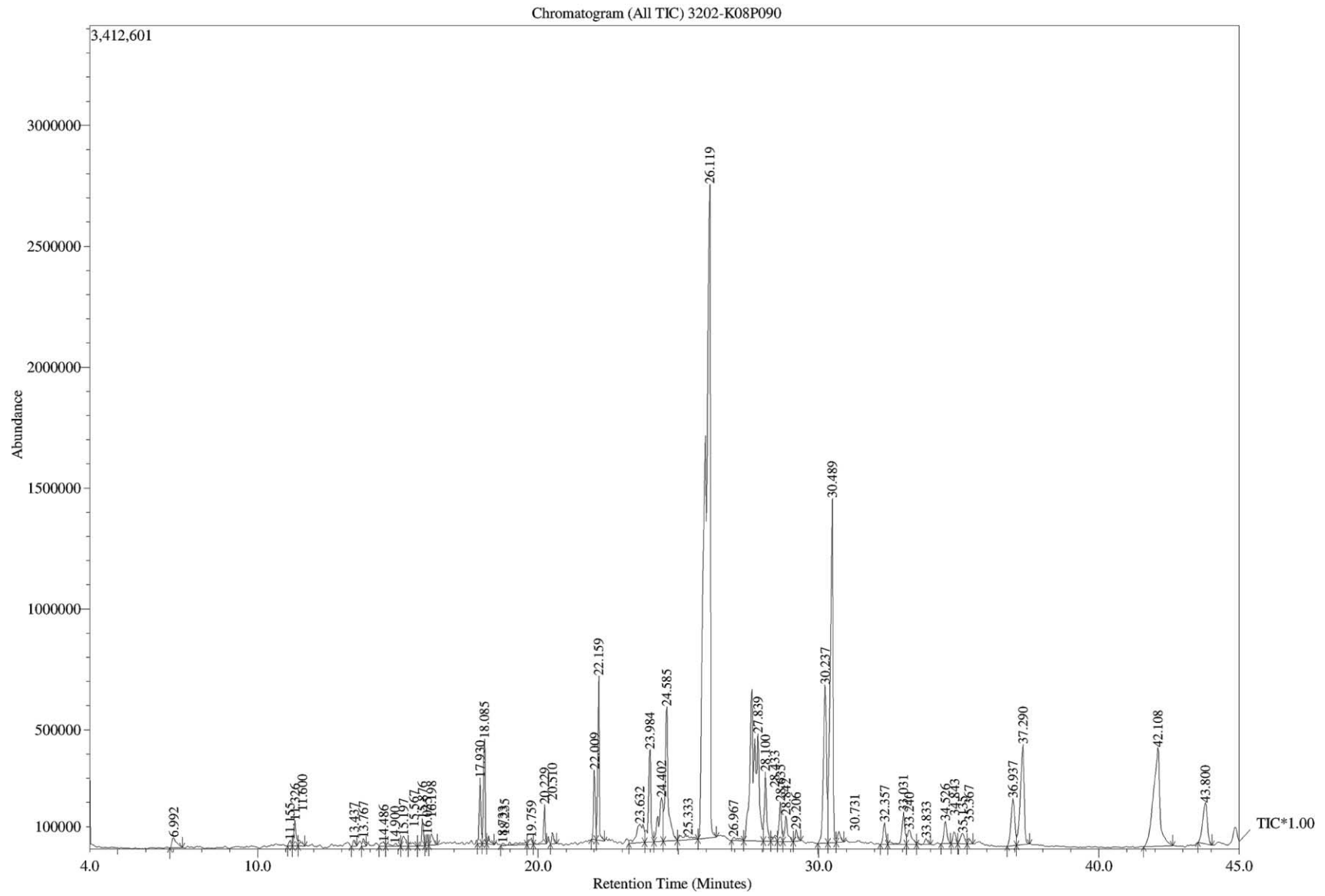


Fig. 6. Total ion chromatogram from T865 amphoriskos base (ARCHEM 3202). (Plot by A. Koh)

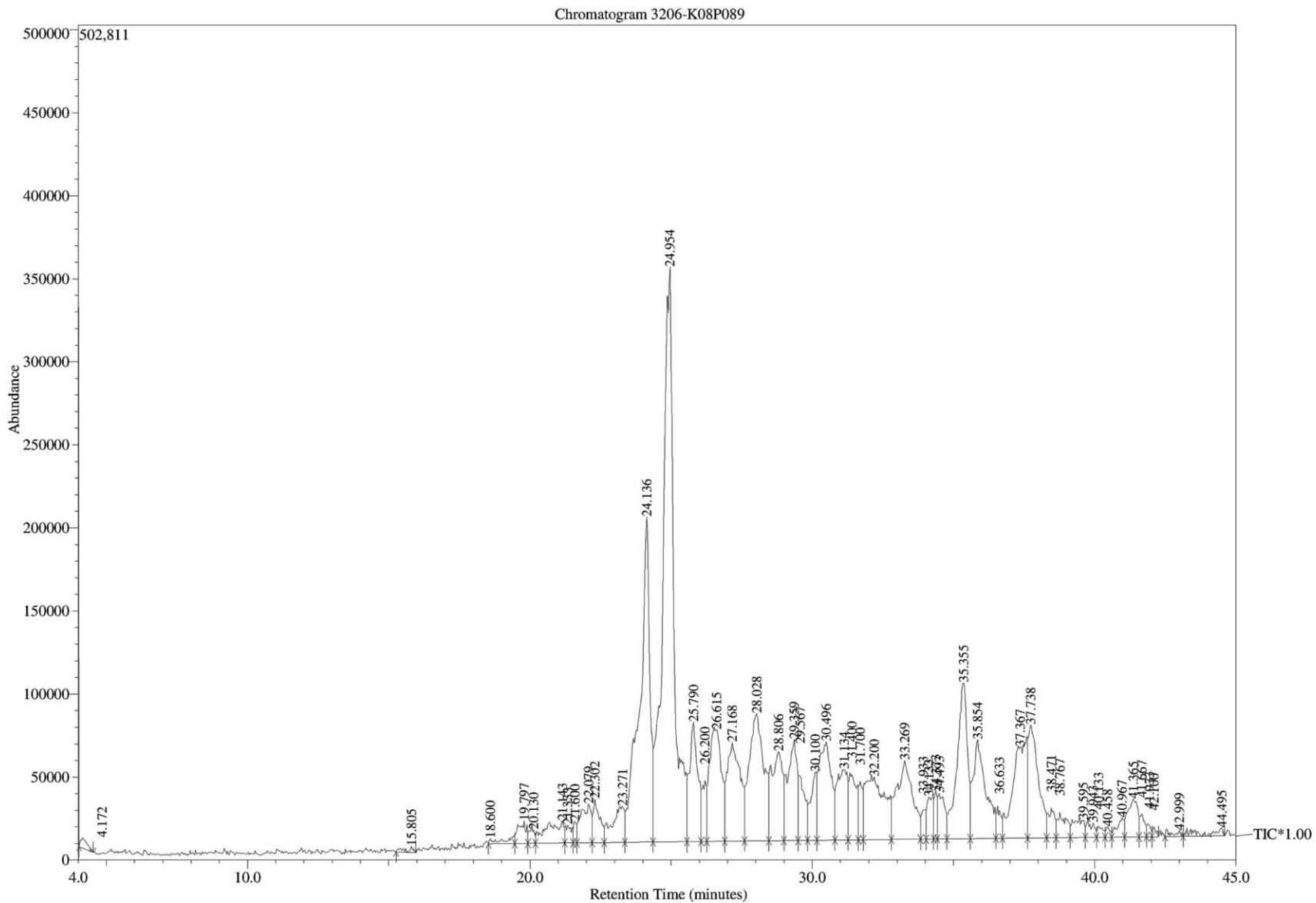


Fig. 7. Total ion chromatogram from T864 amphoriskos shoulder (ARCHEM 3206). (Plot by A. Koh)

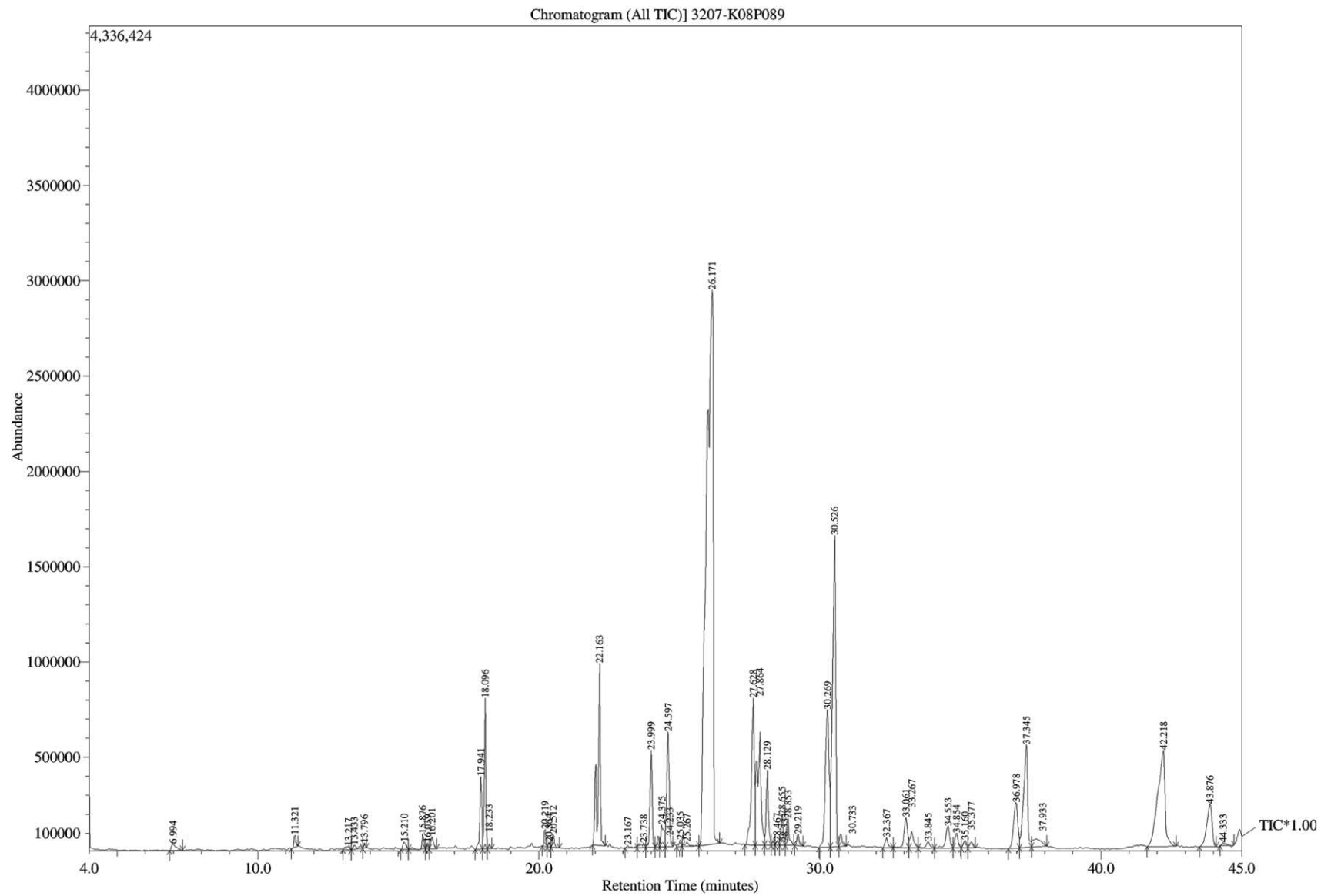


Fig. 8. Total ion chromatogram from T864 amporiskos base (ARCHEM 3207). (Plot by A. Koh)



**Fig. 9.** (a) Ethnobotanical and ethnographic samples from *Liquidambar orientalis* (Rhodes); (b) ethnobotanical source for *Styrax officinalis* (Crete). (Photos by A. Koh)

ensures that the cedar oil at Kedesh was sourced from *Cedrus* rather than *Juniperus*. A number of trace monoterpenes found in the two amphoriskoi base samples serve as additional biomarkers for *Cedrus*, including pinene, camphene, and myrcene (Boudarene et al. 2004).

The true cedar oil empirically identified in these samples represents the well-known Cedar of Lebanon (i.e., *Cedrus libani*), a large evergreen conifer native to the mountains of the northern Levant and Anatolia, but most

famously attached to Phoenicia (e.g., the barque of Amun in the Tale of Wenamun, Solomon's Temple in the Hebrew Bible—1 Kings 9:11), the land in which Kedesh resides. *C. libani* was harvested for its valuable wood and resin, the preparation of which is described by numerous ancient authors (Koller et al. 2003; Cockle 1983). In addition to its preservative qualities, cedar oil has the added benefits of repelling pests and odors, which is how it is largely known today, whether it derives from a true cedar source or not.

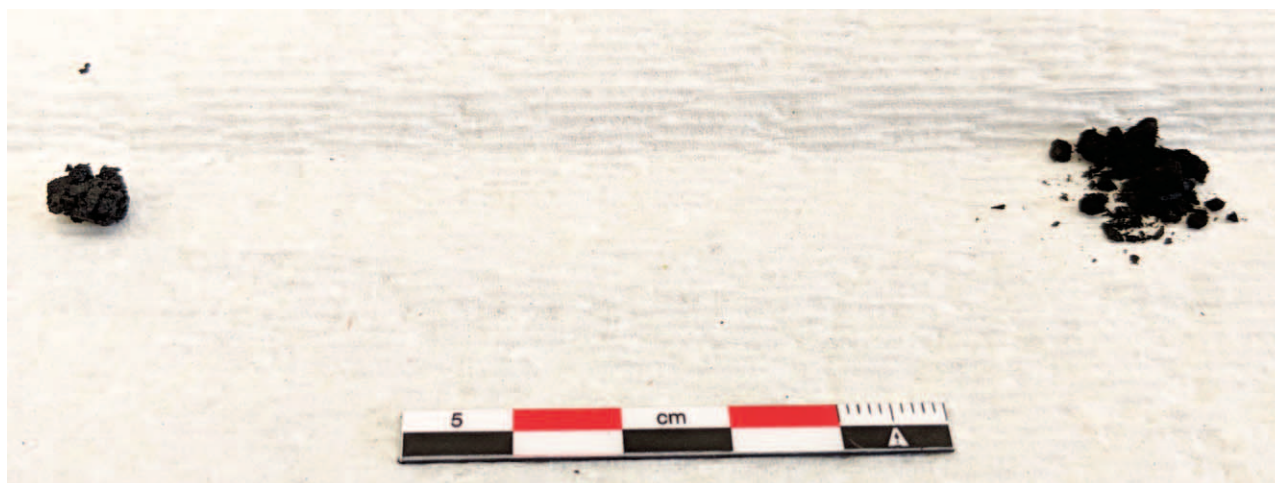


Fig. 10. Ethnographic resin samples from *L. orientalis*, storax balsam (left), and *S. officinalis*, storax benzoin (right). (Photo by A. Koh)

In antiquity, Herodotus famously mentions the Egyptian practice of embalming the dead, including sacred apis bulls, by injecting cedar oil *per anum* prior to the application of natron over the body (2.87), while Diodorus writing several centuries later simply states the body was anointed with cedar oil prior to the application of additional aromatic ingredients (1.91; cf. Lucas and Harris 2011).

#### **Storax Balsam from *Liquidambar Orientalis* (Sweetgum)**

- Cinnamic Acid (C<sub>9</sub>H<sub>8</sub>O<sub>2</sub>, 148 MW, 13.767 min in ARCHEM 3202, 3207)
- Cinnamate (C<sub>11</sub>H<sub>12</sub>O<sub>2</sub>, 176 MW, 26.1 min in ARCHEM 3202, 3206, 3207)
- Oleanolic Acid (C<sub>30</sub>H<sub>48</sub>O<sub>3</sub>, 456 MW, 43.80 min in ARCHEM 3202, 3206, 3207)

#### **Storax Benzoin from *Styrax Officinalis* (Snowbell)**

- Cinnamic Acid (C<sub>9</sub>H<sub>8</sub>O<sub>2</sub>, 148 MW, 13.767 min in ARCHEM 3202, 3207)
- Vanillin (C<sub>8</sub>H<sub>8</sub>O<sub>3</sub>, 152 MW, 13.4 min in ARCHEM 3202, 3207)
- Cinnamate (C<sub>11</sub>H<sub>12</sub>O<sub>2</sub>, 176 MW, 26.1 min in ARCHEM 3202, 3206, 3207)
- Vanillate (C<sub>10</sub>H<sub>12</sub>O<sub>4</sub>, 168 MW, 30.2 min in ARCHEM 3202, 3206, 3207)

Storax is an important aromatic resin famed throughout Eurasia and obtained locally in the Levant from *Syrax officinalis*, which produces storax benzoin, or imported from the southern coast of Anatolia from *Liquidambar orientalis*, which produces storax balsam. Ethnohistorical

accounts repeatedly convey the belief that storax balsam was superior to storax benzoin (Koh and Birney 2019),<sup>4</sup> though they were used somewhat interchangeably, just like cedar oil sourced from different plants today.

As with cedar oil, storax resin is known as a preservative due to its strong antioxidant and antimicrobial properties, which have been linked to its high concentrations of cinnamic acid. Cinnamic acid is a white, crystalline compound with a pleasant, leathery odor and was present in large quantities in the Kedesh amphoriskoi, along with related cinnamates. These preservative qualities hold true for storax resin sourced from both *L. orientalis* and *S. officinalis*, although concentrations of cinnamic acid differ between species and even disparate stands of the same species (Shu and Lawrence 1997), which could serve in the future as a means of pinpointing plant sources with greater specificity and reconstructing paleoecologies. This class of compounds has been shown to inhibit dramatically both bacterial growth and even tumor cell line development in vitro, which is why it is being intensely studied today for its anticarcinogenic potential (Liu et al. 1995; Akao et al. 2003; De, Baltas, and Bedos-Belval 2011; Sova 2012). These properties help explain why storax was likely added post-crush but pre-fermentation to ancient wine

<sup>4</sup> In addition to Greek and Roman sources, Chinese authors (e.g., Hou Han Shu of the Later Han, Guo Yi Gong of the Jin, and Tai Ping Yu Lan of the Northern Song) considered storax benzoin, their “Sogdian storax,” inferior to storax balsam they attached to “Storaxland,” later clearly equated with Daqin, i.e., the Romans/Byzantines and especially the cities of Antioch and Constantinople. By the Middle Ages, storax benzoin from *Styrax benzoin* was exported *en masse* from Sumatra and its surrounding region to all of Eurasia, facilitating the fall of storax balsam into relative obscurity.

from nearby Tel Kabri during the Middle Bronze Age—to impede the acetification process while encouraging fermentation (cf. Koh, Yasur-Landau, and Cline 2014; Yasur-Landau et al. 2018). It was also utilized with Late Bronze Age perfumed olive oils to serve the same preservative purpose with added fixative properties (Koh 2006; Koh and Birney 2017, 2019). At Kedesh, storax's antimicrobial and antioxidant qualities would have enhanced the preservative qualities of cedar oil, helping to delay any spoilage or changes in its chemistry, while imbuing it with a distinctive scent that could automatically elicit a synthesesitic response in connection with the equally distinctive visual typology of an amphoriskos (cf. Butler and Purves 2013).

The question at Kedesh is whether its cedar oil was infused with storax balsam or storax benzoin. Strong cinnamate signatures, the strongest in fact from the amphoriskoi base samples, testify to the presence of storax resin in some form or another. At Kedesh, in the first known scenario to-date in ORA studies, biomarkers that are uniquely diagnostic for both balsam and benzoin were found—i.e., oleanolic acid and vanillin/vanillate respectively (Modugno, Ribechini, and Colombini 2006; Koh and Birney 2019; cf. <https://phytochem.nal.usda.gov/phytochem/plants/report/1185.pdf>)—indicating the presence of both balsam and benzoin versions in the amphoriskoi, either in unison or in sequence (more below). It should be duly noted with vanillin that the presence of this phenolic aldehyde, despite the obvious etymological connection, should not be automatically construed as deriving from the fruit of the *Vanilla* genus, barring convincing corroborating evidence—archaeological, ethnohistorical, ethnobotanical, etc.

Neither ethnohistorical nor ethnobotanical data diminish the likelihood of the presence of both storaxes as reflected by the extant chemical compounds, and, in fact, they support this very possibility by verifying their overlapping functions and histories through their regular conflation. The Roman historian Pliny the Elder interchangeably describes storax balsam and benzoin in the same breath, but makes clear that red, sticky storax balsam is superior to brown, white-mold storax benzoin, even if he does not delineate their disparate botanical origins (Pliny, *Nat.* 12.55). If we equate storax with biblical *stacte/nataf* (στακτή, נֶטֶף) as many scholars do (Exod 30:34), the connection between storax balsam and benzoin stretches back centuries before the Hellenistic and Roman periods. Unlike *L. orientalis*, which grew on the southern Anatolian coast between Rhodes and perhaps as far east as Mount Amanos (Pliny, *Nat.* 12.55), *S. officinalis* was and remains plentiful throughout the Levant, and would seem to be the more convenient botanical source for storax in Phoenicia. However, *S. officinalis* does not exude resin in the quality or quantity that matches some descriptions of *nataf*, and indeed *L. orientalis* corresponds better to the biblical de-

scriptions of stacte in terms of color, scent, and viscosity. As with Pliny, we must wonder whether the biblical sources are conflating the two resinous products. Yet, it is likely that storax balsam was distinctive and desirable enough for both its superior natural properties (e.g., medical applications as a bandage) and more appealing scent that it was worth importing into Phoenicia, perhaps serving as an important branding characteristic of Phoenician cedar oil.

One reason why the conflation of the two under the single gloss of storax—rather than specifying as balsam or benzoin—can be problematic is exemplified by the literal conflation of the two in the Kedesh cedar oil: it potentially obscures our ability to distinguish between local and imported resources. Moreover, while both storaxes have similar chemical properties, they are different enough chemically, both in their physical expression and in the processing steps required to extract and store their active ingredients, that distinguishing the two could affect the manner in which one interprets its use in a given context, on top of ramifications related to importing storax balsam. These concerns underscore the need for a more careful assessment of these terms in ancient sources, which can now be verified and elucidated through techniques such as ORA. We can carefully consider all the available evidence—physical, chemical, historical—to identify and connect flora to what we detect empirically, resulting in a level of specificity and certainty between plant and product not easily attainable in the past. Introducing this higher level of resolution will not only illuminate commercial connections that may have gone previously unnoticed, but also help us better understand the many and varied uses of these extraordinary, and historic, organic commodities and goods.

### Summary of ORA Results

The collective chemical composition of the organic residues from the two Kedesh amphoriskoi suggests that they both contained true cedar oil infused with storax resin. Both amphoriskoi had numerous diagnostic biomarkers for *Cedrus* at significant peak strength, which supports its identification as the main ingredient in the vessels. As to be expected, there are subtle differences between the contents of the two amphoriskoi due to their unique histories and object biographies, but the ORA results closely mimic each other and indicate that the liquid contents were as similar as their containers.

Trace compounds, when they appear in number and quality as they do here, often reveal interesting and important nuances that can come to define the essence and value of the commodity in question (e.g., cooking oil vs. aromatic oil), though they can also be the most difficult to

characterize definitively. At Kedesh, once the raw ORA data for the amphoriskoi was initially assessed and characterized through the aid of chemical reference samples, detailed background studies immediately commenced to support phytochemical interpretations that could reliably source the chemical compounds back to their natural origins. This included the slow process of collecting botanical samples (i.e., ethnobotany) and conducting documentary research (i.e., ethnohistory). As a result, this study can say with confidence that the amphoriskoi contained a base cedar oil augmented by storax resin, which, when considered with its location within an administrative archive with hundreds of sealings, supports its use as a preservative for papyrus documents famous for repelling unwanted pests and odors.

### Extended ORA Observations: Compound Expressions and Vessel Topography

It is clear from the samples taken from the two amphoriskoi bases that they contained the same liquid commodities, judging by the consistency in their compound expressions (Table 1). The two significant variances were the absolute abundances of their maximum peaks (both referencing cinnamate with T864's peak 43.65% more abundant in quantity than T865's) and himachalene being nearly three times as abundant in relative terms in T865. The former variance is easily explained, as variables inherent to organic residue adsorption and extraction (calcitic inclusions in fabric, vessel time in service, depositional angle, vessel sample size) naturally affect the quantity of organics isolated. The higher relative abundance (RA) of himachalene in T865 is a little more difficult to explain, especially with the slightly higher concentration of atlantone in T864 as a contradicting trend. As a diagnostic compound, elevated levels of himachalene could suggest more storax balsam was present in T865, but unless there is corroborating evidence to suggest the same, it is difficult to say with certainty. The higher concentration of atlantone in T864 instead suggests that the high levels of himachalene in T865 is more likely due to post-depositional processes that somehow allowed it to preserve better. The situation might be moot as these subtle variances do not alter the overall interpretative outlook.

In addition to variances in compound expressions, extraction location—and, by extension, vessel topography (Koh and Birney 2017)—is often ignored in ORA studies, but it clearly warrants documentation as a natural part of archaeological research design (Koh and Birney 2019). For reasons that are unclear, the sample extracted from the shoulder of T864 (ARCHEM 3206), judging by RA, unexpectedly preserved himachalol much more successfully than the two extractions from the amphoriskoi bases.

Himachalene's RA in ARCHEM 3206 is halfway between the RAs found in the bases, thus nothing extraordinary with this particular compound. In contrast, himachalol is at roughly the same RA as himachalene in the shoulder sample, which is notable as it is four to eight times more abundant than in the base samples.

The sample from the amphoriskos shoulder was expected to produce significantly weaker signals overall than the base samples, simply due to upper portions of vessels generally experiencing less prolonged exposure to their organic contents. This makes himachalol stand out all the more. After sampling hundreds of body sherds by the ARCHEM project, the trend of producing lower concentrations of organics from body sherds has almost uniformly held true, which makes the higher incidence of himachalol in the shoulder sample unusual.

Once again, post-depositional processes related to oxidation/degradation and object biography are likely at play here (Koh and Birney 2017), though details are difficult to ascertain without extensive additional studies. What we know is that the 52 vessels in the Kedesh archive assemblage appear to have been covered quickly by mudbrick collapse, largely preserving the deep archive as it was on the day it burned (Herbert and Berlin 2003; Herbert and Ariel forthcoming). Most important for ORA studies is that the collapse immediately created a sealed anaerobic environment for the vessels. In addition to any adsorption variances introduced by vessels tipping over during deposition, the intervening years between excavation in 1999/2000 and extractions in 2008 likely introduced randomized oxidation processes to the vessels in the modern day, which have been empirically noted with legacy objects and presumably tied to vessel topography and the peculiarities of deposition (Koh and Birney 2017). All things equal, one would expect himachalol to survive in higher concentrations the sooner extractions take place after excavation, which could explain its prevalence in ARCHEM 3206, but then makes it difficult to explain the lower RAs of himachalol in the two base samples (ARCHEM 3202 and 3207), which were excavated, stored, and sampled in the same manner as the shoulder sample (ARCHEM 3206), and in one case comes from the exact same vessel, though from a different location. We are learning more about compound expressions and vessel topography as we make efforts to note patterns through both planned experimentation and the normal course of analysis, but there is clearly much more to learn.

### Discussion

The discovery and verification of true cedar oil in amphoriskoi at Kedesh raises interesting questions about its role in the Upper Galilee region and beyond (cf. Eller and

King 2000). ORA has allowed us to identify with certainty one of the better-known, value-added commodities from ancient Phoenicia, oil from *Cedrus libani*. Based on what we know about amphoriskoi from ancient literary sources, the indisputable archival context in which they were found at Tel Kedesh, and the roughly similar volumes inherent to them—i.e., large for a day-to-day perfumed oil container, but small for storing more common liquid commodities, such as wine or olive oil—it is probable in this particular instance that true cedar oil infused with storax was used to preserve archival documentary papyrus.

One limitation of ORA is the fact that it does not directly reveal when an organic commodity was housed within a vessel, which can complicate interpretation in cases of reuse. Hints are provided by vessel typology and archaeological context in concert with the relative quantitative strength of ORA signals (e.g., significantly weaker diagnostic signatures, such as the case for oleanolic acid vs. vanillin in our amphoriskoi). In one Hellenistic example on Crete, a well-used Koan amphora produced weak signals for wine in a fairly rustic domestic context (Koh 2014). The most logical interpretation is that the amphora was imported from Kos with wine based on the type's well-known history, but subsequently reused as a makeshift hydria, which explains its well-worn fabric and weak ORA signatures for wine. Vessel reuse has a long history, as demonstrated by a mended Early Bronze Age wine jar that was no longer watertight and likely repurposed to hold grain (Koh and Betancourt 2010).

At Kedesh, while it is possible that both storax cedar oils were simultaneously present in the amphoriskoi, the more likely possibility based on a holistic examination of all the evidence is not dissimilar to the Koan amphorae found in Hellenistic Crete. We know based on petrography that this particular class of amphoriskoi originated from Tyre (Berlin et al. 2012) and was exported throughout the Mediterranean. As with Koan wine, logic dictates that a high-quality cedar oil product was originally shipped inside the amphoriskoi and was the branded good of concern to the consumer. As with Koan wine in amphorae, Minoan perfumed oils in stirrup jars, and Coca-Cola sodas in their curved glass bottles, it is reasonable to believe that the Phoenician semi-fine amphoriskos became instantly recognizable in antiquity for both its contents—storax balsam-infused cedar oil—as well as its recognized geographic and cultural points of origin, Phoenicia (Berlin 1997). It would explain why Roman elites considered *Phoenician* cedar oil the best. In essence, the organic product together with its ceramic packaging became regional markers synonymous with Phoenician culture, transforming commodity into a value-added good (i.e., branding).

The above observations highlight some unique perspectives ORA can bring to archaeological research along

with some inherent challenges. They open further possibilities for discussions about the general importance of context for ORA research, the nature of these culturally-branded amphoriskoi, the role they played in participant societies, and the mechanisms and systems in place that facilitated their production, exchange, and consumption in Phoenicia and beyond during the Hellenistic period.

### Embedded ORA Interpretations: The Role of Archaeological and Ethnographic Context

When attempting to characterize ancient organic commodities and goods such as fermented beverages (Koh, Yasur-Landau, and Cline 2014) and perfumed oils (Koh 2006; Koh and Birney 2019), it is always helpful to determine the extent to which ingredients were intended to be aromatic, preservative, or even psychotropic in nature. Here embedded interpretations, particularly archaeological and ethnographic contextualization, are critical to informing chemical data—e.g., the absence of ORA compounds should not be immediately construed to mean certain ingredients never existed (cf. Roumpou 2017). In the case of the Kedesh amphoriskoi, however, the relatively simple recipe gleaned from the chemical data appropriately reflects what archaeological and ethnographic contextualization tell us. Namely, the function of the cedar oil was primarily practical in nature (i.e., preserving papyrus), which fits with the archaeology presented and abundant ethnohistorical accounts. Once again, oxidation and degradation are always a concern, but existing ORA precedents can help rule out alternatives (e.g., perfumed oils) while typological precedents (fabric type, vessel size) can serve as interpretative guides as well.

Ancient literature is littered with rich details concerning the role of Phoenician cedar oil as a preservative of papyrus and textiles against damage from pests and the general ravages of time. Spread across centuries, these accounts convey in unison how revered Phoenician cedar oil was in antiquity, both on a practical level, and at times bordering on the apotropaic, as the following references reveal:

Can we hope for poems to be fashioned that are worthy to be smeared with Oil of Cedar and kept in polished cypress? (Horace, *Ars* 331–32)

Your title shall not be tinged with cinnabar, nor your papyrus with Oil of Cedar. (Ovid, *Tr.* 1.1)

Just as resin comes from cypress and pine, so from cedar comes the oil which is called Oil of Cedar. When objects such as books are rubbed with it, they are impervious to worms and dry rot. (Vitruvius, *De arch.* 2.9)

Is there anyone who would deny the desire to earn the praise of the people? Or, when he has produced compositions



good enough for Oil of Cedar, to leave behind poetry that has nothing to fear from mackerels or incense? (Pliny, *Sat.* 1.41–43)

Some people call this tree the coniferous cedar. From it comes the oil held in the highest esteem while its timber lasts forever. (Pliny, *Nat.* 13.11)

Any material that had been dipped in Oil of Cedar will never know decay or worms. (Pliny, *Nat.* 16.76)

Whose gift do you wish to be, little book? You may now strut oiled with cedar, your twin brows handsomely decorated. (Martian, *Epigrams* 3.2)

The inclusion of storax resin in the Phoenician amphoriskoi at Tel Kedesh aligns well with these literary descriptions as they pertain to the production, use, and export of cedar oil in antiquity. As one of the strongest antibacterial, antiviral, and antifungal substances known from nature, storax would have only raised cedar oil's already formidable antimicrobial properties to legendary status, while sweetening its aromatic qualities, which must have been a welcome quality in musty archives. In terms of considering any adaptations necessary for maximizing practical applications, embedding the chemistry in ethnography once again enhances interpretative resolution. A modern ethnographic study of traditional pitch production from *C. libani* in the Taurus Mountains of Turkey supports the notion of adaptations in antiquity for the practical applications of cedar oil by documenting a method of production that is virtually identical to the one described by Pliny, but with modern concerns that invert value between products. The desired product today is the thicker pitch that comes later in the process, as the earlier, lighter product described by Pliny, and of primary concern to us, is discarded as economically inconsequential (Kurt, Kaçar, and Isik 2008). While it was this lighter, less viscous oil that was used on ancient papyrus, as its application would not alter the legibility of texts, it is the darker, more resinous material that holds value today as pitch in a world that no longer needs to protect paper in the same manner as papyrus. Adding storax resin in controlled ratios to the light cedar oil fraction would have aided application in antiquity without any adverse effects, by increasing the viscosity of the light cedar oil that was now absent its heavier, resinous fraction.

#### ***Phoenician Amphoriskoi as a Proxy and Regional Marker***

The discovery of cedar oil in the Phoenician semi-fine amphoriskoi found at Kedesh broadens our understanding of the use of this commodity at this one site, but questions remain about cross-the-board correlations, whether

at sites located in the same general region or as distant as Palmyra and Pompeii. We may reasonably postulate from their extant chemical signatures that the typologically identical amphoriskoi in question found across Kedesh contained the same storax-infused cedar oil as the two chemical type vessels presented here. Nevertheless, it is important to consider other uses for these vessels, most probably through refilling, especially for vessels found at some distance from their Phoenician source (see further discussion below).

A large number of semi-fine amphoriskoi (177 vessels), very similar in shape and type to the vessels from Kedesh, were found at the small, low-lying mound Tel Anafa in the Hula Valley. In the later 2nd century B.C.E. a large peristyle courtyard villa was constructed on the top of the mound; the finds strongly indicate that the owners had direct contact with the city of Tyre and perhaps worked in part as conduits in a regional market network between the coast and the interior (Herbert 1994; Berlin and Slane 1997). There is no evidence for an archive in the villa, but other finds offer a likely application for cedar oil, if that is what the amphoriskoi there contained. An unusually high number of tools for textile work was found here, and it may be that weaving and cloth production was carried out on something like a commercial scale (Larson and Erdman 2018). This in turn may suggest that cedar oil was used to preserve textiles instead of papyrus. Another possibility is that Tel Anafa was a secondary production or distribution point for cedar oil. Ethnographic evidence strongly suggests that cedar oil was initially processed close to their stands and then transported to secondary production and/or distribution centers in large containers for final processing and distribution. Tel Anafa may have been a convenient point for additional processing, for example, by adding storax, and subsequent decanting into the more consumer-friendly amphoriskoi manufactured in Tyre. It is also possible that the amphoriskoi at Tel Anafa found a second life there for a completely different purpose, as Early Bronze Age and Koan wine vessels did on Crete.

At Shiqmona, amphoriskoi are one of the most common ceramic forms found in the Hellenistic stratum, but a wide range of other ceramic types were found, including cooking, dining, serving, and storage vessels (Elgavish 1976). Given that the Hellenistic material comes from the destruction layer in what was likely a Seleucid garrison, the large number of amphoriskoi probably relate to a different scenario than that at Tel Kedesh or Tel Anafa; a garrison was unlikely to keep an extensive archive or serve as a production or distribution center for textiles. If the amphoriskoi found here held cedar oil, it may have been for medical or pharmacological purposes.

Even if amphoriskoi are found to have contained cedar oil at a given site, caution would be advised in utilizing it

as an automatic proxy for the presence of papyrus or textiles, since textual evidence, as previously discussed, clearly demonstrates that cedar oil was also used for other purposes, such as mummification, embalming, and pharmacology, depending on the archaeological and cultural context.

There are clear signs that typologically distinctive vessels such as Phoenician amphoriskoi served as regional markers, i.e., brands, for desirable imports in cross-cultural contexts. This is not only true for elite goods, whether it is modern Rolls-Royce automobiles or ancient Egyptian jewelry, but it also holds true for more accessible items such as modern Rolex watches and ancient Greek funerary perfumes. Exported Phoenician amphoriskoi likely fell towards the latter end of this spectrum, though it is even possible that different classes of Phoenician cedar oil existed, depending on intended applications and assigned quality. Embedded interpretations and object biography, once again, are key to unraveling the role it played in various participant societies, and the mechanisms and systems that determined how its production, use, and export might have been tailored for each market, whether it is Olympia or Alexandria.

There always remains the high possibility for vessel reuse. Amphoriskoi were sturdy utilitarian vessels with thick walls, characteristics that appear regularly with vessels used to ship commodities. In this case, it is likely based on the chemistry and context that the amphoriskoi were expediently refilled with the same class of cedar oil product, if inferior, utilizing local storax benzoin from *Styrax* rather than imported storax balsam from *Liquidambar*. Anyone who is familiar with inkjet printer technology in the modern day would be acquainted with this phenomenon of replenishment with a less expensive, if reasonably similar product.

What happened with empty amphoriskoi consumed far from Phoenician shores? Perhaps they were refilled with a local product that approximated true cedar oil or were simply kept as exotic curiosities. Perhaps there were creative and adaptive reuses, as with wine amphorae on Crete pressed into service as hydrias and grain containers. These examples emphasize once again that ORA research must be integrated with contextual information more regularly if one is to provide accurate archaeological interpretations and unlock its potential to glean socio-cultural meaning from the human past.

## Conclusions

When reconstructing complex ancient organic commodities from their trace remains, it remains essential to leave open the possibility that certain ingredients perhaps

did not survive the ravages of time, which is difficult to accomplish purely through empirical science. Archaeometric results are always more meaningful when they can be placed in ongoing conversation as constituents within a larger ecosystem of knowledge. In addition to integrating ethnographic and archaeological evidence, focused comparisons with existing scientific studies are invaluable when interpreting new samples, as patterns often exist. The OpenARCHEM database for ORA is designed to help connect typology to original contents and tap into the promise of big data by facilitating comparisons and sharing results. They are ultimately resources by which even relatively small datasets, such as the one presented here, can be amplified to help answer larger archaeological and historical questions.

ORA is evolving far beyond its traditional lab-bound role to become an integrated element of field methodology and a fundamental part of archaeological research design. Moreover, it stands ready to harness the power of big data to address larger questions of economy, technology, ecology, and environment. Ultimately, it is through the interdisciplinary application of tools such as ORA that we can answer some of the more complex questions posed by vessels such as the Hellenistic amphoriskoi found in the Kedesh archive. Additionally, in order for ORA to be most successful and useful, it must be contextually informed by embedding itself in multivariate approaches that remain in constant dialogue with archaeology and ethnography. With big data now in play, it is through open and collaborative databases such as OpenARCHEM (<http://openarchem.org>), in concert with like-minded databases such as the Levantine Ceramics Project (<https://www.levantineceramics.org>), ToposText (<https://topostext.org>), and PubChem (<https://pubchem.ncbi.nlm.nih.gov>), that all components can remain in constant conversation with each other for a healthy, academic ecosystem that is accessible to all.

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