Ultramarine Blue, Natural and Artificial

JOYCE PLESTERS

Ultramarine Blue, Natural

Current Terminology
English: ultramarine (natural)
French: outremer (lapis)
German: Ultramarin (echt)
Italian: oltremare (genuino)
Spanish: ultramar (ino) (verdad e ro)

Obsolete Terminology and Synonyms
Azur(om) ultramarinum, azur(om) trans­
marinum, az(urr)o ultramarino, azur d’Acre,
pierre d’azur, Lazurstein, lapis lazuli ultramarine
(alternative spellings shown in parentheses).

Early nomenclature is complex. The name of
the mineral from which the pigment is obtained,
Lapis lazuli, derives from the Latin lapis, a stone,
and lallllu s, a Latinized form of the Persian
word for blue. The term ultramarine was originally used
as an adjective, as for example in azur(om) ultrama­
rinum, and was applied to other imported com­
modities. It served to distinguish the genuine lapis
lazuli ultramarine, which was imported from
Asia, from other blue pigments, in particular from
the blue copper mineral pigment azurite, which
went under the name of az(urr)o dell’Alto­
magna (frequently corrupted to az(urr)o clara­
saurium [see chapter 1]). The history of the no­
mencature of ultramarine has been discussed by
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Merrifield (1849), who formed the opinion that
the term ultramarine must have been in use in Italy
by the beginning of the fourteenth century and by
Cetens (1950). Villanini (1890) wrote in 1464,
"Fine blue is derived from a stone and comes from
across the seas and so-called ultramarine."

Composition
A complex sulfate-containing sodium alumi­
nium silicate, given in Dana (1971) as
(Na,Ca)(AlSiO₄)(SO₄,S₂O₃), the proportions of
aluminum (Al), sulfur (S), and oxygen (O) being
fixed in an aluminosilicate framework, the other
elements present as cations and anions are variable
(see also Chemical Composition).

Source
The mineral, lapis lazuli, from which the pigment
is made, is a complex rock mixture. Fundamen­
tally it is a mineralized limestone containing
grains of the blue cubic mineral called lazurite,
which is the essential constituent of the pigment;
although two isomorphous minerals of the
sodium-aluminum-silicate group, baryte and
sodalite—the former containing a sulfate group
and the latter, chloride—may also be present,
both of which sometimes occur in a blue form as
well as in a variety of other colors. Other silicate
minerals, such as diopside, forsterite, muscovite,
and wollastone, are likely ingredients of lapis la­
zuli, while inevitably present are calcite (optically
active crystalline calcium carbonate) and pyrites
(iron sulfide). (For further details of the mineral-
and are collected by settling at the bottom of the vessel, while most of the colorless crystalline material and other impurities remain behind in the doughy mass. The effectiveness of this method probably depends on the preferential wetting of the blue particles. The largest and densest-colored blue particles emerge first and it was usual to carry out at least three separate extractions by this method was given by Denninger (1964). It should be noted that however carefully the extraction is carried out, some natural impurities, notably calcite, still seem to remain in the pigment, and these serve to distinguish the natural from the synthetic product (see, for example, fig. 4A and B).

History of Use

Although archaeological evidence and accounts in early literature have shown that lapis lazuli was used as a semi-precious stone and decorative building stone from early Egyptian times, and the mineral was probably described by such classical authors as Theophrastus and Pliny, there is so far no evidence that it was used ground as a painting pigment either by the ancient Egyptians or by the Greeks and Romans (all of whom had in any case been given by Cennino Cennini, writing at the beginning of the fifteenth century, but, in general, describing fourteenth-century practice (Thompson, 1933), and in the fifteenth-century Bolognese manuscript, which gives numerous variations differing only in detail (Merrifield, 1849). A full account of the Bolognese manuscript methods and other recipes recorded in the earliest manuscript account of Egyptian blue, the secret of the manufacture of which subsequently was lost. The earliest literature to describe lapis as used in a painting pigment was noted by Gettens (1950) as a multiplicity of ingredients appearing to be present in a sixteenth-century manuscript (Kueller, 2006) which states that lapis lazuli was used as a medium for paintings in the sixteenth century. The other traditional blue pigments have also been reviewed and presented in table form (Kuella & Strauss, 1983). The principle of the method was that the ground pigment was mixed into a medium of wax, resin, and oil, and then the mixture was used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium. The blue pigments were then used as a painting medium.
constitutional formulas in respect to the proportions of sodium and sulfur. In 1890, Bogger and Blößner (1891) showed that lapis lazuli, the term by then typified for the characterized blue pigment, was a complex sulfur-containing aluminosilicate, similar in some respects to other reactive or ion-exchange materials. Work up to the end of the seventeenth century is well summarized in a monograph by Hoffmann (1962). Meanwhile, in 1828 artificial ultramarine had been successfully synthesized (see section on artificial ultramarine), subsequently analyzed, and found to duplicate the chemical composition and structure of natural ultramarine. Its costliness would make it an obvious subject for such practices.

Although in paintings of the past the pigment is mainly to be seen unmixed with pigments of other colors except white, ultramarine’s slightly violet-blue hue made it of more value for producing purple colors by mixing it with crimson rather than using the somewhat greenish-toned azurite. Occasionally physical mixtures of ultramarine with a crimson-colored lake pigment such as a madder lake were used, but more often the purple color was produced by superimposed layers of either ultramarine lake or an opaque pink or crimson body color, or else by a crimson lake over an opaque blue body color of ultramarine mixed with white. Examples of these techniques are given under Notable Occurrences.

Chemical Composition and Structure

The powdered blue pigments extracted from lapis lazuli to counteract the mineral’s new designated status, the approximate compositional formula of which is given above as $\text{Na}_3\text{AlSi}_5\text{O}_{10} \cdot (\text{SO}_4,\text{S}_2\text{O}_3)$, chemically, is the most complex of all the mineral pigments. Its composition was not elucidated until the thirty-ninth century when the first complete quantitative analysis was carried out (on samples of the pigment extracted in the traditional manner) by Desormes and Clément (1806). Results of subsequent careful analyses by various workers gave puzzling variations in constitutional formulas in respect to the proportions of sodium and sulfur. However, in the nineteenth century is well summarized in a monograph by Hoffmann (1962). Meanwhile, in 1828 artificial ultramarine had been successfully synthesized (see section on artificial ultramarine), subsequently analyzed, and found to duplicate the chemical composition and structure of natural ultramarine. The relationship between natural ultramarine and artificial ultramarine was established, and the use of artificial ultramarine as a substitute for natural ultramarine was, until the early nineteenth century, mainl
color, up to the sixteenth century thought to be due to the presence of iron, is now considered to be dependent on the presence of polyvalent radical ions and their location in the crystal lattice.

Lazurite is one of several rare felispathic minerals in which the basic structure is a three-dimensional basketlike framework built from aluminosilicate tetrahedra, with positive ions (principally Na⁺ and Ca²⁺) occupying the interstices. In lazurite, small quantities of rhabdite, carmellite, or orpiment may be incorporated.

A diagram and a photographic stereo-pair of the structure is found in Wells (1984). In addition to the cations, anions such as Cl⁻, SO₄²⁻, and S²⁻ (x = 2, 3) are essential constituents, and it is from these last entrapped species that the color of the mineral arises via anion to anion charge transfer (Nassau, 1983). Mineralogically related to lazurite are sodalite, containing chloride, and barynite and neoalbite, both of which contain sulfur. Sodalite is variable in color, but is often found in a blue form.

Work by Hofmann et al. (1969) proposed the presence in ultramarine of the highly reactive radical ions S⁻ and S₂⁻, which, according to molecular orbital theory, must contain unpaired electrons and are only stabilized by their occupancy of the aluminosilicate framework. The radical anions have been detected by their electron spin resonance spectra (Hofmann et al., 1969) while theoretical calculations indicate the importance of S⁻ in producing the blue color in lapis lazuli (Cotton et al., 1976).

**Particle Characteristics**

The blue particles are of irregular size and angular shape (as distinct from the comparatively small, uniform, and rounded grains of artificial ultramarine). Although x-ray crystallography shows lapis lazuli to be a crystalline compound, and rhombohedral crystals occasionally occur in deposits of the mineral, recognizable crystalline forms are rare in pigment samples, and particles are often flattened, sometimes with a conchoidal fracture. An excellent scanning electron micrograph of a single lapis particle was published by Feller (1972). There are usually appreciable amounts of crystalline mineral impurities, mainly colorless, mixed with the blue particles. These consist chiefly of other silicate minerals (see Chemical Properties) and calcite.

**Optical Properties**

The particles are of a translucent pure blue by transmitted light, deep opaque blue by reflected light. The small, uniform rounded granules of the synthetic pigment appear more opaque than those of the natural pigment when viewed under the microscope, although the difference in refractive index of the two is not really significant. The refractive index is comparatively low, given by Larson and Berman (1954) as 1.508 ± 0.001, that is, lower than that of Canada balsam and Azocoll and only slightly higher than that of fresh linseed oil. Having a cubic crystal structure, ultramarine is isotropic, so that the blue particles (unlike those of azurite) are not strongly birefracting, and when the pigment is examined under the polarizing microscope, they undergo complete extinction between crossed polars (see figs. 4B and 5B). Any calcite crystals present appear on the other hand, strongly birefringent, and as the analyzer of the polarizing microscope is rotated, those particles suitably orientated to the plane of this is usually traceable to overlapping with calcite particles. Two samples of natural ultramarine when viewed by ordinary light and then with crossed polars are shown in figures 4 and 5. The proportion of calcite, and other mineral impurities present, varies with the quality of the mineral and the thoroughness of the extraction; but in producing the blue color in lapis lazuli to be a crystalline compound, and rhombohedral crystals occasionally occur in deposits of the mineral, recognizable crystalline forms are rare in pigment samples, and particles are often flattened, sometimes with a conchoidal fracture. An excellent scanning electron micrograph of a single lapis particle was published by Feller (1972). There are usually appreciable amounts of crystalline mineral impurities, mainly colorless, mixed with the blue particles. These consist chiefly of other silicate minerals (see Chemical Properties) and calcite.

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**Fig. 4 Particles of natural ultramarine, Rowney's old stock.**

A. Transmitted light, 615x.

**Fig. 5 Grains of natural ultramarine pigment from an illuminated Armenian MS.**

A. Transmitted light, 645x.

B. The same specimen between partially crossed polars. Certain mineral impurities associated with the lapis lazuli, principally calcite, are strongly birefracting.

**Fig. 6 Ultramarine particles from the Virgin's blue robe in an altarpiece by Perugino, The Virgin and Child with Saints Raphael and Michael. National Gallery, London, No. 218.**

Transmitted light with oil immersion, 1,200x.

Photo: A. Roy.

**Ultramarine Blue**

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getting the use of mass spectrometry to determine the sulfur isotope ratios for "S Jardin (National Gallery, London, no. 6296) - ultramarine particles were present in good condition extracted described above, or, as recommended in the seventeenth-century De Meyer manu-
script (Van der Graaf, 1958), as a labor-saving method of purifying the pigment, must have de-
pended to some extent for its success on the speed and timing of the operation. Presumably the ob-
ject was to dissolve some of the calcium carbonate present. In experiments carried out by this author, samples of natural ultramarine were appreciably more slowly decolorized by dilute mineral acids than were samples of synthetic pigment of similar color, but it has not yet been firmly established whether this difference might depend on the slightly coarser particle size of the natural pig-
ment. A similar observation on the rate of attack of acids on the natural and artificial pigments was made by Church (1915).

Permanence and Compatibility with Other Pigments

On innumerable pastel paintings and illuminated manuscripts, natural ultramarine can be seen in a perfect state of preservation even though it is a few centuries old, and in general it behaves as a comparatively permanent pigment. Although it is popular in the 19th century, the sulfur is usually readily liberated as H$_2$S in pastes of the past when it was regularly mixed with lead of a pigment. The author has made some progress in this direction with artificial ultramarines using industrially. De Wild (1929) discussed the subject and felt that de-
composition of the pigment is brought about in most cases by the action of atmospheric sulfur dioxide and moisture. At the same time, he suggested that acidity of an oil- or oleo-resinous paint medium might be an alternative cause and this has been experimentally confirmed. In the author's opinion, the best procedure for determining the origin of a pigment is to test the sample for sulfur by heating to redness and observing the appearance of blackening of the lead pig-
ment to lead sulfate. A disorder known as "ultramarine sickness" has occasionally been noted on paintings as a grayish or yellowish gray mottled discoloration of the paint surface, and it also occurs from time to time with artificial ultramarine used industrially. De Wild (1929) attributed this to slow drying of the oil-
medium. Any hydrogen sulfide evolved will produce a brownish black stain of lead sulfide on the paper. Ultramarine is unaffected by ammonia or caustic alkalis, except on very prolonged and drastic treat-
ment by the latter, but it is very readily decom-
powered by acids. Dilute mineral acids—dilute HCl, HNO$_3$, or H$_2$SO$_4$—rapidly destroy the blue color with evolution of hydrogen sulfide gas, with a white or yellowish residue of undissolved silica remaining. Even very dilute acids will, on long standing, decolorize and decompose ultramarine, presumably because hydrogen ions (H$_3$O$^+$) are small enough to enter readily the open alumino-silicate framework and react with the enclosed polysulfide ions. Acetic acid attacks the pigment rather more slowly than do mineral acids. The practice of washing lapsis lazuli with vinegar, either as a preliminary to the "dough" method of extraction described above, or, as recommended in the paint film but were mixed with small, a blue cobalt-glass pigment which has sometimes been found to be associated with discoloration and dis-
tination of the oil-medium in which it has been used (see chapter 5). Hence the visible symptoms described above and generally termed "ultramarine sickness" cannot at present be assigned to a single cause. Most reported cases are on oil paint-
ings. Assessment of the nature of discoloration should also be made with caution. In a recent in-
vestigation of Sassoferrato's The Virgin in Prayer (National Gallery, London, no. 200), the Virgin's ultramarine robe showed before cleaning the ap-
ppearance of severe degradation of the blue pig-
ment. However, after cleaning, the disturbance to the blue was found to be due to a small black-
colored deposit on the external layers; the original ultramarine paint layer remains in an excellent state of preservation (fig. 7) (Dunkerton, 1986).

As mentioned above, ultramarine, of both natural and artificial varieties, is stable to am-
monia and caustic alkalis in ordinary conditions, it has been reported that cases have occurred of artificial ultramarines fading when in contact with lime, when, for instance, it is used to color con-
crete or plaster (see Ultramarine, Artificial). These findings lead to speculation that possible fading of the natural pigment may possibly be the result of its contact with the lime plaster of fresco paintings.

Microchemical Tests

Heat Resistance

This distinguishes ultramarine from azurite or Prussian blue. The sample of pigment or the un-
treated paint fragment is placed on a platinum spoon, wire, or foil in a hard-glass combustion tube and covered to be heated to redness. On cooling, the sample may be observed under the micro-
scope or with a handheld lens. The blue color of ultra-
marine remains unchanged, whereas azurite is converted to black copper oxide, and Prussian blue is converted to orange-brown ferric oxide, while indigo sublimes with a blue vapor leaving no appreciable residue. Small, cobalt blues, maa-
sen and Prussian blues are also heat-resistant in these conditions, but may be dis-
tinguished from ultramarine by their lack of reac-
tion with acids. For discussion of this topic, see articles by Bernstein (1945), Gettens and Stout (1935-1936), and Augusti (1935).

Test for Hydrogen Sulfide

Liberated by Acid

A drop of dilute HCl—3 M, or approximately 1 part concentrated HCl to 3 parts water by vol-
tume—placed on the sample of pigment or the fragment of paint containing ultramarine usually rapidly destroys the blue color and liberates hy-
drogen sulfide. Bubbles of gas can generally be seen arising from the blue pigments, although these may not be evident if the particles are layered up in an oil- or oil-resin medium; hence, bubbles of carbon dioxide may also be evolved, either from carbonic acid as an impurity in the natural mineral, from the blue copper carbonate pigment, azurite, or from white lead present in the paint sample, it is advisable to test for sulfide. In sizeable yet still quite small samples—that is, greater than about 3 mm diameter—it is often pos-
sible to detect the characteristic smell of "rotten eggs" associated with H$_2$S. Where this fails, chemical tests must be applied. As suggested by De Wild (1929), place the sample in the hollow of a cup slide, and add a drop of dilute hydrochloric acid, and cover at once with a glass cover slip on the underside of which has been pressed a small slip of filter paper moistened with lead acetate solu-
tion. Any hydrogen sulfide evolved will produce a brownish black stain of lead sulfide on the paper.
Table I Continued

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*Compiled by W. Thomas Clark, D.E.*

**Ultramarine Blue, JCPDS File 2-035 (Courtesy of JCPDS International Centre for Diffraction Data).**

† X-ray data for charcoal black (Hilger Refr., JCPDS 2-0325). First supplementary cards of x-ray diffraction data, compiled and published by joint committee of ASTM, American Society for X-ray and Electron Diffraction, and Institute of Physics of London. Conditions: Cu radiation, Ni filter, 10° scattering angle, measurements corrected for film shrinkage. Some impurities, especially quartz, can be observed macroscopically in this synthetic ultramarine. Silk is probably present in all ultramarine samples both natural and synthetic.

§ Paint prepared on black background. Measurements corrected for film shrinkage. Based on analysis of X-ray patterns.
their firm purchased supplies from Indian suppliers who brought it in small batches to London via Paris and probably prepared it in their own houses by the traditional method. Winsor & Newton Ltd. always seem to have made a specialty of stocking the natural pigment ever since the establishment of the firm in 1832, although in that same year they were simultaneously offering the artificial pigment. Since 1940 they have had difficulty in maintaining a supply, but apparently a certain demand still exists and both natural ultramarine and ultramarine ash continued to be offered in the 1980s when batches of lapis lazuli from Afghanistan were encountered in Europe.

An investigation into the materials and method was made by Paramasivan (1937-1938). An investigation into the materials and method was made by Paramasivan (1937-1938). At this site, ultramarine seems to have been the homes by the traditional method. Winsor & Newton Ltd. always seem to have made a speciality of mixed with yellow ochre to give green, a practice not encountered in Europe.

On a Romanesque fresco of the twelfth century A.D. in the German Romanesque church of Iden, described by Geilmann (1938). Since 1940 they have had difficulty in maintaining a supply, but apparently a certain demand still exists and both natural ultramarine and ultramarine ash continued to be offered in the 1980s when batches of lapis lazuli from Afghanistan were encountered in Europe.

On an Armenian illuminated manuscript The Four Gospels (c. twelfth century) f. 183 recto, Freer Gallery of Art no. 50.3. Identification made by Rutherford J. Gettens, see figure 5A and B.

On wall paintings of the fourteenth century a.d. in the Byzantine church of Our Saviour, Monastery of the Chora (Kariye Camii), Istanbul, identified by Gettens and Stout (1958), as the brighter and purer blue of blue draperies otherwise painted in azurite.

On the drapery of a Romanesque polychromed wooden crucifix dated from an early Norwegian oil painting on panel (Historisk Museum, Bergen), c.1260/1280, as a pale grey-blue layer for the draperies of figures, possibly simply ground lapis lazuli or "ultramarine ash" (Plahther, 1976).

The pigment was present on a rudimentary anicon's painting on silk said to have come from Dun-huang in Western Kansu Province of China:

On two Chinese paintings on silk said to have been identified by Gette (1907-1908a). Genette (1937-1938b) also identified ultramarine in wall paintings in Chinese Tukuchan of the fifteenth to eighteenth centuries a.d.


The pigment was present on a rudimentary anicon's palette discovered on the spandrel of a fourteenth-century Italian panel painting, The Virgin and Child, by Paolo Venetiano in the collection of the Louvre, Paris. Reported by Bazin et al. (1958).
Emission Spectrometric Analysis
See Ultramarine, Natural.

X-ray Spectrometric (X-ray Fluorescence) Analysis
See Ultramarine, Natural.

Tummal et al. (1986) demonstrated that all the elements present in synthetic ultramarine may be detected by the new methods of particle-induced x-ray emission spectroscopy (PIXE) and particle-induced gamma ray emission spectroscopy (PIGME).

X-ray Diffraction Analysis
See Ultramarine, Natural (fig. 9 and table 1).

Visible, Infrared, and Ultraviolet Spectrophotometry
A color reflectance curve for wavelength between 400 and 700 nm for synthetic ultramarine, painted on rag paper with thin parchment-glue medium, was published by Barnes (1938–1939). He gave the dominant wavelength as 467.3 nm, relative correctness at 7.84%, and excitation purity as 72.1% (see also fig. 10). Mattielli (1946) published spectrophotometric curves of a sample consisting of black or mixed pigment, unblended with medium, identified by Butler (1954) for wavelengths between 300 and 1,000 nm. The depth of color of the blue pigment is related to the absorbance of the pigment (Bosshara, 1978). One of the most striking features of the curve is the rising reflectance in the red and the high reflectance in the ultraviolet—also noted in the case of the natural pigment—for this reason, artificial ultramarine has been used in camouflage and heat-resisting paints.

X-Radiography
See Ultramarine, Natural.

Notable Occurrences
Although it might be expected that artificial ultramarine would have been used in insubstantial nineteenth- and twentieth-century paintings, and also featured in the detection of forgeries, records of specific identifications in the literature are very few. A possible reason is that fewer pictures of recent date undergo the thorough technical and scientific examinations so frequently applied to "Old Masters." The following are some selected occurrences that have been reported:

(a) Extensively in the second stage of painting (c. 1886) of August Renoir's Les Parisiennes (National Gallery, London, no. 3268). The first stage of the composition (c. 1881) contains exclusively cobalt blue (Bosshara et al., 1990). See figure 13.

(b) Mixed with other pigments in Claude Monet's Gare St. Lazare (National Gallery, London, no. 6479) (Roy, 1985) and Edouard Manet’s The Waitress (National Gallery, London, no. 4058) (Bromfield & Roy, 1983). Also detected microscopically and with the electron micro-beam probe in a blue highlight on the water of Monet’s Waterlilies in the National Gallery, London (no. 6343).

(c) In paintings by Manet, Renoir, and Paul Cézanne in the collection of the Musee du Louvre, reported by Delbeaux and Rivero (1974), and in eight paintings by Cézanne, identified by Butler (1984). In Cézanne’s Mountains in Provence (National Gallery, London, no. 4130) (Roy, 1985).

(d) In the deepest blues and in certain samples of mixed green from Vincent van Gogh's Cornfield with Cypress (National Gallery, London, no. 3865) identified by Ashok Roy.

(e) Reported by Köbe (1960) in a number of nineteenth-century German paintings in the Schuck-Galerie, Munich, including works byArnold, Anselm Feuerbach, Franz von Lenbach, Carl Rottmann, and Ernst Willers.

(f) Identified by van Asperen de Boer (1975) on two curved wooden reliefs dated 1873 from Pan­ner­nold, Holland.

(g) Used unnamed with other pigment in a deep blue area of a watercolor and graphite painting, L.Escargot, by Henri Matisse (Tate Gallery, London, no. T540), dated 1953.

(h) In a forgery claimed to be a painting by Frans Hals, The Merry Cavalier. The question of the authenticity of this painting was the subject of a detailed technical examination by Veth (1972). An account of the matter was given by Veth (1925) and also by De Cruez (1925) who, although he strongly disputed the scientific evidence, concluded that the validity of the microscopic identification of synthetic ultramarine, repudiated most of the significant documentary evidence of the case in his book on the subject.

(i) In two areas of overpaint on the Van Eyck polyptych, Adoration of the Mystic Lamb, on the Ve­rin’s blue in the panel depicting the virgin reading (Crommelynck, 1954) and in the sky of the central panel (Jean Thissen, private communication).

(j) In a model’s mixture with other pigments to match embossed "cocker rose" on the extended edges of Raphael's St. John the Baptist Preaching (National Gallery, London, no. 6460) (Bromfield & Wyld, 1984).

(k) Identified on occasion by Rutherford J. Getts (private communication) in pigment mixtures used in making artificial pearls on Chinese trousse.

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(Norman, 1912) F. Norman, ed. and tr. A. Treatise concerning the Arts of Painting, written by St. Hilarius, by Nicholas Hilliard, with introductory and concluding notes, in the Journal of the Walpole Society 1 (1912), 1-34. For Mr. Hilliard's comments on natural ultramarine see p. 33.


(Pacheco, 1649) F. Pacheco. Arte de la Pintura (Seville, 1649), 39.


(Rachkov, 1956) Rachkov's (Colours Ltd., Ultramarine, Their History and Character (Hull, England, 1954), 143 pp. See p. 16 for chemical composition of various artificial ultramarines, pp. 13-14 for particle size, p. 134 for refractive index, p. 120 for notes on fading of ultramarine-printed paper in art atmospheres, f. 5, 7, 8, and 9 for spectrophotometric curves.

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