Chapter 15

Scientific Study Tour of Ancient Israel

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More than a dozen scientific techniques have been applied for the study of archaeological artifacts excavated from various sites of Ancient Israel by an international field of researchers. These methods include Amino Acid analysis, Ancient DNA analysis, Accelerated Mass Spectrometry, Atomic Absorption Spectroscopy, Particle-Induced X-ray Emission, X-Ray Fluorescence, X-Ray Diffraction, Fourier Transform Infrared spectroscopy, Nuclear Magnetic Resonance spectroscopy, Electron Microprobe Analysis, Scanning Electron Microscopy, High-Performance Liquid Chromatography with Photo-Diode Array (HPLC-PDA) detection, and Hygric Expansion Coefficient measurements. This paper discusses the significance of the results of the analyses performed with these methods on artifacts found in four representative archaeological sites in Israel, travelling from north to south, over a 450 km stretch of land. The science tour starts in northernmost Tel Dan, the ancestral home of the biblical Tribe of Dan, yielding the extraordinary House of David stele and the royal or priestly bronze scepter head. The results of archaeo-metallurgical analyses depict a portrait of the simple socioeconomic living conditions of the Iron Age inhabitants of Tel Dan from three millennia ago. Travelling down to the dry and hot climate of the Dead Sea area, we encounter a region that was inhabited by a 2,000-year old Jewish sect. This region yielded tens of thousands of fragments from the famous biblical and communal scrolls, which were stored or hidden in the caves of Qumran.
and nearby areas. Various scientific analyses of the scrolls produced the following results: the parchments were produced from the skins of goats and other local animals, about which there is still an on-going debate; scientific analyses of the black ink used in the scrolls clearly determined that it was not iron-based, but rather carbonaceous (charcoal, soot, lampblack, etc.); the rare red ink found on only four separate fragments was cinnabar (vermilion). Continuing along the Dead Sea route but travelling a bit more south, we arrive at the famous mountaintop of Masada, the 2,000-year old palatial hideaway of King Herod. Scientific analyses of the wall paintings identified the typical Roman-period pallet of inorganic artists’ pigments. Chromatographic analyses on textiles from Masada identified the biblical reddish-purple Argaman dye on a weave from probably a royal cloak of King Herod, and, on a different textile, the dark bluish-purple (or violet) biblical Tekhelet dye was found. On the last stop of our science tour, just before we arrive at the southernmost point of Israel on the Red Sea, is the Timna Valley, which was an ancient copper-mining area, originally believed to have been mainly used during King Solomon’s era. However, the finding of an Egyptian sanctuary at the site caused various archaeologists to date the site to a few centuries earlier. Yet, recent radiocarbon analyses have shown that the main copper activity was indeed as originally proposed, and hence these are still known as King Solomon’s copper mines. The science tour of Ancient Israel, which can be employed for the study of any region with a rich ancient history, shows how advanced scientific analyses of archaeological artifacts are essential for understanding the life and times of ancient societies.
Introduction

The various abbreviations used in this article, both from archaeology and science, are given with their meanings in Table 1.

Table 1. Abbreviations Used (in Alphabetical Order)

<table>
<thead>
<tr>
<th>Used in Archaeology:</th>
<th>Used in Scientific Analyses:</th>
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<tbody>
<tr>
<td>BCE Before the Common Era</td>
<td>AA Amino Acid analysis</td>
</tr>
<tr>
<td>BP Before Present</td>
<td>AAS Atomic Absorption Spectroscopy</td>
</tr>
<tr>
<td>CE Common Era</td>
<td>aDNA Ancient DNA analysis</td>
</tr>
<tr>
<td>cent./cents. century/centuries</td>
<td>AMS Accelerated Mass Spectrometry</td>
</tr>
<tr>
<td></td>
<td>EDXRF Energy Dispersive X-Ray Fluorescence spectroscopy</td>
</tr>
<tr>
<td></td>
<td>EMPA Electron Microprobe Analysis</td>
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<tr>
<td></td>
<td>FTIR Fourier Transform Infrared spectroscopy (or spectrometry)</td>
</tr>
<tr>
<td></td>
<td>HEC Hygric Expansion Coefficient measurements</td>
</tr>
<tr>
<td></td>
<td>HPLC High-Performance Liquid Chromatography</td>
</tr>
<tr>
<td></td>
<td>NMR Nuclear Magnetic Resonance</td>
</tr>
<tr>
<td></td>
<td>PDA Photo-Diode Array detector</td>
</tr>
<tr>
<td></td>
<td>PIXE Particle- (or Proton-) Induced X-ray Emission</td>
</tr>
<tr>
<td></td>
<td>SEM Scanning Electron Microscopy</td>
</tr>
<tr>
<td></td>
<td>XRD X-Ray Diffraction</td>
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<tr>
<td></td>
<td>XRF X-Ray Fluorescence</td>
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This paper will discuss some of the advanced scientific analyses performed on archaeological artifacts excavated from the area ascribed to “Ancient Israel”. It is difficult to delineate the borders of this ancient land as its borders shifted with various political waves over several thousands of years. Various maps show the shifting borders of this land from the time of King David and his son, King Solomon, three millennia ago, which according to various biblical scholars and cartographers consisted of the greatest land mass (1). These borders were reduced throughout history to present day Israel, whose international borders have still not been finalized. The archaeological term of “Ancient Israel” is used to represent
the areas encompassing the modern day State as well as its environs, in what some also refer to as the “Holy Land”, and has been used in other publications (2, 3).

With its vast ancient history, Israel, from north to south, can be considered as one large archaeological site. In this paper we will take a tour to various important archaeological sites with an emphasis on the scientific analyses that have been performed on various objects that were found there. These sites span various epochs over thousands of years. This article is not an encyclopedic treatise on the subject, and various tomes have been published on the archaeology of this area (4–7). It is difficult to choose which archaeological sites in Israel to highlight, and though the land area is relatively small, yet there are over 50 major archaeological sites and a list from A to Z is available (8). The emphasis of this paper, though, is to single out a few of these sites, which I consider to be representative of many of the other sites, and provide examples of how and why different scientific methods were used for such analyses. The sites and cities mentioned in this article are shown in Figure 1.

![Figure 1. Satellite map showing the locations of some of the places mentioned in the paper. The four archaeological sites of Tel Dan, Qumran, Masada, and Timna are shown with a text box border. (image adapted from NASA Visible Earth, Wikimedia Commons).]
The advanced scientific analyses performed on archaeological objects found in Ancient Israel go in tandem with modern cutting-edge breakthroughs that have been made in science and technology as exhibited by the eight Israeli Nobel Prize winners in chemistry and economic sciences since 2002 (9). Prof. Daniel Kahneman (b. 1934), an Israeli-American research psychologist at Princeton University and with academic roots at the Hebrew University in Jerusalem, was a co-recipient of the Nobel Memorial Prize in Economics in 2002 for his mathematical development of “prospect theory”, a behavioral economic theory based on the psychology of judgment and decision making. The second Nobel Prize in Economics awarded to an Israeli was given in 2005 to Prof. Robert Aumann (b. 1930), a co-recipient, for his mathematical development of the correlated equilibrium concept associated with conflict and cooperation through game-theory analysis.

In the chemical sciences, six Israelis were awarded the Nobel Memorial Prize in Chemistry. Prof. Avram Hershko (b. 1937) and Prof. Aaron Ciechanover (b. 1947), both from The Technion – Israel Institute of Technology in Haifa, were co-recipients of the Nobel Prize in 2004 for their discovery of the ubiquitin-proteasome pathway of protein-degradation leading to various diseases. Prof. Ada E. Yonath (b. 1939), working at the Weizmann Institute of Science in Rehovot, received her share of the prize in 2009 for her studies on the crystalline structure and function of the ribosome, and in so doing made a bit of history: She is the first Israeli woman to win the Nobel Prize and the first woman from the Middle East to win a Nobel prize in the sciences, as well as being the first woman in 45 years to win the Nobel Prize in Chemistry. In 2011, Prof. Dan Shechtman (b. 1941) of the Technion received his prize for discovery of quasi-periodicity in crystals, though two-time Nobel Prize winner, Linus Pauling (1901-1994) completely opposed that revolutionary concept. The most recent Nobel laureates are Prof. Arieh Warshel (b. 1940) of the University of Southern California and Prof. Michael Levitt (b. 1947) of Stanford University, who in 2013 shared the prize for the development of multiscale models for complex chemical systems.

Advanced scientific techniques, comparable to Nobel-type breakthroughs, were also used for the study of ancient societies from this part of the world. We will travel back in time to historical moments that not only had local importance but also helped shape world history. All this immense human achievement was recorded over a relatively short geographical distance from almost northernmost Israel to nearly its southernmost point, spanning only about 450 km, less distance than travelling from Boston to Philadelphia in the eastern USA. So fasten your safety belts as we travel on this journey along Israel’s spine from the Tel of the Tribe of Dan in the north to King Solomon’s copper mines in the Timna Valley in the south. We will make two important stops along Israel’s mid-section in the Judean Desert’s Dead Sea and visit the Qumran caves where the famous scrolls were found as well as climbing to the mountaintop of King Herod’s Masada as invited guests.
The scientific tour of Ancient Israel begins now.

The Biblical Tel of the Tribe of Dan

**GPS coordinates:**
N33.2490, E35.6520

**Web sites:**
*Israel Nature and Parks Authority:*
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=~25~~970478950~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

*Tel Dan Excavations:*
http://teldan.wordpress.com

The biblical archaeological site of Tel Dan, a key city in the ancient northern Kingdom of Israel, is situated in the middle of the 120-acre Tel Dan Nature Reserve, a natural wonderland of streams flowing into a wild Dan River, which is the largest source of the Jordan. In the reserve are various species of trees, such as, laurel, Italian buckthorn, and Syrian ash, as well as shady hiking trails including a wheelchair-accessible trail. Nearby is Bet Ussishkin, the regional museum of nature and archaeology.

For first-time guests on an archaeological tour, a “tel” (also spelled as “tell”) is an archaeological city mound formed when a new city is built on top of a much older one with a resulting rise in the city’s level. Our first such area to visit will be Tel Dan, and it is an excellent example of how chemical analyses of archaeological objects found at a site can open a historical window to reconstruct the socio-economic living conditions of an ancient community. But first, a brief background on this historically important biblical and pre-biblical city.

The major excavations at this site began in the mid-1960s by Israeli archaeologist Prof. Avraham Biran (1909-2008), and a number of books have been published on these expeditions by the Jerusalem-based Nelson Glueck School of Biblical Archaeology at the Hebrew Union College – Jewish Institute of Religion (10). The ancient city of Dan, named after its biblical inhabitants, the Tribe of Dan, is situated in the Galilee panhandle and is one of the northernmost of cities of modern Israel. The place is mentioned several times in the Bible as also the northern border of the ancient Kingdom of Israel. Prior to it being a biblical settlement, there is archaeological evidence that this city was inhabited as far back as during the Neolithic and Chalcolithic periods of the 6th to 4th millennia BCE (11). Egyptian execration texts, which list troublesome neighboring states and symbolically put a curse on them, as well as cuneiform tablets from the Mesopotamian city of Mari, both attest to Dan’s significance in the early second millennium BCE (10, 11). Throughout the Iron Age, Israelites, Aramaeans, and Assyrians vied for control of this city whose cultic and political significance also spanned the Greco-Roman, Medieval and Ottoman periods (10, 11).
There has been a number of important archaeological finds from Tel Dan (10, 11), and one of them is the world’s oldest known gated archway from the Bronze Age – a triple-arched mud brick gate, more than 1500 years before the Romans were to develop their arch. Also discovered are massive Early Bronze Age stone fortifications and even more imposing mud brick structures from the Middle Bronze Age. Additionally, a temple complex was found that pre-dates the Israelite period, but was probably also used from the late 10th cent. BCE by King Jeroboam. This is the monarch, as the Hebrew Bible relates, who seceded from the Kingdom of Judah and established his own break-away temple to challenge the Temple in Jerusalem for religious supremacy.

With all these discoveries, there are still two more that have major historical significance. One of the most important finds from Tel Dan is shown in Figure 2, and it is a basalt stone with a late 9th century BCE inscription written in Aramaic, a close relative to – and used the same alphabetic script as – ancient Hebrew. The writing on the stele bears a victory text in which an Aramean king claims to have killed the kings of ancient Israel, which was at the time split into two kingdoms – Judah and Israel, as mentioned above. In the existing inscription, the words “King of Israel” appear, and even more importantly, the dynastic Kingdom of Judah, which originated with King David, is mentioned with the words “House of David” (10, 11), which are highlighted in the figure. This is an amazing historically important object as it is the oldest mention of the Kingdom of David outside of the Bible.

Another important object was found beneath a four-horned stone altar in the temple complex. This find was reported to be a bronze and silver scepter head (12), and is shown in Figure 3. However, it is not known if it belonged to a king or priest, and whether its location underneath the altar was deliberate in order to hide it or part of a cultic ritual. The top of the beautiful scepter head resembles a miniaturized altar and contains horns at the four corners, paralleling the four corner horns typically present in altars from other Iron Age sites in Israel.

The scepter head is an example of other metallic cultural material objects found throughout Israel as well as at this site (13–15). We shall return to this scepter head at the end of this section, but first we will discuss the metallographic and chemical aspects associated with the archaeo-metallurgical objects found at Tel Dan.

Metallurgical industrial remains dating to the 12th–11th cents. BCE were excavated at Tel Dan (13–15). These included tuyères (clay pipes for directing streams of air to increase the oven fire’s temperature), crucibles, slags, ash pit, intact metal tools and objects (such as a pin, needle, hook, and arrowheads), and numerous metal pieces found in and around an open air metal workshop. Also included in the metallic finds are sharp “points”, which could have been awls, drills, picks, or spearheads. The archaeo-metallurgist Prof. Sariel Shalev performed compositional and metallographic studies on these objects in order to understand the nature of this activity in the Iron Age I society of Tel Dan (15).

The chemical composition of various slag pieces and metal samples were analyzed via Atomic Absorption Spectrometry (AAS) in Israel at the Institute of Archaeology at Tel Aviv University, and by means of Electron Microprobe Analysis (EMPA) in England at the Department of Materials at Oxford University.
From the analyses of 18 elements and oxides and the degree of corrosion that the metal objects exhibit, a good picture of the metallurgical activity at this Tel Dan site can be obtained. The analyzed slags represent mainly a bronze-working industry with copper and a variable – uncontrolled – relatively low quantity of tin in the alloy, not an uncommon chemical composition of metals from other Iron I sites of the eastern Mediterranean (15).

According to Shalev (15), the results of the chemical and metallographic analyses indicate that the activity at the bronze-producing workshop at Tel Dan at the beginning of the Iron Age consisted mainly of melting/remelting processes as opposed to the first stages of metal production – smelting and refining. This is reflected by a number of factors: the presence of numerous broken bronze items near the crucibles; their tin content as compared to that in the slags; the varying and relatively low content of tin. The latter observation indicates that the Tel Dan bronzesmiths did not control the quantity of tin in the melt and thus did not obtain an optimal amount of tin in their bronzes. This is also indicative of the metal workers not adding tin, but rather using whatever tin was already present in the metal scraps.

Figure 2. (Top) Tel Dan stele consisting of joined fragments with Aramaic inscriptions including mention of the “King of Israel” and “House of David”; the latter is highlighted with the added white markings (image courtesy of the Hebrew Union College). (Bottom) A drawing of part of the 8th and 9th lines of the stele inscription (adapted from the drawing by Schreiber, Wikimedia Commons), showing the following words highlighted in red: 8th line (from right to left): MLK YSREL (“King of Israel”). 9th line (from right to left, after the first dot): BYT DVD (“House of David”).
Thus, these analytical results can reflect upon the socio-economic conditions of the population living in Tel Dan during the Iron Age of the end of the 2nd millennium BCE (15). Shalev reports that the bronze-manufacturing process practiced at Tel Dan was not a sophisticated and complex industry, but rather consisted of a simple local industry that basically met the needs of the immediate population in domestic tools and in weapon accessories. The smiths recycled broken and defective scrap bronze pieces to produce their new wares. All aspects of the analyses lead to the conclusion that this was a simple population needing simple objects made from scrap materials.

We now return to that beautiful bronze scepter head, which by its very material character, I propose also depicts a simple way of life presented by the people of this settlement. The kings and priests of many cultures possessed scepters made of precious gold, which has so far not been found at this site. The fact that such a sacred or royal (or both) important object is composed of mainly bronze shows again that these people did not possess great material wealth, but could only afford to fashion their ritual objects from bronze. This bronze scepter head could have certainly been produced in the local metal-working workshop, but is awaiting further chemical analyses before a final judgment is declared on that object.

We now leave the relatively green Galilee landscape and travel 200 km due south to the arid land of the Dead Sea to visit the next archaeological site and understand the scientific analyses on the objects that were found there.
Qumran and Dead Sea Scrolls Science

GPS coordinates:
N31.7412, E35.4591

Web sites:
Israel Nature and Parks Authority:
http://old.parks.il/BuildaGate5/general2/data_card.php?Cat=~25~~882773155~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

Israel Museum Shrine of the Book, Jerusalem:
http://www.english.imjnet.org.il/page_899

The Qumran National Park, overlooking the northwestern shore of the Dead Sea, includes a Visitors Center that is designed like Qumran’s ancient buildings and shows a dramatic audiovisual presentation of the site where many of the “Dead Sea Scrolls” were found. The ruins include a dining hall, ritual bath, and other finds that recall the living habits of the people whose separatist ascetic nature led them to the desert in search of ritual purity. From the site of the ruins there are breathtaking views of the caves in the curvaceous mountainous area. The trail through the ruins is wheelchair-accessible, and there are also special signs for the visually impaired. Some of the more important scrolls are exhibited in the Shrine of the Book at the Israel Museum in Jerusalem.

The Dead Sea

There is probably no other archaeological area anywhere in the world on which so much has been written than the Dead Sea and on the main artifacts found there, known cumulatively as the Dead Sea scrolls. The term “Dead Sea scrolls” has been applied not only to the parchments and papyri that were found in the caves in Qumran (also spelled Kumran), but also to all the writings discovered in neighboring sites in the Judean Desert (see Figure 4).

The body of water known as the “Dead Sea” has been misnamed – it is neither “dead” nor a “sea” – but this name has been used in the English language, though the Hebrew name for this body of water is known as the “Salt Sea” – a better name. The Dead Sea itself is about 400 m below sea level, the lowest point on earth, which produced the world’s highest recorded barometric pressure at about 800 mm Hg (16). It is also the most saline of any body of water with about 350 g total salt/L, which is incredibly about 10 times that of the oceans, and is thus devoid of most sea life (16). This high buoyancy makes it easy to float in the Dead Sea, which anyone who has visited the area knows very well.

The climate of the Dead Sea area can be inhospitable to humans who have not prepared themselves for the science tour, especially in the summertime, due to its extremely dry, hot climate, coupled with strong solar radiation. Summertime temperatures can easily climb well into the high 40s (degrees Celsius) – high enough to boil some organic solvents, such as, diethyl ether, dichloromethane, and
pentane, and of course can easily melt the francium (Fr), cesium (Cs), and gallium (Ga) metals to liquid.

Though the Dead Sea area is deprived of much natural vegetation, this body of water is very much alive with archaeological and mineral treasures, and has been one of the most intellectually fruitful areas for mankind. Though the artifacts from this area, which is geographically situated in the eastern part of the world known as the Near East or modern Middle East, it has been of vital importance to western civilization.

Figure 4. Qumran caves in the Dead Sea area. (© Zvi C. Koren).

Dead Sea Scrolls – General Discussion

Much has already been written on these scrolls and about the makeup of the population of the Jewish sect inhabiting this area, and there are even two different publication series on this topic: Discoveries in the Judaeoan Desert (DJD) published by Oxford University Press (17) and Dead Sea Discoveries (DSD) published by Brill (18), each dedicated to the scrolls and related artifacts. Much current information about the scrolls is available at the scrolls digitization project of the Israel Antiquities Authority (19). One of the scientists who has published extensively on the analyses of these scrolls is Dr. Ira Rabin of the BAM Federal Institute for Materials Research and Testing in Berlin, and some of her recent publications are listed in the references (20–26).

The legendary story of the discovery of the Dead Sea scrolls is well-known (19), and as the anecdote is told, in 1947, a young Bedouin shepherd stumbled upon the scrolls in caves while looking for a lost goat or sheep. Originally, seven scrolls were found, but between 1947–1956 tens of thousands of fragments, mostly parchments and some papyri, from perhaps hundreds of documents were found in
Qumran and neighboring areas of the Judean Desert. Some of the scrolls that were wrapped in linen were found in closed clay jars, while others were not. Other scrolls were found in broken or open jars, and yet others were discovered on the cave floors, in niches in cave walls, and also buried in the earth of the cave floor. It is then no wonder that environmental conditions to which the scrolls fragments were exposed for about 2,000 years resulted in degradation of many of the scrolls. One exceptional scroll was written on a sheet of copper, and is known as the “copper scroll”.

The writings of the scrolls consist of biblical and non-biblical or sectarian communal rules to be followed in order to adhere to a unified community. The scroll collection consists of partial or complete copies of every book in the Hebrew Bible, except the Book of Esther, which describes the events occurring outside of Israel (ancient Persia). Most of the Hebrew Scrolls are written in the standard “square” (or “Jewish”) script, very similar to today’s Modern Hebrew that can be read even by a child. One of the more famous of such scrolls is the one containing the “Ten Commandments”, which are written twice in the Hebrew Bible (Exodus 20 and Deuteronomy 5), and is shown in Figure 5. Other scrolls are written in paleo-Hebrew, an ancient script of the First Temple era, and a few were written in Aramaic and Greek.

The scientific aspects related to these scrolls will now be discussed.

The Age of the Scrolls

Based on the writing styles (paleography) of the manuscripts, experts in that field have dated the oldest scrolls to the mid-3rd cent. BCE and the youngest to 68 CE, when the Qumran community was destroyed by the Romans (19). However, arguments began surfacing regarding the validity of dating of the scrolls based on paleography alone, and so, to rectify this situation, scientific tests were also performed.

Radiocarbon dating analyses on the scrolls themselves were published only in 1992 (27) and later in 1995 (28). Previous to the 1992 paper, only related items were analyzed via radiocarbon tests. The first radiocarbon test on a sample from one of the Qumran caves was performed in 1950 by the 1960 Nobel Laureate in Chemistry, Willard Libby (1908–1980), who developed the Carbon-14 dating method at about the same time that the scrolls were discovered. In the original method, large quantities (several grams) of samples were needed for the destructive test, and hence the scrolls themselves were not analyzed at the time. Libby analyzed a linen sample from one of the caves and found the date of the textile to be 1917 ± 200 BP (Before Present, the conventional way that radiocarbon years are presented), that is about 2,000 years old.

One of the major problems associated with C-14 tests on any organic sample is in the handling and treatment of the artifact after it has been removed from its archaeological location (29). Some of the scrolls underwent treatment with organic oils, such as castor oil, in order to improve the visibility of the writings, or with rice paper and glue, which were used in the conservation/preservation stage. Hence, radiocarbon dating analyses could lead to younger dates due to the application of these modern materials.
Figure 5. Dead Sea scroll parchment with the Ten Commandments. Manuscript ID: 4Q41 – 4Q Deut⁶; Plate 981, Frag 2, B-314643; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-314643. (photo by Shai Halevi, full spectrum color image, courtesy of the Israel Antiquities Authority).
The first published radiocarbon dating of the scroll was performed at the ETH-Zürich Institute for Medium Energy Physics, and was reported in 1992 (27). In that report, analyses on eight Qumran scrolls were performed via AMS (Accelerated Mass Spectrometry). The oldest scroll that they dated was from 309–235 BCE, and the youngest was 21 BCE – 61 CE. The correlation between the radiocarbon and paleographic dates was reported as good. The radiocarbon dates were older than the paleographic ones, which is logical due to the fact that the writing occurred after the parchment was prepared. Assuming that the space of time between producing the parchment from animal skins and the date at which the writing occurred was relatively short, the calibrated C-14 ages of the scrolls were then a logical, on average, 35 years older.

A few years later, C-14 results on 15 Qumran scrolls were performed at the NSF Arizona Accelerator Mass Spectrometer Facility at the University of Arizona in Tucson, and published in 1995 (28). Their published results show that paleographic dating based on the scribal style of writing usually matches the scientific testing. The oldest dated scroll that they measured was from 272 ± 101 BCE, while the youngest scroll date had a calibrated age of 182 ± 48 CE.

Animal Sources of the Parchments

According to Jewish law, Halakhah, a parchment for the writing of sacred texts may only originate from the hides of a kosher animal, such as a cow, sheep, or goat. The evidence to date regarding which animals were used for the production of the parchments is not decisive. The earliest determination was in 1958 when Dr. Michael L. Ryder, a British expert in the history of sheep and analysis of wool fibers (30, 31) analyzed specimens of eighteen scroll fragments to aid his work on the evolution of the domestic sheep. He determined that both goat and sheep skins were used for the parchments, although a calf-skin was also used. Additional analyses also determined that goat and sheep skins were used as well as and one calf skin fragment (32, 33).

However, it was believed that there was a wider range of species used for parchment production due to the physical variations of texture, color, thickness, and follicle number and distribution in the surviving parchments (34). Additionally, it was claimed that the exact species identification is impossible using Ryder’s microscope-based technique (34).

Ancient DNA (aDNA) work was begun in the mid-1990s (34) and continued thereafter (35) in order to determine the source of the animal skins used for the parchments. In the first study, eleven scrolls were analyzed by extracting aDNA from small portions of parchment fragments of the Dead Sea Scrolls with the aim of identifying unique genetic signatures of the fragments. The study found the use of goat skins, but also of gazelle or ibex. However, this investigation disagreed with Ryder in that they did not find the use of sheep skins for the parchments. In the latter study (35), mostly domestic goat skins were found to be used as well as some local Nubian ibex.

More research in this area is needed in order to produce indisputable proof as to which animals were used for the parchments.
The Black Ink on the Scrolls

The color of the ink used in practically all the scrolls is black (see Figure 5, for example), as is obvious and to be expected, but there are four scrolls where a red ink was used for some of the writing, and the chemical composition of this red ink will be discussed in the next section.

The two types of black ink that was typically available in the ancient world are succinctly referred to as “carbon-black” and “iron-tannate”. The carbon-based ink was produced from ground charcoal, soot, or lamplblack. The iron-based ink was an insoluble pigment formed from the reaction between an iron salt and various tannins available from oak galls or gall nuts.

The first study that attempted to determine the chemical composition of the inks used in the Dead Sea scrolls was begun in the 1950s, but a detailed scientific report on it was not published. In 1955, Dr. Harold James Plenderleith (1898-1997), a Scottish art conservator, archaeologist, and chemist, and formerly Keeper of the Research Laboratory of the British Museum, studied the conservation treatments needed in order to preserve the scrolls (36). Plenderleith noted that in his tests, he treated the scrolls with water and a mild bleaching agent and while some of the dark contaminants on the scrolls did clear up, these treatments had no effect on the ink. From these observations and from his microchemical tests on the inks, he concluded that the black ink on the scrolls that he investigated did not contain iron.

Steckholl (37) gave more details concerning Plenderleith’s analyses and he reported that twelve separate fragments with residual ink were tested with potassium ferricyanide in the classic wet chemical analysis for the detection of iron. In the case of the inks from these Dead Sea scrolls, no iron was detected. Further, as reported by Steckholl, “the ink was quite black and showed no tendency to turn rust colored.” Additionally, bleaching agents had no visual effect on the intensity of the ink. Steckholl agrees with Plenderleith’s conclusion that the black ink is not iron-based, but rather carbonaceous. Steckholl continued his report by noting that Plenderleith used a spectrograph to examine an ink sample whose main component was carbon and calcium and also contained traces of copper, tin, lead, silver, iron, and manganese. Steckholl surmised that these trace metals in the ink sample indicated that the original ink was contaminated by the metals leaching out of a bronze inkwell. Such a small container was found at Qumran by Father Roland de Vaux (1903-1971) of the École Biblique of Jerusalem who was digging there between 1951–1956 (38). Finally, Steckholl reports on another ink residue found in a clay inkwell that was tested by Dr. George Adler of the Brookhaven National Laboratories in New York with the result that the sample did not contain an appreciable amount of iron since it did not fluoresce when tested with a copper X-ray tube. Hence XRF (X-Ray Fluorescence) also confirmed that of all the inks examined, none pointed to an iron-based compound.

More analyses of the inks were performed in the mid-1980s at the Crocker Nuclear Laboratory at the University of California, Davis, using PIXE, particle-(or proton-) induced X-ray emission. Though it was unpublished, nevertheless, it was reported on by the Israeli researchers Dr. Yoram Nir-El and Dr. Magen
Broshi, formerly of the Soreq Nuclear Research Center in Yavne and of the Shrine of the Book at the Israel Museum in Jerusalem, respectively (39). This elemental analysis technique did not detect any appreciable quantities of metallic elements, though in some samples traces of copper were detected, usually with traces of lead. Hence, since the chemical composition of the black ink could not be ascribed to a metallic content in it – specifically iron – it was thus concluded, once again, that the nature of the ink is carbon- and organic-based, which PIXE could not detect.

Dr. William S. Ginell (40), working at the Getty Conservation Institute, led a team that performed certain analyses on the Dead Sea scrolls and published a lengthy report on the findings in 1993. The methodologies that he and others used included FT infrared spectroscopy, nuclear magnetic resonance spectroscopy, x-ray fluorescence analysis, amino acid analysis, chromatography and hygric deformation methods. His main mission was to study the degree of degradation of the Dead Sea scrolls and also to determine the optimum environmental conditions (such as, relative humidity and temperature) required for storage and display of the scroll fragments.

Infrared spectroscopy could not detect the presence of organic tanning agents, if present. Ginell also utilized XRF in order to analyze the black ink on a badly deteriorated fragment of the Genesis Apocryphon scroll. This is a unique scroll written in Aramaic on four sheets of leather, whose extra-biblical narrative describes a mythical conversation between Methuselah’s son Lamech and his son Noah. The parchment shows severe degradation in certain parts along the inked writing where elongated voids were thus formed. Ginell also analyzed parchment samples from other Qumran scrolls. In all these cases, he did not find any difference between the iron-content in the area with ink and in the blank unwritten part of the parchment. Hence, according to Ginell too, iron-based ink was not used in these writings.

Ginell notes that two other scrolls (identified by their manuscript IDs as 4Q115 Daniel D and 4Q270 Daniel E) exhibit the same type of inscriptive degradation as does the Genesis Apocryphon. All three scrolls were written in Aramaic whereas all the others that he analyzed were in Hebrew. He conjectures that the scribes who wrote these documents originated from the same area where the ink ingredients were similar or identical and different from the other inks. It is very likely that the inks used in Aramaic scrolls were different from most of the other inks, which are carbonaceous-based. He also indicates that the deterioration of the parchment around the inked areas was accelerated by the high moisture content resulting from opening of the parchment and storing it in an environment with a relatively high relative humidity. However, Ginell does not provide any explanation of why specifically the Genesis Apocryphon scroll shows inscription degradation much more than the other scrolls that shared the same environmental fate over two thousand years of time.

In 1996, Nir-El and Broshi published the results of their own XRF examinations of the black ink on three papyrus fragments (39). Their results agreed with Ginell’s in that they found no difference between the relative iron content in the inked and non-inked areas of the samples. They also measured the relative content of other elements in the ink, including sulfur (S), chlorine (Cl), potassium (K), titanium (Ti), chromium (Cr), manganese (Mn), nickel (Ni), zinc
(Zn), bromine (Br), and strontium (Sr), and found no appreciable levels of these elements in the ink, and thus the composition of the ink cannot be based on them. However, Nir-El and Broshi’s results on the relative copper and lead content in the inked region showed that these metals were about 3–4 times more abundant in the inked regions than in the blank parts of the papyri. However, they surmise that this abundance was not observed in the measurements that were performed on other Qumran scrolls, and thus the black ink is not due to the presence of these two metals. These two elements were nevertheless only trace quantities in the ink. Rather, their presence would seem to be an artifact – an accidental or non-deliberate inclusion of these elements in the ink. They posit, as did Stockholl, that these elements could have leached into the ink from the use of a bronze inkwell. To corroborate their claim, they note that ancient bronzes contain, by weight, approximately 75% Cu, 20% Pb, and 5% Sn, relative percentages that they claim were found in their ink analyses.

Nir-El and Broshi also analyzed parchment samples from other scrolls including the famous Genesis Apocryphon. In all these cases, as in the papyri fragments, there was no uniformly excessive iron in the ink relative to the non-inscribed areas, and thus, once again, these analyses show that the ink was not iron-based, but composed of a carbonaceous pigment. Though in all papyri and parchment samples examined the iron content was relatively high, the authors assume that this metal is not from the natural presence of iron in the animal skin or from the use of the Dead Sea water used in the processing of the hides, which in both cases have very low iron content. They presume that in antiquity pumice stone, which according to their EDXRF analyses contains high iron content, was used as an abrasive to prepare the substrates for writing by first smoothing the papyri or parchment by rubbing. They also contended that they detected rubidium in the parchment and papyrus fragments, which is an element present in pumice stone but not in Dead Sea water.

Though they did find considerably higher values of copper and lead in several deteriorated parchment samples, especially in the Genesis Apocryphon, they nevertheless still attribute the presence of these metals to leaching from a bronze inkwell, and here too they conclude that the ink is carbonaceous in nature.

Nir-El and Broshi theorized that the reason the parchment with the inked area degraded in some of the writings of the Genesis Apocryphon is not due to the ink itself but to the binder. The binding material was not analyzed by the authors, but they assume that it could have been vegetable gum, animal size, oil, honey, or others. These materials, according to the authors, can cause the chemical and physical degradation of the parchment regions where ink was applied. This degradation could have been aided by certain environmental factors such as humidity, temperature, light, oxygen, air pollutants, insects, and animals. Additionally, the salts that are present in the parchment from the processing of the animal skins to parchment are hygroscopic and an increase in the water content can cause the denaturation of the collagen in the parchment to gelatin, and would also create mechanical problems – stress and elongation – in the parchment leading to the flaking of the ink layer.

Nir-El and Broshi’s claim that the binding material used in the ink for the Genesis Apocryphon is different from – and more detrimental to – the parchment,
than the binders used in the ink in all the other scrolls has not been laboratory tested. Though they insist that the ink used in the Genesis Apocryphon is the same carbon-based type as used in all the other scrolls, they do indicate that there is a minor role that the copper and lead ions present in the Genesis ink may play. They conjecture that the metals’ chemical action on collagen can cause the deterioration of the collagen where the ink has been used.

I propose that it is possible that the ink that was used in the Genesis Apocryphon scroll is different from the other inks. Based on the publications by Ginell and also by Nir-El and Broshi, which report that the copper content was indeed higher in the Genesis Apocryphon ink than in the others, then that determination adds more weight to the thesis that a copper-based ink was in fact used. Consequently, as inferred by Nir-El and Broshi, the copper may be instrumental in degrading the collagen of the parchment. It is known that copper ions facilitate the decarboxylation of RCOO– groups in proteins and thus cause the deterioration of the proteinaceous material (41).

The Talmud may have referred to such a copper-based ink as the Mishnah of the Babylonian Talmud (Gittin Ch. 2, Shabbat Ch. 12, Sotah Ch. 2, Megilah Ch. 2) and the Mishnah of the Jerusalem Talmud (Megilah Ch. 2, Shabbat Ch. 12) mention an ink by the name of kankanthom or kankanthum, whose meaning is shoemaker’s black pigment (charta de ’ushkafei in Aramaic). That is, this was originally a black pigment for coloring leather. A variant Talmudic spelling is also given in the Mishnah of the Jerusalem Talmud (Gittin, Ch. 2; Sotah, Ch. 2) as kalkanthos. These words are linguistic modifications of the Greek χάλκανθος (chalkanthon) and χάλκανθος (chalkanthos), respectively. These terms probably refer to cupric sulfate since the dictionary definition of these equivalent compounded Greek words derives from χάλκο (copper) and άνθος (flower) (42). This “copper flowers” compound has produced the following etymological variants, such as, cupri rosa, cuprosa, etc., which has evolved into the modern word “copperas” (43, 44). Though, in modern times copperas is used to denote iron sulfate – or green vitriol – in its original context it was associated with the soluble sulfate of copper (blue vitriol), though there was probably some iron impurity mixed with it (45).

The mention of the ink known as kankanthom or kalkanthos in the Mishnah, which was compiled over the first two centuries of this era, indicates that this type of ink must have been known to the Jerusalem or Qumran scribes by the 2nd cent. CE. Further, the Roman historian Pliny the Elder (23–79 CE), in his treatise on Natural History (46), also mentions (in Book 34, Ch. 32) shoemaker’s black pigment known as chalcanthum produced from dissolved copper found in well water in Spain. Additionally, Pliny’s 1st cent. CE contemporary, Dioscorides (40–90 CE), the Roman physician, pharmacologist, and botanist of Greek origin, who wrote a treatise on herbal medicines and related medicinal substances (47), also mentioned this colorant. In Book 5, Ch. 114, of his work he refers to a blue compound called χάλκανθος (chalkanthon) that produced a black dye, and in the last chapter (Ch. 138) of Book 5, after he mentions a black ink produced from soot, he then goes on to describe a medicinal concoction that includes chalcanthum.

Hence a copper-based pigment was already well-known in the Roman Empire already by the 1st cent. CE and could have been used for the Dead Sea scroll known
as the Genesis Apocryphon. Finally, with regard to this scroll, it is noteworthy to mention that Avigad and Yadin, who were the first to publish the contents of the Genesis Apocryphon in 1956, commented on the decomposition of the ink, and that it was different from the ink used in other scrolls (48). However, they never had the Genesis ink analyzed.

In summation of this section, in spite of the various errors appearing in the literature – both in the print and electronic media – most of the black inks used in the Dead Sea scrolls were carbonaceous-based (from soot, lampblack, charcoal, etc.) and were not composed of iron-tannate.

**Rare Red Ink in the Scrolls**

A most unusual find was that out of the thousands of Dead Sea scroll fragments, four pieces contained lines written with red ink, and two such examples are given in Figure 6. The red ink on all four fragments was analyzed by Nir-El and Broshi by means of two related techniques, XRF and XRD (49).

The results clearly showed the preponderance of mercury in the red inscription area, and of all the red mercury compounds, mercuric sulfide, HgS (known as cinnabar or vermilion) is the most abundant natural mineral. According to the authors, the use of a red ink pigment as found in the Dead Sea scrolls is more than a thousand years older than the previously known example of cinnabar as an ink. It is well-known that this artists’ pigment was used with other such colorants in Byzantine and Medieval manuscripts (50). The two-thousand year old mystery, though, still remains: Why did the scribe or scribes find it necessary to use red ink in a few rare instances.

An attempt to track down the geographical source of this pigment requires an international travel package together with geo-chemical detective work. According to geochemists Dr. Naomi Porat and Dr. Shimon Ilani, working at the Geological Survey of Israel in Jerusalem, cinnabar ores have not been discovered in Israel or in its neighboring regions (51, 52). Thus, this pigment was exported into this region, but from where? The two other cases where cinnabar was detected from Ancient Israel was in the palaces of King Herod (73–4 BCE) at Masada and Jericho (53, 54), and in both cases as a paint pigment for wall paintings, and not as an ink for writing manuscripts (51, 52). At Jericho, not only was cinnabar detected on wall paintings, but it and other pigments were individually placed in their native state in artists’ bowls ready to be applied to the walls (51, 52).

The source of the cinnabar in King Herod’s palaces can be determined from his political background. This ruler, known as King Herod of the Jews, was a Rome-appointed king of Judea, and his style of living and artistic preferences would be that of Rome. Cinnabar was well-known in the Roman world (55), and the typically bold red color used in Roman-period wall paintings is cinnabar. Both the 1st century BCE Roman-period sites of Masada and Jericho are in relatively close geographic proximity and contemporaneous with the Qumran scrolls period; thus, all these sites would have shared the same materials. Whatever was available in Rome was eventually transported into Ancient Israel by the Roman artisans. According to the afore-mentioned 1st cent. CE Pliny’s Natural History (Volume
9, Book 33), the Romans imported cinnabar mostly from Spain— from the mine of Sisapo (Almaden) in the Baetic region (46). Nir-El and Broshi then concluded that this red pigment on the Dead Sea scrolls made its long journey from Spain to Rome to Judea.

Figure 6. Two parchment fragments with red ink; actual height sizes are about 2 cm and 7.5 cm, for top and bottom images, respectively (adapted from photos of Shai Halevi, full spectrum color images, courtesy of the Israel Antiquities Authority). (Top) Manuscript ID: 2Q15 – 2Q Job; Plate 741, Frag 26, B-366041; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-366041.

(Bottom) Red ink is visible at the bottom line. Manuscript ID: 4Q27 – 4Q Num\textsuperscript{b}; Plate 1082, Frag 2, B-295285; website: http://www.deadseascrolls.org.il/explore-the-archive/image/B-295285.
We will now travel about 50 km south from the Qumran area, but still hugging the Dead Sea to our left, on the east, in order to reach the fabled Masada.

King Herod’s Masada

GPS coordinates: 
N31.3156, E35.3538)

Web sites:
Israel Nature and Parks Authority:
http://old.parks.org.il/BuildaGate5/general2/data_card.php?Cat=25~736559308~Card12~&ru=&SiteName=parks&Clt=&Bur=557477527

The Yigael Yadin Masada Museum:

The Masada National Park has been declared as a UNESCO World Heritage Site due its universal values. Masada includes the preservation of a 1st century BCE Roman-period palace built by King Herod of the Jews, and 1st century CE remains of the Roman siege structures and vestiges from the tragic struggle for freedom from Roman occupation by the Jewish rebels atop this mountaintop in ancient Judea. Based on the latter-mentioned aspirations of these inhabitants who met a catastrophic end, this mountaintop site has been dubbed as a “symbol of determination and heroism”. The top of this natural plateau can be reached via three modes, whereby the easiest is by means of a cable car to near the summit. The other two means are by foot trails, the formidable “snake path” in the east and the less steep “ramp trail” approached from the city of Arad in the west. At the base of the mountain is a moving audiovisual presentation that introduces the visitor to the Masada story, as well as the Yigael Yadin Museum that exhibits various artifacts excavated at the site. From March to October, a sound and light show is presented against the dramatic backdrop of the western side of Masada.

Masada (Figure 7) is probably the most visited archaeological site in Israel outside of Jerusalem. At this mountaintop cliff overlooking the Dead Sea in the Judean Desert, King Herod built his palatial fortress in the last quarter of the 1st cent. BCE (56). King Herod’s short-lived dynasty was to be the last monarchy of Ancient Israel. The name of this site is derived from its Hebrew name, Metzadah, which means fortress or fortification. Still extant are various buildings, floor mosaics, and wall paintings. One can visit this 400-meter high cliff by hiking up one of the footpaths, such as the Snake Path, or take a cable car to near the top of this cliff.

The main story of Masada consists of two periods, separated by about a century. The first Herodian period is the glorious construction of remarkable architecturally challenging edifices commissioned at this site by King Herod, and various artifacts have also been found from this period. The second period associated with Masada is the tragic one as recounted by Flavius Josephus
(37–100 CE), the Jewish-Roman historian (57). Josephus was originally the Jewish general Yosef ben Matityahu of the priestly and royal Hasmonean dynasty, who led the Galilee brigade fighting the “Great Revolt” against the Roman occupation of Judea in the latter half of the 1st century CE. However, as he was vastly outnumbered by the Roman army, he surrendered to General (later to be Emperor) Titus Flavius Vespasian (9-79 CE), whose son Titus (39-81 CE) defeated the Jewish revolt. After being taken to Rome, he was granted Roman citizenship, and appended the name Flavius to his Romanized Hebrew name, Josephus, to honor his patron, the emperor Vespasian, founder of the Flavian dynasty. In these new Romanized surroundings, Josephus embarked on his new – and invaluable – role as historian of that period.

Figure 7. Masada – aerial picture; the three-level northern palace is shown in front; top left is the Dead Sea. (photo credit Andrew Shiva, Wikimedia Commons).
As Josephus recounts in his epic Wars of the Jews, the Herod’s magnificent palatial fortress of Masada was also the setting for one of the worst tragedies befalling the struggling Jewish nation, about a century after the Herodian complex was built. Alas, Masada became the last stronghold of those Jews who rebelled against the Roman occupation of Judea. Josephus recounts the ghastly mass self-carnage that was performed by nearly one thousand men, women, and children desperately attempting to stave off the mighty Roman army. After three years of fighting, when the end was near, their leader Elazar passionately appeals to the masses atop this palace-fortress to end their lives instead of being taken in captivity with all the dire results that may befall them. According to Josephus, Elazar ends his exhortation with these words (57):

“Let us die before we become slaves under our enemies, and let us go out of the world, together with our children and our wives, in a state of freedom … Let us therefore make haste, and instead of affording them so much pleasure, as they hope for in getting us under their power, let us leave them an example which shall at once cause their astonishment at our death, and their admiration of our hardiness therein.”

In the following chapter, Josephus continues his narrative and relates the bone-chilling events that transpired immediately after Elazar’s speech, wherein the men killed their families – women and children – and then committed mass-suicide, leaving nearly a thousand dead atop the mountain. Yet, two women and five children had concealed themselves in caverns underground, and survived to tell the Masada story, which is spellbinding to this very day. Some of the personal effects found at this site are sandals, prayer phylacteries boxes with straps, comb, mirror, and even, chillingly, an intact young girl’s braided hair.

The major excavations of this site were performed in the early 1960s by the dean of Israeli archaeologists, Prof. Yigael Yadin (1917–1984), together with many Israeli and international volunteers. There were so many finds from that site that to date eight detailed volumes have been published by the Israel Exploration Society in Jerusalem on the analyses of these finds and these publications are still ongoing (58). The second archaeologist who continued Yadin’s work was Prof. Ehud Netzer (1934–2010), who unfortunately recently tragically passed away after encountering a fatal fall at another Herodian site near Jerusalem, known as Herodion, that he was excavating.

The pigments on the wall paintings of Masada (Figure 8) were analyzed by Porat and Ilani via XRD and SEM, and, not surprisingly, most were found to be identical to the ones used at Herod’s other palace at Jericho (50, 51). The pigments identified included red (cinnabar, vermillion), orange (minium), green (celadonite), black (soot), white (chalk), pink (kaolinite), brick-red (hematite), yellow (goethite), and blue (cuprorivaite).

Among the many archaeological treasures that were excavated at Masada, perhaps none are more personal than the textiles that were also found there, most of them belonging to the Jewish rebels. These were the household furnishings used in their makeshift dwellings and garments that clothed them.

It was with this calamitous Masada background haunting me that I braced myself to actually touch those fabrics and to study them. One of the first textiles that I examined from this site was a small fragment (Figure 9) that was excavated in
an area that was part of the royal refuse dump of the western administrative palace and was situated at the northeast corner of that edifice (59). A “throne room” was discovered in that palace in which four rectangularly arranged niches were found in the floor in a corner of this chamber (56). These niches were undoubtedly used for the supporting poles of a royal canopy in a room that was large enough for people to have an audience with the king. Based on the fact that this textile was found with other artifacts, which have been stylistically and archaeologically dated to the Herodian period of the 1st cent. BCE, and not to the Jewish rebels from a century later, so too was this textile dated from the Herodian period.

Figure 8. Original remnants of wall paintings at Masada. (© Zvi C. Koren).

The Herodian textile weave contained weft yarns that were entirely reddish-purple, whereas the warp yarns, consisted of plied yarns for extra strength – one red-purple and the other undyed yellowed fibers. The HPLC-PDA chromatographic and spectrometric results of my analyses of the red-purple fibers detected indigo together with related brominated indigoid components (Figure 10). The resultant HPLC chromatogram shows the three major indigoid components as well as a minor, but nevertheless significant, amount of the doubly-brominated indirubinoid. Since the latter component’s absorption is at about 540 nm, the chromatogram is depicted at that wavelength for visualization purposes, and not for quantification.

The quantitative results of the chromatographic peak areas of the blue, violet, and reddish components are shown as percentages at the standard wavelength of 288 nm. These brominated indigoid components are the trademark of a pigment that can only be produced from certain sea snails (59). These specific mollusks are the Muricidae species, and the purple pigment was produced in antiquity from the substances contained in the colorless fluid of the hypobranchial gland of these Murex sea snails. Based on the fact that the MBI dye consisted of a relatively large quantity, the malacological provenance of this purple pigment must be from a specific species, the Hexaplex trunculus sea snail. This is because only that purple-producing species can yield an abundant quantity of that dye (54). Further, the chromatographic fingerprint of this archaeological dyeing showed a much
greater amount of the dibrominated indigoid dye (DBI) than the unbrominated indigo colorant (IND) (61), which indicates that the H. trunculus sub-species that produced it was the DBI-rich variety (62).

The finding of a true-purple molluskan dye in a textile is highly significant. We know that this dye was used in the textiles for kings (“Royal Purple”), high priests, and in the textile furnishings of the Tabernacle in the Temple in Jerusalem. This rare molluskan pigment has also been known as “Tyrion Purple”, after one of the capital cities of the sea-faring Phoenicians, the foremost traders and merchants of the ancient world, whom history has credited with perfecting the craft of purple dyeing.

Figure 9. Microscopic image of a Herodian textile fragment (maximum width of about 2 mm) found at Masada. (© Zvi C. Koren).
Figure 10. Qualitative and quantitative depictions of the results of the HPLC analyses of a DMSO-extract of the dye from a miniscule reddish-purple yarn excised from the Herodian weave of Figure 9. The abbreviations of the dye components are as follows: IND (indigo), MBI (6-monobromoindigo), DBI (6,6’-dibromoindigo). (Top) HPLC chromatogram shown at 540 nm for visualization purposes. (Bottom) Quantification of the chromatographic peak areas (as percentages) of the blue, violet, and reddish components calculated at the standard wavelength of 288 nm. (© Zvi C. Koren).

Based on the chemistry, malacology, history, archaeology, and religion associated with this molluskan dye, the significance of the discovery of Murex purple on this fabric can be highlighted as follows: (a) this was the first time that a Murex purple fabric from Ancient Israel has been discovered; (b) the fabric found in the Herodian layer must have belonged to King Herod himself since the dye – “Royal Purple” – was the prerogative of kings; (c) based on the physical structure of the weave, the whole fabric, and not just this small fragment, was purple-colored; (d) the type of weave of this textile is one typically found in a cloak or mantle; thus, the fragment analyzed may have been part of the royal cloak or mantle of King Herod; (e) the color of this fabric was most likely that of the Argaman dye, one of three biblical dyes.
Thus, one of the most important biblical treasures ever to be found, the biblical Herodian *Argaman* dyeing worn by kings and priests and unearthed at Masada, established the true color of this biblical dye. One key to the puzzle of the trilogy of sacral colors was now deciphered.

Recently, I have chemically discovered another historically and bibliically important textile from Masada, and it was a very small embroidery consisting of bluish-purple (dark violet) yarns on an undyed textile. Analysis of this textile proved that its origin was also from a *H. trunculus* snail due to its appreciable MBI content. However, it came from an IND-rich snail that possessed higher IND than DBI. This then was the other biblical dye known as *Tekhelet*, the holiest of all three biblical dyes, the discovery of which was originally reported on in *The New York Times* (63). A detailed scientific report on it will be forthcoming.

We will now travel 200 km due south to get to our final science tour destination.

**King Solomon’s Copper Mines at Timna**

**GPS coordinates:**
N29.7823, E34.9562

**Web sites:**
*Timnah Park:*
http://www.parktimna.co.il/EN/

*The Central Timna Valley Project (CTV):*
http://archaeology.tau.ac.il/ben-yosef/CTV

The Timna Valley National Park, located in the southwestern Arava, about 30 km north of the city of Eilat, is an expansive 15,000-acre area encompassing beautiful geologic scenery, such as unusual rock formations, and important antiquities spanning millennia of copper-mining history. At the Visitors Center, a multimedia presentation portrays Timna’s fascinating story from Egyptian times to the present. Fun activities are also available at the park and these include climbing through rock pillars, pedal boating on the lake and crafting colored sand bottles with the minerals in the area.

The archaeological and scientific background to this historic site has recently been published in a comprehensive article by Dr. Ezer Ben-Yosef et al., which contains a good archaeological and scientific background to this historic site (64). The archaeology connected with Timna’s copper production goes back three millennia. In the Arabah region, the smelting sites at Timna were considered to be the southern complement to the copper site in the northern Arabah site of Faynan (today’s Jordan). Early on, based on ceramic finds and historical considerations, scholars have dated these two sites as both forming cooperative enterprises from the Iron Age II time frame, about the 10th cent. BCE (65, 66). This date would thus be contemporaneous with King Solomon’s rule over Ancient Israel, which included this territory (11). Figure 11 shows the famous iconic sandstone pillars,
known as Solomon’s Pillars, from the Timna Valley, and chunks of copper ore unearthed at Timna are shown in Figure 12.

However, the discovery of an Egyptian temple in the 1960s and a reappraisal of the ceramic typology by other archaeologists swung the copper production site back to older dates, 14th–12th cents. BCE (64, 68). The pottery found at the smelting sites, as it was claimed, was similar to the style found at the Egyptian sanctuary at the time of the Pharaohs Seti I and Rameses V (19th and 20th dynasties) of the Egyptian New Kingdom, spanning the Late – Early Bronze Age. Thus, the legend that at this site the main copper production occurred during King Solomon’s time lay in ruins.

The scientific story now swings back to only a few years ago, when Ben-Yosef reports on new dating measurements that were done at this site (64). The newer archaeo-metallurgical analyses were based on radiocarbon dating of short-lived organic samples via the high-precision AMS methodology coupled with high-resolution archaeo-magnetic dating of the artifacts themselves. This was the first time that absolute dates for the main copper production were evaluated for this Timna Valley site. Previously, relative dating was established at Timna based on ceramic typology and a comparative scrutiny of the material culture. The determination of accurate dates for the different phases of copper production in this Arabah region is important for the understanding of the social, economic, and political environment at the time as well as reconstructing the material culture.

Figure 11. Sandstone columns known as the “Pillars of Solomon” in the Timna Valley. (image from Wikimedia Commons).
Figur e 12. Copper ore pieces found at Timna. (image courtesy of Erez Ben-Yosef).

Ben-Yosef reported on radiocarbon dating measurements on a number of organic samples, such as wood twig and bark, olive pit, grape and date seeds, as well as charcoal, found at this site. Finding charcoal at a metallurgical processing site is important as this raw form of carbon was the reducing agent in antiquity that was needed for the reduction of copper ore to elemental copper by the uptake of oxygen from the ore. It is important to note that radiocarbon dating of this woody sample would pre-date the activity of the actual site by about a century since it takes time for the plants and trees to grow before they are cut down for burning into charcoal.

The radiocarbon measurements produced new dates for Timna and showed that there was indeed significant Iron Age I – II copper production, which was after the Egyptian presence in the region. Thus, the most recent evidence shows that the main copper smelting sites in Timna do belong to the 11th – 9th centuries as originally proposed, which would be the approximate time line of King Solomon’s reign in Ancient Israel. Further, it would also place the Timna and Faynan sites to be contemporaneous with each other.

Hence, the legend that this Timna Valley site is part of King Solomon’s empire is on firm grounds and intact. At the conclusion of this science tour, we can head down south and enjoy the rest and relaxation that the warm resort city of Eilat provides and swim in the Red Sea, full of interesting marine zoology. But this can wait for the next science tour.

Conclusions

Our journey to some of the more famous archaeological sites from Ancient Israel has provided us with the opportunity to understand the scientific analyses that were performed on various cultural heritage objects found at these locations. These historical artifacts were studied by an international cast of scientists teaming together to understand our shared past. Many of the archaeological objects have yet to be analyzed and wait for the next generation of scientists who will participate in the next scientific study tour of Ancient Israel.
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References

34. Woodward, S. R.; Kahila, G.; Smith, P.; Greenblatt, C.; Zias, J.; Broshi, M. Analysis of Parchment Fragments from the Judean Desert Using DNA Techniques. In Current Research and Technological Developments on the


41. Scott, D. A. Copper and Bronze in Art: Corrosion, Colorants, Conservation; Getty Publications: Los Angeles, CA, 2002; p 76.


46. Pliny the Elder. In The Natural History; Bostock, J., Riley, H. T., Translators; Taylor and Francis: London, 1855.


