First Identification of Authentic *Tĕkēlet*

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Discoveries in chemistry and marine biology reveal the secret of the ritual "blue" textile of ancient Israel.

Introduction

Three colored wools, designated in Hebrew *tĕkēlet*, *ʾargāmān*, and *tôlaʿat šānî*, are prescribed often in the Bible for use in ritual and regal fabrics. The fibers were from an animal source, and the three dyes applied to them were also of animal origin (Forbes 1964: 99–114). *Tôlaʿat šānî*[1] is identified as kermes, the scarlet dyestuff extracted from *Kermococcus vermilis* and related species of scale-insects that live on oak trees (Born 1938; Brown 1975; Baranyovits 1978; Sternlicht 1980). *ʾArgāmān* is 6,6′-dibromoindigotin, the Tyrian purple (*purpura blatta*), which was produced from various sea snails (fig. 1), especially spiny dye-murex (*Bolinus brandaris*) and the rock shell *Thais* (*Purpura*) *haemastoma*, (Baker 1974; Born 1937) until the decline of the Byzantine Empire. Ancient textiles dyed with *tôlaʿat šānî* and *ʾargāmān* have been found in particular abundance at Palmyra (Pfister 1934; 1937; 1940), and potsherds colored with *ʾargāmān* at Tell Shiqmona (Spanier and Ziderman 1982),[2] and at Sarepta (McGovern and Michel 1984).[3]

Regarding *tĕkēlet*, however, no claim has thus far been made as to its discovery in archaeological excavations or in antique collections. Indeed, an attempt to do so has not been possible, due to the uncertainty and confusion concerning the identity of *tĕkēlet*. While *tĕkēlet* has been recognized (Dedekind 1898; Born 1937; Forbes 1964: 111, 114; Herzog 1919; 1921; 1954; Herschberg 1924: 267–77; Kaplan 1981: 91) to be a purple dye (specifically the blue-tinted variety *purpura hyacinthea*) derived, like *ʾargāmān*, from shellfish, the actual species of mollusk involved and the chemistry of its dye have until recently been unclear (Forbes 1964: 120; Ziderman 1981; 1982; 1983; 1985; 1986a; 1986b; in press; Kaplan 1981: 87–95). Unfortunately the problem has been further obscured by the ambiguity too frequently created when *tĕkēlet* has been confused with *ʾargāmān* (Tyrian purple) in discussions of its source, color, and chemistry (e.g., Feliks 1971; 1981; Jensen 1963; Loewenstamm 1950; Milgrom 1981; 1983; Yadin 1963: 182–87).

Purple dyes are actually an artifact derived from colorless mucus from the hypobranchial gland of certain sea snails. Rideout and Sutherland (1981) surmise that the naturally-occurring precursor chemical, sodium tyrindoxyl sulphate, may function as a biological deterrent of predatory fish. The Tyrian purple recently identified in the acorn worm is apparently not an artifact (Higa and Scheuer 1976).

Tĕkēlet cloth was widely known as one of the most precious treasures in many ancient civilizations. The Hebrew word *tĕkēlet* is equivalent to *ugni* in the Nuzi texts from Mesopotamia (3500 years old), *iqnu* in Ugaritic (3000 years old), *takiltu* in Akkadian (2700 years old), and *hyakinthos* in Greek (Forbes 1964: 120). It is also equivalent to the Latin terms *purpura hyacinthea* (*p. hyacinthina*), *purpura amethystina, purpura violacea, purpura ianthina*, and *color principalis* (Born 1937: 113). Its age-long importance as an item of international trade and tribute (Eilat 1977: 87–97) and as an adornment for sanctuaries and sovereigns was apparently brought to a sad end during the seventh century A.D., following the collapse of the purple-dyeing industry during the Moslem conquest of the Levant with the fall of Tyre in 638 (Herzog 1919; 1921; 1954).

Fig. 1. Shells of marine snails mentioned in the text. Left to right: *Trunculariopsis* (*Murex*) *trunculus*, *Bolinus* (*Murex*) *brandaris*, and *Thais* (*Purpura*) *haemastoma*.

A study of the intriguing problem of identifying *tĕkēlet* must of necessity be interdisciplinary. It seems appropriate to direct a comprehensive report to the attention of archaeologists.

Methodology For Characterizing Tĕkēlet

A systematic procedure for identifying *tĕkēlet* should include three steps: (1) determination of the molluscan species from which *purpura hyacinthea* was prepared; (2) characterization of the chemical composition of the dye obtained from the species chosen; and (3) development of a chemical analysis for detecting the presence of the dyestuff in archaeological specimens.

In selecting the authentic species of sea snail (step 1), the following criteria should be considered:

(a) *Archaeological*: Ancient piles of its shells (preferably broken close to the location of the hypobranchial gland, which contains the chromogenic mucus; fig. 2) should be found on Phoenician shores at possible dyeing sites.
(b) *Biological*: Its appearance and behavior should comply with the Talmudic descriptions (*Talmudic Encyclopaedia* 1976; Nyer 1972; 1975: 51–60; 1983: 98–104; Kaplan 1981: 87–95; Ziderman 1985; in press).
(c) *Analogical*: The dye obtained should have a hue similar to *qĕlā'îllān*, the counterfeit *tĕkēlet* of Mishnaic times, which was dyed with vegetable indigo (Feliks 1971; 1981; Herzog 1919; 1935; Tykocinski 1970: 58–60; Kaplan 1981: 89).
(d) *Technical*: The dyeing could have been performed with the means available in ancient times, using the species chosen.
(e) *Chemical*: The dyed wool should be chemically stable, to give a high degree of color-fastness.
(f) *Hyacinthine*: The hue obtained should be a more bluish purple than *'argāmān*.

Although it may not be possible in practice to comply with each of these criteria in an unequivocal manner, it is necessary that an acceptable candidate for the *tĕkēlet*-shellfish should not be explicitly disqualified based on any particular criterion.

The Radzin Pigment

In 1888 Rabbi G. H. Leiner announced that he had restored the process for making ritual *tĕkēlet*, and he set up a dye house in Radzin, Poland, for that purpose. The color was produced in the chemical reactions that occur when sepia is treated with certain chemicals. His followers still wear such blue threads on their *ṣîṣit* (fringe, tassel, Num

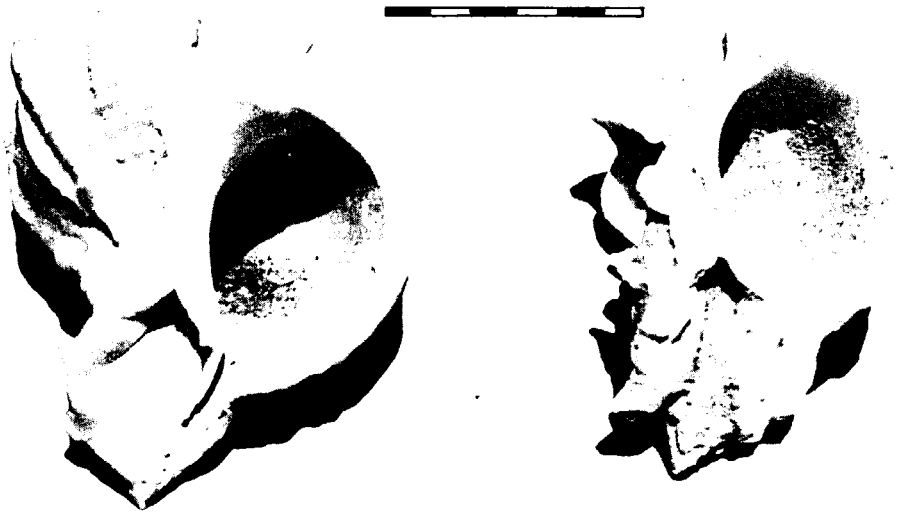

Fig. 2. A large intact *T. trunculus* shell, beside a fragment found at Israel Roll's excavations at Apollonia in a Persian stratum. The removed spine would expose the hypobranchial gland, permitting extraction of the chromogenic mucus.

15:38). However, since cuttlebones of the cephalopod have not been found in ancient dyeing sites, criterion *a* is not satisfied. Furthermore, chemical analyses (Herzog 1919; Spanier and Ziderman 1982; Ziderman 1981) have established that the coloring matter obtained was actually a cyanide salt of iron called Prussian blue, the first modern synthetic pigment, originally prepared in Berlin in 1704 with bullock's blood, and shortly thereafter with flesh or other animal matter (Coleby 1939). In 1749 Prussian blue was introduced in France for dyeing wool and silk. By 1890 when Leiner prescribed the use of Prussian blue from sepia as *těkēlet*, chemists had already prepared the inorganic pigment from cyanide without using any naturally-occurring material. The Radzin pigment is thus discredited as an authentic *těkēlet*, not only by virtue of criterion *d*, but also because a shellfish is not even a necessary source. Rabbinic authorities, too, have rejected the Leiner *těkēlet* for halachic reasons (Tykocinski 1970: 51–55; *Talmudic Encyclopaedia* 1976; Kaplan 1981: 92–95).

The Trunculus *Theory*

The key to our solution of the *těkēlet* problem is provided by the results of a thorough chemical study of gastropod purple dyes conducted by Fouquet (1970; Fouquet and Beilig 1971). In contrast to the presence of 6,6′-dibromoindigotin as the sole major colorant in *ʾargāmān* derived from the species (fig. 1) *B. brandaris, Th. haemastoma* and *Ocenebra* (*Murex*) *erinaceus*,[4] the bluish purple dye prepared from banded dye-murex, *Trunculariopsis* (*Phyllonotus*) *trunculus* was found (Bouchilloux and Roche 1954; 1955) to be a mixture of approximately equal amounts of 6,6′-dibromoindigotin and indigotin, the latter being a blue dyestuff.

With criteria *e* and *f* thus satisfied, Fouquet and Beilig (1971) concluded that *purpura hyacinthea*, the ancient *těkēlet*, was obtained preferably from *T. trunculus*. Dedekind (1898) apparently first proposed[5] that biblical *těkēlet* was derived from this species, which complies impressively with criterion *a* (Baker 1974; Born 1937; Bruin 1967; Forbes 1964; Jensen 1963). In fact, the largest extant Phoenician mound of its shells, all broken close to the gland, was found near Sidon in 1864, separated from a second pile that contained only the shells of *B. brandaris* and *Th. haemastoma*, surely a striking indication (Dedekind 1898; Herzog 1919; 1932) of separate dyeing sites for *těkēlet* and *ʾargāmān* on the shores where *těkēlet* was once manufactured (*Talmudic Encyclopaedia* 1976). According to this differentiation, the production centers in antiquity utilized the species available locally. Thus, in Lebanon, *T. trunculus* was employed

elsewhere in the Talmud (Bab. *Sota* 34b). This suggested meaning would represent the seven-month cycle for harvesting the sea snails that is recommended by Pliny (Forbes 1964: 120); this was demonstrated by Spanier (1981) in an experimental study of the marine biology of *T. trunculus*.

Having observed that some of the *T. trunculus* shells found in Tel Akko and Caesarea had drilled holes, Spanier and Karmon (1980) found under laboratory conditions that such holes were only drilled by cannibalistic conspecifics in the absence of alternative food. They consider this to indicate that the ancients maintained these snails in captivity, presumably until a sufficient quantity for dyeing had been accumulated.

Analytical Archaeometry of Těkēlet

Our success in establishing the identity of *těkēlet* prompted a reexamination of the published analyses of ancient purple textiles from the excavations at Palmyra (Pfister 1934; 1937; 1940) in the hope of finding mention of specimens dyed with a mixture of indigotin and 6,6′-dibromoindigotin. Hitherto such a finding would have been routinely assumed to indicate a double-dyeing with vegetable indigo and molluscan *ʾargāmān*. Our conclusions would provide an alternative interpretation of major importance; this would be the first discovery of an authentic remnant of *těkēlet* some 1700 years old.

Among the scores of specimens dyed with 6,6′-dibromoindigotin, Pfister reports only one (1937: 23, specimen No. L.41, woolen weft yarns colored bluish-violet) in which indigotin was also present. Pfister confirmed the necessary presence of a halogen (bromine) by a chemical reaction.

In Pfister's experiments (1937: 11) with live sea snails, *B. brandaris* yielded a reddish-violet dye containing a single component (6,6′-dibromoindigotin), while the bluish violet he obtained from *T. trunculus* comprised a mixture of 6,6′-dibromoindigotin with a second component that resembled indigotin. Thus Pfister anticipated later findings, but did not grasp their significance for *těkēlet*.

Pfister utilized the differential solubility of the dyestuffs in various liquids, a technique that gives only qualitative results. Various methods have since been described for the separate identification of indigotin and 6,6′-dibromoindigotin.[8] Indigotin may be detected by electron spin resonance spectrography (Bruin, Heinekin, and Bruin 1963; Bruin 1967), thin layer chromatography (Geiss-Mooney and Needles 1981; Masschelein-Kleiner and Maes 1970; Hofenk-de Graff 1974), ultraviolet/visible absorption spectrography[9] (Geiss-Mooney and Needles 1981) and infrared spectrography (Schweppe 1975). The techniques for identifying 6,6′-dibromoindigotin include photochemical debromination[10] (Driessen-Hengelo 1944; Schweppe 1975)[11] and absorption spectroscopy (Masschelein-Kleiner and Maes 1979). Abrahams and Edelstein (1964) have developed a method for separating indigotin and 6,6′-dibromoindigotin from dyed fabrics and then subjecting each chemical compound to infrared spectrography for positive qualitative identification.

A facile technique for directly identifying a mixture of indigotin and 6,6′-dibromoindigotin has now been demonstrated (M. Saltzman and I. Ziderman, unpublished). A solution of the sample in concentrated sulfuric acid is analyzed by visible absorption spectrophotometry to reveal its semiquantitative composition.

Since quantitative data on the relative proportions of indigotin, 6,6′-dibromoindigotin and accompanying minor ingredients in the dyes are required for a definitive chemical authentication of the presence of *těkēlet* in a specimen, plans are to develop an appropriate analytical procedure at the Israel Fiber Institute in Jerusalem. We have also conducted preliminary studies of a novel method for dyeing wool as *těkēlet*, using hypobranchial gland mucus of *T. trunculus* (cf. Elsner and Spanier, in press).

When chemical analysis of dyed textiles, colored pot sherds, and other items reveals the presence of a mixture of 6,6′-dibromoindigotin ("true Tyrian purple") with indigotin, a genuine *těkēlet* obtained from *T. trunculus* is indicated. A recent find in southern Israel has been examined accordingly.

Conclusions

The discovery of archaeological specimens dyed blue-violet with a mixture of indigotin and 6,6′-dibromoindigotin provides confirmatory evidence for the view that ancient *těkēlet* was prepared from *T. trunculus*.

The *trunculus* theory for the molluscan source of biblical *těkēlet* provides archaeometry and art conservation with new malacological and chemical criteria for an unequivocal differentiation between the biblical textiles *těkēlet* and *ʾargāmān*, which have hitherto frequently been confused with each other.

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NOTES

[1]In the context of *tôlaʿat šānī*, the word *šānî* has been erroneously rendered (Brunello 1973; Gerber 1978: 12) as "doubly dyed," allegedly alluding, by association, to the *diphaba* process used by Phoenicians in some purple dyeings. Its correct meaning is the red color ("scarlet" or "crimson") of the *kermes* dyeing.

[2]A purple-colored encrustation on pot sherds from 11th century B.C. Tell Keisan (Puech 1980: 226–27) has not yet been characterized chemically. For more on the archaeological evidence for the shell purple-dye industry, specifically dates and sites where it was conducted in the eastern Mediterranean, see Horn (1968), Reese (1979), Spanier and Ziderman (1982), and N. Karmon (Master's thesis, Center for Maritime Studies, Haifa University). In addition to the sites noted in the text, particular mention may be made of Tell Mor in Israel and Late Bronze Age Hala Sultan Tekke in southern Cyprus. The earliest site for purple-dyeing is located in MMIII/LMI Crete. D. S. Reese's analysis of the Sarepta shells is to appear in the forthcoming report on Sarepta by J. B. Pritchard.

[3]To explain the anomalous absence of indogotin in the purple from Sarepta, supposedly made from *Ph. trunculus*, McGovern and Michel (1984) speculate that this ingredient was removed from the dyebath by prolonged oxidation. However, this scenario is quite unlikely, because *inter alia* an effective reducing (vat) system is created in the dyebath due to the release *in situ* of mercaptans from the natural dye precursors (Elsner and Spanier, in press). Since the 6,6′-dibromoindigotin of Sarepta was not found on a textile but rather deposited on a vessel, it does not necessarily represent the dye composition of the bath liquor or of a dyed textile. A more acceptable interpretation would involve preferential deposition of 6,6′-dibromoindigotin, which is less soluble than indigotin.

[4]A much smaller creature yielding less dye, *O. erinaceus* is in fact quite rare in the Mediterranean basin, and is not known archaeologically from any of the dyeing locations. It was found at one Early Bronze Age site in Greece (D. S. Reese, personal communication).

[5]Venetian organic chemist B. Bizio is reportedly the first who proposed that *B. brandaris* gives Tyrian purple, while *T. trunculus* is the source of hyacinthine purple. (Grimaud de Caux and Gruby 1842).

[6]By way of comparison, another ancient animal-intensive textile product may be mentioned. During a recent visit to Tokyo, I learned that no fewer than *ten thousand* silkworm cocoons are required to provide the 3 kg of raw silk needed for weaving a single traditional kimono. An area of 2.6 acres of mulberry bushes is necessary to raise this number of worms.

[7]The ancients performed dyeing on unspun wool tops (Baker 1974; Yadin 1963: 182–87; Brunello 1973: 51), a practice documented for *tĕkēlet* both in the Bible (Exodus 35, compare vv 23 and 25; Herzog 1921) and in the Talmud (Bab. *Moed Qatan* 19a). The uneven dyeing obtained, due to differential affinity of indigotin and 6,6′-dibromoindigotin for wool, is thereafter conveniently masked on spinning.

[8]Mass spectrometry may be used to identify indigotin or 6,6′-dibromoindigotin. (O. N. de Wong, Master's thesis, Massachusetts Institute of Technology, 1977, has completed a study of pre-Columbian Andean textiles by this method.)

[9]Saltzman (1978) has pioneered the use of solution ultraviolet/visible absorption spectrophotometry for characterization of archaeological and ethnographic textiles, and was the first to identify 6,6′-dibromoindigotin in pre-Columbian Peruvian fabrics, demonstrating that these purple-dyeings were performed using one of the local species of muricid shellfish. He also proved that indigo, cochineal (an analog of *tôlaʿat šānî*), and an imitation-purple "*qĕlāʾîllān*" (indigo with a red dye) too were used in America two thousand years ago.

[10]It has now been suggested (Verhecken 1984; Elsner and Spanier, in press) that *tĕkēlet* was merely indigotin blue, as prepared by a photochemical debromination of the leuco-form of 6,6′-dibromoindigotin. This supposition can be refuted *inter alia* by recognizing that the Phoenicians could have achieved the same result more easily by using plant indigo directly (Ziderman 1985).

...chemical tests to distinguish *tĕkēlet* ... *Menahot* 42b) proves that *tĕkēlet* ... merely indigotin. Verhecken (1984) ...rmising that Judaism would have ...ation of a dye of vegetable origin on ... were actually required for *tĕkēlet*: th... ...diverse kinds (Deut 22:11) forbids onl... ...with linen (Ziderman 1985).

...ous application of the method of Driessen... ...44) has identified Tyrian purple in a microscopic specimen taken from the second-century Syrian "Cologne Fabric of the Three Kings" (Wagner 1982).

Note Added in Proof

V. Daniels (1985) has detected *tĕkēlet* in textile remnants 2000 years old.

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