

Indigoid Dyes in Peruvian and Coptic Textiles of The University Museum of Archaeology and Anthropology

RUDOLPH H. MICHEL

Museum Applied Science Center for Archaeology (MASCA), The University Museum of Archaeology and Anthropology, University of Pennsylvania, Philadelphia, Pennsylvania 19104

JOSEPH LAZAR

Central Research and Development Department, The Dupont Company, Wilmington, Delaware 19880-0228

PATRICK E. MCGOVERN

Museum Applied Science Center for Archaeology (MASCA), The University Museum of Archaeology and Anthropology, University of Pennsylvania, Philadelphia, Pennsylvania 19104

ABSTRACT In the ongoing investigation of indigoid dye processing in antiquity, the refinement of analytical techniques has played a crucial role in establishing the composition of the natural materials and of their chemical changes during dyestuff processing. High-resolution mass spectrometry has proven to be a particularly expeditious and precise technique for positively identifying indigoid dyes of molluscan origin, including purple 6,6'-dibromindigotin and blue indigotin.

The analysis of seventeen Peruvian and Coptic textiles in the collections of the University Museum of Archaeology and Anthropology reveals that purple dyeing was practiced over long time spans in both the Old and New Worlds. Moreover, refined analytical methods enable combinations of indigoid dyes to be ascribed to specific molluscan species, which have specific geographic distributions around the world. A combination of three indigoid dyes in one of the Peruvian fibers is very similar to the glandular secretions of a Pacific molluscan species, *Concholepas concholepas*. *Murex trunculus*, a Mediterranean mollusk whose secretions produce a mixture of the same three indigoids, is the probable source of purple in one of the Coptic textiles. This purple is the first chemically attested instance of molluscan indigoid dyes in museum collections of Coptic textiles; more often, purple was achieved by combining blue and red dyes from separate plant and insect sources or by spinning together separately dyed blue and red fibers to give the appearance of purple.

INTRODUCTION

Our interest in the ancient Mediterranean Purple dyeing industry (Michel and McGovern 1987a; 1987b; 1990; McGovern and Michel 1985; 1990) has gradually led to the development of analytical techniques with greater sensitivity, thus making it easier to detect and identify indigoid dyes. At present, high-resolution mass spectrometry is our instrumental method of choice, since it best satisfies these needs (McGovern, Lazar, and Michel 1990; 1991; Michel, Lazar, and McGovern, forthcoming). The Peruvian and Egyptian Coptic textile collections of the University Museum of Archaeology and Anthropology provided an excellent resource for extending

our studies of the cultural and technological significance of indigoid dyeing.

Indigoid dyes were used long before their synthesis by nineteenth- and twentieth-century chemists, and were among the most ancient and renowned of dyes (Brunello 1973: 13-14, 28-31). The blue dye, indigotin (Fig. 1), was obtained in antiquity by the fermentative processing of certain plants. In ancient India, the art of dyeing textiles with *Indigofera tinctoria* was already highly developed. Here and in other Eastern equatorial countries, *Indigofera tinctoria* was also processed into a blue powder, which was exported to the Mediterranean world and Europe. Until the Renaissance, it was primarily used in the West as a pigment (e.g., in fresco paintings), rather than as a

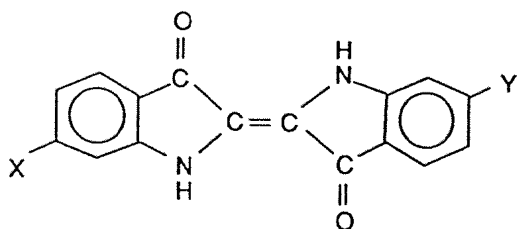


Fig. 1. Indigoid structures: Indigotin, X=Y=H; 6,6'-dibromoindigotin (DBI), X=Y=Br; 6-bromoindigotin (MBI), X=H, Y=Br



Fig. 2. *Murex trunculus*. (Reprinted from Besnier 1877-1919, Vol. 4: 770, fig. 5887)

textile dye. The woad plant (*Isatis tinctoria*), which grows in Europe, Asia, and northern Africa, was another widely available source of indigo, and the technology for using it in textile dyeing was known in Europe. These textiles, however, were inferior to imports dyed with *Indigofera tinctoria*, and the use of woad was eventually terminated (Brunello 1973: 144-145).

In the New World, fermentative dye baths from *Indigofera suffruticosa* (Stone 1949) for extracting and dyeing with indigo were employed in pre-Columbian times (Saltzman 1963; 1978; cf. Martoglio et al. 1990: 1125A). Interestingly, here too, indigo served as a pigment, as well as a dye; Maya Blue, an indigo-clay composite (Kléber, Masschelein-Kleiner, and Thissen 1967; Roundhill, McGovern, and Michel, forthcoming), was the main blue colorant in Mayan frescoes (de Henau et al. 1966) and was also applied to vessels and masks.

A second indigoid dye, purple 6,6'-dibromoindigotin (DBI; Fig. 1), which is sometimes violet in color when combined with indigo, is obtainable only from certain marine mollusks in the Old and New Worlds. It is, of course, best known for its association with the ancient Phoenicians of the first millennium B.C. (and their predecessors, the Canaanites), who as mariners traveled throughout the Mediterranean and set up dyeing works in many of their colonies (Reese 1979-1980).

Three Mediterranean molluscan species of the *Murex* and *Purpura* genera (see McGovern and Michel 1990: fig. 2) were exploited by these peoples in making Royal or Tyrian Purple. One species, *Murex trunculus* (Fig. 2), is of special interest because it naturally produces a mixture of indigo,

6-bromoindigotin (MBI; Fig. 1), and DBI which is violet in color (the relative amount of each dye varies depending on sex, possibly season of the year, and other factors; see McGovern, Lazar, and Michel 1991; Michel, Lazar, and McGovern, forthcoming). MBI, like DBI, occurs naturally primarily in this species.

After extracting the dye precursors from the hypobranchial glands of the mollusks, the secretions had to be exposed to light and air for full development of the dyes (McGovern and Michel 1990; also see Baker 1974; Fouquet and Bielig 1971). The description of the dyeing process in the writings of the Roman scholar Pliny the Elder suggests that the molluscan dyes were made fast to textiles by vat dyeing, i.e., reduction of the dye to the soluble leuco form, and then reoxidation to the water-insoluble dye, which is entrapped in the textile fibers. How much earlier than the Roman period vat dyeing was practiced is not known, but Pliny credits the Phoenicians with the discovery of the dye. Because of the poor yield of the dye from the animals (for one gram of Purple, as many as 10,000 glands must be extracted) and because of the expertise needed to produce a fast dye, Purple in particular was very costly, and its use in clothing was eventually restricted to high religious and political leaders.

In the New World, related species of mollusks were also exploited for purple and violet dyes. The glands of *Purpura patula pansa*, which occurs along the Pacific shores of central America (Gerhard 1963), and of

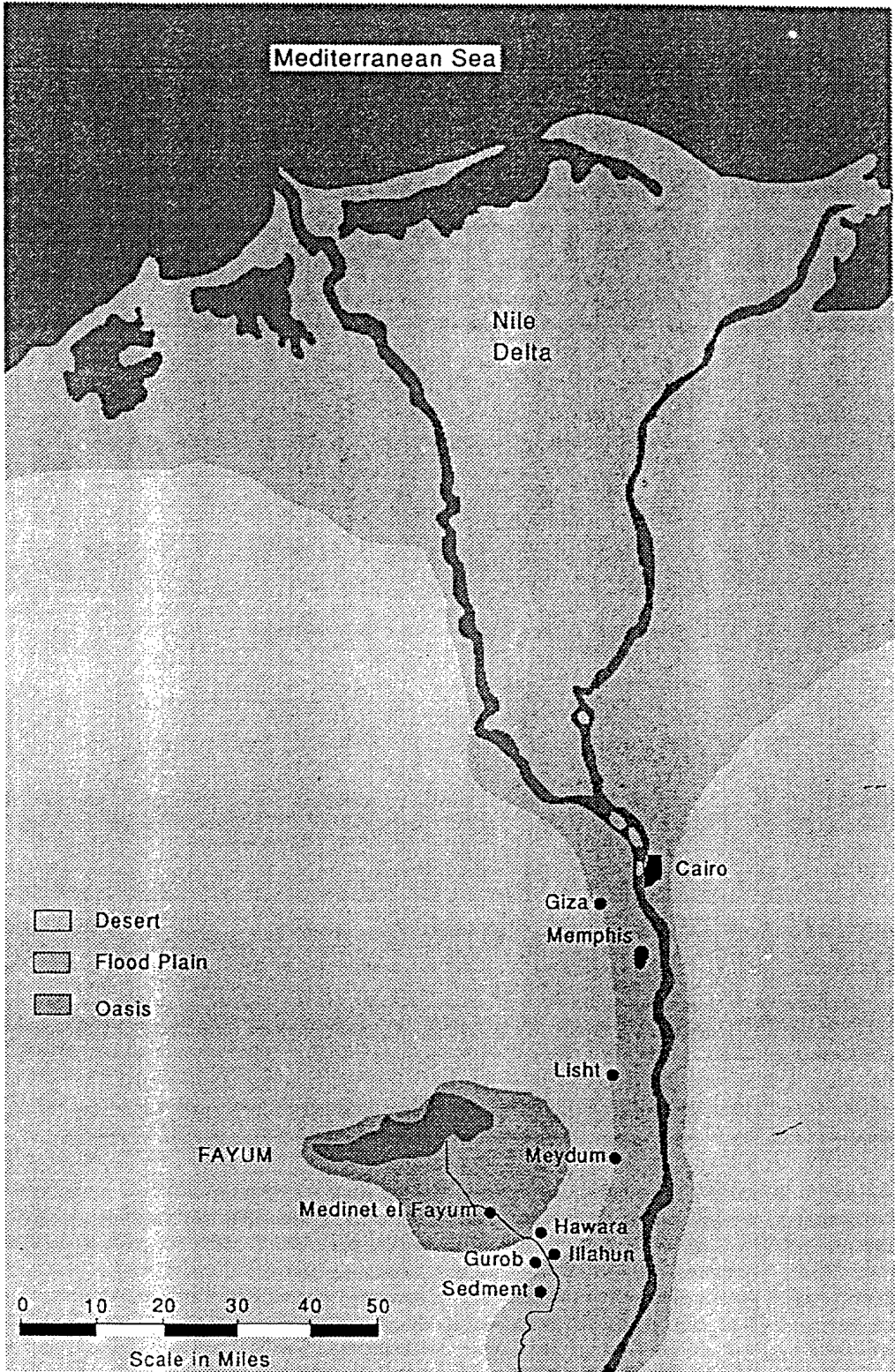


Fig. 3. Middle and Upper Egypt, showing the Fayum region

TABLE 1. University Museum textiles analyzed

Museum no.	Description	Color of fiber		Color of dimethyl sulfoxide (DMSO) solution	Mass spectrum bands (M/Z; order of decreasing strength)
		Under fluorescent lighting	Under natural lighting		
Egyptian Coptic textiles					
E16884	Bottom of skirt, with angle band and knee roundels. Design of human figures, dogs, other animals, plants, and geometric designs. Wool. Warp 1.0 m. x weft 0.64 m. Ca. 8th-9th c. A.D.	violet/purple	purple	very light greenish blue	262 (weak)
E17093C	Fragment. Bands with stems and sprouting spade leaves paired, one on either side. Wool (violet) and linen. Warp 0.445 m. x weft 0.47 m. Ca. 3rd-4th c. A.D.	dark violet	violet	blue	262,340,418
E17094	Tunic fragment. Roundel with disc, dot, cross, and vegetation designs. Wool (purple) and linen. Warp 1.15 m. x weft 1.175 m. Ca. 3rd-4th c. A.D.	purple	reddish	very light blue	262
Peruvian textiles (Pachacamac)					
29758a (Uhle 385e)	Fragment. Plain weave with zoomorphic design patterned by discontinuous supplementary wefts. Purple-"painted" checkerboard surrounding zoomorphic motifs. Cotton plain weave and supplementary wefts of wool. Cemetery I. Probable first half of Late Intermediate Period.	purple	purple	blue	420?
29801 (Uhle 999)	Spindle pouch. Warp-faced plain weave with warp stripes. Cotton and wool warp and cotton weft. Cemetery I. Probable first half of Late Intermediate Period.	purple	purple	blue	418,262,340
29911 (Uhle 1090a)	Border fragment. Geometric design. Slit tapestry. Cotton. Beneath temple. Middle Horizon/2B-Late Intermediate Period 2.	purple	reddish brown	brown	—
29964b (Uhle 1264p)	Fragment. Geometric design with zoomorphic motifs. Slit tapestry. Cotton warp and wool weft. Miscellaneous context. Uncertain date.	purple	reddish brown	brown	—

Concholepas concholepas and *Thais chocholata*, found along the west coast of South America (Saltzman 1963; 1978), are most likely to have been used. These animals were a major food source in antiquity, as attested by midden heaps and pits which included shells of these species that are associated with pre-Columbian sites dating as early as 1800 B.C. (Quilter et al. 1991; Bird 1985).

In exploiting the mollusks for food, the unusual and intense coloration of the light- and air-developed glandular secretions and their suitability for dyeing would have been readily appreciated. In all likelihood, dyeing processes using the molluscan secretions might then have been independently discovered in the New World. Some scholars (Nuttall 1909: 380-384; Born 1937; Ger-

TABLE 1. *Continued*

Museum no.	Description	Color of fiber		Color of dimethyl sulfoxide (DMSO) solution	Mass spectrum bands (M/Z; order of decreasing strength)
		Under fluorescent lighting	Under natural lighting		
29980b (Uhle 3229b)	Fragment. Geometric design with zoomorphic motifs. Slit tapestry. Cotton warp and wool weft. Miscellaneous context. Uncertain date.	purple	reddish brown	brown	—
30253 (Uhle 2039)	Fragment. Warp-faced plain weave with warp stripes. Cotton warp and wool weft. Cemetery I. Probable first half of Late Intermediate Period.	purple	reddish brown	brown	—
30396 (Uhle 2104g)	Fragment. Alternating colored stripes on plain ground. Slit tapestry. Cotton and wool. Cemetery II. Probable first half of Late Intermediate Period.	purple	reddish brown	brown	—
CG852008-123	Fragment. Geometric design. Cotton. Miscellaneous context. Uncertain date.	purple	reddish brown	brown	—
Peruvian textiles (Nasca)					
SA 3658	Shawl. Plain weave with geometric design on knit fringed border. Cotton and wool. Probable Early Intermediate Period 3-4.	violet/purple	violet/purple	reddish-brown	—
SA 3659	Shawl fragment. Gauze with embroidered border with anthropomorphic design. Cotton gauze and wool border. Probable Early Intermediate Period 3-4.	violet/purple	violet/purple	violet	262
SA 3660	Shawl. Gauze with embroidered border with elaborate floral and zoomorphic design. Cotton gauze and wool border. Probable Early Intermediate Period 3-4.	violet/purple	violet/purple	violet	262
Peruvian textiles (Huaca Paraiso)					
33729 (Uhle 3488d)	Fringed border fragment. Diagonal stripes. Slit tapestry. Wool. Uncertain date.	purple/violet	purple/violet	reddish brown	—
33838 (Uhle 901b)	Fragment. Plain weave with supplementary wefts with geometric and zoomorphic motifs. Cotton plain weave and supplementary wefts of wool. Uncertain date.	violet	lavender	colorless	262?

hard 1963: 179-180; 1964: 28) have argued that molluscan dyes in Peru eventually were imbued with symbolic import and became the prerogative of the ruling and priestly classes.

SAMPLE SELECTION

The Coptic and Peruvian textiles in the collections of the University Museum were

chosen for analysis on the basis of their colors (Table 1) using the available fluorescent lighting in the storerooms. Because of metamerism (i.e., different human perceptions of color under different lighting conditions), the colors were later examined in the laboratory under natural lighting.

A limitation of our study is that many of the textiles in the collections were not sci-

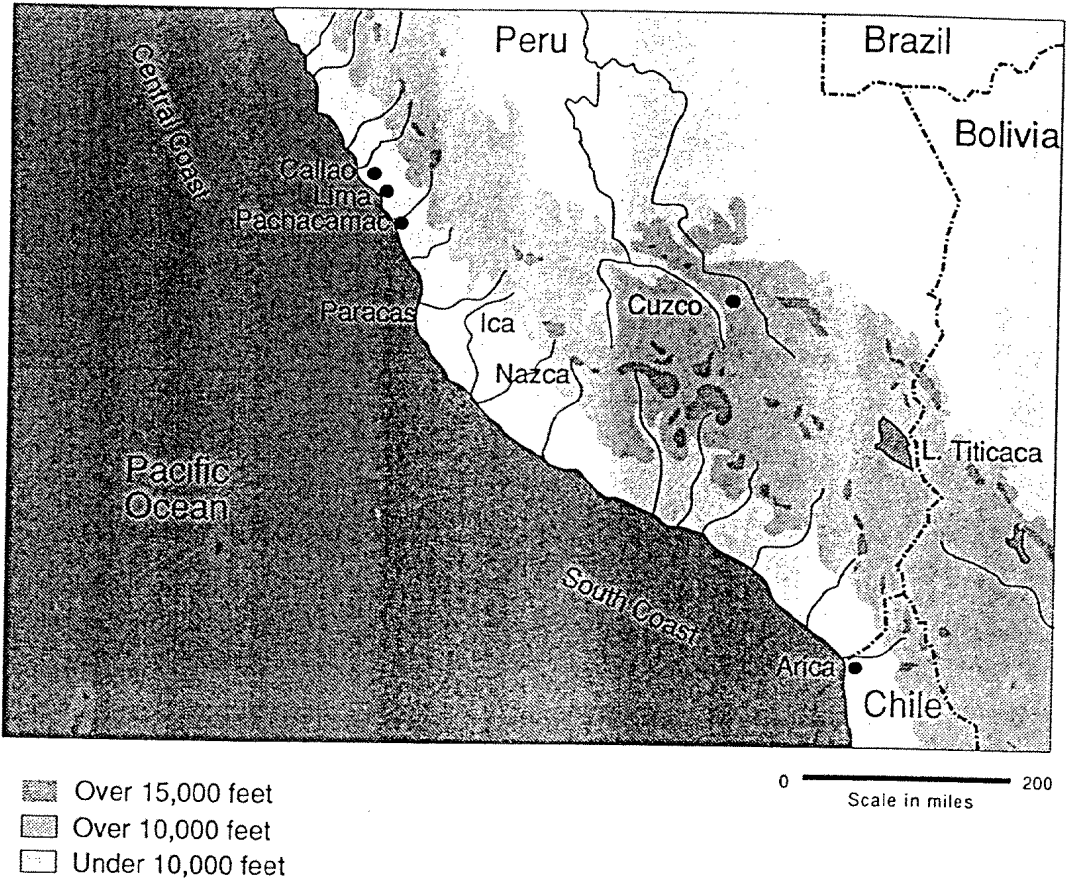


Fig. 4. Central Peru, showing sites mentioned in the text

entifically excavated, so that their precise dating and archaeological context are uncertain. In the case of the Coptic textiles, they were purchased by Sir Flinders Petrie at Illahun, Hawara, and other towns and sites in the Fayum area of Egypt (Fig. 3) and were most likely recovered from somewhere in this area. Louisa Bellinger of Dumbarton Oaks fully described the textiles included in this study according to material, dye color, direction of yarn spinning, and artistic design (Table 1). The relative dates for the Coptic textiles were assigned on art historical grounds. Even the "Coptic" origin of some examples is questionable because they include Islamic motifs.

The textiles from Pachacamac, Peru (Fig. 4), are from the 1896 excavations by Max Uhle at this south central coastal site (see also VanStan 1967). The most interesting

examples were excavated beneath the Pachacamac temple and in Cemeteries I and II. According to Ann P. Rowe (personal communication, 6 December 1991), the textiles from beneath the temple date most probably between Middle Horizon 2B and Late Intermediate Period 2, and those from Cemeteries I and II belong to the earlier half of the Late Intermediate Period. These assessments are based primarily on the styles of the textiles and to some extent on their archaeological context (also see Rowe and Rowe 1970; Rowe 1979). According to the chronological chart by Shimada (1991: XVII), the Middle Horizon dates to ca. 550–900 A.D. and the Late Intermediate Period to ca. 900–1476 A.D. Ornately decorated examples from miscellaneous contexts, such as nos. 29964b (Uhle 1264p) and 30396 (Uhle 2104g), are unfortunately of uncer-

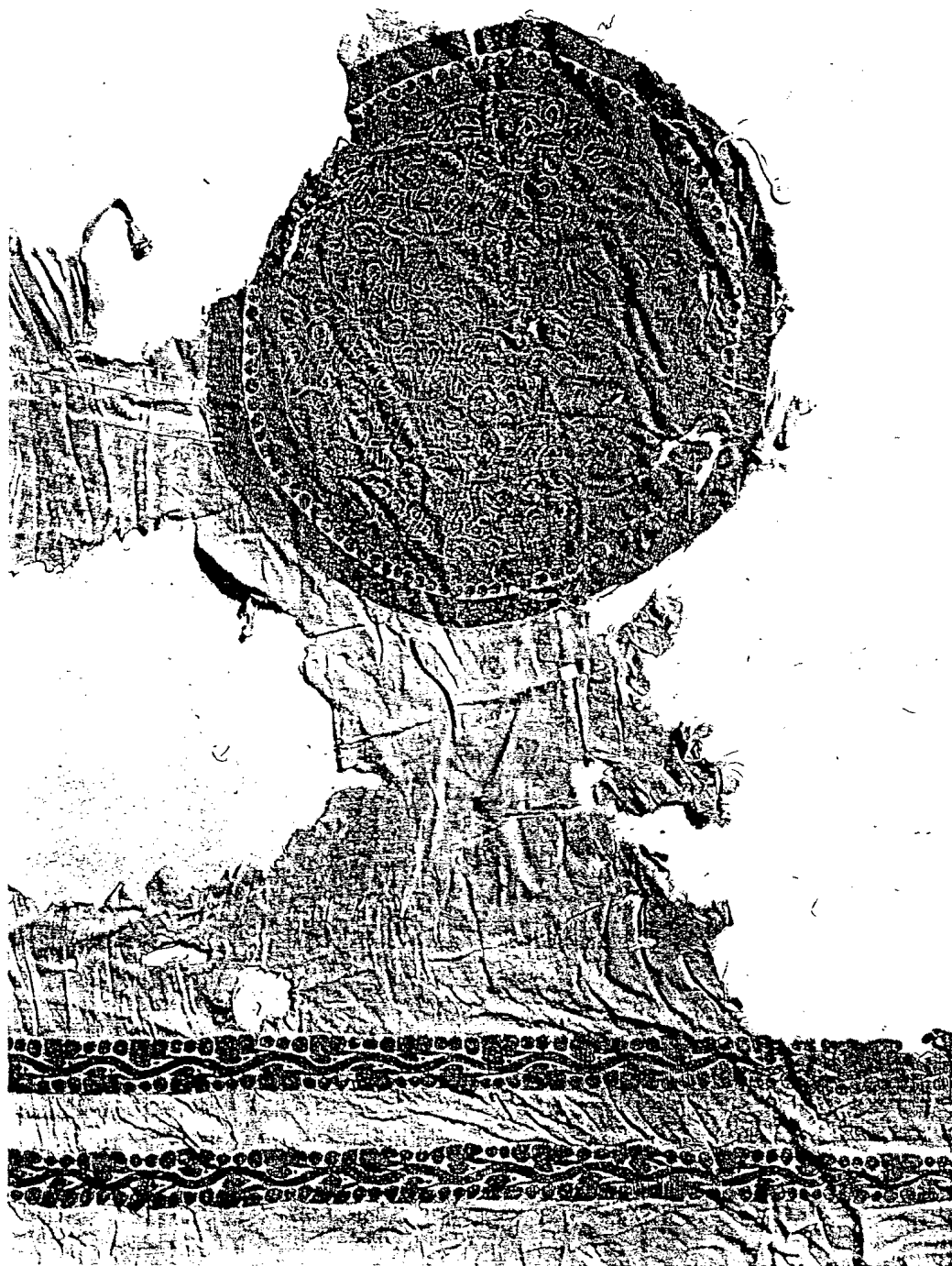


Fig. 5. Coptic textile no. E17094. (Photograph courtesy The University Museum of Archaeology and Anthropology)

tain date, but have a *terminus post quem* of Middle Horizon 2, the earliest period clearly represented in the Uhle corpus.

The Huaca Paraiso and Nasca textiles

are not from controlled excavations, having been either excavated or purchased by Max Uhle in 1896 and William C. Farabee in 1922-1923, respectively. Their dating by

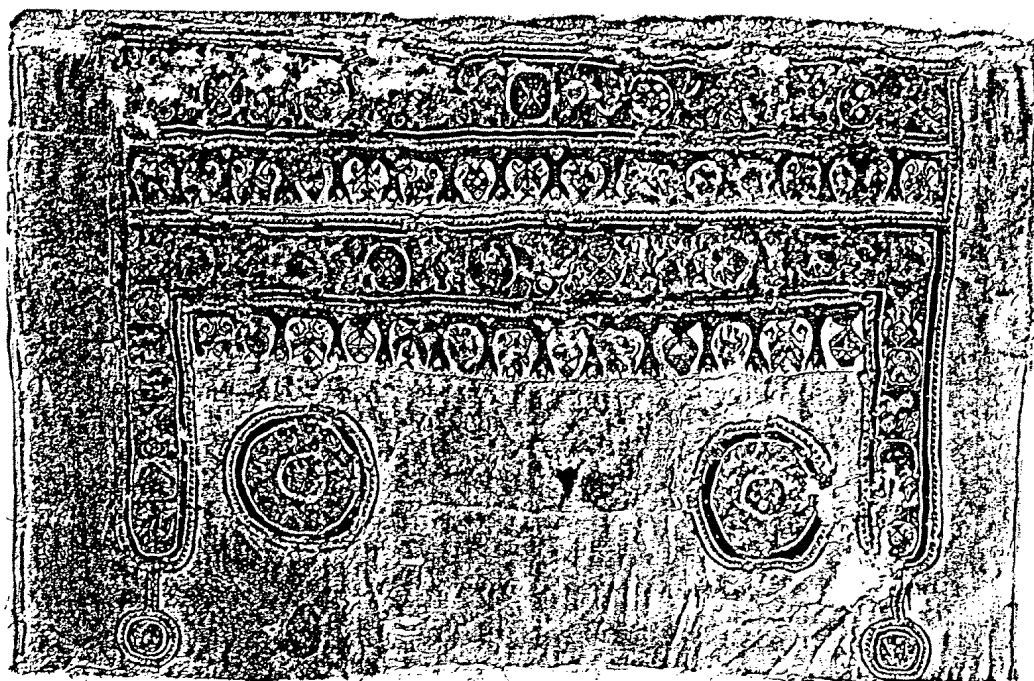


Fig. 6. Coptic textile no. E16884. (Photograph courtesy The University Museum of Archaeology and Anthropology)

Ann Rowe (personal communication) is again based on art historical considerations, some associated artifacts, and inferences from notes in Uhle's "packing list" and Farabee's "field records." The Nasca period textiles are most plausibly assigned to the Nasca 3-4/Early Intermediate Period 3-4 (the approximate dates for this period are 400 B.C.-550 A.D.; see Shimada 1991), and probably belong to a single grave lot. Because the analyzed textiles from Huaca Paraiso have not been closely examined by Ann Rowe, they are listed as being of uncertain date in Table 1. Notes by Uhle, however, indicate that some of the material found at the site dates to the Late Horizon (post-A.D. 1476).

Hundreds of textiles were examined for violet and purple colorations in the Coptic and Peruvian collections. Of these relatively few candidates for analysis were discovered; the analyses of those chosen are reported here. Minimally, we hoped to provide chemical evidence for the exploitation of molluscan indigoid dyeing over extended time periods in the Old and New Worlds.

On the basis of the analytical results, hypotheses about the molluscan sources of the dyes and the level of technological expertise needed to dye the textiles were also developed, which can be tested by future analyses of better-provenanced and better-dated material.

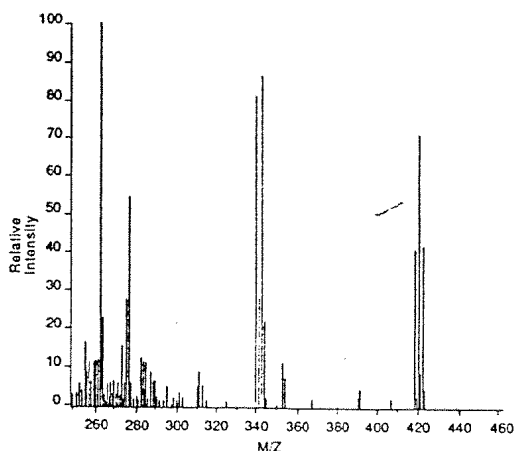


Fig. 7. Mass spectrum of violet dye from Coptic textile no. 17093c, recovered from DMSO solution

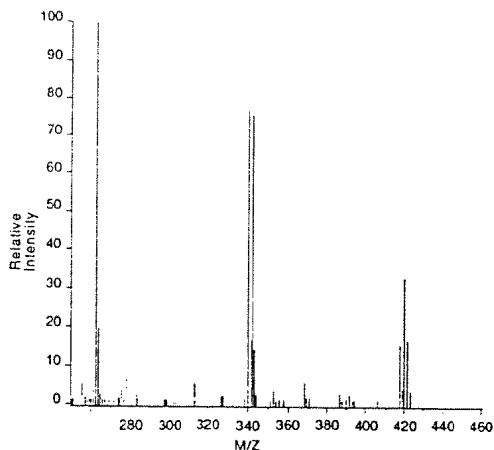


Fig. 8. Mass spectrum of dye from *Murex trunculus* glandular secretions, after full exposure to sunlight, recovered from DMSO solution

MASS SPECTROMETRIC ANALYSIS

The mass spectrometric analytical procedures have been described in detail elsewhere (McGovern, Lazar, and Michel 1990; 1991; Michel, Lazar, and McGovern, forthcoming). In brief, the indigoid dyes in the textile fibers are extracted with hot di-

methyl sulfoxide (DMSO). The solutions are transferred to melting point capillary tubes, and the solvent evaporated under vacuum. The tubes with samples are inserted into the mass spectrometer probe, and vaporized at temperatures of up to 400°C. Accurate mass measurement of the indigoids at a resolving power of $M/\Delta M = 10,000$ (10% valley) is possible. It was found that a minimum of 3–4 mg. of fiber, usually about 1 cm. in length, is required for definitive results.

Of the three Coptic fibers (Table 1; Figs. 5, 6), which appeared to be violet or purple, two showed only indigotin in their spectra. This result is not surprising, since Egyptian alchemical texts of the third century A.D., which probably incorporate earlier Hellenistic traditions, speak of duplicating purple or violet colors by mixing blue and red dyes from different sources (see Papyrus Leidensis—Berthelot 1887, and Papyrus Graecus Holmiensis—Lagercrantz 1913; also see Forbes 1964). The blue indigo is said to have been derived from woad. The red, whether derived from kermes (ker-

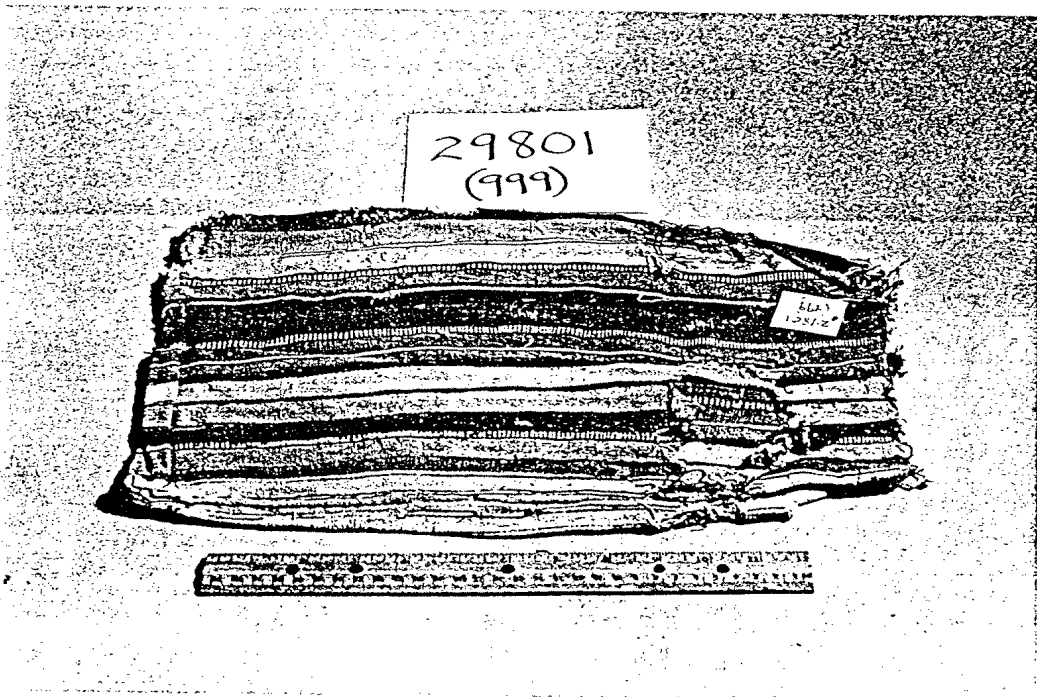


Fig. 9. Pachacamac textile no. 29801 (Uhle 999). (Photograph courtesy The University Museum of Archaeology and Anthropology)

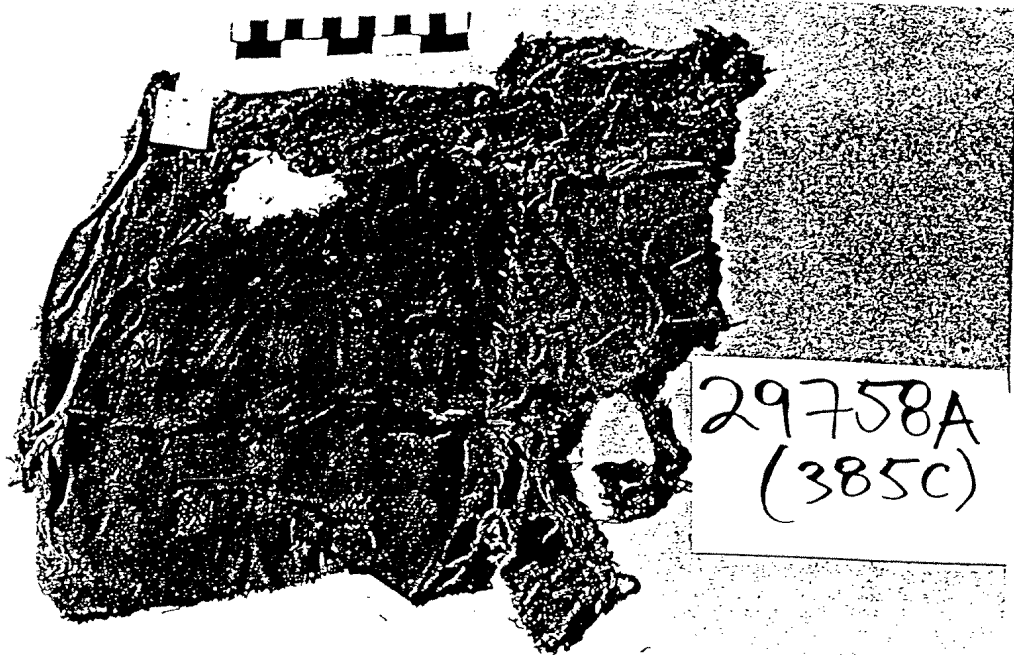


Fig. 10. Pachacamac textile no. 29758a (Uhle 385e). (Photograph courtesy The University Museum of Archaeology and Anthropology)

mesic acid) or from madder (alizarin), is not detected by mass spectrometry. It was not necessary to analyze the purple of a tunic fragment (no. E1443G-I), which probably dates from about the sixth or seventh century, because the color was achieved by spinning together separately dyed blue and red fibers, which were indistinguishable to the unaided eye.

Three indigoid dyes—indigotin, MBI, and DBI—were present in a Coptic textile fiber (no. E17093c) which is dated to the third or fourth century A.D. The relative amounts of the three indigoids, as seen in the characteristic mass spectrum of Figure 7 (indigotin [M/Z = 262], MBI [M/Z = 340,342], DBI [M/Z = 418,420,422]), indicates that hypobranchial gland secretions of *Murex trunculus* are very probably the source of the dyes (Fig. 8; McGovern, Lazar, and Michel 1991; Michel, Lazar, and McGovern, forthcoming). To our knowledge, this is the first time that a molluscan purple in a Coptic textile has been definitely identified by physicochemical analysis.

Turning to the New World, eight Pachacamac textile fibers (refer to Table 1; Figs.

9, 10), mostly from burial contexts and dating broadly between A.D. 600 and 1200, were analyzed. Six examples, which were reddish brown in natural lighting, showed no evidence of indigoids. Their DMSO solutions were uniformly brown in color.

Two Pachacamac samples were purple under both fluorescent and natural light-

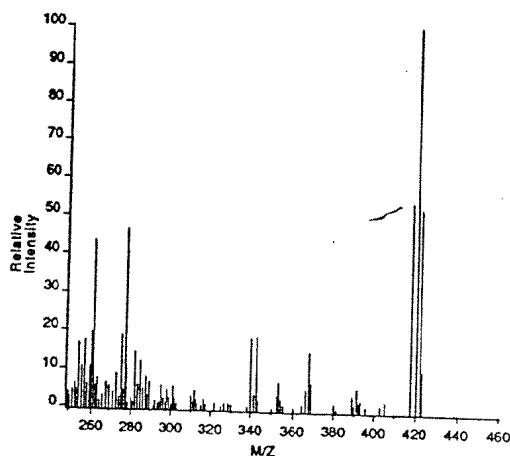


Fig. 11. Mass spectrum of purple dye from Pachacamac textile no. 29801 (Uhle 999), recovered from DMSO solution

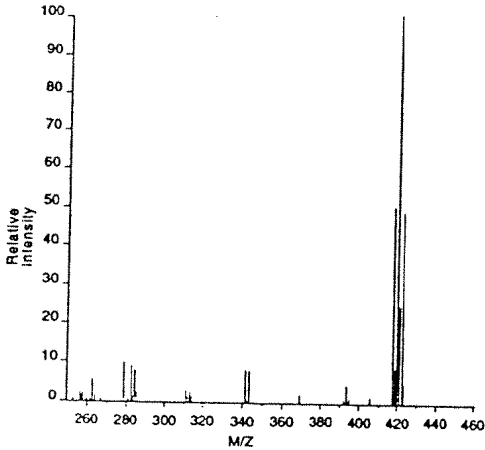


Fig. 12. Mass spectrum of dye from *Concholepas concholepas* glandular secretions, after full exposure to sunlight, recovered from DMSO solution

ing. As for the Coptic fiber which contained a combination of three indigoid dyes, their DMSO solutions were blue. One of these fibers (no. 29801, Uhle 999; Fig. 9) was in fact a mixture of the same three indigoids (Fig. 11). The sample was undoubtedly dyed

with molluscan secretions. The location of Pachacamac along the south central Pacific coast, about 30 km. south of Lima, is close to the area where *Concholepas concholepas* is plentiful, i.e., south of Callao, Peru (Marincovich 1973; Dall 1909). A sample of the hypobranchial gland secretions from living specimens, collected by Antuñez de Mayolo in 1977 and provided to us by M. Saltzman, gave a mass spectrum (Fig. 12) that clearly shows the presence of all three indigoids. Like textile no. 29801, the relative amounts of MBI and indigotin are less than that for DBI (in contrast to Figs. 7, 8, for the Coptic textile and *Murex trunculus*). Many more examples of molluscan secretions and textiles, however, would have to be tested before statistically valid comparisons can be made.

The purple warp fibers comprising Pachacamac textile no. 29801 had clearly been dyed before they were woven, since they were dyed uniformly around their circumference while the weft remained undyed. Furthermore, a much higher concentration

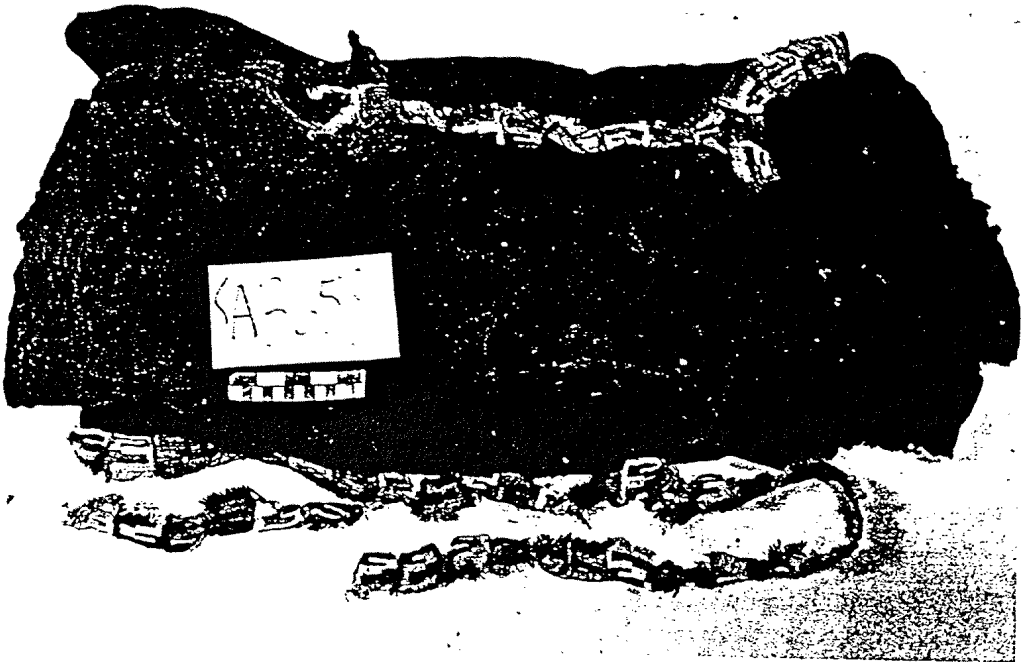


Fig. 13. Nasca textile no. SA3658. (Photograph courtesy The University Museum of Archaeology and Anthropology)

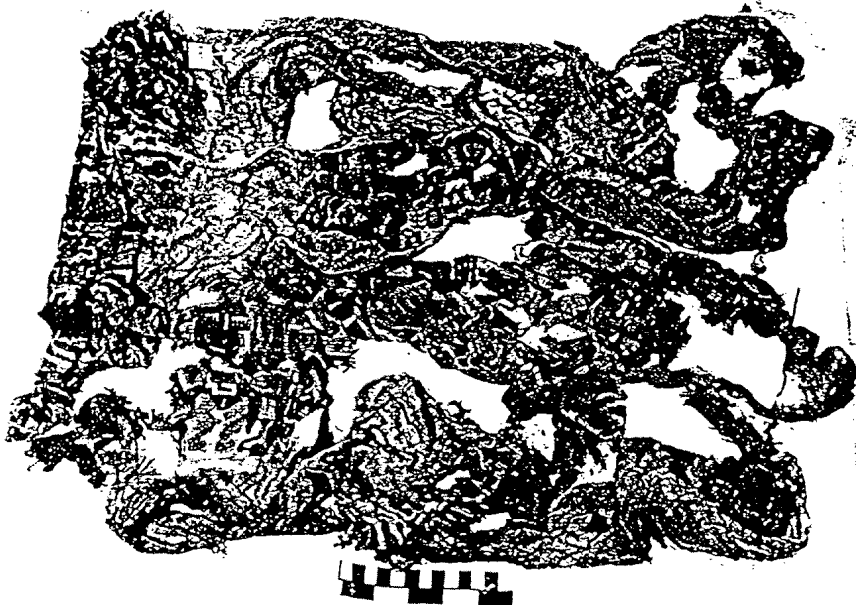


Fig. 14. Nasca textile no. SA3659. (Photograph courtesy The University Museum of Archaeology and Anthropology)

of the purple dye on the surfaces of the fibers as compared to their cross sections indicates that the glandular secretions were not processed for vat dyeing but were smeared onto the fibers, as has been observed in twentieth-century Mesoamerica (Nuttall 1909; Born 1937; Gerhard 1963; 1964). Cross sections of the red, blue, and green fibers were dyed throughout.

The second purple Pachacamac textile fiber (no. 29758a, Uhle 385; Fig. 10), although appearing purple and giving a blue DMSO solution, had only a weak, inconclusive DBI band ($M/Z = 420$). It is possible that too small a sample was analyzed, and that more material is required to show the bands for the three indigoids. A reduced amount of purple dye is probably due to the painting or smearing onto the fabric of the glandular secretions. Possibly, less dye was originally applied, or the nonfast dye was worn off or washed out.

The three Nasca area fibers (Figs. 13, 14) all appeared purple, with a tinge of violet or bluish coloration, under fluorescent and natural lighting. Only two of the samples, however, tested positively for an indigoid, and this was indigotin. Evidently, a reddish

dye not detected in the mass spectrometer was mixed with the blue dye to give the violet purple. Similar dye mixtures, the blue deriving from plant sources and the red from cochineal and/or reibunium, were recorded by Saltzman (1978) in Paracas textiles. The third Nasca fiber (no. SA 3658) showed no indigoid; the reddish brown DMSO solution, which correlates with the absence of indigoids, supports this finding.

Only one of the Huaca Paraiso fibers (no. 33838, Uhle 901b) showed a very weak and questionable indigotin ($M/Z = 262$) band. A mixture of blue and red dyes to yield a violet or lavender color is possible. The second sample gave a reddish brown DMSO solution, and a mass spectrum lacking indigoids.

CONCLUSIONS

The refinement of analytical techniques for detecting indigoid dyes in well-preserved textiles has one very obvious advantage. These dyes can now be rapidly and relatively nondestructively analyzed for, so that the time range and extent of their use in various parts of the world can be readily assessed. Beyond this objective, which also

depends on the recovery of well-dated and well-provenanced textiles, refined techniques also hold out the possibility that the dyes can be inferred to derive from specific natural sources, as we have proposed for the Peruvian and Coptic purples which contain a combination of three indigoid dyes. A data base of the indigoid dye compositions of molluscan species around the world is gradually being built up from which comparisons can then be made to ancient dyes. For example, *Purpura haemastoma*, a Mediterranean species, and *P. patula pansa*, a New World species, sometimes show minor amounts of indigotin and MBI. The secretions of *Thais chocolata*, a more common food source than *Concholepas concholepas* in modern Peru, is yet to be characterized.

The processing of molluscan dye extracts, especially in the New World, was only touched upon in the foregoing discussion. In view of the fact that fermentative vat dye baths were used for indigo, in combination with other dyes (e.g., cochineal and relbunium), the possibility remains that vat-dyeing of molluscan purple might have been developed. We have discussed the archaeological, historical, and chemical evidence for the hypothesis of vat dyeing in the Mediterranean world of the Roman period and earlier (Michel and McGovern 1987a; 1987b; 1990). Closer study of a chronological sequence of Peruvian textiles, using a range of microscopic and microchemical

techniques, might reveal a gradually evolving, more sophisticated industry.

The presently available evidence, however, indicates that only direct application of molluscan purple secretions to skeins of yarn was practiced in the New World. The earliest date for direct dyeing is the Early Horizon 9-Early Intermediate 1 in the Ocucaje region of Peru (Saltzman 1978; A. P. Rowe, personal communication; ca. 500–300 B.C., according to the chronological chart in Shimada 1991). As reported here, direct dyeing is also attested in nearby Pachacamac over a thousand years later during the first half of the Late Intermediate Period. In Mesoamerica, this simple technique has been documented for the early twentieth century (Nuttall 1909). Thus, because of the perpetuation of direct dyeing with molluscan secretion, one could argue that New World dyeing with molluscan indigoid dyes was never complex.

We have focused our attention on molluscan indigoid dyes. Many investigators (Fester 1940; Saltzman 1978; Schweppe 1986; Martoglio et al. 1990), using thin-layer chromatography, UV-visible and infrared spectroscopy, and other techniques, have shown that the ancient Peruvians exploited a wide variety of other plants and animals in their environment to produce natural dyes. Many of these dyes were mordanted to natural fibers (cotton, alpaca, and llama hair, etc.) by naturally occurring aluminum- and iron-containing minerals.

Acknowledgments

The extension of our indigoid dye studies to the New World was kindled and nourished in innumerable ways by Dr. Max Saltzman. As a small token of our appreciation to a master dye chemist, we would like to dedicate this article to Max. Any errors of fact or judgment, however, are solely the responsibility of the authors.

Robert Robertson of the Academy of Natural Sciences in Philadelphia apprised us of the most recent malacological research in the New World. We are especially grateful to Ann P. Rowe of the Textile Museum for her advice in dating the Peruvian textiles. Clark L. Erickson, Assistant Curator in the American Section, and Kay Candler, a Research Associate in the American Section of the University Museum, also advised us on many fine and not so fine details of Andean and Mesoamerican archaeology. Michael Bassinet of the University Museum and Hero Granger-Taylor of the British Museum helped us assess the dating and cultural significance of the Coptic textiles. Allesandro Pessati, a Research Archivist, and Douglas Haller, the Archivist of the University Museum, enabled us to examine Max Uhle's unpublished notebooks of the Pachacamac excavations.

We also thank Pamela Roth and Cihan Gürol, who had the arduous but important task of searching through the thousands of Peruvian textiles for that rare violet or purple. Lucy Fowler-Williams, Keeper of the American Section, has provided detailed descriptions of the textiles discussed here. Drs. David O'Connor and David Silverman, Associate Curators of the Egyptian Section of the University Museum, Pamela A. Hearne, Coordinator of Museum Services, and Lucy Fowler-Williams very kindly allowed us to examine, sample, photograph,

and otherwise document the Coptic and Peruvian textiles in their care. Virginia Greene, Conservator at the University Museum, assisted in the sampling process. The map graphics were ably prepared by Mary Brush of MASCA.

Al Bolinski of The Dupont Company is especially to be thanked for his continued assistance in the processing of mass spectrometric samples.

REFERENCES

- Baker, J. T.
1974 Tyrian Purple: An Ancient Dye, A Modern Problem. *Endeavor* 33: 11-17.
- Berthelot, M. P. E.
1887 *Collection des anciens alchimistes grecs*. G. Steinheil, Paris.
- Besnier, M.
1877-1919 *Dictionnaire des antiquités grecques et romaines*, edited by C. Daremberg and E. Saglio. Hachette, Paris.
- Bird, J. B.
1985 *Preceramic Excavations at Huaca Prieta*. American Museum of Natural History, New York.
- Born, Wolfgang
1937 The Use of Purple among the Indians of Central America. *Ciba Review* 4: 124-127.
- Brunello, Franco
1973 *The Art of Dyeing in the History of Mankind*, translated by Bernard Hickey. Neri Pozza, Venice.
- Dall, William H.
1909 Report on a Collection of Shells from Peru, with a Summary of the Littoral Marine Mollusca of the Peruvian Zoological Province. *Proceedings of the U.S. National Museum* 37: 222.
- Fester, G. A.
1940 Les Colorantes del antiguo Peru. *Archaeion* 22: 229-241.
- Forbes, R. J.
1964 *Studies in Ancient Technology*, Vol. 4. E. J. Brill, Leiden.
- Fouquet, H. and H.-J. Bielig
1971 Biological Precursors and Genesis of Tyrian Purple. *Angewandte Chemie (International)* 10: 816-817.
- Gerhard, Peter
1963 Shellfish Dye in America. In *XXV Congreso de Americanistas, Mexico, 1962 Actas y Memorias 3*, pp. 177-191. Mexico City.
1964 Emperors' Dye of the Mixtecs: Indians Tap a Snail's "Tyrian Purple." *Natural History* 1: 26-31.
- de Henau, Pierrick, Robert Kléber, Liliane Masschelein-Kleiner, Jean Thissen, and Frieda Tricot-Marcckx
1966 Les Peintures murales Mayas de Bonampak: Analyse des matériaux. *Bulletin, Institut Royal du Patrimoine Artistique* 9: 114-124.
- Kléber, Robert, Liliane Masschelein-Kleiner, and Jean Thissen
1967 Étude et identification du "Bleu Maya." *Studies in Conservation* 12: 41-55.
- Lagercrantz, O.
1913 *Recepte für Silber, Steine, und Purpur*. Almqvist and Wiksells, Uppsala.
- Marincovich, Louie, Jr.
1973 Intertidal Mollusks of Indique, Chile. *Natural History Museum of Los Angeles County Science Bulletin* 16: 35.
- Martoglio, Pamela A., Steven P. Bouffard, André J. Sommer, and J. E. Katon
1990 Unlocking the Secret of the Past: The Analysis of Archaeological Textiles and Dyes. *Analytical Chemistry* 62: 1123A-1128A.
- McGovern, Patrick E., Joseph Lazar, and Rudolph H. Michel
1990 The Mass Spectrometric Analysis of Indigoid Dyes. *Journal of the Society of Dyers and Colourists* 106: 22-25.
1991 Caveats in the Analysis of Indigoid Dyes by Mass Spectrometry. *Journal of the Society of Dyers and Colourists* 107: 280-281.
- McGovern, Patrick E. and Rudolph H. Michel
1985 Royal Purple Dye: Tracing Chemical Origins of the Industry. *Analytical Chemistry* 57: 1514A-1522A.
1990 Royal Purple Dye: The Chemical Reconstruction of the Ancient Mediterranean Industry. *Accounts of Chemical Research* 23: 152-158.
- Michel, Rudolph H., Joseph Lazar, and Patrick E. McGovern
forthcoming The Chemical Composition of the Indigoid Dyes Derived from the Hypobranchial Glandular Secretions of *Murex* Mollusks. *Journal of the Society of Dyers and Colourists*.
- Michel, Rudolph H. and Patrick E. McGovern
1987a The Chemical Processing of Royal Purple Dye: Ancient Descriptions as Elucidated by Modern Science. *Archeomaterials* 1: 135-143.
1987b The Chemical Processing of Royal Purple Dye: Addendum. *Archeomaterials* 2: 93.
1990 The Chemical Processing of Royal Purple Dye: Ancient Descriptions as Elucidated by Modern Science, Part II. *Archeomaterials* 4: 97-104.
- Nuttall, Zelia
1909 A Curious Survival in Mexico of the Use of the purpura Shellfish for Dyeing. In *Putnam Anniversary Volume*, pp. 368-384. G. E. Strechert, New York.
- Quilter, Jeffrey, Bernardo Ojeda E., Deborah M. Pearsall, Daniel H. Sandweiss, John G. Jones, and Elizabeth S. Wing
1991 Subsistence Economy of El Paraíso, an Early Peruvian Site. *Science* 251: 277-283.
- Reese, David S.
1979-1980 Industrial Exploitation of Murex Shells: Purple-dye and Lime Production at Sidi Khrebish, Benghazi (Berenice). *Libyan Studies* 11: 79-93.

- Roundhill, Linda S., Patrick E. McGovern, and Rudolph H. Michel
 forthcoming *Maya Blue: A Fresh Look at an Old Controversy. Mesa Ronda, Palenque 1989 Conference Proceedings.*
- Rowe, Ann P.
 1979 *B. Bird Pre-Columbian Textile Conference May 19th and 20th, 1973*, edited by Ann P. Rowe, E. P. Benson, and A.-L. Schaffer, pp. 185-218. The Textile Museum and Dumbarton Oaks, Trustees for Harvard University, Washington, D.C.
- Rowe, J. H. and Ann P. Rowe
 1970 *Review of Textiles from beneath the Temple of Pachacamac, Peru: A Part of the Uhle Collection of the University Museum, University of Pennsylvania* by Ina VanStan. *American Anthropologist* 72: 949-951.
- Saltzman, Max
 1963 *The Identification of Colorants in Ancient Textiles. Dyestuffs* 44: 241-251.
 1978 *The Identification of Dyes in Archaeological and Ethnographic Textiles. In Archaeological Chemistry II*, edited by G. F. Carter, pp. 172-185. *Advances in Chemistry* 171. American Chemical Society, Washington, D.C.
- Schweppe, Helmut
 1986 *Identification of Dyes in Historic Textile Materials. In Conservation and Characterization*, edited by H. L. Needles and S.H. Zeronian, pp. 153-174. American Chemical Society, Washington, D.C.
- Shimada, Izumi
 1991 *Introduction. Pachacamac: Report of the William Pepper, M.D., LL.D. Peruvian Expedition of 1896*, by M. Uhle. University Museum of Archaeology and Anthropology, Philadelphia.
- Stone, Doris
 1949 *The Boruca of Costa Rica. Papers of the Peabody Museum of American Archaeology and Ethnology* 26: 17.
- VanStan, Ina
 1967 *Textiles from beneath the Temple of Pachacamac, Peru: A Part of the Uhle Collection of the University Museum, University of Pennsylvania. University Museum Monograph* 30. University Museum, University of Pennsylvania, Philadelphia.