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Color My World
A Personal Scientific Odyssey into The Art of Ancient Dyes

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PROLOGUE

"An ordinary day," I mused. This was to be a normal day at the lab for my student and me. Today we were continuing our quest to decipher the makeup of certain ancient colorants adorning various woolen fibers from sheared and washed fleece, yarns, and weaves. Leah was attempting to extract the coloring substance from the minuscule purple-colored fibers in preparation for subsequent analytical chemical and intrumental tests. "Something is not going right here, Zvi," she exclaimed. I turned my eyes from the computer screen and asked her what was wrong. It seemed that the colorant on the fibers was so stubborn that it was not leaching into solution. Up to this moment, I and other assistants and students had worked on numerous fibers dyed with various shades of red, from scarlet (orange-red), to salmon, pink, bright red, crimson (bluish-red), brick-red, and red-purple. In the past, all of these reds yielded themselves to the attractive powers of the liquid potion – the solvent that strips the dye from the fibers, which is the prerequisite step in the overall scheme of dye analysis. However, today would be different.

My first reaction was that Leah did not follow all the requisite procedures that I had formulated for dissolving that pigment; perhaps she used the wrong solvent system, the temperature was not as high as it should be, or the time elapsed was not sufficient for the dye to dissolve. So, I gave her a typical "try it again" answer, and returned to my computer work. But something was still troubling me as to why that red dye was not being solubilized with the highly acidic alcohol concoction that we have been using. Leah was an excellent student and chances were good that she did everything right. I couldn't completely focus on my computer work, and so this time I had one eye on the computer screen and the other on her experimentation as she began to repeat the process. After the necessary time had elapsed for the possible dissolution of the dye, we both looked at the liquid inside the extraction vial and then looked at each other, puzzled. The liquid was colorless – no colorant was extracted from the fibers. Mystified at first as to why a reddish dye would not yield to the powers of the extracting solvent, I then trembled at the thought of what this could portend regarding the nature of that colorant. I had known from my and other scientists' experimental work that there is only one pigment of a red-purple (maroon or bordeaux) or violet hue that would not budge when treated with that solvent system. It was never discovered on any textile from ancient Israel and its discovery would be historic.

This time I had to perform the analysis by myself in order to witness first-hand the awe-inspiring result that I anticipated should inevitably materialize. With hands nearly shaking and with much trepidation, I placed a few fibers from that minuscule purple fragment excavated at the famous Judean Desert archaeological site at Masada into a vial. When tiny droplets of the special organic elixir that is specific for that dye were added to the fibers, nothing developed for the first few seconds. But soon thereafter the colorant finally began yielding itself to the powers of that liquid, with the noble red-purple colorant forced to produce a beautiful sky blue solution. As the dissolving process had finally begun, I shuddered with astonishment and I must have uttered a divine exclamation of some sort. I hastened the stripping of the dye from the fibers by raising the mixture to a high temperature. Though more tests were needed to be performed on this dye solution, I nevertheless already knew that in my hands was one of the most important biblical treasures that have been found – a royal and priestly color of historic proportion. One key to the puzzle of the trilogy of sacral colors was now deciphered.

A PERSONAL HISTORICAL ODYSSEY

When he entered my office about a decade ago, I thought a cherub had descended from the sky. That was the first time I had met this great humanitarian, an enthusiastic supporter of the fusion between science and art for the sake of humanity. Clemens was, is, and will always be the cheerleader that one needs, especially when hitting a seemingly dead end in one's investigations. Meeting him at the time was a much-needed catalyst to continue searching for newer and creative pathways in my scientific investigations of ancient colorants.

My first experience with ancient colorants, a field that is of special appeal to Clemens, began nearly fourteen years ago, exactly a year after hearing the call of Zionism beckoning me and my family to make *aliyah* (literally "going up") to Israel in the summer of 1990. I had left the dream positions of professor of chemistry and chairman of that department at the School of Engineering at the Cooper Union for the Advancement of Science and Art in the East Village of Manhattan in New York City, where I had begun my academic career in January 1977. That institution was founded in 1859 by the wealthy industrialist Peter Cooper, a son of New York City, whose mandate was to give free higher education to deserving students in engineering, art, and architecture. In 1860, Abraham Lincoln spoke there while electioneering for president and gave his famous "Right makes might" speech. Thomas Alva Edison studied there. To this day, Cooper Union is the only tuition-free private institution in the United States offering baccalaureate and master's degrees in these fields. My appointment to this position was thanks to the noted chemists, Professor John Bové and the late Professor Julius (Jack) Klerer, to whom I will be eternally grateful.

During my first year in Israel, I was able to sample the academic programs at five institutions, including Shenkar College of Engineering and Design, the institute with which I am now permanently associated. The variety of institutions would allow me to study the nature of academia in Israel and thus I would be better equipped to decide at the end of that year where I would like to direct my academic and research energies. But fate played its hand before I had a chance to venture into the long and elaborate decision-making process, and I was offered a proposition that I could not refuse.

During that first year, I had read that Professor Mary Virginia Orna, a sister of the Order of Saint Ursula (OSU), of the College of New Rochelle in New York, had co-authored a textbook, *Chemistry and Artists' Colors*. This was a field I knew nothing about but that sparked my interest. Mary Virginia has become an international expert on inorganic pigments used in historic paintings and illuminated manuscripts as well as a leader in the field of chemical education.

She and I go a long way back. My first meeting with her was in 1976, a year before I received my PhD in physical chemistry from the City University of New York, where my doctoral research was performed at Brooklyn College, my *alma mater*, in the area of stable isotope separation by means of inverse vapor pressure effects. That first meeting was actually an interview for a position at her college, a most prominent all-women Catholic institution. I remember giving a seminar to the students and faculty on laser-induced chemical reactions, a very hot and exciting field in chemistry at the time. I believed that my talk and subsequent interviews went well, but alas, I didn't get the job, because, as Mary Virginia later explained, they were looking for someone with biochemical-related research. However, she and I remained collegial friends and every few years would run into each other. Our last meeting while I was still living in the States was at the national American Chemical Society annual conference in Boston in the spring of 1990, where I presented a paper on a consumer-oriented spectrophotometric investigation of sunscreen ointments.

The scene now skips ahead one year to my first year in Israel; I am teaching part-time in Shenkar. I read that her book was coming out and contacted her to inquire how I would be able to acquire a copy, as I was living in Israel. She wrote back that, as it turns out, she would be visiting Israel soon and would be glad to bring me a copy. She also stated that she would be visiting a certain institution here and it would be good if I could meet her there. She wasn't sure if I knew where the college was, but I could of course inquire as to its location. She told me the institution's name was Shenkar College and that it was located somewhere in the city of Ramat Gan. I then coyly responded that, yes, as a matter of fact I happened to know where it was, and I would meet her there with a surprise in store.

At our meeting, she was most surprised to find out that not only did I know where Shenkar was, I was already teaching here. The purpose of her trip was not completely clear to me at the time, but she told me that she was sent by a Dr. Sidney M. Edelstein to do a feasibility study – both academic and financial – to determine whether Shenkar could host a center dedicated to the analysis of Israeli antiquities. I learned later that Dr. Edelstein was chairman of the board of the Dexter Chemical Corporation in the Bronx, New York – a great philanthropist who supported many educational programs both here and in the States, and a great fan of science for the sake of archaeology. I also discovered later that he himself studied the colorants on textiles excavated in the early sixties by the dean of Israeli archaeologists,

Figure 1a (from left to right): *Dr. Sidney M. Edelstein and Mrs. Mildred Malka Edelstein (both of blessed memory), Professor David Samuel, and the author (1993).*

Figure 1b (from left to right): *Professor Amotz Weinberg, Professor Heini Zollinger of Switzerland (of blessed memory; an international expert on color chemistry and champion of the State of Israel), and the author (1995).*

Yigael Yadin, and published widely on the topic of textile chemistry. I didn't know much else about the subject she was pursuing and wished her success with her work and visit in Israel. At the time, I didn't realize the impact of her main mission here and continued with my academic business.

A few weeks after she returned to the States, I was approached by two prominent academicians at Shenkar who were eager to speak to me concerning a most pressing matter. One was the then president of Shenkar College, Professor David Samuel, third Viscount Samuel of Mount Carmel, a peerage he had inherited from Lord Herbert Samuel, his grandfather (fig. 1a). The other individual was the head of the Department of Textile Chemistry at the time, Professor Amotz Weinberg, who is the current president of the College (fig. 1b). They explained to me that Mary Virginia had submitted a glowing report to Dr. Edelstein. It concluded that Shenkar was the right

Figure 2. The author with the former president of the State of Israel, Chaim Herzog (of blessed memory), perusing the doctoral dissertation of President Herzog's father, Rabbi Dr. Isaac Halevy Herzog (of blessed memory), at the inauguration of the Edelstein Center in 1994. Rabbi Herzog, who was the chief rabbi of Ireland from 1921 and later the first Ashkenazi chief rabbi of the newly established State of Israel wrote his seminal thesis for the University of London in 1913 on Hebrew Porphyrology, the biblical Tekhelet and Argaman dyes, a field that is today one of the major scientific research areas of the Center. © Zvi C. Koren

institution in Israel to host a center for the analysis of Israeli antiquities as it possesses capable faculty and staff who would be able to perform investigations in these areas. Dr. Edelstein's motive can be termed "blue-and-white" after the colors of the Israeli flag; that is, his Zionistic ideals dictated that what is found here is investigated here. After discussing the matter with Dr. Edelstein, and with his approval, they now approached me and asked if I would like to head a center dedicated to the analyses of ancient artifacts. I asked what such a position would entail, and more importantly, what I would do in such a post. Their answer was simple and to the point: "We don't really know. Just do something." There had never been a position like it in Israel, so there was no precedent on which to tailor it. Everything would need to be built from the ground up.

I agreed to the challenging undertaking, but was still not sure what would be expected of me. The more global question, one I had been pondering ever since deciding to make *aliyah*, was how I would be able to contribute to the academic and research fields of this still nascent country Israel. While not completely fathoming the activities I would undertake as director of the Edelstein Center, I began to understand that herein lay the meaning of my Zionism. The position would allow me to put Israel on the international map in the new area of scientific investigations of ancient colorants, for the sake of humanity.

In my first year in this new position I carried out discussions with museum curators, archaeologists, artists, and scientists in order to learn of the scientific needs and results that each sector desires. In the following year, I understood what my course of action would be: to develop modern, state-of-the-art analytical instrumental methodologies that would reveal the technologies associated with one of the oldest crafts – the dyeing of textiles – and investigate the dyes and pigments associated with the color industry and artistry of antiquity.

Thus began the Edelstein Center for the Analysis of Ancient Textiles and Related Artifacts, whose permanent lab was officially inaugurated in 1994, shortly after the departure of Dr. Edelstein, of blessed memory, from this world (figs. 2, 3). My interaction with Mary Virginia continued, and she was honorably chosen as a Fulbright scholar for 1994–5 and spent the fall semester at the Edelstein Center here at Shenkar (fig. 4).

Since the inception of the permanent home of the center, we have been privileged to have made a number of hitherto unknown discoveries, some of which are described in this essay.

STUDY OF ANCIENT COLORANTS FOR HISTORY AND HUMANITY

The study of the coloring matters produced by the ancients opens a historical window to understanding the processes associated with one of the oldest chemical technologies – textile dyeing. Color analysis of a textile involves the identification of the colorants and of the processes utilized to produce that color or hue on the textile, as well as the identification of the fiber material, the substrate, which can also influence the final hue produced. The analytical investigations involve chemical detective work to help decipher the identities and sources of the dyestuffs used in antiquity. Research into the colorants used by ancient peoples involves a multidisciplinary approach that combines history, archaeology, religion, botany, entomology, marine zoology, and forensic microscale analytical and instrumental chemistry methods.

Knowledge of the natural dyes used in different regions in antiquity increases our understanding of local and international trade and commerce in ancient times. The identification of the dyestuffs used can indicate the movement of dyed goods and the transfer of dyeing methods from one geographical area into another. Such an examination of the textiles of past cultures uncovers the development and technological advancement of the 'scientific art' of textile dyeing through various archaeological periods. In addition, the study of ancient textiles enhances our understanding of the standard of living, textile art, fashion, and color preferences of ancient peoples.

Conservation treatments on degraded textiles require knowledge of the nature of the coloring substance so that the colorants will not be damaged during this process as different colorants can react differently to the cleaning solvents. If a textile artifact is to be partially or fully restored, then the philosophical ideal is for the restoration to be performed with the same fibrous materials and natural colorants that were used in the original fabric in order to maintain the historical and cultural integrity of the artifact. In addition, a technical reason for restoring with identical materials is to maintain the uniformity of the overall hue of the

Fig. 3. The Edelstein Center's scientific activities involve (above) *designing and performing chemical experiments on natural dyes and pigments, and* (below) *computerized chromatographic and spectrometric instrumental analyses of these colorants.*

fabric. Different colorants have different light fastness properties and the addition of a foreign colorant in the restoration process may, in time, yield a different shade in the restored part from that of the original. The varying fading rates of different colorants is also an important factor in determining the length of time that such an artifact should be displayed under the appropriate lighting conditions in a museum or exhibition gallery.

THE ADVENT OF DYEING

One of the oldest 'pictures' portraying colored garments is from Beni (or Bani) Hasan in eastern central Egypt (fig. 5). This is an important Middle Kingdom archaeological site dating from about 1900 BCE, and situated on the eastern bank of the Nile, about 150 miles south of Cairo. The site is known for its rock-cut tombs of important officials from the eleventh and twelfth dynasty (2125–1795 BCE). In the tomb of Khnumhotep II, a high-ranking Egyptian official, there is a wall painting that depicts Egyptian men with skirts of white linen, the typical haute couture for them at the time, whereas the Asiatics or Canaanites – Semites – are wearing colored striped skirts and colorful clothing as they enter Egypt at the time of the Patriarchs.

Were these colored garments worn by our forefathers? Did Joseph's amazing striped dream-coat resemble any of these clothes? We of course can never know for sure, but what is definite is that this painting is conclusive, though indirect, proof that the dyeing of fibers in vivid colors of blue and red existed at least about four thousand years ago.

THE COLORANT RULE

In antiquity, both inorganic and organic colorants were used for decorating various substrates. Mineral-based inorganic pigments were primarily used for adorning and painting such objects as walls, sarcophagi, clay vessels, and the surfaces of burial shrouds. Organic colorants, which originated from flora and fauna sources, were typically used in the dyeing of textiles. The vegetal sources for these dyes were certain roots, leaves, stems, and flowers of various plants, and the bark, branches, leaves, and berries of certain trees. There were two animal sources for the dyes: entomological and marine. Certain species of scale insects produced red dyes of crimson (bluish-red) or scarlet (orangey-red). From the sea, certain mollusks produced purple and violet pigments that were used for the dyeing of fibers to be used in royal and sacral vestments. The material that was best suited for the chemical uptake of these colorants was protein-structured wool, a practice that began probably about four millennia ago. Linen from flax was also sometimes dyed in less vibrant colors than in the case of wool, and that practice originated at least six millennia ago (see below). Dyed cottons, which have a cellulosic molecular structure similar to linen, appear from about the later Roman to Byzantine Periods, nearly two thousand years ago.

As a general rule, with only a few exceptions, we see an interesting empirical law practiced by the ancient colorist: "organic on organic, inorganic on inorganic". That is, inorganic pigments were in use on stone and clay, whereas organic dyes were utilized for natural organic fibers such as wool.

It is important to understand the difference between coloring by means of painting and by dyeing. Decorating a fabric by means of painting would not be used for everyday garments that need to be laundered on a regular basis, since the surface-applied pigment would simply wash out of the cloth after a few washes. However, for burial shrouds there was of course no desire to wash the surface-colored fabric, and thus that simple technique of color application was satisfactory. True dyeing, as opposed to painting, consists of a process whereby the dye has been dissolved in an aqueous solution, allowing the individual dye molecules to penetrate into the interior of the fibers and bond to them through physical and chemical attractions. This dyeing process rendered a relatively stable color production on the fibers and good wash-fastness.

METHODOLOGY OF A DYE DETECTIVE

There are several essential steps involved in the chemical identification of an organic dye or pigment present on a dyed textile (a dyeing) or on a pottery shard from a dyeing vessel or vat. Most analyses proceed according to the following scheme (Koren 1993a, 1994a, 1995a).

First, an appropriate chemical reagent is administered to a very small sample that has been removed from the dyeing in order to strip the dye off the fibers and dissolve the extracted colorant. After filtering this mixture, a colored solution is obtained (fig. 3, *top*).

The next stage is the identification step, and it usually involves running

Figure 4. Professor Mary VirginiaOrna, Sister of the Order of Saint Ursula (OSU) and an international expert on inorganic pigments, with the author at the American Chemical Society awards ceremony honoring her with the Pimentel Award in Chemical Education. Anaheim, California, 1999. © Zvi C. Koren

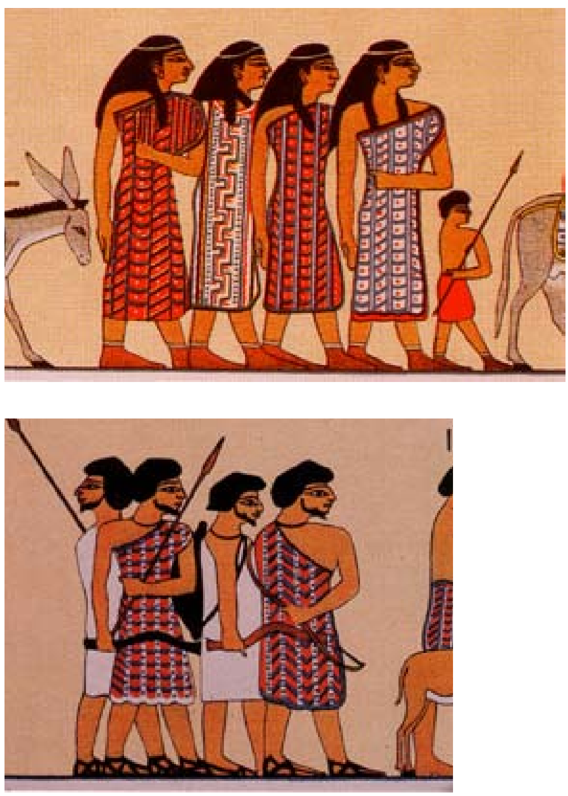

Figure 5. Artist's reconstruction of fragments of a wall painting from Beni Hasan, Egypt, showing (top) *Semitic women and* (bottom) *men, dressed in variegated garments, 1900 BCE.*

Source: M. Soloweitschik 1926. *Die Welt der Bibel. Ein Bilderatlas zur Geschichte und Kultur des biblischen Zeitalters*. Jüdischer Verlag, Berlin; figure 179. These figures were reproduced from: C. R. Lepsius 1849-1859. *Denkmaeler aus Aegypten und Aethiopien*. Abtheilung ii, Band iv. Nicolaische Buchhandlung, Berlin, page 133.

the dye solution through an instrumental detection setup. The instrument can be a spectrometer, which radiates light typically in the ultraviolet, visible, or infrared regions of the electromagnetic spectrum. The intensity of light absorbed by the extracted dye solution at different wavelengths is electronically measured, and a graph – or spectrum – of the resulting absorptions is obtained. This profile can be characteristic of the major dye component present in a specific natural dyestuff source. This spectrum is compared with other spectra of known components and when a match is obtained, the dye source – vegetal or animal – can be ascertained.

Another analytical instrument that has been the major workhorse of dye analyses is known as a chromatograph, so-named for its ability to separate out various colorants (chroma = color). The main instrument for such analyses is known as a high-performance liquid chromatograph (HPLC), and is highly capable in separating out all the major components present in the natural dyestuff. This is a major advantage over spectrometric techniques alone (fig. 3, *bottom*).

In the HPLC instrument, a sample consisting of ten or so microliters of the extracted dye solution is injected into the instrument by means of a special accurately calibrated syringe. The liquid is then chased after and mixed with a series of solvents – called the eluents – that also flow through the system and whose composition can change with time. These solvents drag the sample into a separation column filled with a certain densely packed material, so that the sample and eluents need to be pushed through this column at pressures as high as 250 times normal atmospheric pressure. The sample is then both attracted to the material in the stationary phase as well as to the solvents in the mobile phase. This mutual competition can be unique for each component and thus produces the necessary separation. The time that it takes for each component to be retained in the separation column before being eluted out by the eluents can be unique and is used to characterize that component. This chromatographic property is known as the sample's retention time.

Additionally, each separated component passes through a spectrometer, known as a photo-diode array (PDA) detector, which measures the sample's ultraviolet and visible spectrum. This spectrometric information is combined with the other chromatographic property, and when all systems have been properly calibrated, the identity of the dye can be determined.

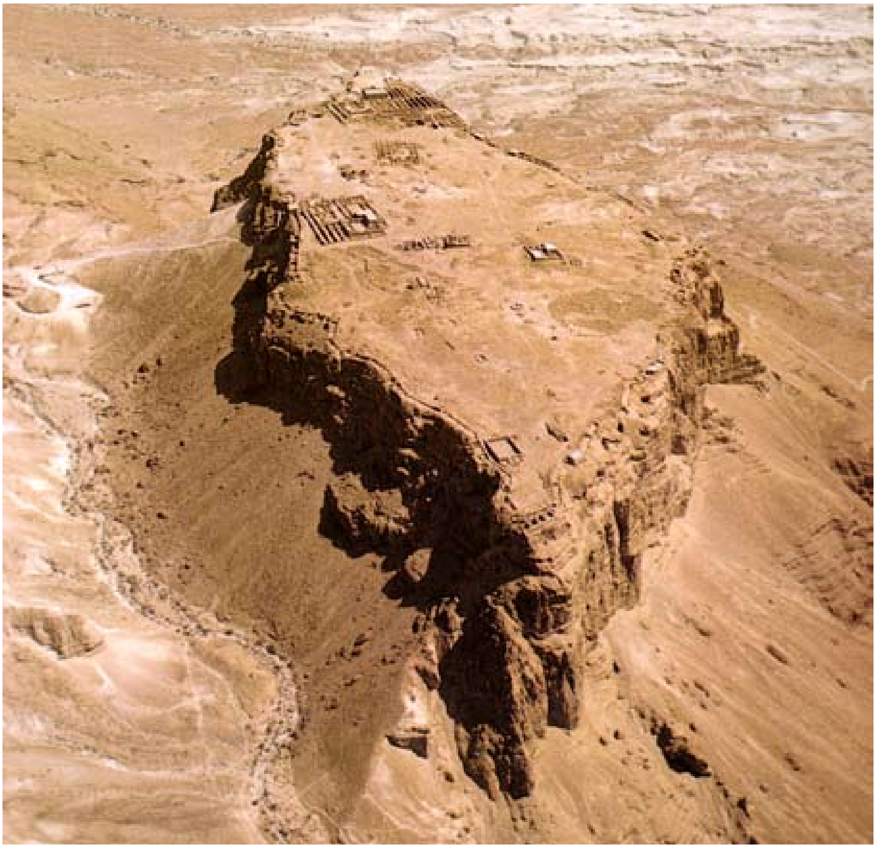

Figure 6. Aerial view of the remnants of the first century BCE *Herodian palace-fortress atop the imposing Masada cliff in the Judean Desert.*
Source: J. Aviram, G. Foerster and E. Netzer (eds.) *Masada IV. The Yigael Yadin Excavations 1963–1965. Final Reports*: Israel Exploration Society, Jerusalem. Reproduced with the kind permission of Dr. Richard Cleave.

MASADA EMOTIONS

One of the first textiles I examined was excavated at Masada, the fortress-palace erected by King Herod in the last quarter of the first century BCE atop an imposing cliff in the Judean Desert overlooking the Dead Sea (Yadin 1980) (fig. 6). The name of this site is derived from its Hebrew appellation – *Metzadah* being Hebrew for 'fortress'. That palatial fortress was also the setting for one of the worst tragedies befalling the struggling Jewish nation in the second half of the first century, about a century after the Herodian complex was built. Masada became the last stronghold of those Jews who were militarily opposed to the Roman rule in ancient Israel from 66 to 73 CE (Josephus 1995). When defeat became imminent, the nearly thousand men, women, and children living in this mountaintop fortress chose a tragic end rather than await their doomed fate at the hands of the Roman captors. The saga of Masada still resonates in the psyche of the modern State of Israel as it has become a symbol of the renaissance of the new Jewish Nation, nearly two millennia later; a kind of phoenix rising out of the ashes of the exiled Jewish people who have sworn that "Masada shall not fall again".

The tragic story of Masada is related by the Jewish-Roman historian Josephus Flavius (37–100 CE) who chronicled the history of the Jews. His previous name was Yosef ben Matityahu, of the priestly and royal Hasmonean dynasty, and he led the Galilee brigade, fighting the "Great Revolt" against the Roman occupation of Judea in the seventh decade of the first century. However, as he was vastly outnumbered by the Roman army, he surrendered to General (later Emperor) Titus Flavius Vespasian, whose son Titus finished the decimation of the Jewish revolt. After being taken to Rome he was granted Roman citizenship. He 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, as history has noted, Josephus embarked on his new – and invaluable – role as historian of that period.

In chapter 9 of his epic *Wars of the Jews*, 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 is near, their leader Eleazar passionately appeals to the masses atop this palace-fortress. According to Josephus (*Wars of the Jews*, bk. 7, ch. 8:7), he ends his exhortation with these words:

> 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 relates the bone-chilling events that transpired immediately after Eleazar's speech (ch. 9:1):

Now as Eleazar was proceeding on in this exhortation, they all cut him off short, and made haste to do the work, as full of an unconquerable ardor of mind, and moved with a demoniacal fury. So they went their ways, as one still endeavoring to be before another, and as thinking that this eagerness would be a demonstration of their courage and good conduct, if they could avoid appearing in the last class: so great was the zeal they were in to slay their wives and children, and themselves also! Nor indeed, when they came to the work itself, did their courage fail them as one might imagine it would have done; but they then held fast the same resolution, without wavering, which they had upon the hearing of Eleazar's speech, while yet every one of them still retained the natural passion of love to themselves and their families, because the reasoning they went upon, appeared to them to be very just, even with regard to those that were dearest to them; for the husbands tenderly embraced their wives and took their children into their arms, and gave the longest parting kisses to them, with tears in their eyes. Yet at the same time did they complete what they had resolved on, as if they had been executed by the hands of strangers, and they had nothing else for their comfort but the necessity they were in of doing this execution, to avoid that prospect they had of the miseries they were to suffer from their enemies. Nor was there at length any one of these men found that scrupled to act their part in this terrible execution, but every one of them dispatched his dearest relations. Miserable men indeed they were! whose distress forced them to slay their own wives and children with their own hands, as the lightest of those evils that were before them. So they not being able to bear the grief they were under for what they had done, any longer, and esteeming it an injury to those they had slain, to live even the shortest space of time after them – they presently laid all they had in a heap, and set fire to it. They then chose ten men by lot out of them, to slay all the rest; every one of whom laid himself down by his wife and children on the ground, and threw his arms about them, and they offered their necks to the stroke of those who by lot executed that melancholy office; and when these ten had, without fear, slain them all, they made the same rule for casting lots for themselves, that he whose lot it was should first kill the other nine and after all, should kill himself. Accordingly, all those had courage sufficient to be no way behind one another, in doing or suffering; so, for a conclusion, the nine offered their necks to the executioner, and he who was last of all, took a view of all the other bodies, lest

> perchance some or other among so many that were slain should want his assistance to be quite dispatched; and when he perceived that they were all slain, he set fire to the palace, and with the great force of his hand ran his sword entirely through himself, and fell down dead near to his own relations. So these people died with this intention, that they would not have so much as one soul among them all alive to be subject to the Romans. Yet was there an ancient woman, and another who was of kin to Eleazar, and superior to most women in prudence and learning, with five children, who had concealed themselves in caverns under ground, and had carried water thither for their drink, and were hidden there when the rest were intent upon the slaughter of one another. These others were nine hundred and sixty in number, the women and children being withal included in that computation. This calamitous slaughter was made on the fifteenth day of the month Xanthicus [Nisan].

It was with this calamitous Masada background haunting me that I braced myself to study those very same textiles that were used by these Jewish rebels and their families. The first time I had the opportunity to marvel at and to actually touch those fabrics was so momentous and mind-boggling that it took me several days of resolve in order to be able to begin analyzing the weaves. These were the garments that clothed their bodies, the most personal of any material effects one can possess, and the household furnishings used in their homes. And so I began to analyze the worldly possessions of our brave and controversial ancestors who departed to an after-life of divine tranquility rather than beenslaved in earthly captivity.

MASADA REDS, PURPLES AND BLUES

There were many stunning examples of colorful and intricate weaves found at Masada. Looking at their majestic beauty, I couldn't help but notice that the color was of such high quality and so miraculously endured the ravages of time that many of these textiles did not look like they were dyed nearly two thousand years ago, but practically only yesterday! Three such examples are shown in figure 7 (Sheffer and Granger-Taylor 1994).

From the dye analyses that I and others have performed on numerous historic textile dyeings from ancient Israel (Koren 1993b, 1994b, 1995b, 1999, 2005a), including Masada dyeings (Koren 1994b; Koren, Sheffer, and

Figure 7. Beautifully dyed ancient woolen weaves excavated at Masada, first century CE*, by the late Yigael Yadin; these fabrics belonged to the Jewish zealots whose last stand against the Roman occupation of Judea finally resulted in their calamitous mass-suicide, as described by the Jewish–Roman historian Josephus. Prior to producing the various patterns in the following textiles, sheared and washed woolen fleece fibers were appropriately dyed, then spun into yarn, and finally woven to construct the design of the weave.*

Figure 7a (left): *Probably from a garment, perhaps a mantle; the salmon pink ground fibers were dyed with madder, and the purple of the notched weft band was produced by double-dyeing fleece fibers with the red-producing madder roots and with the blue indigo-producing leaves of probably the woad plant.*

Figure 7b (top right): *Perhaps from a tunic; ground fibers were dyed with madder red, and the weft band fibers with indigo blue.*

Figure 7c (bottom right): *Possibly a cushion cover; part of a repeated design of stylized flowers and leaves in a geometric framework using indigo blue and undyed fibers.*

Source: J. Aviram, G. Foerster and E. Netzer (eds.) *Masada IV. The Yigael Yadin Excavations 1963–1965. Final Reports*: Israel Exploration Society, Jerusalem. Reproduced with the kind permission of the Israel Exploration Society.

Figure 8. Madder plant roots held by the author near Avignon, France, exposing the location of the red dye in the inner part of the roots. Dyeing with this dyestuff is effected by pulverizing the roots, adding water, and heating to less than boiling to dissolve mostly the dye, and then introducing the wool that has been treated (mordanted) with a hot solution of the mineral alum.

Granger-Taylor 1994), a picture of the botanical expertise of the ancient dyer becomes apparent. Results show that practically all of the red dyeings from about two millennia ago were produced by the use of the inner root parts of the plant known as dyer's madder, or botanically as *Rubia tinctorum* (literally "red dye") after the system devised by the botanist Linnaeus (fig. 8). During the Roman Period, this plant was grown in the Levant as well as in Europe, and a related species was also native to India and environs.

In order to perform dyeing with this vegetal colorant, the sheared and washed woolen fleece first had to undergo a pre-dyeing mordanting stage. In this step, the wool was immersed in a hot solution in which the mineral alum had been dissolved in water allowing the molecules of the aluminum compound to impregnate the interior wool fibers. This alum "bites" into the fibers and is thus considered a "mordant" (from the French *mordre*, to bite). After about an hour or so has elapsed, the mordanted wool – wet or dry – is introduced to a hot liquid mixture in which the colorants from the madder roots have been extracted. This dye extraction is accomplished by mixing the ground powdered madder roots with very hot water. As the colorants in solution come in contact with the textile, they bond better to the alum, which is already bonded to the fibers, than to the fibers themselves. Hence, the mordant alum acts as an intermediary and as a bridging agent between the fibers and the colorants and yields more vibrant and more stable colors than if the dye were to bond directly to the fibers. Such alum-mordanted

Figure 9. The author holding a lump of dark blue-violet indigo pigment. This was produced by fermenting the leaves of the woad plant in order to reduce and dissolve the forerunner to indigo blue, the yellow colorant from the leaves. The solution was then bubbled in air, allowing the colorant molecules to couple via air-oxidation and form the insoluble indigo pigment.
© Zvi C. Koren

dyeings yield various hues or shades of red including salmon-orange, red, and brick-red colorations. These shades are possible as there are various colorants in the madder roots; two of the principal colorants are the orange-red dye known as alizarin and a purple one know as purpurin, named for the dye's hue. Examples of the use of the madder roots to produce red dyeings can be seen in the in the grounds of the following Masada textiles: the salmon-pink of figure 7a and the red of figure 7b.

The dyeing with plant-extracted blue was effected by means of a fermentation process involving the steeping of certain plant leaves in warm water made alkaline by either stale urine, lime, plant ash, or the mineral natron (carbonate of soda), also known as *nitron* in Greek, *nitrum* in Latin, and as the biblical and Talmudic Hebrew *neter*. The process could now continue in one of two directions. If dyeing is to be performed at this stage, the fleece is added to the greenish yellow solution containing the dissolved and reduced colorant. After the textile is removed from the dye bath, the dye molecules in the fibers undergo air-oxidation to produce the blue insoluble pigment in and on the fibers. In the second possibility, if the dyeing is not to be immediately performed, then the dye solution is beaten and stirred in order to introduce as much air as possible so that the solid blue pigment will precipitate and settle to the bottom for later use (fig. 9). This type of dye is known as a vat dye, which requires it to be dissolved by reducing it to another state, followed by air-oxidation to form the solid pigment. This dye has been identified as indigotin (or indigo, for short) and it was the only source for the production of a blue dyeing in the ancient world.

In the Levant and Europe of the Roman period, the source available for the blue indigotin pigment was undoubtedly the leaves of the woad plant, *Isatis tinctoria* L., whereas *Indigofera tinctoria*, known as the "indigo" plant native to "India" and environs, as its name implies, was another source for the blue pigment in that far-flung part of the world.

Examples of the use of the blue dye indigotin were detected in the Masada weaves of figure 7: in the weft band of the red textile (fig. 7b) and in the floral patterned fabric (fig. 7c).

A most interesting use of indigotin blue is in producing purple bands, such as the example in figure 7a. In addition to reds and blues, purple hues were also the haute couture color of that period. The most noble of these was known as Tyrian purple, which was produced from the hypobranchial glandular extracts of various *Murex*-type sea snails (Koren 1995c, 2005b). The violets and purples produced from these mollusks were the most expensive, complex, sacral, and royal of all the dyes used in antiquity, and adorned the textiles of emperors, caesars, kings, military generals, Israelite high priests, and temples (see below). Various edicts were enacted to "persuade" the common folk that it would not be advisable for them to wear such real purple-dyed garments. All of these technical and legislative obstacles precluded the dyeing of *Murex*-purple by those who were on the lower rung of the socioeconomic scale. Nevertheless, the clever dyers found a means of circumventing these difficulties by developing a double-dyeing process to produce these popular hues, which I call the "poor people's purple." This "fake" purple was fabricated by dyeing with a red colorant, such as by using madder roots, followed by vat dyeing with blue indigotin, or in reverse order. The ancient color theorist realized that a combination of blue and red yielded purple colors whose desired hue could be fashioned by controlling the relative quantities of the red and blue components. Dye analyses on the above-mentioned purple notched band showed that it was produced by this double-dyeing process.

THE BENI HASAN BLUES

Let us return to that famous Egyptian burial site of Beni Hasan that was previously discussed. Officials at the Egyptian Antiquities division at the

British Museum in London gave me a small fragment from a linen cloth (EA 38007), perhaps from a burial shroud, found in a pot at one of these tombs. Traces of light blue stripes were noticeable on the edge of this fabric (fig. 10). The chromatographic analyses performed on this colorant clearly showed the unmistakable trademark of the blue indigotin dye. Thus, this nearly 4000-year-old blue-dyed linen sample is one of the oldest surviving blue dyeings, as are other contemporaneous examples that are on display at the British Museum.

THE BAR KOKHBA REBELS' TEXTILES

Many textile fragments belonging to the rebel leader Bar Kokhba and his followers and possibly their families were found in one of the caves in the Judean Desert (Yadin 1963). This site has been named "Cave of Letters", as various documents and correspondences written on scroll parchments were found and were attributed to these rebels.

It is important to understand the historical milieu of the analyzed textiles so that the impact of their discovery, examination, and interpretation is fully appreciated not just on the scientific level but also on the emotional and human scale. The accounts associated with the above-mentioned archaeological site of Masada and the Bar Kokhba rebellion are well known in Jewish history as they represent national tragedies during the Roman occupation of Judea.

The third and last wave of rebellion against the Romans in ancient Israel during the reign of Hadrian was waged from 132 to 135 CE by Bar Koziba, literally "son of Koziba" (Koziba probably being his native town). As history recounts, he was a charismatic leader and to some a messianic figure. In fact, historically he is known more by his famous *nomme de guerr*e, Bar Kokhba (Son of a Star), which was coined by the Talmudist Rabbi Akiba, who believed that Bar Kokhba was the Messiah who would redeem the Jews from their Roman troubles. R. Akiba applied to him the verse in Numbers 24:17–18:

> There shall come a star [*kokhav*] out of Jacob, and a scepter shall rise out of Israel, and shall strike the corners of Moab, and destroy all the sons of Seth. And Edom shall be a possession, Seir also, his enemies, shall be a possession, and Israel shall do bravely.

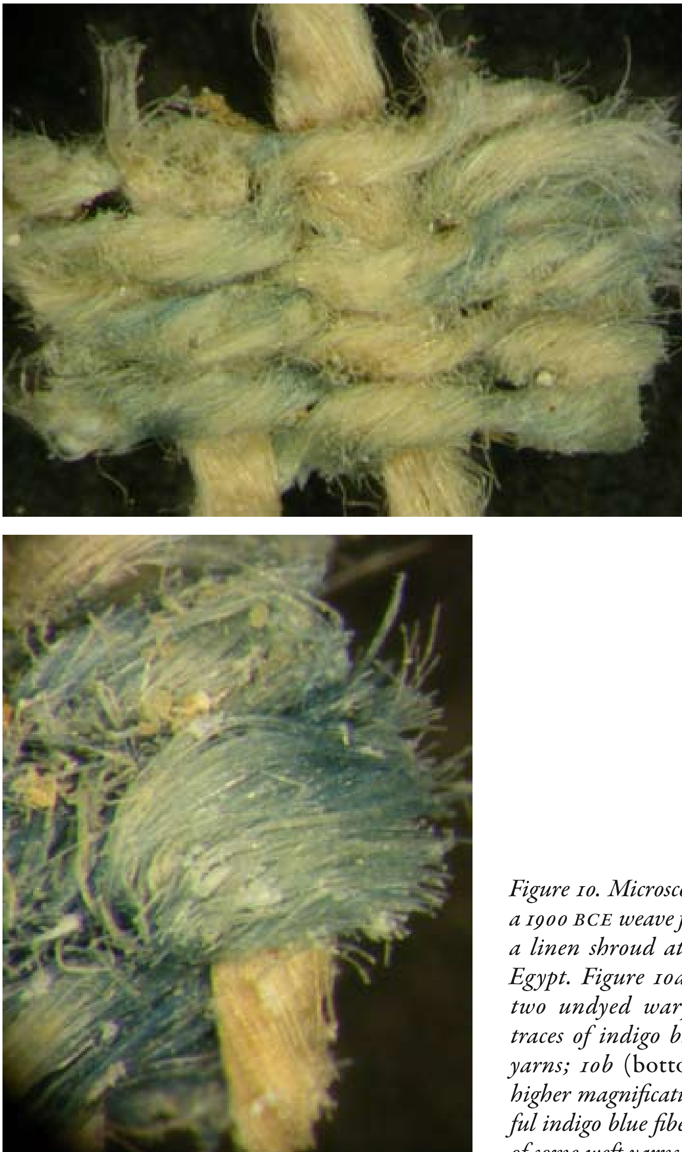

Figure 10. Microscope pictures of a 1900 BCE *weave fragment from a linen shroud at Beni Hasan, Egypt. Figure 10a* (top) *shows two undyed warp yarns and traces of indigo blue dyed weft yarns; 10b* (bottom) *shows at higher magnification the beautiful indigo blue fibers at the ends of some weft yarns.* © Zvi C. Koren

The revolt met with initial success, and Bar Koziba maintained his independence for about three years until the disastrous siege of Beitar, at which Bar Koziba was killed. That tragic end to the war was more colossal than the expiation of any individual, as it also was a great tragedy to the Jewish nation as a whole, leading to the final exile of many Jews from their homeland. The catastrophic consequences of this military venture lead many Talmudic-period Rabbis to be utterly contemptuous of Bar Kokhba's actions, as we can see from the following legendary tale in the Talmud (Sanhedrin 93b):

> Bar Koziba reigned two and a half years, [and then] he said to the Rabbis, "I am the Messiah." They answered, "Of Messiah it is written that he can smell [a man] and judge [him, whether he is innocent or guilty]. Let us see whether you can smell and judge." When they saw that he was unable to judge by the scent, they slew him.

Additionally, so distraught were the Rabbis of the time with the tragic results of Bar Koziba's rebellion that they ridiculed his family name (pronounced "Kozeeva") by stating that it was derived from *kazav*, whose etymological root denotes a lie and a disappointment.

It is with this background in mind that I set out to perform dye analyses on the Bar Kokhba textiles, which were first analyzed by the landmark pioneering work of Dr. Sidney Edelstein, who founded the center which I now head, and the then vice president of his company, David Abrahams (Abrahams and Edelstein; 1963, 1964). An example of a beautiful Bar Kokhba weave is the scroll wrapper decorated in a variety of colors, where the madder roots described above were used for the red background (fig. 11). The various weft bands are blue from indigotin, and yellow and green from a combination of the blue and yellow colorants.

Various shades of purple fleece were also found at this site. An example is shown in figure 12. The early analyses, performed more than four decades ago, reported that this purple was produced from the double-dyeing of the blue indigotin dye and a red colorant extracted from certain insects (see below). However, when I analyzed such purple samples it was conclusively shown that, in addition to blue indigotin, the red colorant used was that from the madder roots, as seen in the Masada example of figure 7a described above (Koren 2005a).

The finding of a dyed fleece is demonstrative of the stages associated with textile manufacturing in antiquity: The technological order was for the sheared and washed fleece to be dyed first (this is known as "dyeing in the fleece") and then spun into yarn, which is used for weaving. As I was investigating these colored fleeces, I marveled at how the ancient passage in the Mishnah, a body of religious and secular laws compiled around the first two centuries of this era (a timeframe contemporaneous with these textiles),

(left) *Figure 11: A multicolored scroll wrapper from the Bar-Kokhba Cave of Letters, second century CE.*
© Zvi C. Koren; adapted from Y. Yadin, *The Finds from the Bar-Kokhba Period in the Cave of Letters (Judean Desert Studies)*: Israel Exploration Society, Jerusalem, 1963; plate 61.

(opposite) *Figure 12: Purple fleece of various shades found at the Cave of Letters, second century CE.* © Zvi C. Koren

was in complete harmony with these findings. The Talmudic exposition from tractate Shabbat (Mishnah 7:2; p. 73a) relates to the work-related activities that are forbidden on the Sabbath, the day of rest:

> The primary labors are forty less one: . . . shearing wool, bleaching it, carding it, dyeing it, spinning, stretching the yarns, the making of two meshes, weaving two threads, dividing two threads, tying, and untying, sewing two stitches, tearing in order to sew two stitches . . .

INSECT SOURCES FOR DYES: COCHINEAL AND KERMES

Entomological dye sources in the Levant for the production of red dyeings, alone or in combination with other dyestuffs, were the scale insects commonly known as cochineal and kermes. These were obviously more prestigious and expensive than botanical sources for biological and chemical reasons. Whereas dye plants can be grown practically in one's backyard, the biology of these unique insects required them to breed only on certain host plants located in specific geographical areas. Additionally, the chemistry of these insect dyes produces certain mordant-to-dye bonds in the fibers that result in more vibrant reds than those obtainable from plant dyestuffs.

In the ancient Middle East, the obvious cochineal to be imported into this area would have been the one that goes by the popular names of Ararat, Armenian, or Turkish cochineal, as well as by kirmiz, and entomologically as *Porphyrophora hamelii* Brandt. This cochineal breeds on the ground-level upper roots of certain grassy weeds. The dried, dark brown mature female insects are relatively flat, with lines or scales on their shell. The main colorant extracted from this cochineal is carminic acid, which produces crimson (bluish red) dyeings on alum-mordanted wool.

The other red-producing insect is known as oak kermes, *Kermes vermilio* Planchon, which breeds on the branches and leaves of certain oak trees at relatively high altitudes. The 'etymology of entomology' is quite interesting, as the Biblical name for kermes in 2 Chronicles has an equivalent name – *karmil*. The round, pea-shaped, dark brown mature female insects are collected together with their larvae for the dye production. Their dye content consists primarily of two components: orange-red flavokermesic acid and the red-purple kermesic acid. Modern kermes dyeings on alum-mordanted wool produce scarlet (orange-red) hues. This insect is the source of the Biblical *shani* dye, which provided flaming orange colors on the vestments of the High Priest and on the textile furnishings of the Tabernacle.

THE FRUGALLY RICH INSECT RED

The skills of the dyer and weaver in so many artistic weaves have been found in many textiles. However, the combination of the economics and beauty of the final product can be evidenced from a rare red fabric excavated at a late Byzantine site at ʻEin Boqeq in close proximity to the Dead Sea, the lowest point on Earth. This site probably served as a way-station along the famous spice route from the Nabatean capital of Petra (now in Jordan) to the Gaza port and on to further points of commerce.

I was given a small red yarn sample to analyze by Avigail Sheffer, a veteran researcher of the physical structure of ancient weaves, who was investigating the various textiles excavated at this site. I found that the red colorant was produced by using the roots of the madder plant. When Avigail then showed me analyses performed in the early 1970s on the same red fabric, I was perplexed. Researchers in Belgium had reported that the red dye was of insect origin. I was perplexed. My scientific analyses clearly showed the presence of the two main colorants making up the madder plant, an orange colorant named alizarin, and a purple one called purpurin. There was no mistaking that result. But the Belgian researchers were top-notch scientists; their report was also iron-clad. I was befuddled.

I then asked for and received a very small weave sample containing warp and weft from the red fabric. Looking at this fabric, I still could not understand why the Belgians and I were getting radically different results. I then placed the minuscule fabric under a microscope, and I noticed immediately that not only did the fabric consist of bright, shining, crimson-colored red yarns, but also of some dull red yarns, considerably visually inferior to the brilliant color reflected from the crimson yarns (fig. 13). This must have been the reason for the discrepancy in the results obtained. Upon further inspection, I noticed that all the dull red yarns formed the warp of the red weave, while the weft yarns were of a dazzling crimson.

Chemical instrumental analyses then showed that the dull-red warp yarns were the ones dyed with the madder roots, whereas the vivid crimson weft yarns were in fact dyed with the dye produced by scale insects. Based on the chemical signature of the components found in this crimson colorant, and also based on the geographical and archaeological context of this textile, I surmised that this dye originated from the Ararat (or Armenian) cochineal insect that breeds on the ground-level upper roots of certain grassy weeds

Figure 13. Microscope picture of a fragment of the woolen red patch from 'En Boqeq, dating from the seventh century CE *late-Byzantine period. Visible are three light red warp yarns produced from madder red, and brilliant crimson weft yarns whose fibers were dyed with the exotic Ararat or Armenian cochineal scale insect.* © Zvi C. Koren

growing at the base of Mt. Ararat. This was the first direct evidence of the use of such an insect dye in a textile from ancient Israel.

Another amazing aspect of this red patch is the clever integration of these two differently colored yarns into the weave. This red fabric is a weft-faced tabby, so that the most visible element of the weave is the crimson weft, while the dull-red warp is largely concealed in the background. The ancient weaver was interested in producing a crimson look for the textile, so the relatively expensive cochineal-dyed yarns took the weft center stage in the production, while the inexpensive red madder-dyed yarns were backstage in the warp. With an eye to the aesthetics of the finished product, red-dyed warp yarns were nevertheless used – not undyed ones – just in case a warp here and there would peek through and become visible.

THE SACRAL INSECT SCARLET

The 2000-year old archaeological site known as 'Ein Rahel (Springs of Rachel), a Nabatean fort in the 'Aravah valley, southwest of the Dead Sea, yielded a surprising and rare weave. A purple band was present in a few of the excavated textiles; however, this color was unlike any of the other purples I had investigated. The major dye component of this band was the purple kermesic acid dye, which can only be produced from the oak kermes insect. Thus, as in the case of the crimson 'Ein Boqeq cochineal-insect dyeing mentioned above, this too was the first time that a dyeing from ancient Israel containing another insect – kermes – was found.

However, the surprising find – or lack of it – was that the orange-red flavokermesic acid colorant, which is always found together with kermesic acid in modern kermes dyeings, was decidedly absent. The absence of this dye is most probably not due to the use of a specific kermes species that only consists of the purple dye constituent, but due to the degradation of the unstable orange-red colorant over the archaeological time frame.

The modern-day implication of ancient kermes dyeings is that "what-you-see-today" is not "what-you-had-yesterday". As the orange component has decomposed over two millennia, it is obvious the original hue of the band in the 'Ein Rahel textile was not purple, but possessed at least a tad of orange to it. This is an important fact in attempting to reconstruct the original color of this and other bands. Were we to find a kermes dyeing from Biblical times, though it would now appear purple, we would know that when originally dyed in antiquity, it would have been the Sacral Scarlet *Shani* dye.

THE SIX THOUSAND YEAR OLD WARRIOR'S BURIAL SHROUD: THE OLDEST DYEING YET FOUND

In 1993, numerous archaeologists embarked on a daring mission code-named "Operation Scroll" in the Judean Desert to find more remnants of Dead Sea type scrolls. Every known cave was searched, but instead of finding significant scrolls, they made a spectacular find of a different sort. Inside a cave located in the cliffs of the lower Wadi el-Makkukh, near Jericho, they discovered the intact burial site of an adult male, a full skeleton in a fetal position, probably a warrior or hunter of high rank, dating to the early fourth millennium BCE (late Chalcolithic Period). The find included several rare, exceptionally wellpreserved funerary objects: a coiled basket, a wooden bowl, a pair of leather sandals, a flint knife, and a bow broken into two parts. The bow had been deliberately and ritually broken, testifying to the ancient mortuary rite of “killing” the bow as a way to symbolize the end of its use upon the death of its owner. The presence of these remains and artifacts at this archaeological site is the basis for naming it the “Cave of the Warrior”.

These remarkable personal articles, and the skeleton, were found in the largest textile yet found from this era, an incredible two-by-seven meter linen-weave, which was folded in four. Additionally, two elaborate and beautifully woven linen textiles were found within the very large shroud that wrapped the body.

The linen textiles I examined showed various earth colors, from beige and brown to dark-brown (nearly ‘black’). The large textile also had reddish spots, composed of the red pigment haematite (red ochre), an iron oxide, which were distributed randomly. This pigment was undoubtedly sprinkled onto the shroud enveloping the skeleton as part of the burial ritual. Red ochre, symbolizing life-blood, has been used in the funerary rites (painting of skull, bones and other parts of the deceased) of various ancient cultures (Brunello 1973).

The decorative bands forming the warp ends in each of the textiles contained dark, brown, and beige yarns. Dark yarns were also present as outer warp threads on both sides of the large textile, and on weft yarns from the decorative bands of the large and the smaller textiles. The sources of these colors were analyzed via microscopic, chemical, and chromatographic tests.

Though the nature of the blackish dark-brown organic colorant has not been completely identified yet, it is nevertheless clear that the Chalcolithic Warrior textile is the earliest example of yarn-dyeing yet discovered anywhere in the world (fig. 14). The colors on even later Neolithic textiles discovered so far were produced by surface coloration – painting or smearing – of part or all of the bulk textile, in contrast to the Warrior textile. In the Warrior weave, the dyeing of individual yarns was performed and then these were introduced during the weaving stage. In addition, the relative uniformity of the dark brown color along the length of the inner dark fibers that comprise the decorations in the Warrior textiles is remarkable, given that this textile is nearly six-thousand-years old!

THE BIBLICAL HERODIAN ARGAMAN

"An ordinary day," I mused; this was to be a normal day at the lab for my student and me. However, in my hands was one of the most important biblical treasures ever to be found – a royal and priestly color of historic proportion. One key to the puzzle of the trilogy of sacral colors was now deciphered. Those minuscule red-purple fibers, mentioned above in the prologue, established at last the true color of the biblical *argaman* dye used for kings, high priests, and in the textile furnishings of the Tabernacle.

Figure 14. Microscope picture of part of the decorative band trim of the linen burial shroud found in the Cave of the Warrior. The shroud is six-thousand years old (late Chalcolithic Period). Visible are weft yarns dyed brown-black prior to weaving. © Zvi C. Koren

The rare molluskan pigment known as royal purple has also been referred to as Tyrian purple, after one of the capitals 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. This pigment was produced in antiquity from the substances contained in the colorless fluids of the hypobranchial glands of certain sea mollusks commonly referred to as *Murex* snails. As described by Greek and Roman historians, such as Aristotle and Pliny, respectively, the dyeing of wool and silk with the solubilized reduced form of this pigment was undoubtedly one of the oldest and most complex of biochemical technologies in the ancient world. During certain eras, this precious dye was worth more than twenty times its weight in gold (Bridgeman 1987). This is no wonder, as experiments performed in my laboratory have shown that approximately ten thousand such snails were needed to dye just one royal cloak from head to toe! The scarcity of this animal dyestuff and the majestic beauty of murex-purple dyed textiles endeared it to kings, emperors, caesars, and ecclesiastics. History has recorded that this purple was the fashion of royalty in the empires of Assyria, Babylonia, Persia, Greece, and Rome. Military generals and nobility were also permitted to adorn at least part of their garments with this imperial dye.

The textile that Leah and I analyzed was excavated along with other textiles and artifacts in an expedition at Masada led by the late Yigael Yadin, the dean of Israeli archaeologists, between 1963 and 1965 (Yadin 1984). The woolen fragment investigated (number 1132/3), whose maximum measurements were approximately 2 × 4 mm, was unearthed in an area (locus 791) that was part of the refuse dump of the western palace and was situated at the northeast corner of that edifice (Netzer 1991). Based on the archaeological dating of the other artifacts found with this textile, it can be conclusively stated that this fabric belonged to the Herodian period of the first century BCE(E. Netzer, personal communication).

The fortress and palatial complex at Masada was built by King Herod, the Roman-appointed Jewish monarch of Judea, during the middle of his reign (37–4 BCE). History recounts that he built the palaces and other structures at Masada as a fortress in case a retreat by him and his family was necessary. King Herod's short-lived dynasty was to be the last monarchy of ancient Israel. The western palace was the first of the two that were built at Masada and it served as an important administrative center (E. Netzer, personal communication). Further, 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 (Yadin 1984). 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.

So, it was not to be an ordinary day. When the analyses on the small yarn were concluded, the chromatographic and spectrometric results indicated that the most probable molluskan source of this purple dye was the hypobranchial glandular fluid of *Murex trunculus* gastropods. Based on the history, archaeology, religion, and marine zoology associated with this molluskan dye, the significance of the discovery of murex purple on this royal fabric is three-fold: (1) This is the first time that a murex purple fabric from ancient Israel has been discovered, and it is among the oldest 'true purple' textiles discovered anywhere in the world; (2) The fabric found undoubtedly belonged to the western Herodian palace at Masada, and, based on the royal dye used and the physical structure of the weave, may have been part of the royal cloak or mantle of that king; (3) The color of this fabric was most likely that of the biblical *argaman* dye (fig. 15).

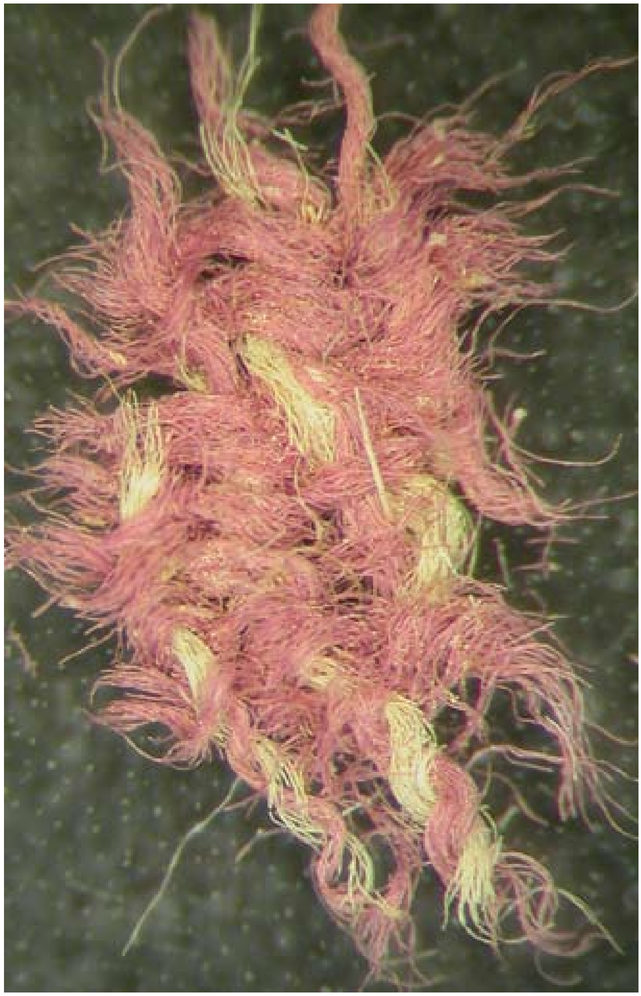

Figure 15. Microscope picture of a fragment of first-century BC *Herodian fabric. Each of the warp yarns in the fabric was produced by plying un undyed (now yellowed) yarn together with a purple yarn. The weft yarns are of purple alone. This construct indicates that the whole fabric was purple in color. The fabric is the only example of real molluskan Royal and Biblical Argaman dyeing found from ancient Israel.*

EPILOGUE

Now that two of the three Biblical dyes have been deciphered, the red-purple molluskan *argaman* and the insect scarlet (orange-red) *shani*, much work still needs to be done regarding the nature and dyeing techniques associated with the third, and most holy, of the sacral dyes. The *tekhelet* dye was also produced from a *Murex* species, undoubtedly from a *Murex trunculus* snail, which already contains a bluer pigment than all the other molluskan pigments. Woolen *tekhelet* dyeings are probably violet or dark-blue in color. There is still much controversy related to this topic. However, the recent breakthrough research that we and John Edmonds of England and Inge Boesken Kanold of France independently conducted in decoding the riddle of how the ancients performed dyeing with the purple pigment with only natural means will hopefully resolve this last purple puzzle (Koren 2005b).

In trying to grasp the secrets of the ancients, one is simply bedazzled and awed by the advanced state of their empirical science in technology, chemistry, botany, entomology, marine zoology, biotechnology, and just as important, their artistry. Even several thousand of years ago, these scientific artisans were great individuals standing at the frontier of the civilized world, and producing great artistic products fashioned from skills honed over the centuries.

And so, my personal and professional scientific quest, cheered on by Clemens, is to help understand the chemical arts and technologies associated with the nature and use of color in antiquity . . . for the sake of humanity.

ACKNOWLEDGEMENTS

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Mr. Clemens Nathan's efforts in championing these studies in science and art for the benefit of future generations.

REFERENCES

Abrahams D. H. and Edelstein S. M. 1963. "A study of the textiles from the color standpoint." In Yadin, Y. *The Finds from the Bar-Kokhba Period in the Cave of Letters (Judean Desert Studies)*: Israel Exploration Society, Jerusalem, 270–279.

———. 1964. "A new method for the analysis of ancient textiles." *American Dyestuff Reporter* 53, 19–25.

Bridgeman J. 1987. "Purple Dye in Late Antiquity and Byzantium." In Spanier E. (ed.) *The Royal Purple and the Biblical Blue: Argaman and Tekhelet. The Study of Chief Rabbi Dr. Isaac Herzog on the Dye Industries in Ancient Israel and Recent Scientific Contributions*. Keter, Jerusalem, 159–165.

Brunello F. 1973. Hickey B. (transl.) *The Art of Dyeing in the History of Mankind*: Neri Pozza Editore, Vicenza, 6–8.

Josephus Flavius. 1995. *Wars of the Jews*. In Whiston W. (transl.) *The Complete Works of Josephus:* Kregel Publications, Grand Rapids, Michigan, Book 7, Chs 8–9, 598–603.

Koren Z. C. 1993a. "Methods of dye analysis used at the Shenkar College Edelstein Center in Israel." *Dyes in History and Archaeology* 11, 25–33.

———. 1993b. "The colors and dyes on ancient textiles in Israel." In Sorek C. and Ayalon E. (eds) *Colors from Nature: Natural Colors in Ancient Times*, Eretz-Israel Museum, Tel-Aviv, 15*–31*, 47–65.

———. 1994a. "HPLC analysis of the natural scale insect, madder and indigoid dyes." *Journal of the Society of Dyers and Colourists* 110, 273–277.

———. 1994b. "Analysis of the Masada textile dyes." In Aviram J., Foerster G. and Netzer E. (eds) *Masada IV. The Yigael Yadin Excavations 1963–1965. Final Reports*: Israel Exploration Society, Jerusalem, 257–264.

———. 1995a. "An efficient HPLC analysis scheme for plant and animal red, blue and purple dyes." *Dyes in History and Archaeology* 13, 27–37.

———. 1995b. "Analysis of the Nahal Shahaq site textile fibers and dyes." *'Atiqot* 26, 49–53.

———. 1995c. "High-performance liquid chromatographic analysis of an ancient Tyrian purple dyeing vat from Israel." *Israel Journal of Chemistry* 35, 117–124.

———. 1999. "Microscopic and chromatographic analyses of decorative band colors on Nabatean 'En Rahel textiles – kermes and shaded bands." *'Atiqot* 38, 129–136.

———. 2005a. "Chromatographic Analyses of Selected Historic Dyeings from Ancient Israel." In R. Janaway and P. Wyeth (eds) *Scientific Analysis of Ancient and Historic Textiles: Informing Preservation, Display and Interpretation*: Archetype Publications, London, 194–201.

———. 2005b. "The first optimal all-Murex all-natural purple dyeing in the Eastern Mediterranean in a millenium and a half." *Dyes in History and Archaeology* 20, 136–149, Col. Pls. 15.1–15.5.

Koren Z. C., Sheffer A., and Granger-Taylor H. 1994. "Table v – Dye Analysis." In Aviram J., Foerster G., and Netzer E. (eds) *Masada iv. The Yigael Yadin Excavations 1963–1965. Final Reports*: Israel Exploration Society, Jerusalem, 251–255.

Netzer, E. 1991. *Masada iii. The Yigael Yadin Excavations 1963–1965. Final Reports. The Buildings, Stratigraphy and Architecture*. Israel Exploration Society, Jerusalem, 369.

Sheffer A. and Granger-Taylor H. 1994. "Textiles from Masada: a preliminary selection." In Aviram J., Foerster G., and Netzer E. (eds) *Masada iv. The Yigael Yadin Excavations 1963–1965. Final Reports*: Israel Exploration Society, Jerusalem, 153–250.

Yadin, Y. 1963. *The Finds from the Bar-Kokhba Period in the Cave of Letters (Judean Desert Studies)*: Israel Exploration Society, Jerusalem.

———. 1980. *Masada: Herod's Fortress and the Zealots' Last Stand*: Random House, New York.

———. 1984. *Masada: Herod's Fortress and the Zealots' Last Stand*: Steimatzky, Tel-Aviv.

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