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A Re-examination of the Inscribed Pomegranate from the Israel Museum

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INTRODUCTION

A small ornamental bone object in the form of a pomegranate, bearing a short Old Hebrew inscription (figs. 1–2), was purchased by the Israel Museum in Jerusalem in 1989. On the basis of its inscription, it was believed to represent the only material evidence discovered so far that could likely be associated with the First Temple in Jerusalem (Lemaire 1981; 1984; Avigad 1989a; 1989b; 1990).

André Lemaire was the first to report the pomegranate after observing it in an antiquities shop in the Old City of Jerusalem in July 1979. After the first scientific publication (Lemaire 1981), an English version of the article was published again in a popular magazine (Lemaire 1984), instantly attracting worldwide attention. Meanwhile, the pomegranate had been smuggled out of Israel and had been placed on exhibit in the Grand Palais in Paris. In 1989, the pomegranate was purchased by the Israel Museum in Jerusalem from an anonymous collector for the sum of $550,000, after the museum received a generous donation for this purpose.

The pomegranate (43 mm. in height; 21 mm. in diameter) was carved of hippopotamus canine (see below) to the shape of a pomegranate in blossom, with a single hole (6.5 mm. in diameter; 15 mm. deep) cut into its base, presumably for mounting on a rod or shaft. The fruit's rounded body tapers down to a flat bottom and is topped by a tall, narrow neck terminating in six long petals, two of which are presently broken. A significant portion of the body is broken away, resulting in the loss of about one-third of the original inscription. A Old Hebrew inscription is incised around the shoulder of the pomegranate in small, carefully engraved and clearly legible letters. Only nine characters remained complete, while three are entirely missing due to the break and three are only partially preserved. Thus, the complete inscription would have had 15 letters. The surviving part of the inscription was transcribed by Lemaire (1981; 1984) as לבי...ה קדש כהנם. Lemaire proposed the following reading: לבית יהוה קדש כהנם, 'Belonging to the Temp[le of *YHW*]*H*, holy to the priests'. On palaeographic grounds, the inscription is dated to the late eighth century BCE, like the Siloam Inscription (1981; 1984).

The authenticity of the inscription had first been established by Lemaire (1981), who had reportedly examined the letter incisions under a microscope and found that traces of what seemed to be ancient patina, covering the surface of the object, also appeared within the incisions. This was compelling evidence for the inscription's antiquity and hence for its authenticity. Later, Avigad (1989a; 1989b; 1990) corroborated this conclusion on the basis of the distinctive feature that the edges of several of the incised lines are rounded and worn, not sharp as would be expected in recent incisions. Moreover, in terms of palaeography the letters exhibit acceptable forms, well contrived by a skilled engraver, who wrote successfully in such small letters on the difficult surface of the pomegranate's rounded shoulder.

Fig. 1. Ivory pomegranate (courtesy of the Israel Museum, Jerusalem)

In September 2004, the directors of the Israel Museum and the Israel Antiquities Authority appointed a special committee in order to examine the authenticity of the ivory pomegranate from the Israel Museum. The committee included the authors of the present article, representing the relevant disciplines of epigraphy and material sciences. The present study was therefore conducted, using the most up-to-date scientific methods, in order

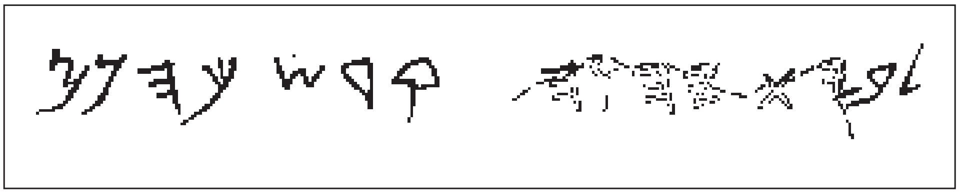

Fig. 2. Inscription; broken line indicates break

to examine the authenticity of the object and its inscription. The method, results and conclusions of the study are hereby presented.

METHOD

The examinations focused on the inscription and the patina, based on the working hypothesis that if the patina on the inscription proved to be authentic, having developed in natural conditions over centuries, the inscription would undoubtedly be authentic, dating from the first millennium BCE. If, however, the patina was a modern imitation, the inscription may or may not be genuine, in which case further analyses would be needed in order to examine its authenticity. The study included the following steps:

1. Epigraphic and micromorphologic study of the inscription was carried out, using a stereomicroscope at magnifications ranging between × 10 and × 60.
2. Detailed surface analyses of the inscription, the patina and other secondary materials were conducted, using an epi-illuminated (metallographic) microscope equipped with brightfield and darkfield illuminations at magnifications ranging between × 50 and × 400.
3. Samples of the patina from the letters and the body of the pomegranate were studied in thin sections under a polarising (petrographic) microscope at magnifications ranging between × 50 and × 400.
4. The entire item and the patina were analysed by scanning electron microscopy (SEM). The SEM examination was conducted in the Department of Nanotechnology of the Hebrew University of Jerusalem, using the FEI Quanta 2000 environmental SEM. This low vacuum SEM with a tungsten electron source is equipped with simultaneous secondary electron (SE), enabling observation of the surface morphology, back-scattered electron (BSE) for the purpose of identifying phases with different molecular weights and energy dispersive X-ray spectrometer (EDS) to identify the elemental compositions. The use of the environmental SEM enabled the examination of the entire artefact (rather than samples of patina extracted from it) under low vacuum conditions and without any need to coat it prior to the examination. With this instrument, surface structure, mineral phases and their growth relations, and chemical composition could be identified, without the need to coat the item with carbon and/or gold.
5. Stable isotope analyses of the carbonates in the patina were conducted by mass spectrometry (MS). The examination focused on oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic composition of the carbonate component within the patina. Isotope composition of oxygen is a function of precipitation temperature and isotope composition of water from which the patina precipitated. Patina samples were taken from the pomegranate surface under the

stereomicroscope using a scalpel. Measurements were conducted using a VG Isocarb system attached to a SIRA-II mass spectrometer at the Geological Survey of Israel. All the $\delta^{18}O$ and $\delta^{13}C$ values were calibrated against the international standard NBS-19, and are reported in permil, relative to the PDB standard (Craig 1957).[1]

RESULTS

A. The Inscription

Micromorphology. — The archaeo-zoologist F. Poplin (in Caubet 2002) performed a taxonomic examination of the bone of which the pomegranate was engraved. The base material of the pomegranate was identified as the canine of *Hippopotamus amphibius* rather than elephant ivory.[2] Similar studies (Caubet 2002) indicate that the use of *Hippopotamus amphibius* teeth for carving ceased in Israel at the end of the Late Bronze Age (*c*. twelfth century BCE). Moreover, on stylistic grounds this elongated-shaped pomegranate accords with Late Bronze Age rather than Iron Age objects of this kind. However, it is theoretically possible that an Iron Age II inscription was engraved on a Late Bronze Age item; hence, this detail does not necessarily indicate that the inscription was added in modern times. As articulated by Caubet (2002: 112), '... je pense que le matériau de la grenade inscrite, l'ivoire d'hippopotame (identification par F. Poplin en 1990), et la forme allongée du fruit et des folioles, militent en faveur d'une datation aux XIII^{e}–XII^{e} siècles; l'inscription a probablement été ajouté, soit au VIII^{e} siècle, soit à l'époque moderne'.

Hippopotamus ivory can be readily distinguished from elephant ivory by several structural features detectable under a stereomicroscope. Elephant tusks are characterised by the Schreger lines typical pattern, which may be observed under magnification even in carved ivory (O'Neil Espinoza and Mann 1993; Palombo and Villa 2001; Trapani and Fisher 2003). As for hippopotamus teeth, the upper and lower canine and incisors are the most common sources of ivory, each one of which has distinctive gross morphology. Close examination of a cross-section of hippopotamus dentine reveals a tightly packed series of fine concentric lines, which can be regularly or irregularly spaced. The orientation of the lines

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[1] There are two internationally accepted reference standards used to report variations in oxygen isotope ratios: PDB (Pee Dee Belemnite) and SMOW (Standard Mean Ocean Water). The PDB standard is used to report carbonate oxygen isotope ratios, and the SMOW standard is used to report variations in water oxygen isotope ratios.

[2] The word 'ivory' is traditionally applied to the tusks of elephants. However, the chemical structure of the teeth and tusks of mammals is the same regardless of the species of origin, and the trade in certain teeth and tusks other than elephant is well established and widespread. Therefore, 'ivory' can correctly be used to describe any mammalian tooth or tusk of commercial interest, which is large enough to be carved or scrimshawed.

follows the overall shape of the particular tooth. This structure results in the fact that cleavage and breakage of the tooth usually occur along the concentric growth lines parallel to the longitudinal axis of the tooth.

Since the pomegranate in question was formed with its longitudinal axis parallel to that of the tooth, as evident by the orientation of the concentric growth lines observed under the stereomicroscope, its breakage or cleavage axis should lie parallel to its longitudinal axis. Indeed, the missing portion of the body was broken along this direction. Close examination of the breakage surface of the missing part under a hand lens or a stereomicroscope reveals that it includes a set of different fractures and fissures (fig. 3). The main surface is weathered, and the fracture edges are rounded by attrition, covered by incrustation and distinguished by its darker hue, similar to the surface of other parts of the pomegranate (fig. 3:1). Under the stereomicroscope it is evident that a small fraction of the bone surrounding the lower shaft was broken and glued (fig. 3:2), evidently prior to the purchase of the pomegranate by the Israel Museum. In the upper part of the broken surface and below the inscribed part there are two new breaks, distinguished from the old break by their brighter colour and sharp fissures. These can also be observed in the view presented by Lemaire (1981: pl. VI, lower left) and Avigad

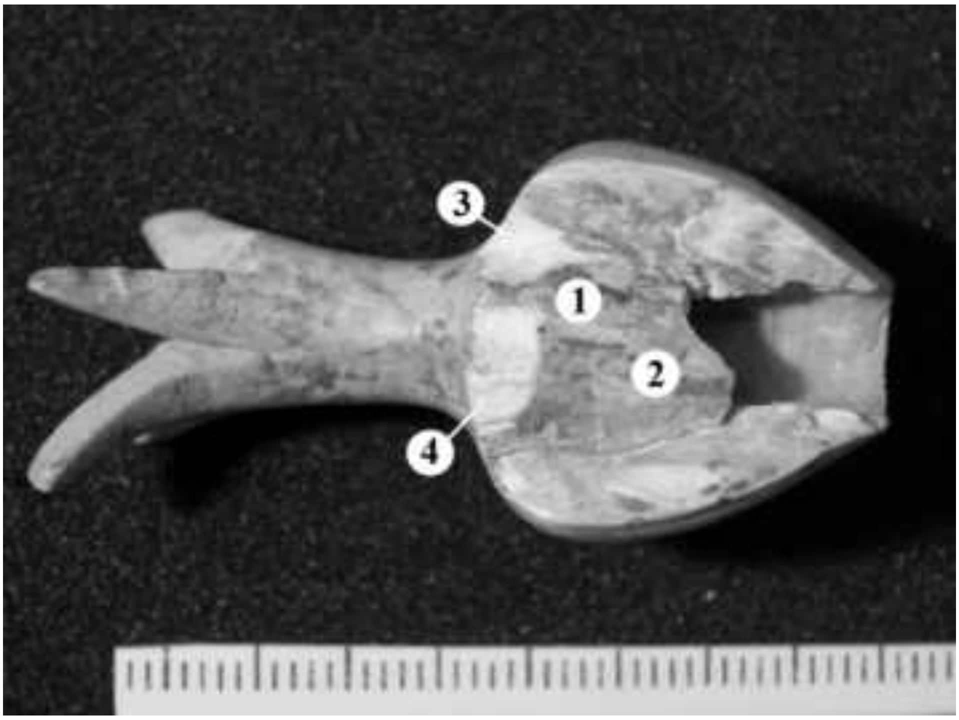


Fig. 3. The break caused by the split of the missing part from the body, displaying (1) the old break; (2) a restored part; (3) the new right break (NRB); and (4) the new left break (NLB)

(1989b: 96, lower left photograph; 1990: 159, centre photograph). The new right break (henceforth: NRB, fig. 3:3) cuts the word *lbyt*, while the new left break (henceforth: NLB, fig. 3:4) cuts the word [*YHW*]*H*.

When examined carefully under the stereomicroscope, these new fractures are most telling. They clearly indicate that the old break already existed and was taken into consideration when the letters were distributed around the limited surface of the pomegranate's shoulder. Moreover, the new breaks (NLB and NRB) were caused by the engraving of some of the letters along the rather sharp edge of the old break, due to the pressure of the engraving tool along the longitudinal breakage axis of the pomegranate. Fig. 4 demonstrates the engraving faults that brought about the formation of the NRB and resulted from it; and fig. 5 shows the way the NLB was created. First, the letters *lamed* and *bet* of the word *lbyt* (fig. 4:1) were engraved on the more secure area, far from the edge of the old break. However, when the engraver attempted to incise the upper and standing lines of the letter *yod*

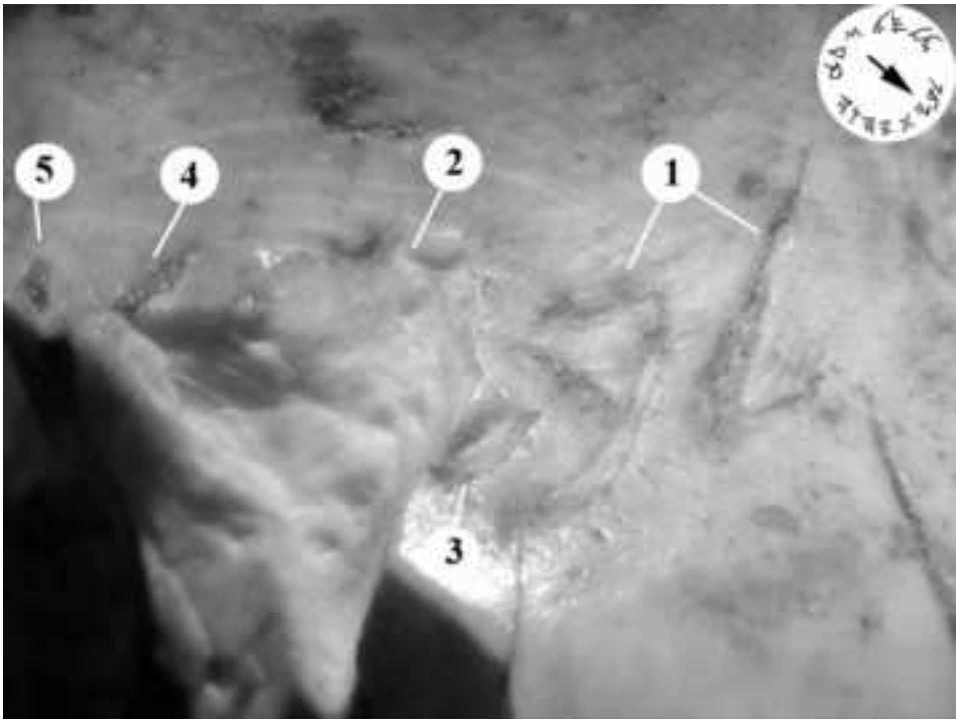


Fig. 4. Stereomicroscopic view of the NRB area, showing the engraving faults of the word *lbyt*; (1) the *lamed* and *bet* are properly engraved; (2) the upper and standing lines of the letter *yod* are engraved, causing the NRB along them; (3) the lower line of the letter *yod* is then engraved without approaching the NRB in order not to extend it; (4) a large space is created and the upper right line of the letter *taw* is engraved without reaching the old break, in order not to break a hanging splinter left by the NRB; and (5) the upper left line is engraved without reaching the old break

near the edge of the old break, the NRB was created along these lines and further to the left, due to the pressure on the edge of the old break parallel to the breakage axis, causing the separation of a splinter from the pomegranate body (fig. 4:2). This forced the engraver to incise the lower line of the letter *yod* without connecting it to the NRB, apparently in order to avoid further breakage (fig. 4:3). Then the engraver turned to the incision of the two upper tips of the X-like letter *taw*. The now existing NRB required leaving a disproportionately large space between it and the previous letter *yod*. The upper right-hand line of the *taw* was then engraved, but without reaching the old break due to the existence of a 'hanging' and already fractured splinter in the space between the NRB and the edge of the old break (fig. 4:4). The upper left tip of the *taw* was then engraved, but it 'fades' towards the meeting with the edge of the old break, presumably in order to avoid any further breakage (fig. 4:5).

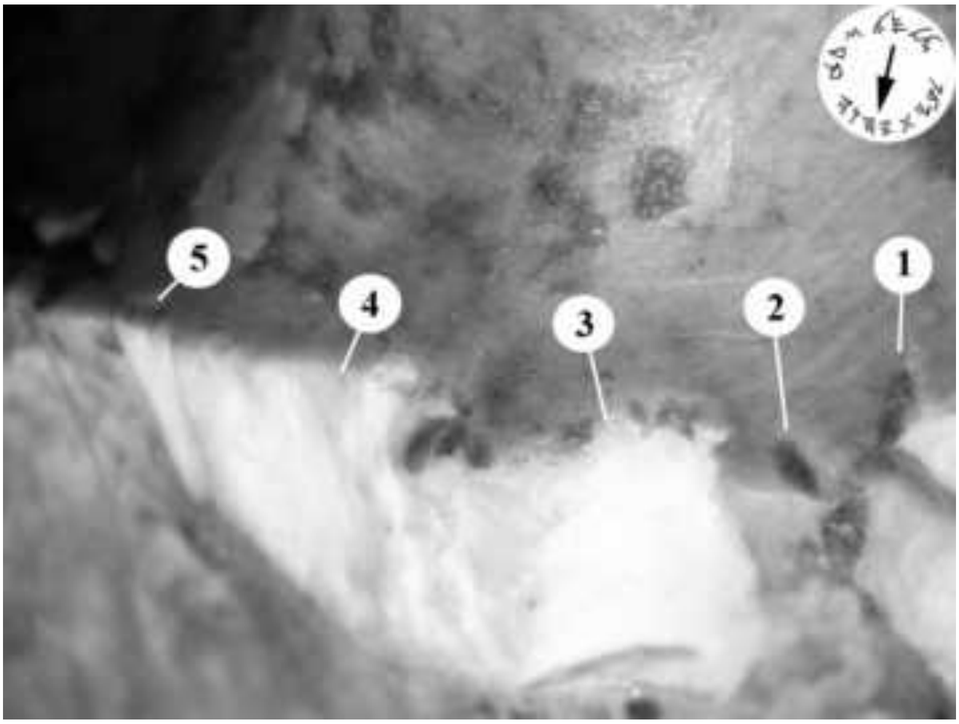


Fig. 5. Stereomicroscopic view of the NLB area, showing the engraving faults of the word *YHWH*; (1) the upper right line of the letter *taw* is engraved without reaching the old break, in order not to break a hanging splinter that was left by the NRB (see fig. 4); (2) the upper left line is engraved without reaching the old break; (3) a new fracture (NLB) is created while engraving the letter *yod* of the word *YHWH*; (4) the fracture continues while engraving the upper lines of the letter *he*, creating the elongated form of the NLB; and (5) the upper and part of the standing line of the second *he* of the word *YHWH* are engraved at the end of the NLB (see fig. 6)

We turn now to the NLB. Careful examination under the stereomicroscope reveals that in this case too it follows and results from the engraving process, this time of the upper letter tips of the word [*YHW*]*H* (fig. 5). A space was left between the above-mentioned upper tips of the letter *taw* of *lbyt* (fig. 5:1,2). Yet the engraving of the upper parts of the following letters *yod* and *he* along the edge of the old break again caused a fracture, this time of the NLB, due to the pressure put by the engraving tool parallel to the breakage axis (fig. 5:3,4). As a result and in order to avoid any further breakage, the upper and part of the standing lines of the second *he* were engraved, but without meeting the old break (fig. 5:5). Consequently, the standing line of the second *he* 'climbs' toward its meeting with the edge of the old break, rather than being cut by it (fig. 6). All these features clearly demonstrate that the old break already existed when the inscription was engraved. The engraver took into consideration both the old and the new breaks that were uncontrollably created during his or her work.

The undamaged part of the inscription includes the words *qdš khnm lb*.... Close examination of the letter incisions discloses that the lowermost depressions of the letters reveal fresh and sharp engravings, while the more elevated parts of the incisions are smoothed and rounded (fig. 7). Lemaire (1984: 26) noticed this

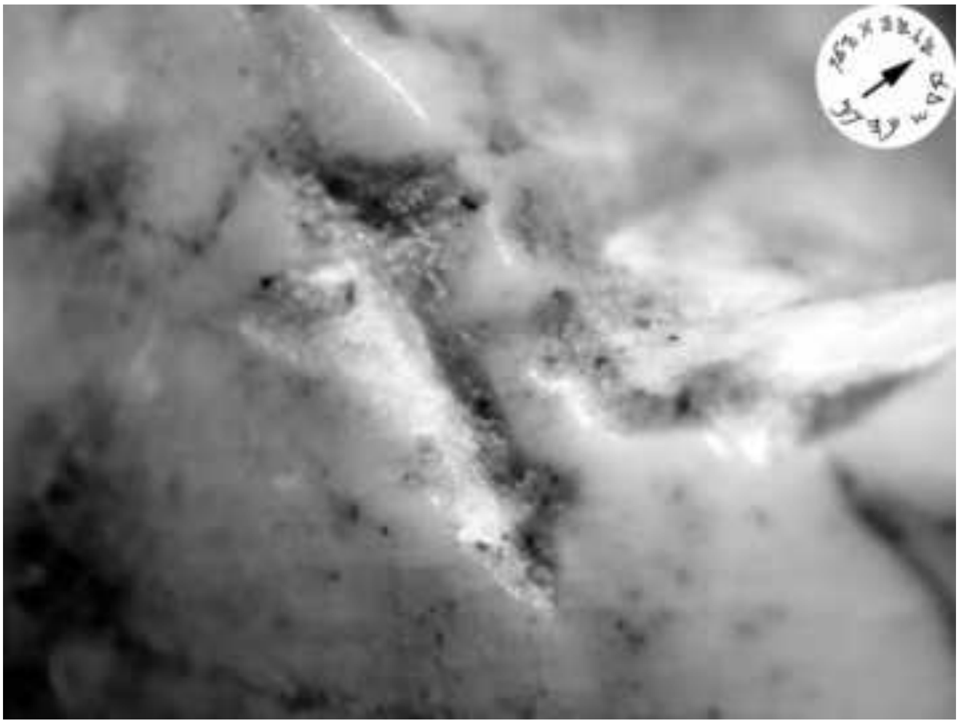


Fig. 6. The upper and standing lines of the second letter *he* of the word *YHWH*, as seen under the stereomicroscope

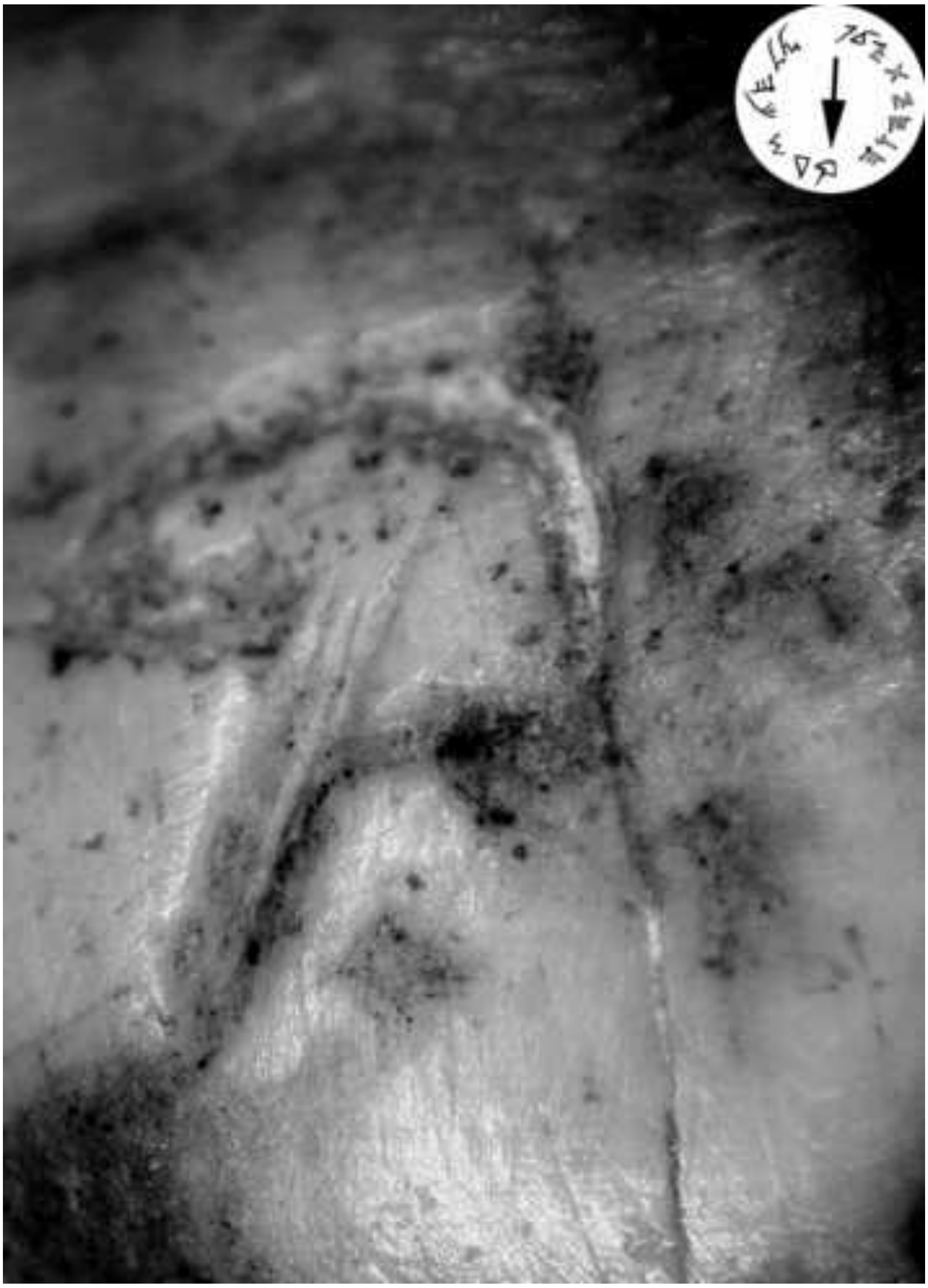


Fig. 7. The letter *qof* of the word *qdš*, as seen under the stereomicroscope; note the fresh engraving mark at the deepest parts of the letter (upper bow-like line and the slip of the engraver’s tool towards the bottom right-hand side of the photo) and the smoothed lines at the shallower lines (the lower line of the letter at the lower left-hand side of the photo)

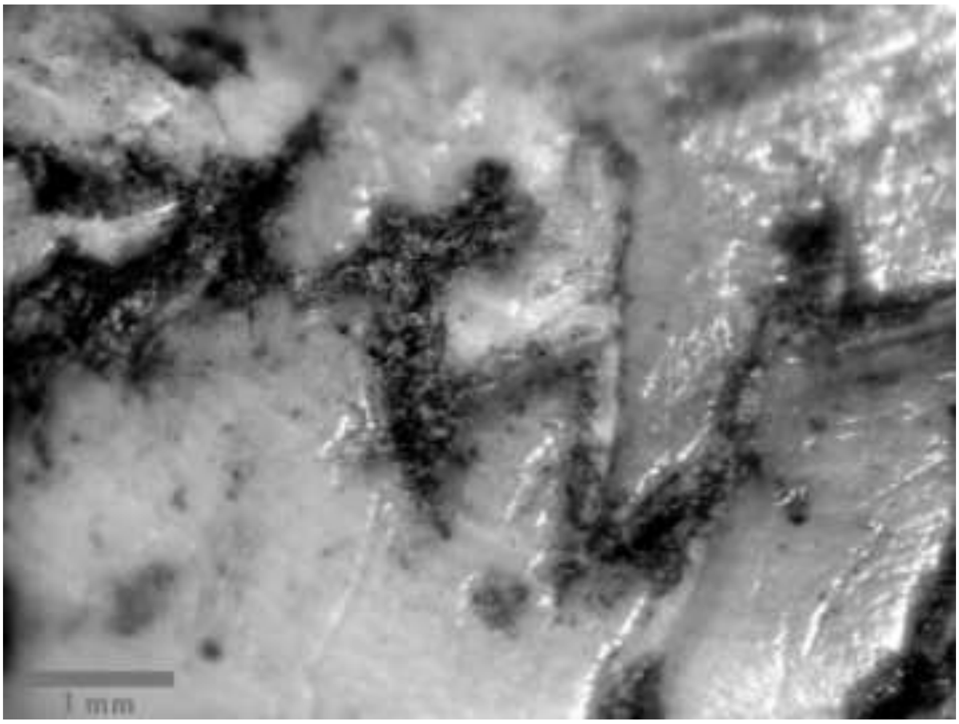


Fig. 8. Stereomicroscopic view of the upper parts of the *nun* and *mem* of the word *khnm*; deep, fresh nail engraving is seen at the deeper elevation of the *mem*, coated in part by patina-like material (the dark matter)

phenomenon and attributed it to a modern cleaning carelessly executed with a needle in order to enhance the inscription or perhaps to clean it prior to its sale. When the object is examined under the stereomicroscope, however, this hypothesis becomes highly unlikely. First, the fresh incision marks appear only in the deepest levels. However, if the letters had been cleaned by a nail, it could be expected that the entire outline of the letter, rather than only the deeper (and hence better preserved) portions of it would be enhanced or cleaned. Moreover, in several instances the microscopic examination reveals that the fresh nail engravings too are coated in places by the patina-like material (fig. 8). Therefore, the only logical interpretation is that the letters were smoothed by an abrasive after their engraving, probably by a hard brush or an abrasive fabric (such as scotch-brite). This did not reach the deepest levels of the engravings, and the latter remained unpolished prior to the coating of parts of the inscription by the patina-like material.

Epigraphy: Syntax. — The syntax of the inscription is awkward, no matter how the inscription is read: either *lbyt* [*YHW*]*H qdš khnm* (Lemaire 1981: 236; 1984: 26) or *qdš khnm lbyt* [*YHW*]*H* (Avigad 1989a: 10–11; 1989b: 99; 1990: 160). Avigad, who was aware of these difficulties, translated it ‘sacred donation for the priests of (in) the House of Yahweh’ (1989a: 11; 1990: 160). However, according to our understanding, the *lamed* in the word *lbyt* does not mean ‘in’, but ‘of, belonging to’. The absence of the genitival *lamed* before the word *khnm* (‘priests’) makes the syntax awkward. In an attempt to understand the phrase, a comparison was drawn from Lev. 23:20: *qdš yhyw lYHWH lkhn*, ‘they (the two loaves of bread) shall be holy to YHWH, for the priest’, and Ezek. 45:4: *qdš mn hʾrṣ hwʾ lkhnm mšrty hmqdš yhyh*, ‘it is a sacred portion of the land, to (for) the priests the servants of the temple it shall be’. Accordingly, the syntax of the inscription should have been: *lbyt YHWH qdš lkhnm*, or *qdš lkhny byt YHWH*. Alternatively, if the term *qdš khnm* is in the construct state, it might be compared to the later mishnaic term *ḥerem shel kohanim*, ‘dedicated property of the priests’ (*M. Nedarim* 2:4).

Palaeography. — From a palaeographic point of view, the most decisive examination of the pomegranate inscription is the one carried out under the stereomicroscope (above), which showed that the upper ‘hands’ of the X-like *taw* of the word *lbyt* did not reach the ancient break in the pomegranate. Similarly, regarding the *yod*, the engraver stayed his or her hand abruptly, avoiding the chipped part, so that he would not cause further damage to the pomegranate. It is possible to see a ‘crest’ in the meeting point of the upper right ‘hand’ of the X-like *taw* and the ancient break; the upper left ‘hand’ does not meet the old break either. The same goes for the ‘leg’ of the last *he* of the tetragrammaton [*YHW*]*H*, which does not meet the break. The most important words in the inscription — *lbyt* [*YHW*]*H* — were apparently deliberately engraved incomplete, as if they had been broken in antiquity.

It is worthwhile to comment on the palaeography, though there seems to be very little to add to the thorough discussion of Avigad (1989a; 1989b; 1990). Almost all the letters can be compared to other ancient Hebrew inscriptions of the eighth–seventh centuries BCE. The only problematic letter is the curious *mem* with the W-like head. This, however, might have been caused by a slip of the engraving tool on the hard surface of the pomegranate’s shoulder, as well as by its small dimensions. Lemaire (1981: 237), comparing it to the Siloam Inscription, ascribed the pomegranate inscription to the end of the eighth century BCE. F.M. Cross (in Lemaire 1984: 29) and Avigad (1989a: 10; 1990: 160–161) dated it to the mid-eighth century: ‘It diverges from the latter [the Siloam Inscription] in various aspects, such as the form of the letters *daleth*, *he* and especially *mem* with its irregular W-shaped head. Moreover, our inscription looks generally more archaic’ (Avigad 1989a: 10; 1990: 161). C.A. Rollston has recently stated that the above inscription ‘is a probable or possible forgery’ and notes that F.M. Cross is now of the same opinion (Rollston 2003: 182, n. 15).

Lemaire and Avigad commented on the space between the words *khnm* and *lbyt*. Lemaire (1981: 236; 1984: 26) believed that the space ‘was the end of the inscription and what followed after the space was the beginning of the inscription' However, Avigad, who preferred to read *qdš khnm: lbyt* [*YHW*]*H*, wrote: 'The vacant space ... located in the middle of the inscription ... may be explained by a miscalculation of space on the part of the engraver, or else by a need to skip a defect on the ivory surface, on the assumption that it is indeed an old defect' (1989a: 11; 1990: 160; cf. 1989b: 99). Unfortunately, both Lemaire and Avigad overlooked the fact that there were equal spaces between the words [*YHW*]*H* and *qdš* and between *qdš* and *khnm*, although they are smaller than the space between *khnm* and *lbyt*.

As a rule, ancient Hebrew inscriptions used word dividers — at first a short vertical line and later a dot. Some ancient Hebrew inscriptions inscribed on ostraca or engraved on seals overlooked the rule, writing *scriptio continua*, i.e. without word dividers, as was the general practice in Phoenician script. Leaving spaces between words was a practice developed by Aramaean scribes. This practice, which is noted as early as the mid-seventh century BCE Assur ostracon, became normative in that scribal tradition (Millard 1970; Naveh 1983). It is unlikely that an ancient Judahite engraver would have left spaces between the words when engraving the ivory pomegranate. The pomegranate inscription should be compared to the Israelite ivory plaque from Tell Nimrud (ND 10150; Millard 1962: pl. XXIVa; Aḥituv 1992: 205), on which the words are separated by dots.

To reiterate, no provenanced ancient Hebrew inscription exhibits spaces between words. Our modern usage was inherited from Aramaic scribal practice together with the Aramaic script, which developed into the Jewish script. The Samaritans, who still write their version of the ancient Hebrew script, adhere to the use of dots as word dividers (cf. Naveh 1983). The engraver of the pomegranate inscription, or the person who composed the text, was unaware of the different practices used in ancient Hebrew and modern Hebrew, and erred.

B. The Patina

A Note on the Surface Coloration. — Experiments conducted by one of the authors (Y.G.) show that the yellowing of ivory cannot be considered an indicator of the age of the artefact, since ivory (including hippopotamus tooth) is very reactive to its environment. Some darkening or 'patina' is the result of the natural aging process, and because it is porous, ivory is also susceptible to staining. It darkens in contact with colorants or oils and can be stained by immersion in tea or other coloured materials. Allowing iron shavings to rust the surface can create an effect similar to oxidation deposition of the soil. Burying ivory in manure gives an overall thin brown staining, which suggests oxide sediment. The bottom line is that this form of coloration over the surface of an ivory object should not be the only determiner for antiquity. Therefore, the surface hue of the pomegranate was not considered a factor in determining the authenticity of the artefact and its inscription.

Optical Microscopy. — Surface examination of the pomegranate under a metallographic microscope, especially in darkfield illumination, reveals the existence of a colourless substance coating the surface in many places. The patina reveals a mixture of white calcium carbonate crystals, brownish matter and green cupric corrosion products. These matters were later examined under the SEM and are discussed below.

Petrographic examination of the patina samples from the inscription and the body of the pomegranate reveals that it is made of calcite (including coccoliths), clay, grains of charred organic material and other opaques. These particles are cemented by amorphous, transparent to translucent, isotropic material with weak yellowish colour in plane-polarised light. The latter is not a natural material. The identification of this cement was made by further SEM examinations.

Scanning Electron Microscopy. — The analysis focused on the surface of the pomegranate and the patina that coats the words *qdš khnm*, showing the smooth surface of the pomegranate with the groove of the letter *kaf* (fig. 9) and the rough surface of the patina-like material (fig. 10a).

Fig. 9. SEM view (SE) of the smooth surface of the pomegranate and the curving of the *kaf* of the word *khnm*

EDS analyses of the patina-like material (fig. 10b) show that it contains several elements (Si, Ca, O, C, Al, Mg, Na, P, K and traces of Fe) indicative of a mixture of calcite grains and clays. In places, small micron-sized grain were identified to contain Cu and Sn, indicative of corroded bronze material. The use of SEM BSE mode within the patina-like material exposes coccoliths as darker patches (fig. 11a, b). The coccolith is composed of calcium carbonate, but the fact that it appears as a darker patch clearly indicates that a material with lower average molecular weight coats it. This was confirmed by the EDS analyses (Fig. 11c), showing that the coccolith contains, in addition to the Ca, significant amounts of C and Si. This points to the presence of a film of carbon-silicate based glue that was applied to glue the patina-like material to the artefact. Additional indication that the coccolith is coated by low molecular weight material is the fact that it was fused by the electron beam (see arrow in fig. 11a, b). A material used as glue was also found on the smooth surface of the pomegranate (fig. 12a, b) and is composed almost entirely of carbon (fig. 12c). This material was also fused by the electron beam, indicating that at least two types of glue were applied, silicon-carbon and carbon based glues.

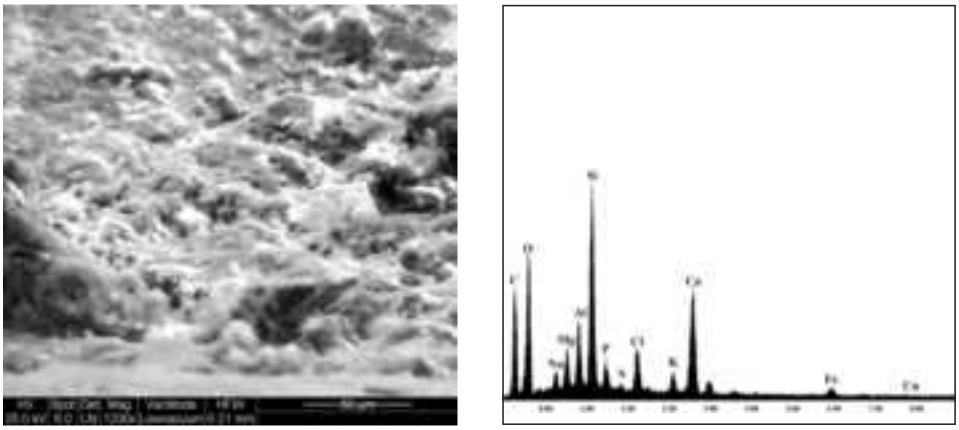


Fig. 10. (a) SEM view (SE) of the rough surface of the patina-like material within the *mem* of the word *khnm*; (b) EDS spectrum of the patina, showing that it is composed of Si, Ca, O, C, Al, Mg, Na, K and minor Fe, which suggests a mixture of calcite and clays

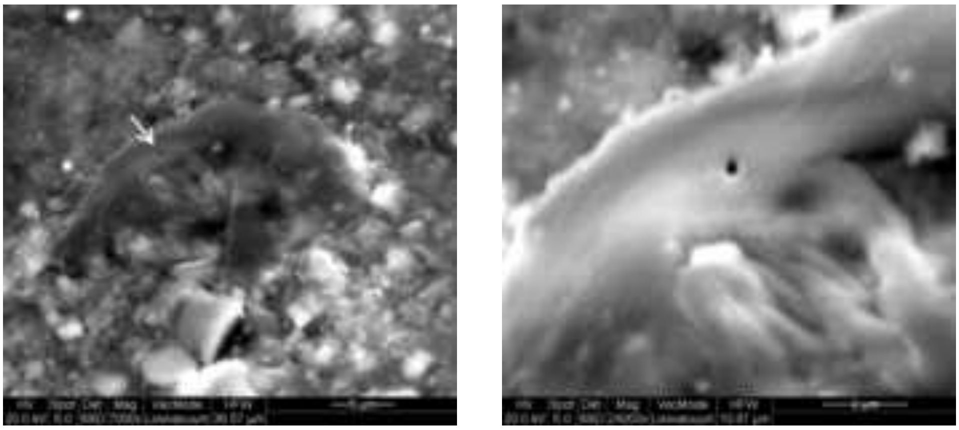
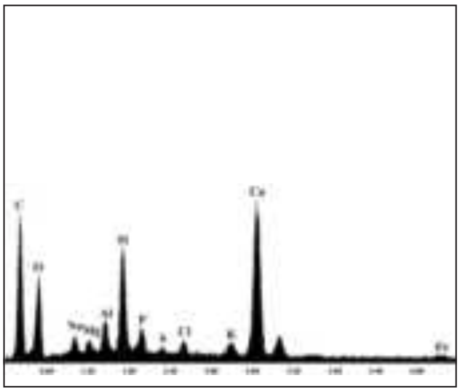
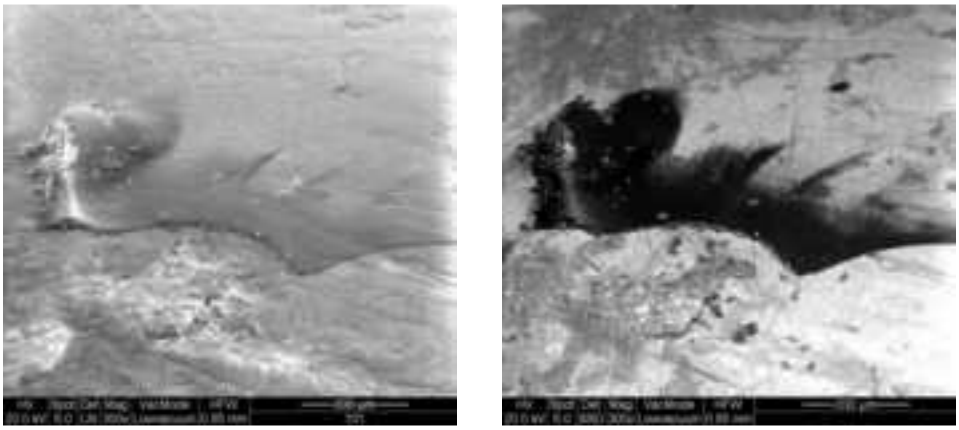


Fig. 11. (a) SEM view (BSE) a coccolith (microfossil of marine nanoplankton) shown as a darker patch within the patina of the *mem* of the word *khnm*; note the hole (marked with arrow) in (a) and in the enlarged image (b) that was drilled by the EDS ray during the analysis, indicating that the particle was coated by some other material that was fused by the X-ray; (c) EDS spectrum of the coating film of the coccolith seen in (a) and (b), revealing the dominance of Si, C and O, which indicates silicon-carbon bond





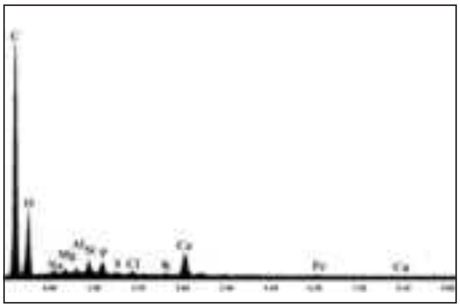


Fig. 12. (a) SEM view (SE) of material coating the surface of the pomegranate near the word *khnm*; (b) BSE image of the same material, revealing that this coating is made of low molecular weight material (dark area) and is composed mainly of carbon, as evident from the EDS spectrum; (c) this material is superimposed on the patina-like material (seen in the lower left-hand part of the photo)

Stable Isotope Analysis. — Isotope composition of oxygen ($\delta^{18}O$) is a function of precipitation temperature and $\delta^{18}O$ composition of water from which the patina precipitated. The carbon isotopic composition ($\delta^{13}C$) is a function of the soil-CO_2 and the $\delta^{13}C$ value of the country rock. The study method is based on background data from our previous studies of secondary calcite (formed in similar conditions to those from which patina is formed) in the Judaean Hills, patinas of Iron Age ostraca from various sites in Israel (Goren *et al*. 2005) and patinas from Early Roman ossuaries excavated in the Jerusalem area (Ayalon, Bar-Matthews and Goren 2004). The data show that $\delta^{18}O$ and $\delta^{13}C$ values in carbonate patina formed on the surface or in shallow burials in these areas in the last three thousand years is in the range of -6.5 to -3.5‰ (PDB) and -5 to -13‰ (PDB) respectively (Goren *et al*. 2005: table 1 and fig. 8). These $\delta^{18}O$ values are in agreement with the expected range of naturally formed secondary carbonates in the climatic conditions prevailing in Judaea during the last 3,000 years ($\delta^{18}O$ water -6‰ to -4‰ (SMOW)[3] mean annual temperatures of 18–19°C and C3 type vegetation (Bar-Matthews *et al*. 1996; Bar-Matthews, Ayalon and Kaufman 1997; 1998).

The premise of our work is that a significantly different patina composition

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[3] See above, n. 1.

from this range would indicate artificial production of patina. Surface patina was sampled from the pomegranate, as well as from three similar, but uninscribed, ivory pomegranates from a private collection that were kindly lent to us for comparison by Mr. G. Chaya, Jerusalem. Two of these pomegranates were reportedly found in a tomb in Samaria together with an assemblage of scarabs of Thutmoses III.

The $\delta^{18}O$ and $\delta^{13}C$ values in patina from the comparative pomegranates lie within the range of -3.5 to -2.8‰ and -7.1 to -5.7‰ respectively (fig. 13). These values are generally slightly higher than the expected $\delta^{18}O$ and $\delta^{13}C$ values of patina that was precipitated naturally in Judaea and probably represent the conditions in the area from where the pomegranate patina was formed.

The patina samples that were taken from the Israel Museum pomegranate were found to contain very little calcium carbonate, but two samples contain enough material for isotopic analyses and hence were removed from the relatively thick layer that covered the letter *mem* (fig. 8) and various parts of the body. The $\delta^{18}O$ and $\delta^{13}C$ values of the patina from these samples reveal two types (fig. 13): (a) a patina sample with $\delta^{18}O$ and $\delta^{13}C$ values that are generally similar to those of the comparative pomegranates (-3.8‰ and -5.6‰); and (b) a patina sample with a similar $\delta^{18}O$ value (-2.8‰) but a higher $\delta^{13}C$ value (0‰). A $\delta^{13}C$ value of 0‰ is typical of marine carbonate rocks. The presence of patina with $\delta^{13}C$ values of 0‰ from the Israel Museum pomegranate can only be explained if it is composed of marine carbonate. This is confirmed by the presence of the coccolith microfossils found within the patina mixed together with the limestone or chalk, clays and charcoal. This value, together with the presence of lower molecular weight material, probably carbon- and carbon-silicon-based glue, confirm their artificial origin. The patina with $\delta^{18}O$ and $\delta^{13}C$ values of -3.8‰ and -5.6‰ respectively most likely represents the naturally-formed patina that covers the pomegranate — as would be expected in an authentic ancient object.

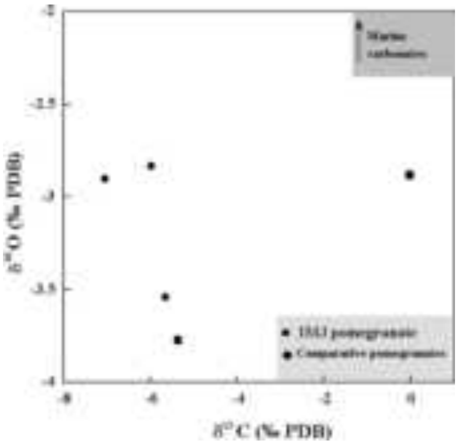

Fig. 13. $\delta^{18}O$ values plotted against $\delta^{13}C$ values of patina samples from the Israel Museum pomegranate (IMJ solid squares); the values of three similar pomegranates (circles) and the isotopic field of marine carbonate rocks are shown for comparison

CONCLUSIONS

The combined results of this study indicate that the ivory pomegranae is ancient, its surface covered by a naturally-formed patina. It probably dates from the Late Bronze Age. The letters of the inscription are well executed (with the exception of the problematic *mem*).

In contrast to the antiquity of the pomegranate itself, the inscription and the patina-like material on the inscription and around it are a recent forgery. The patina-like material is a mixture of marine and continental carbonates, clay, carbonised organic material and corroded bronze, together with modern adhesive (most likely silicone-carbon glue), coated by another adhesive (organic carbon-based glue). The inscription was inscribed on the pomegranate after it had already been broken in ancient times, causing some new breaks to occur due to the pressure forced by the engraving tool on the edge of the old break and causing the incompletion of the *taw*, *he* and *yod* in relation to the break in the pomegranate. This convinced us that the inscription was engraved after the pomegranate had already been broken in antiquity. Indeed, no-one would have dared to donate a broken item to the Temple and then engrave upon it. The conclusion, therefore, is that inscription must be a recent one, very cleverly executed. The use of spaces as word dividers, the awkward syntax, and the execution of the broken part of the inscription, together with the fake patina over it, reveal the true character of the inscription as a sophisticated recent forgery.

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Authenticity Examination of Two Iron Age Ostraca from the Moussaieff Collection*

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INTRODUCTION

Two ostraca belonging to a private collector and bearing palaeo-Hebrew inscriptions, have been published in recent years and discussed by several scholars, suggesting that they are authentic and should be incorporated in the assemblage of Hebrew inscriptions of the Iron Age II. After the first publications (Bordreuil, Israel and Pardee 1996; 1998; Shanks 1997; 2003), some scholars challenged their authenticity on the basis of several epigraphic, palaeographic and syntax oddities (Ephʿal and Naveh 1998; Rollston 2003: 145–147). The first ostracon (henceforth: ostracon 1) deals with an order by King Ashiyahu (presumably King Joshiahu) to give a man named Zecharyahu three silver shekels for the House of *YHYW* (fig. 1). The second (henceforth: ostracon 2) contains a plea of a widow to some official to maintain her ownership over her late husband's property (fig. 2).

The present study focuses on the question of authenticity of these two ostraca after examining them by means of micromorphology, petrography and oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic compositions of the secondary materials (patina) on their surface. The term 'patina' refers to the natural coating that is created over the surface due to the absorption or loss of various elements (Dorn 1998). It is commonly thought that the process of patination is slow; thus, genuine patina may be used as an indication for the antiquity of an object. A large body of literature has accumulated over the past four decades concerning the processing, weathering

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* The ostraca were reportedly purchased by the antiquities collector Mr. S. Moussaieff, who loaned them for inspection to the Israel Antiquities Authority (IAA) and the Israeli police as part of a legal investigation of alleged forgeries. This study was carried out under special commission by Mr. S. Dorfman, Director of the IAA, with the kind help of Mr. A. Ganor, Head of the Antiquities Theft Inspection Unit of the IAA, and Major Jonathan Pagis of the Fraud Unit of the Israel Police. The examinations were conducted in the Laboratory for Comparative Microarchaeology of the Institute of Archaeology, Tel Aviv University, and the Stable Isotope Laboratories of the Geological Survey of Israel. We thank all the above, as well as Dr. A. Bein, Director of the Geological Survey of Israel, for their collaboration. We also thank Prof. A. Matthews for his critical comments of the manuscript. All authors contributed equally to this work.

Fig. 1. Ostracon 1

Fig. 2. Ostracon 2

and dating possibilities of patina. From this data, it is evident that patination by itself is a somewhat unreliable indicator of antiquity, since patina-like coating can be created in the laboratory by various methods. While one can readily accept that genuine patina formed over an inscription is younger than the script, there are several difficulties in evaluating its age. Climatic factors, among them the presence of fluids and the pH, have considerable influence and can accelerate, delay, or completely inhibit patina formation. Moreover, the application of various dating techniques to the patina is dependent upon many factors (Bednarik 1996). Therefore, the presence or absence of patina over an artefact cannot be used *a priori* as an indicator for its authenticity.

In the creation of patina, two factors play a crucial role. The first is the composition of the substrate over which the patina is processed, its capillary and absorbed water content. The second is the nature of the environment, namely, the sediment, pH, temperature and humidity that surround it, as well as the physical conditions (such as erosion and exfoliation). Obviously, an artefact subjected to a subterranean environment would develop different patina types from one subjected to an atmospheric environment. Since the composition of patina is the result of reaction between the base material and the surroundings, it is expected to reflect in its composition the characteristics of the depositional environment. While on exposed items the patina composition is usually the outcome of the autochthonous minerals, a buried artefact is coated by patina that results more from the mineralogy of the surrounding environment.

As for the ostraca, based on their epistolary style and textual content, it is evident that they were supposed to be written (and perhaps also found) in Judaea. The lithology of the Judaean Hills and their foothills includes a set of Cenomanian-Turonian and Senonian limestone, chalk and dolomite series, typically capped by Terra Rossa or brown rendzina soils. In the Shephelah, mainly Eocene chalk series are exposed, capped by brown and pale rendzina soils (Arkin, Brown and Starinsky

1965; Buchbinder 1969). This would result in significant enrichment of calcite ($CaCO_3$) in the patina, as compared with the original sherd.

Taking all the above into consideration, the ostraca and the patina types over them were subjected to a set of micromorphologic, petrographic and geochemical examinations in order to examine their authenticity as a factor for assessing the antiquity of the inscription. Special attention has been paid to micromorphologic features, namely, the integrity of the inscribed surface as observed under the microscope, in comparison with the same features in legally excavated and well recorded ostraca from Arad, the City of David, Lachish, Tel Beer Sheva, Ḥorvat ʿUza, and Tell el-Farʿah (S).[1]

METHODS

The following procedure has been applied in order to examine the authenticity of the ostraca.

1. Tiny samples of the sherds were removed from the obverse of the ostraca for standard petrographic examination. This analysis was not intended for the examination of the authenticity of the ostraca *per se*, but in order to examine whether the petrography of the sherds was in agreement with the recorded composition of Iron Age pottery from Judaea. For comparison, we used our collection and database of archaeological vessels from Israel and adjacent areas, kept in the Institute of Archaeology of the Tel Aviv University.
2. Surface investigation of the ostraca was made under a stereomicroscope at magnifications up to ×60 and under an incident light microscope at magnifications of ×40–×400, using brightfield and darkfield illuminations.
3. Two sample sets of patina were taken from the ostraca, using a scalpel and a set of dental tools. One set was used to prepare petrographic thin sections and the other set was used for the stable isotope analysis. The thin sections were examined under a polarising microscope at the same magnifications.
4. The oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic composition of the carbonate component within the patina was analysed, using a VG Isocarb system attached to a SIRA-II mass spectrometer. All the $\delta^{18}O$ and $\delta^{13}C$ values were calibrated against the international standard NBS-19, and are reported in permil, relative to the PDB standard (Craig 1957).[2] Patina samples were collected for stable

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[1] We thank Ms. H. Katz, Head of the National Treasuries in the IAA, and Prof. Itzhak Beit-Aryeh and Ms. Lily Avitz-Singer from the Institute of Archaeology, Tel Aviv University, for supplying us with the ostraca for inspection.

[2] There are two internationally accepted reference standards used to report variations in oxygen isotope ratios: PDB (Pee Dee Belemnite) and SMOW (Standard Mean Ocean Water). The PDB standard is used to report carbonate oxygen isotope ratios, and the SMOW standard is used to report variations in water oxygen isotope ratios.

isotope analysis from the inscribed surfaces of the ostraca. A control group of samples was taken from the sherds in order to check their original carbonates that could occur within the clay paste or the inclusions (temper). Caution was taken to avoid contamination of the patina samples by the underlying sherd. The results of the patina samples were compared with the $\delta^{18}O$ and $\delta^{13}C$ values from well-dated secondary calcite (speleothems) deposited inside caves in the Jerusalem area during the last 3,500 years (Kaufman *et al*. 1998; Bar-Matthews, Ayalon and Kaufman 1998; Frumkin, Ford and Schwarcz 1999), and of patinas from Early Roman Period ossuaries excavated in the Jerusalem area (Ayalon, Bar-Matthews and Goren 2004). In addition, the patina of a collection of legally excavated ostraca was analysed by the same method for comparison.[3]

RESULTS

A. Petrography of the Sherds

The petrographic examination of ostracon 1 revealed the following composition (fig. 3): The matrix is reddish-tan in PPL, silty (~20%), non-carbonatic, ferruginous, exhibiting isotropism (namely, absence of birefringence resulting in partial vitrification due to high firing temperature). The silt includes predominantly quartz with accessory hornblende, zircon and feldspars. The inclusions are made of well-sorted sand of quartz, some chert and remains of limestone that was decomposed by the high firing temperature (estimated at 900°C).

The petrography of ostracon 2 is as follows (fig. 4): the matrix is carbonatic, foraminiferous (rich in microfossils), slightly silty (~2%) and partially isotropic in

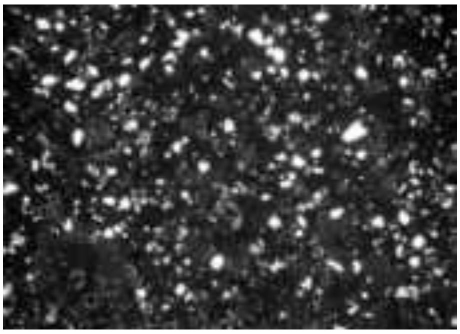

Fig. 3. Ostracon 1 under petrographic microscope, crossed polarisers (see text for details)

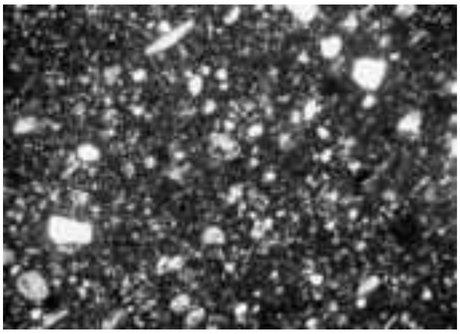

Fig. 4. Ostracon 2 under petrographic microscope, crossed polarisers (see text for details)

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[3] The following ostraca were used for comparison: Lachish (IAA no. 39.799), Tell el-Farʿah (S) (no. 395 F-C), Arad (no. 67-1894), the City of David (no. 96-3280), Tel Beer Sheva (nos. 2462/1 and 2177/1) and four additional ostraca from Ḥorvat ʿUza.

places. The firing temperature is estimated at ~700°C. The inclusions contain rounded sand-sized grains of quartz, chert, chalk and Nari.

The matrix of ostracon 1 is readily identified as Terra Rossa soil mixed with fine sand. This soil unit occurs in the hilly areas of Israel, where a semi-arid Mediterranean climate prevails. The parent material is hard limestone, dolomitic limestone, or dolomite. Terra Rossa soil is rich in silt-size quartz grains and very fine sand of 30μm–100μm (Wieder and Gvirtzman 1999). Terra Rossa soil is widely exposed over the mountainous regions within the Mediterranean climatic zones of the southern Levant, including the central highlands, Mt. Carmel and the Galilee. They also appear in the Shephelah, in wadi channels draining these regions. The use of Terra Rossa as clay for ceramic vessels is known from assemblages belonging to the central hill country or the Upper Shephelah. In the City of David, most of the numerous clay figurines were made locally of this soil (Goren, Kamaiski and Kletter 1996). More relevant is the case of the *lmlk* stamped jars. A selection of 180 items of this jar type was examined by NAA (Mommsen, Perlman and Yellin 1984). The results suggested that the jars were produced at a single site, perhaps located in the Upper Shephelah. In a more recent study, samples of these jars were examined petrographically and proved to be made of Terra Rossa soil and quartz, chalk, and chert temper (similarly to ostracon 1).[4] Based on these data, it is logical to assume that ostracon 1 was written on a body sherd of an Iron Age jar from Judaea.

The petrographic properties of the matrix of ostracon 2 represent pale rendzina soil. The inclusions contain chalk, chert and Nari from the mother-rock of the rendzina soil and some wind-blown quartz sand. Brown rendzinas occur together with pale rendzinas in the semi-arid Mediterranean climate. The distribution of the two soils is related to catenary differentiation (Dan *et al*. 1972). The brown rendzina derives from the Nari upper crust, where dissolution and recrystallisation processes destroy the foraminifers, while pale rendzina is made of the lower Nari where approximately 30% foraminifer biorelicts occur. The appearance of the foraminifers is one of the important components in the description and classification of these soils and of the pottery that is made from them.

The combination of rendzinal matrix with chalk, chert, Nari and quartz inclusions is known from several sites in the Shephelah. It appears in Late Bronze to Iron Age pottery from Lachish (Goren and Halperin 2004), Tel Ḥarasim and Tel Maresha. Therefore, the sherd could have originated in the Shephelah, and it accords with Iron Age pottery technology.

B. Surface Examination under an Incident-Light Microscope

Micromorphologic examination of the ostraca under the stereomicroscope and the

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[4] The study, carried out by Y. Goren and S. Bunimovitz (Tel Aviv University), is as yet unpublished.

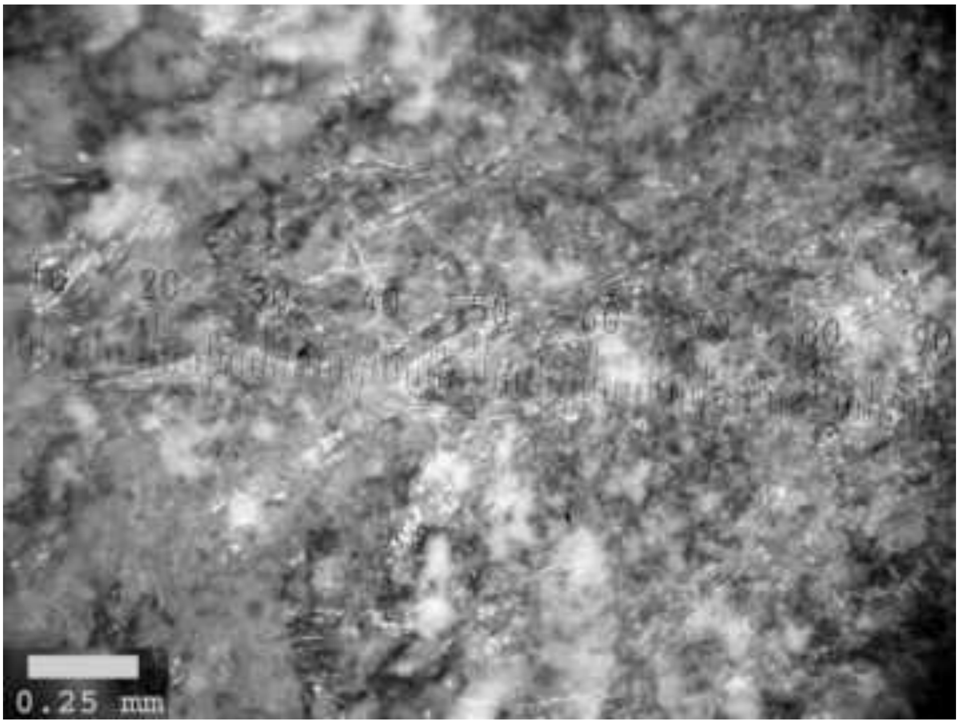

Fig. 5. Ostracon 1 as viewed under incident-light microscope (brightfield). Dark areas represent part of letter, written with black ink. Fresh scratches made by sharp metallic tool are seen, covered by patina-like material (the bright 'cloudy' areas)

incident-light microscope revealed that they share the same properties. A thin layer of translucent material has been observed, coating the surface of the sherd over the inscription (fig. 5). This material is soft when scratched by a sharp tool and melts easily when exposed to the flame of a mini gas burner spreading the smell of paraffin. When examined in thin section under the petrographic microscope, it is seen as translucent greenish matter with no crystalline properties, isotropic under crossed polarisers. Hence it was identified as wax (paraffin).

The letters under the paraffin were written with a dark pigment. The examination of small samples of the pigment under the incident-light and petrographic microscopes suggests the use of carbonised matter with no added colorants (e.g., iron or manganese minerals), and it may be assumed that carbon ink was used here. However, this issue was not investigated in depth since carbon inks, similar to the types that were used in antiquity, are still commercially sold.

Under incident-light microscopy, the letters of the two ostraca reveal fresh treatment signs by a sharp metallic tool (figs. 5, 6), appearing underneath the paraffin coating and the patina layer.

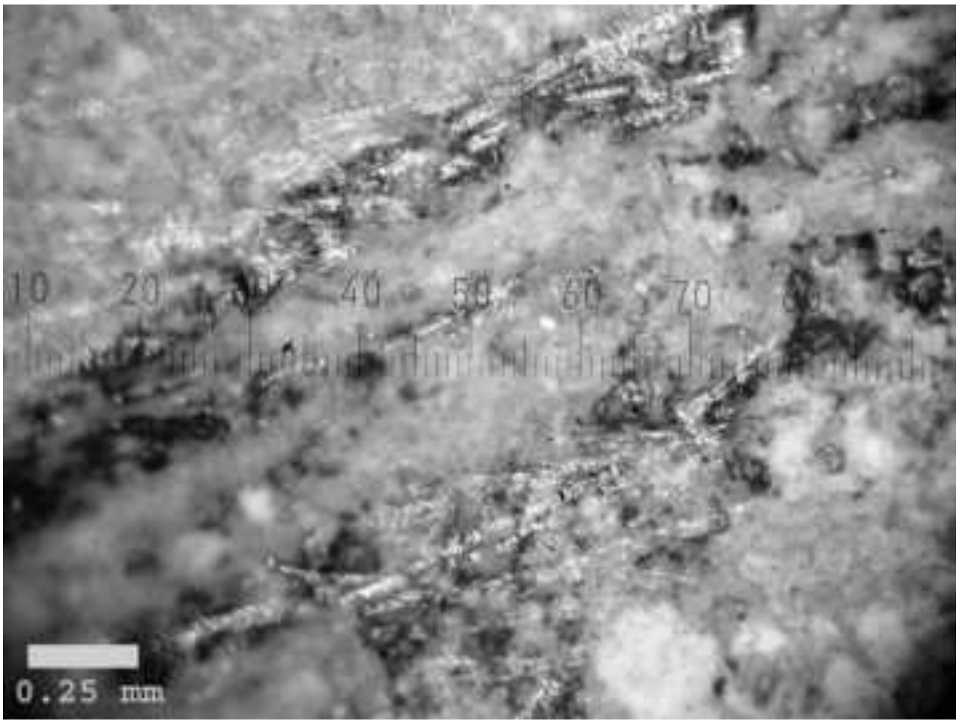

Fig. 6. Ostracon 2 as viewed under incident-light microscope (brightfield), presenting same features as ostracon 1 (fig. 5)

C. Petrographic Examination of the Patina
White calcitic patina overlies the inscriptions and the paraffin layers in the two ostraca (figs. 5, 6). When examined in thin section under the petrographic microscope, the patina is seen to contain three components. It is dominated by an accumulation of micron-sized, fibrous crystals of calcite, typical of burnt lime (Gourdin and Kingery 1975; Goren and Goldberg 1991; Goren and Segal 1995). This material is locally stained by some reddish clay (fig. 7) and mixed with abundant phytoliths and some carbonised organic matter, representing ash from vegetal material. These characteristics are typical of the patina of the two ostraca.

The examination of the legally excavated ostraca from Lachish, Tel Beer Sheva, Arad, the City of David, Ḥorvat ʿUza and Tell el-Farʿah (S) discloses entirely different traits. In all cases, the pigment forming the letters is seen under the incident-light microscope as dispersed matter appearing mainly in the sherd's cavities, lacking any fresh scratches by a sharp tool and coated directly by calcitic patina with no paraffin inlay. When examined in thin sections under the petrographic microscope, the patina samples exhibit microcrystalline accumulation of euhedral calcite crystals, dissimilar to the fibrous texture of the

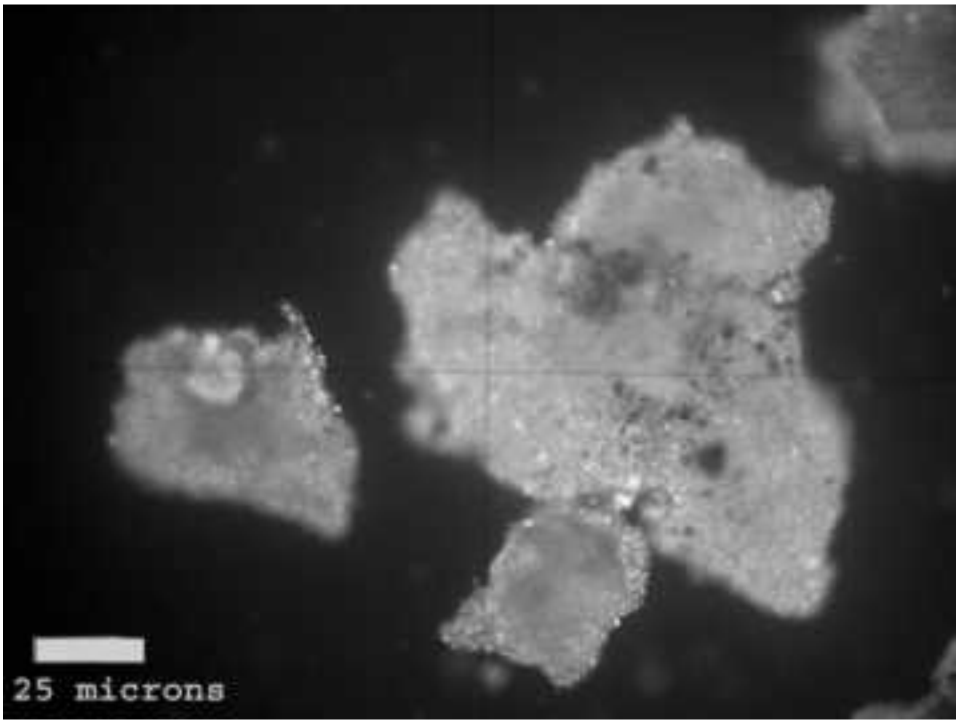

Fig. 7. Patina-like matter from ostracon 2 as seen under petrographic microscope (crossed polarisers), exhibiting fibrous, micron-sized carbonate crystals typical of burnt lime, together with some clay (darker spots) and few opaques (probably iron minerals, appearing as dark dots)

patina-like material coating the ostraca. Hence, the two ostraca in question are markedly different in these properties from the control group of the authentic items.

D. Oxygen and Carbon Isotopic Examination

The study focused on oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope composition in the calcite samples taken from the objects' surface. Isotope composition of oxygen is a function of precipitation temperature and isotope composition of water from which the patina precipitated. The carbon isotopic composition is a function of the soil CO_2 and the $\delta^{13}C$ value of the country rock. The study method is based on background data from our previous studies of secondary calcite (formed in similar conditions to those from which patina is formed) in the Judaean Hills, Samaria, Galilee and the northern Negev. The data show that the $\delta^{18}O$ value in carbonate patina formed on the surface or in shallow burials in these areas in the last three thousand years is in the range of -6.5 to -3.5‰ (PDB) (table 1 and fig. 8). These $\delta^{18}O$ values are in agreement with the expected range of naturally formed secondary carbonates in the climatic conditions that prevailed in Judaea during the last 3,000 years ($\delta^{18}O$ water -6‰ to -4‰ [SMOW])[5] and mean annual temperatures of 18–19°C (Bar-Matthews *et al.* 1996; Bar-Matthews, Ayalon and Kaufman 1997).

The premise of our work is that a significantly different patina composition from this range would indicate artificial production of patina. This theory was tested by examining the subject artefacts as well as the above-mentioned ostraca from legal excavations. Surface patina was sampled from all the items in order to test whether the patina samples contain calcite from the sherd itself (which also contains carbonate); it was tested as well for its isotope composition.

The $\delta^{18}O$ and $\delta^{13}C$ values in patina from the ostraca found at legal archaeological excavations lie within the range of -6.8 to -3.1‰ and the range of -13.4 to -4.9‰ respectively. These values are within the expected oxygen and carbon isotope composition of patina that was precipitated naturally. $\delta^{18}O$ and $\delta^{13}C$ values of the calcite in the sherd samples vary between -6.0 and -1.5‰ and between -10.0 and -6.1‰ respectively (fig. 8). In the sherd we also find 'modified' calcite, the isotope composition of which changed as a result of the firing process at high temperatures

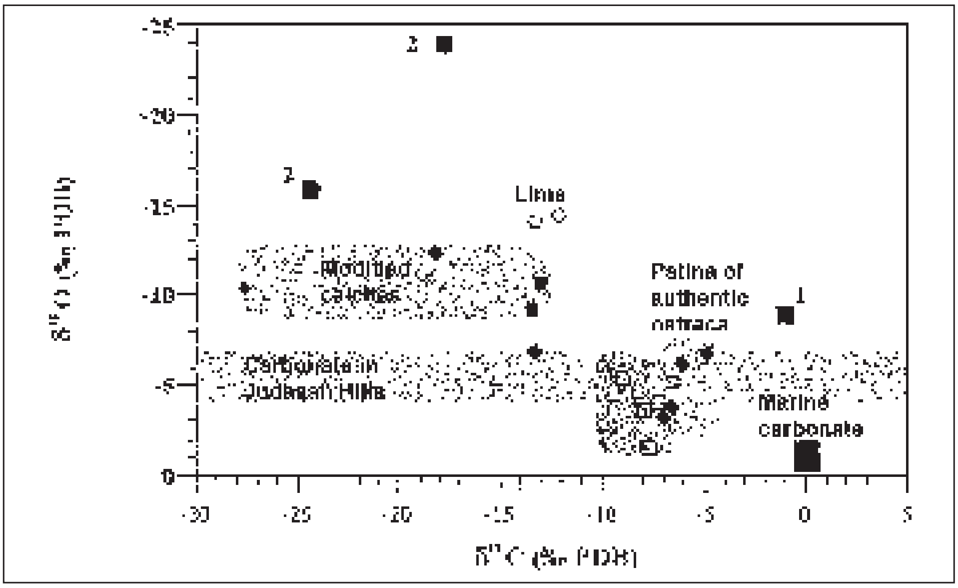

Fig. 8. Oxygen and isotopic composition of patina from ostraca 1 and 2 (solid squares) and patina of ostraca (solid rhomboheders) from collections found in methodical and documented archaeological excavations (Tell el-Farʿah [S], Tel Lachish, Tel Arad, Tel Beer Sheva and City of David). Also shown: isotopic compositions of calcite present in sherd (open squares) and 'modified' calcite (solid circles) from the studied ostraca. $\delta^{18}O$ and $\delta^{13}C$ values of lime (open circles), marine carbonate and carbonates from the Judaean Hills are shown for reference

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[5] See above, n. 2.

(above 750°C, similar to lime production), leading to partial breakdown of the calcite present in the sherd. This calcite is characterised by significantly low $\delta^{18}O$ and $\delta^{13}C$ values (-12.4 to -9.1‰ and -27.6 to -5.7‰ respectively; table 1 and fig. 8).

Table 1. Oxygen and carbon isotopic composition of patina, sherd and 'modified calcite' sampled from the studied ostraca

Sample no.	Description	Oxygen $\delta^{18}O$	Carbon $\delta^{13}C$
Patina			
No. 1	Ostracon 1	-8.95	-0.98
No. 2	Ostracon 2	-15.82	-24.34
No. 2	Ostracon 2	-23.89	-17.78
No. 3	Tel Lachish	-3.78	-6.62
No. 3	Tel Lachish	-3.11	-7.06
No. 4	Tell el-Farᶜah (S)	-6.74	-4.87
No. 5	Tel Arad	-6.08	-6.07
No. 6	City of David	-6.84	-13.42
No. 7	Tel Beer Sheva (no. 2462/1)	-6.42	-8.37
Sherd			
No. 1	Ostracon 1	-1.47	-7.68
No. 2	Ostracon 2	-4.55	-8.25
No. 3	Tel Lachish	-3.57	-7.98
No. 4	Tell el-Farᶜah (S)	-6.04	-9.97
No. 4	Tell el-Farᶜah (S)	-4.07	-7.34
No. 6	City of David	-5.38	-9.05
No. 7	Tel Beer Sheva (no. 2462/1)	-3.85	-9.12
No. 7	Tel Beer Sheva (no. 2177/1)	-3.75	-6.14
'Modified' calcite			
No. 3	Tel Lachish	-10.63	-27.63
No. 4	Tell el-Farᶜah (S)	-12.38	-18.24
No. 4	Tell el-Farᶜah (S)	-9.20	-13.45
No. 5	Tel Arad	-10.63	-27.63
No. 7	Tel Beer Sheva (no. 2177/1)	-9.08	-5.72
Commercial lime samples		-14.13	-13.33
"		-14.46	-12.24

The relatively low $\delta^{13}C$ values may indicate alteration of the sherd's calcite. This calcite should be carefully treated during patina sampling in order to prevent contamination of the sample by calcite of particularly low composition.

To substantiate our finds, samples of industrial lime were tested for comparison. Both oxygen ($\delta^{18}O$ = -14.5 and -14.1‰) and carbon ($\delta^{13}C$ = -13.3 and -12.2‰) show characteristically low values.

Ostracon 2 has a thick patina layer, which allows taking a reliable sample, uncontaminated by the sherd. The oxygen (and carbon) isotopic composition of the patina samples from the inscribed surface of ostracon 2 reveals extremely low oxygen and carbon isotope values. $\delta^{18}O$ and $\delta^{13}C$ values of patina from these ostraca range between -23.9 and -15.8‰ and between -24.3 and -14.9‰ respectively (fig. 8), and were significantly different from the expected calcite values in the geographical areas mentioned above (fig. 8). These values are also significantly lower than those of the patina of the letters in the James ossuary (Ayalon, Bar-Matthews and Goren 2004) and of the patina on the Jehoash tablet (Goren *et al.* 2004). The $\delta^{18}O$ and $\delta^{13}C$ values of the patina from ostracon 1 are -8.5 and -0.98‰ respectively. This value is found in the isotope value range measured in the patina of the letters on the James ossuary and the Jehoash tablet. It should be noted that this object has a relatively thin patina layer in comparison with the other ostraca tested, and it is possible that the isotopic composition measured in this sample represents a mixture of the isotopes of the patina with the sherd.

The very low $\delta^{18}O$ and $\delta^{13}C$ values found in the 'modified' calcite in the sherd, in the comparative commercial burnt lime sample and in the patina which covers ostraca 1 and 2 are the result of isotopic fractionation due to kinetic effects which accompany the firing process, which increase with increasing temperature during the firing. Previous investigators found good correlation between the firing temperature in preparing pottery vessels and the $\delta^{18}O$ and $\delta^{13}C$ values in calcite in clays that contain carbonate and that were fired at temperatures between 500°C and 700°C (Baertchi 1952; Bottinga 1968; Shieh and Taylor 1969; Nissenbaum and Killebrew 1995). They found that original carbonate was either completely decomposed or that it exchanged with environmental CO_2 to demolish the original isotopic signature. Very low $\delta^{13}C$ values (-21‰ to -26‰) and $\delta^{18}O$ values (-17.8‰ to -22‰) were reported for quicklime prepared from chalk heated to 900°C and cooled in room temperature (Ambers 1987)

The oxygen and carbon isotope composition of the patina of ostracon 2 is clearly different from the range of values expected for carbonate patina formed today and from that formed in the Judaean Hills, northern Negev, Samaria and Galilee in the last three thousand years. Assuming customary burial conditions and given the very negative values for oxygen and carbon isotope composition in the patina of this object, this patina could not have formed naturally under typical climatic conditions and water composition in the above-mentioned geographical zones within the last three thousand years.

The very negative oxygen and carbon isotope values clearly indicate that the isotopic composition can be used as criteria to demonstrate that the patina that covers ostracon 2 is in fact an artificially-made lime, which was poured onto the surface of the object.

Oxygen isotope composition in the patina of ostracon 1 is also different from the expected range for naturally-formed carbonate patina, indicating that the patina is not natural. As noted, this item exhibits a relatively thin patina layer when compared to the other nine ostraca, and it is possible that its isotope composition represents a mixture of patina with sherd. Therefore, based on its oxygen isotope composition alone, it is impossible to determine whether or not the patina of this object developed naturally.

CONCLUSIONS

The micromorphologic, petrographic and isotopic examination of the two ostraca indicate without a doubt that these are modern forgeries. The results of the analyses presented here enable the reconstruction of the sequence of actions taken by the forger(s). First, a body sherd from an Iron Age large vessel was selected. The surface of the sherd was cleaned from its original patina to enable writing on it. The inscribing was carried out in carbon ink, presumably using a calligraphy pen. After drying, the letters were 'aged' by scratching them with a scalpel or a razor blade, in order to give them a weathered appearance. In order to enable the 'patination' process and to prevent dissolution of the letters by water, the entire inscribed surface was coated by a thin film of paraffin, over which the simulated patina was applied. The latter was made by mixing commercial burnt lime with some plant ash and clay, most likely in order to give it the greyish hue that is typical of genuine calcareous patina. Since the two ostraca share precisely the same forging technique, it may be suggested that they could both have been prepared in the same workshop, although this hypothesis cannot be proved conclusively. It should be noted that this forgery technique is not very sophisticated and that expert laboratories can readily notice the presence of the irrelevant materials (paraffin and lime).

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