JOSEPH DOUMET

TYR

Etude sur la couleur pourpre ancienne

A Study on ancient purple

JOSEPH DOUMET

A study on the ancient purple colour

and an attempt to reproduce the dyeing procedure of Tyre as described by Pliny the Elder

The study on the purple colour published in 1980 demonstrated the presence of an enzyme in the Murex Trunculus.

Since this publication Professor Elmon Coe of the Department of Biochemistry at the American University of Beirut undertook a detailed biochemical study to isolate the enzyme. The abstract form of his work is published in this second edition.

ABSTRACT FORM

THE VII SCIENCE MEETING OF THE LEBANESE ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (LAAS) WITH THE SUPPORT OF THE C.N.R.S.

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Title of Paper: Biochemistry of Tyrian Purple Synthesis.
II. Murex Bromoperoxidase Activity

Authors: Randa Jannun and Elmon Coe

BIOCHEMISTRY OF TYRIAN PURPLE SYNTHESIS: BROMOPEROXIDASE AND PURPURASE ACTIVITIES OF *MUREX*. *E.L. Coe, R. Jannun, W.S. Ward, C. Chen, and J. Doumet.* Biochemistry Dept., American Univ. of Beirut, Lebanon.

Murex sea snails have been known for their production of the dye "Tyrian Purple" since ancient times. Intermediates are known to include a bromoindoxyl sulfate derivative which dimerizes after hydrolysis by an aryl sulfatase ("purpurase"). Bromoperoxidase activity has now been identified in extracts of the dye-producing gland of M. Trunculus. Generation of Br_2 from Br^- in the presence of H_2O_2 is detected by conversion of cresol red to bromocresol purple. Activity is localized in the particulate fraction but is solubilized in 1% Triton X-100 and differs from bacterial chloroperoxidase in its high pH optimum (8) and its low activity with Cl. Aryl sulfatase activity, which is present in the soluble fraction of the gland extract, shows a K_M of 10^{-4} M with P-nitrophenyl sulfate at pH 7.5 and is competitively inhibited by phosphate. Its high pH optimum distinguishes it from digestive aryl sulfatases of other molluse (The authors thank the D.T. Sabbagh Fund and the A.U.B. Medical School for support.)

Contents

1

Description of the problem

Mrs. Nina Jidejian, author of several books on Phoenician cities (Tyre, Sidon, Byblos, Beirut), while assembling the necessary information to write a new book on the ancient industries of the Middle East, became interested in the old ways of obtaining the purple dye from Murex gasteropods. This was one of the most important industries dating from the Late Bronze age up to and including the Roman empire period.

The ancient dyeing procedure was common to the entire Mediterranean basin. Tyre stood out as the dye center mainly during the Roman era (1).

It was decided to study this problem using only the techniques available to the dyers of that time.

The goals of this project will be: a) to study the method of dyeing and obtain the simplest procedure; this process would probably be the oldest used on the Mediterranean coast; b) to study the differences between this simple procedure and Pliny's description of dyeing in Tyre; in case of differences, the Tyrians must have derived their fame from some special indigenous process: c) if so, to find this special process used in Tyre.

2

Ancient and modern references

2.1 Ancient references

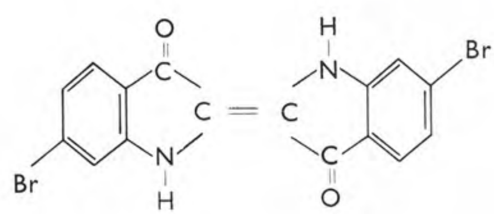
As has been mentioned in the first part, the description of Pliny (1) will play an important part in this study.

The discovery, during the excavations of Late Bronze Age sites around the Mediterranean basin, and especially at Sarafand, of the remains of Murex confirms the importance of Tyre in the dyeing industry. In any case Tyre was one of the cities mentioned by Pliny.

2.2 Modern references

In 1909 Friedlander obtained 1.4 gram of colored material from 12,000 Murex and he showed that this ancient purple had a dibromoindigo structure (2).

Several new dyes have been obtained by the bromination of synthetic indigo, for example, tetrabromoindigo (CIBA Blue 2B).



We know from modern practice that these dyes should be applied in their reduced colorless form in alkali media. The dye precipitates on the fibers and the color appears upon oxidation (vat-dye). "The principle of vat-dyeing is to reduce the insoluble dye to a phenolic derivative, the so-called leuco-compound, which is soluble in alkali" (3).

3

Initial verification of the procedures for dyeing

3.1 A list of the means available at that time

Before attempting to dye using Murex, a list of the relatively few materials available to the people at that time must be made:

a) Sea water is slightly alkaline (pH = 7.9); it could have been used as an alkali medium at the time of the discovery of the dye.

b) Alkalinity could also have been provided by the fermentation of urine, or from the solution obtained when a water-ash mixture is decanted, or from lime-water.

c) The ancients used lead utensils (1); the surface of lead which is easily removable could have served as a reducing agent. Sugars could also have been used as reducing agents.

d) Vinegar could have been the source of acid.

e) Air would be the oxidant.

3.2 Initial results and first attempts to dye

The shellfish (Murex Trunculus), once crushed, give a product, which in principle is colorless but is actually slightly brownish because of small particles of flesh. This product is oxidized by air and quickly starts to change to purple and precipitates at the same time. It does not seem that light plays a part in this process because, even when protected from light, the dye still precipitates. The presence of alkali slows down the precipitation, while acidity speeds up the process. Acid and heat cause an immediate appearance and precipitation of the dye.

It is possible to dye silk and raw wool with Murex Trunculus in the following manner: Five hundred cubic centimeters of sea water is used for every 1,000 g. of shellfish. The water is preboiled and cooled in order to remove oxygen. The shells are crushed with their openings towards the bottom and mixed with sea water in order to take out the dye. Every fifteen minutes, over a period of two hours, the bath is stirred vigorously. This procedure takes place at room temperature and in a lead vessel. After two hours the solution starts to become violet. It is decanted and then filtered through a fine material in order to remove as much as is possible the pieces of flesh that are in suspension. To this decantant one hundred cubic centimeters of rinse water is added and thirty grams of wool are then immersed for three days. After three days the wool is taken out of the bath and immersed in some vinegar at room temperature for one hour. Although the colors were pale, the results were encouraging.

When this same wool is placed in a freshly prepared dyeing solution the colors are satisfactory.

After three days the dye bath has become a beautiful purple color but it can no longer be used for dyeing because the dye has precipitated in a colloidal form. The dye in this form is impossible to filter. However, if the bath is made acidic with vinegar and boiled, the dye can be filtered, collected and dried. The precipitate is violet colored and is insoluble in common organic solvents (benzine, acetone, chloroform, carbon disulfide, ethyl alcohol, methyl alcohol, etc.)

Plates I, II, III, IV show the following samples: raw wool, wool after the first dyeing, after the second dyeing, and the precipitated dye.

4

Differences between these initial results and the writings of Pliny

Pliny tells us (1):

> "Three days is the proper time for it to be steeped (as the fresher the salt the stronger it is), and it should be heated in a leaden pot, and with 50 lbs. of dye to every six gallons of water kept at a uniform and moderate temperature by a pipe brought from a furnace some way off. This will cause it gradually to deposit the portions of flesh which are bound to have adhered to the veins, and after about nine days the cauldron is strained and a fleece that has been washed clean is dipped for a trial, and the liquid is heated up until fair confidence is achieved. A ruddy colour is inferior to a blackish one. The fleece is allowed to soak for five hours and after it has been carded is dipped again, until it soaks up all the juice. The whelk by itself is not approved of, as it does not make a fast dye; it is blended in a moderate degree with sea-purple and it gives to its excessively dark hue that hard and brilliant scarlet which is in demand; when their forces are thus mingled, the one is enlivened, or deadened as the case may be, by the other. The total amount of dye-stuffs required for 1,000 lbs. of fleece is 200 lbs. of whelk and 111 lbs. of sea-purple; so is produced that remarkable amethyst colour. For Tyrian purple the wool is first soaked with sea-purple for a preliminary pale dressing, and then completely transformed with whelk dye. Its highest glory consists in the colour of congealed blood, blackish at first glance but gleaming when held up to the light; this is the origin of Homer's phrase, 'blood of purple hue'."

It seems that Pliny is writing about a different procedure than that which is described in section 3. It is not possible either to leave the shells soaking for three days in a pure lead vessel or to concentrate the liquid over a period of ten days without precipitating the dye. We could then suppose that the process described by Pliny was special to Tyre. This process made it possible to produce different shades from light to dark by concentrating the baths.

As has been mentioned, the dye precipitates upon oxidation. If the Tyrians could concentrate the dye baths they must have had a reducing agent which would prevent the precipitation of the dye.

Therefore to find such a reducing agent, which would also be available to the residents of Tyre of that era, would permit the dyeing with Murex in the manner described by Pliny. This would lead to the discovery of the process which made Tyre famous at that time (see section 6).

5

Alkaline substances available to the Tyrians during the time of Pliny

As mentioned in section 2.2, the purple is a dye of the vat-dye class (leuco) and therefore it is necessary to use the dye in an alkaline medium. It should also be mentioned that fabrics dyed by this process by modern chemical industries are treated, after dyeing, in an acetic acid bath in order to better fix the color (eg. the use of vinegar in section 3.2).

The Tyrians had available, during the Roman era, the following alkaline materials (as well as sea water):

a) wood ashes (potassium alkalinity)

b) fermented urine (ammonium hydroxide)

c) lime-water (the basicity is limited by the solubility of calcium hydroxide in water)

Potassium alkalinity: An alkaline solution can be made from a mixture of wood ashes and water; the mixture is allowed to settle and is decanted. The solution can reach a pH of 12. The alkalinity is due to the potassium content of wood which becomes concentrated in the ashes.

Ammonium hydroxide: Urine, fermented at room temperature for a week, can reach a pH of 9.5. This is accounted for by the conversion of urea into ammonia. It must be mentioned here that Tyre practices above all the dyeing of wool (1). Wool is attacked by strong bases but not by ammonium hydroxide. The potassium mentioned above is not strong enough to harm the wool because it is a potassium carbonate.

Calcium hydroxide: An alkaline solution can be obtained by dissolving quicklime or slake lime in water. This is due to the slight solubility (approximately one gram per liter) of calcium hydroxide in water.

6

Attempts to find the dyeing procedure of Tyre as described by Pliny

6.1 Search for a reducing agent

a) The indigo dye industry of more recent times used indigos and thiondigos as dyes and as a reductant a compound known in the trade as "hydro" but correctly called sodium dithionite or sodium hydrosulfite. The dyeing is carried out in an alkaline bath.

The precipitated dye obtained experimentally (section 3.2) has been reduced, dissolved and reused by the action of sodium dithionite in alkaline solution.

A simple experiment was performed in which an attempt was made to produce sodium dithionite in wood ashes of a fireplace. Sulfur is placed in the hot ashes that fall from the grill of a fireplace in the hope that sulfur dioxide would be produced. If the sulfur dioxide (SO_2) would then combine with the potassium of the ashes (K_2O), potassium sulfite might be produced (K_2SO_3). The sulfite which is in contact with the hot ashes might be reduced to potassium dithionite ($K_2S_2O_4$). The results, however, were negative, the presence of dithionite could not be proven.

b) In a further searching of the literature on dyes and dyeing the following texts on white indigo were found:

> "The most interesting property of indigo, that of which the industry takes the most advantage, is the ability of the molecule to be reduced and converted to a colorless molecule (white indigo), soluble in aqueous alkaline and alkaline earth solution and capable of reproducing indigo upon oxidation.
>
> The alkaline reducing agents have the greatest effect, nevertheless one obtains a form of white indigo also by treatment with zinc in sulfurous acid solution.
>
> The following is a list of the systems that will reduce indigo:

1. alkali metals, sodium amalgam; these molecules affect the decomposition of water and produce hydrogen gas and at the same time the base necessary to dissolve the reduced indigo.

2. *metals and metalloids which decompose water in the presence of base — tin, antimony aluminum and phosphorus; there is no effect except in the presence of base and at a temperature close to boiling.*

3. Mineral acids capable of going to a higher oxidation state — phosphorus and hypophosphorus acids; again there is no effect unless there is excess alkali present.

4. some sulfides, arsenides and phosphides — arsenic sulfide.

5. a few oxidizable organic substances in basic media — glucose, gallic acid, pectinic acid.

6. reductive and alkaline fermentation — butyric acid fermentation" (6)

"The reduction of the dye is carried out in sodium, calcium or potassium hydroxide solution. The type of reducing agent used depends on the nature of the fabric which is to be dyed, and on the dye itself. Sodium hydrosulfite ($Na_2S_2O_4$). $2H_2O$ and formaldehyde sulphoxylate $H_2C(OH)OSONa$. $2H_2O$ are largely used. However, zinc dust, *stannous salts, reducing sugars and ferrous compounds* will serve under certain circumstances. (3)"

The preceding texts on indigo force us to consider for any new experiments the following:

The inhabitants of Tyre had available alkaline materials (section 5) and they also knew about tin and antimony as well as lead. Pliny (1) mentions explicitly, in describing the dyeing procedure of Tyre, the use of lead utensils in the actual process of dyeing as well as in the concentration of the solution.

In order to keep the colorant in its reduced form (leuco) during the digestion and subsequent concentration of the bath, the preceding references suggest the use of lead and tin alloys.

The following procedure was used in each of the three vessels made of: 1. pure tin; 2. lead with 25% tin; 3. lead with 25% antimony.

Alkaline water (potassium alkalinity, pH = 12), with 40 grams of salt per liter (1), was poured in the vessels, heated to boiling in order to deoxygenate and produce nascent hydrogen (6), and then cooled. The crushed Murex (1,000 g for 600 cm^3 of water) were immersed in the three vessels. In each case no precipitate appeared after three days.

The three experiments could be considered a success. The keeping of the product taken from the Murex in a reduced form is in principle due to the release of hydrogen brought about by the reaction of tin and alkali. Potassium stannate is also produced (equation 1).

$$2KOH + Sn + 4H_2O \quad K_2Sn(OH)_6 + 2H_2 \ (1)$$

If ammonium hydroxide is the source of alkali then ammonium stannate is produced. If the vessel contains antimony then stibates are produced. Oxides of tin and antimony which are themselves reducing agents are also formed.

6.2 Concentration of the solution

The solutions were concentrated in the same three vessels at a temperature that never exceeded 45°C. The basicity of the baths decreased during concentration because of the formation of stannates. In time there appeared, on the surface of the bath, the purple colorant. This served as an indication that alkali should be added. The concentration of the baths was successful in the pure tin vessel but not in the alloyed vessels. Therefore in the experiments that follow the digestion of the shells is carried out in alloyed vessels (6.1) and the concentration in pure tin (6.2).

In two lead alloy vessels (25% tin), 1,000 grams of Murex Trunculus are placed to digest in 500 cm^3 of aqueous potassium alkaline solution (from ashes). No precipitate appears. After three days the liquids are decanted. Thirty grams of wool are placed in one of the vessels and left for six hours at room temperature. After this first dyeing the remaining part of the bath is added to the unused bath to give a total volume of 830 cm^3. The bath is concentrated (tin vessel) over a period of 72 hours at 40°C. The volume of liquid is reduced 310 cm^3. The same thirty grams of wool are reimmersed for six more hours. An identical procedure was used for silk.

The second phase of the dyeing was carried out at $pH = 9$ (see Plate V for the silk and Plates VI, VII and VIII for the wool samples).

Therefore it has been shown that in vessels of lead-tin and lead-antimony alloys one can prevent the precipitation of the dye during digestion but that the concentration must be carried out in pure tin vessels. However, it is impossible under these same conditions to reduce (that is, to return to the leuco state) a bath in which the color has already precipitated.

The dyed material (wool or silk) in this process becomes colored when it is exposed to air after removal from the bath. The color obtained is a shade of blue-violet. If the dyed materials are treated in a vinegar bath at 70°C the color turns more red. This change of shade in the vinegar is particularily noted for natural silk (Plate V).

6.3 Attempts to use sugars as reducing agents

(molasses of the *carob* and *grapes.*)

The Carob tree and grapes were known to the ancients and therefore it was important to try to use the sugars of their molasses as reducing agents (3,6). The sugars present in the molasses are sucrose and glucose. The use of these two sugars as reducing agents to prevent the precipitation of the dye was unsuccessful.

6.4 Attempts to use lime-water as an alkaline medium

Lime-water must have been an alkali medium available to the people of that time in as much as they were familiar with pottery. The problem with lime is its limited solubility in water (approximately 1 gram per liter). Lime is more soluble if the water contains some sugars; it forms a calcium saccharate but keeps the alkaline characteristics of lime (9). The results of the attempt to dye with Murex Trunculus in a lime-water and sugar solution were deceptive. During the concentration of the solution the lime preciptated and the precipitated lime absorbed the dye.

7

Initial results for each of the Murex used

Several gasteropods (called Murex) have been tried and they can be classed in two catagories: the first type of gasteropods are those which resemble Murex Trunculus. This type includes three different but closely related species as seen in the photographs on Plates XIII, XIV, and XV. With the Murex on Plates XIII and XIV the purple dye can be produced in the same way that has been described in the previous sections. The Murex of Plate XV did not give the dye; it appears to be the Purpura Haemastoma.

The second type of gasteropod which has a long funnel is represented by a Murex Brandaris (Plate XVI). It was also not possible to produce a dye bath with this gasteropod.

It was then necessary to study the problem posed by the use of Murex Brandaris and Purpura Haemastoma in dyeing in as much as these two shellfish were used especially by the Tyrians (communication of G. Dardaud and N. Jidejian).

8

A study of the use of Murex Brandaris and Purpura Haemastoma for dyeing

Not having obtained dye with these two types of Murex by the procedures mentioned, it was decided to make an incision along the back of the gasteropod after having broken the shell. This incision should in principle cut the protecting wall and permit the dye to dissolve in the alkali bath. Still, no dye was produced.

It was noted that R. Dubois demonstrated the existence of enzymatic action in the appearance of the purple color (8). In as much as Murex Trunculus gives the color without difficulty it was decided to prepare dye baths using Purpura Haemastoma and Murex Brandaris and ten percent only of Murex Trunculus with the hope of introducing into the process the enzymes of Murex Trunculus. The experiment carried out as described in section 6.2 was a success.

The first sample on Plate IX is one dyed by Purpura Haemastoma with 10% Murex Trunculus. The second sample on Plate X was dyed in the same way with Murex Brandaris.

With these positive results and since the bath of Purpura Haemastoma and Murex Brandaris remains colorless before the addition of a small amount of Trunculus, it becomes possible to imagine that the Tyrians had the means to concentrate the baths, that is, to do it before the addition of Trunculus. Therefore it was decided to perform the following experiment:

A kilogram of Purpura Haemastoma was left to stand in a bath in a white lead vessel (tin) Ref. 12 for three days. No color appeared even after concentrating the bath to one tenth of the volume at 40°C. To this bath (at 35°C) was added the digestion solution of 100 g. of Murex Trunculus in sea water. Forty eight hours after the inoculation by Trunculus the bath was useable for dyeing.

The success of the experiment was complete, making the following conclusion evident. In the experiments on Murex Trunculus (section 6) the concentration of the bath could only take place in tin because the dye precipitated in lead-antimony vessels.

While doing more research in Pliny the Elder's Natural History concerning lead, the following passage was found: (12)

"The next topic is the nature of lead of which there are two kinds: black and white. White lead (tin) is the most valuable; the Greeks applied to it the name "cassiteros" and there was a legendary story of their going to islands of the Atlantic Ocean to fetch it and importing it in platted vessels made of osiers and covered with stitched hides."

(Note: Pliny's "black lead" is lead and his "white lead" is tin. Neither must be confused with the "black lead" and "white lead" of modern times.)

9

The definite results

Three methods have yielded positive results. The first two methods can be applied to Murex Trunculus or to a mixture of a small amount of Murex Trunculus with Murex Brandaris or Purpura Haemastoma.

The first and simplest is to immerse the broken shellfish in sea water; This produces a dye bath that must be used before precipitation of the dye which occurs quickly. The dye which does not precipitate in the interior of the fibers of the fabric is then lost. The color of the fabric can be darkened by repeated dyeing.

In the second method the dye was prevented from precipitating by the use of a tin or alloyed vessel. The baths must be decidedly basic. Of the vessels used it is only possible to concentrate the bath in pure tin and this must be done below 50°C. Even in a tin vessel the reduction of the already precipitated dye is impossible.

The third method is applicable only to Purpura Haemastoma and Murex Brandaris. This method allows the use of alloyed vessels for digestion.

After concentration in tin vessels a small quantity of Murex Trunculus has to be added to inoculate the enzyme, therefore the use of a tin vessel (white lead) is necessary.

The colors obtained are variable according to the species of Murex used. Murex Trunculus gives a red color with a slight violet tinge (Plate XI). Murex Brandaris gives a very delicate violet-pink color (Plate X). Purpura Haemastoma gives a violet color (Plate IX).

When the baths are diluted or almost used up, one obtains with all the Murex a blue-violet color. This color will change to the proper color according to the species upon a second or third dyeing. After this one cannot significantly alter the colors.

Before treatment in vinegar all the dyes, irrespective of their own shades are more violet; this treatment lightens and brightens the dye.

10

A comparison of the shellfish used with those mentioned in the text of Pliny

Pliny tells us (1):

> "Shellfish supplying purple dyes and scarlets—the material of these is the same but it is differently blended—are of two kinds: the whelk is a smaller shell resembling the one that gives out the sound of a trumpet, whence the reason of its name, by means of the round mouth incised in its edge; the other is called the purple, with a channelled beak jutting out and the side of the channel tube-shaped inwards, through which the tongue can shoot out; moreover it is prickly all round, with about seven spikes forming a ring, which are not found in the whelk, though both shells have as many rings as they are years old. The trumpet-shell clings only to rocks and can be gathered round crags."

> "It is most profitable for them to be taken after the rising of the dog-star or before spring-time, since when they have waxed themselves over with slime, they have their juices fluid. But this fact is not known to the dyers' factories, although it is of primary importance."

Pliny says "there are two kinds of shellfish which give the purple and other colors". In fact it is possible to dye in purple using four kinds of shellfish, those shown in Plates XIII to XVI. Plate XIII shows a shell identified as a type of Murex Trunculus (10) which appears to be the buccin of which Pliny is speaking. It should be noted that its form resembles the instrument "that gives out the sound of a trumpet". The opening is rounded with a canal that Pliny calls a hollow.

Plate XIV shows a shell which has been identified as another type of Murex Trunculus (10), but with two canal-like openings called purple by Pliny. The shell is "covered with bristle-like needles until the end of the spine". The remaining part of the description of Pliny coincides with Murex Brandaris (Plate XVI) (10). Furthermore it is the Murex

Brandaris which assembles in spring as Pliny has mentioned. Normally, this Murex lies buried in the sand.

It is difficult to identify the Purpura Haemastoma from Pliny's description. This shellfish lives in the rocky bottoms of the sea, and is shown in Plate XV.

11

Conclusions

As has been seen in section 9, this study has shown that three methods may be used to dye wool and silk. The first two can be used with Murex Trunculus or with a mixture of a small quantity of this type with Murex Brandaris or Purpura Haemastoma. The last method can only be applied to this last mixture before inoculating the enzyme of Murex Trunculus.

Vessels of lead, tin or lead alloys can be used. The dyeing is carried out in alkali media which can be produced from a mixture of water and wood ashes.

The precipitation of the dye can be inhibited by a reducing agent. The reducing agent is produced by the action of alkali on the tin of vessels used for dyeing that Romans called white lead.

Finally, if one uses the third method as mentioned in section 9, one can then add to the text of Pliny (1) (section 4) the following remarks:

> *"Three days is the proper time for it to be steeped (as fresher the salt the stronger it is), and it should be heated in a leaden pot"*, White lead (tin), *"with 50 lbs. of dye to every six gallons of water"*. (The excess of aqueous alkali used means that more does not have to be added during the process), *"kept at a uniform and moderate temperature by a pipe brought from a furnace some way off"*, (as has been seen, the temperature, must be kept below 50°C).
>
> *"This will cause it gradually to deposit the portions of flesh which are bound to have adhered to the veins, and after about nine days the cauldron is strained"* (one now can add to the bath of Murex Brandaris or Purpura Haemastoma a bath produced by the digestion of a small amount of Murex Trunculus in sea water, if not added at the beginning), *"and a fleece that has been washed clean is dipped for a trial"*.

The Murex which were used in this study were furnished by the sponge fishers of the region of Batroun. The interest shown by these workers in the methods of dyeing used by their ancestors has been a source of encouragement throughout this work.

12

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13

Samples dyed with Murex

Plate (Paragraph 3.2)	**I**	Raw wool.
	II	Wool after the first dyeing.
	III	Wool after the second dyeing.
	IV	The Precipitated dye.
Plate (Paragraph 6.2)	**V**	Natural silk.
		Silk after the first dyeing (bath before concentration)[1].
		Silk after the first dyeing (bath before concentration, but the sample is dipped in vinegar).
		Silk after the second dyeing (bath concentrated in tin vessel).
		Silk after the second dyeing (bath concentrated in tin vessel, but the sample is dipped in vinegar).
Plate (Paragraph 6.2)	**VI**	Wool after the first dyeing.
	VII	Wool after the second dyeing (double bath)[1].
	VIII	Wool after the second dyeing (double bath but the sample is dipped in vinegar).
Plate	**IX**	a) Wool sample dyed with Purpura Haemastoma.
	X	b) Wool sample dyed with Murex Brandaris.
Plate (Paragraph 8)	**XI**	a) Wool sample dyed with Murex Trunculus.
	XII	b) Sample of the coloring product concentrated by dissolution in alkaline.
Plate	**XIII**	Picture of both sides of a Murex known as Murex Trunculus[10].

Plate	**XIV**	Picture of both sides of a Murex known as Murex Trunculus[10].
Plate	**XV**	Picture of both sides of a shellfish known as Purpura Haemastoma[10].
Plate	**XVI**	Picture of both sides of a Murex Brandaris[10].

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Planches
Plates

Planche I

Laine écrue

Raw wool

Planche II

Laine première teinture

Wool after the first dyeing

Planche III

Laine deuxième teinture

Wool after the second dyeing

Planche IV

Précipité colorant

The precipitated dye

Planche V

Soie écrue

Natural silk

Soie première teinture
(liquide encore crue[1])

Silk after the first dyeing
(bath before concentration)

Soie première teinture
(liquide encore cru mais l'échantillon est traité au vinaigre)

Silk after the first dyeing
(bath before concentration. but the sample is dipped in vinegar)

Soie seconde teinture
(liquide concentré dans l'étain)

Silk after the second dyeing
(bath concentrated in tin vessel)

Soie seconde teinture
(liquide concentré dans l'étain avec traitement au vinaigre)

Silk after the second dyeing
(bath concentrated in tin vessel, but the sample is dipped in vinegar)

Planche VI

Laine première teinture

Wool after the first dyeing

Planche VII

Laine seconde teinture
(double bain[1])

Wool after the second dyeing
(double bath[1])

Planche VIII

Laine seconde teinture
(double bain mais l'échantillon
est traité au vinaigre)

Wool after the second dyeing
(double bath but, the sample
is dipped in vinegar)

Planche IX

Échantillon de laine
teint au Purpura Haemastoma

Wool sample dyed
with Purpura Haemastoma

Planche X

Échantillon de laine
teint au Murex Brandaris

Wool sample dyed
with Murex Brandaris

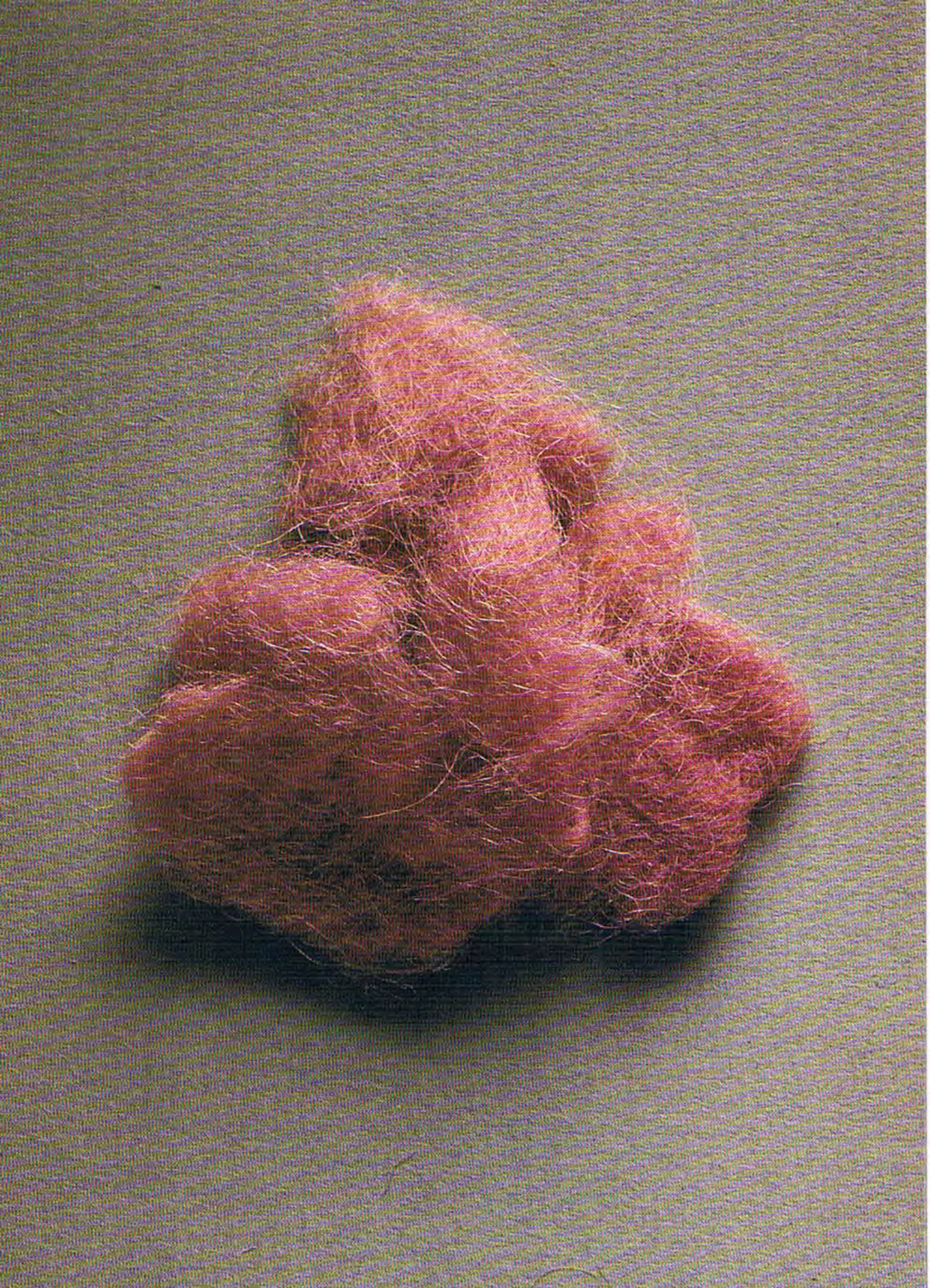


Planche XI

Échantillon de laine
teint au Murex Trunculus

Wool sample dyed with
Murex Trunculus

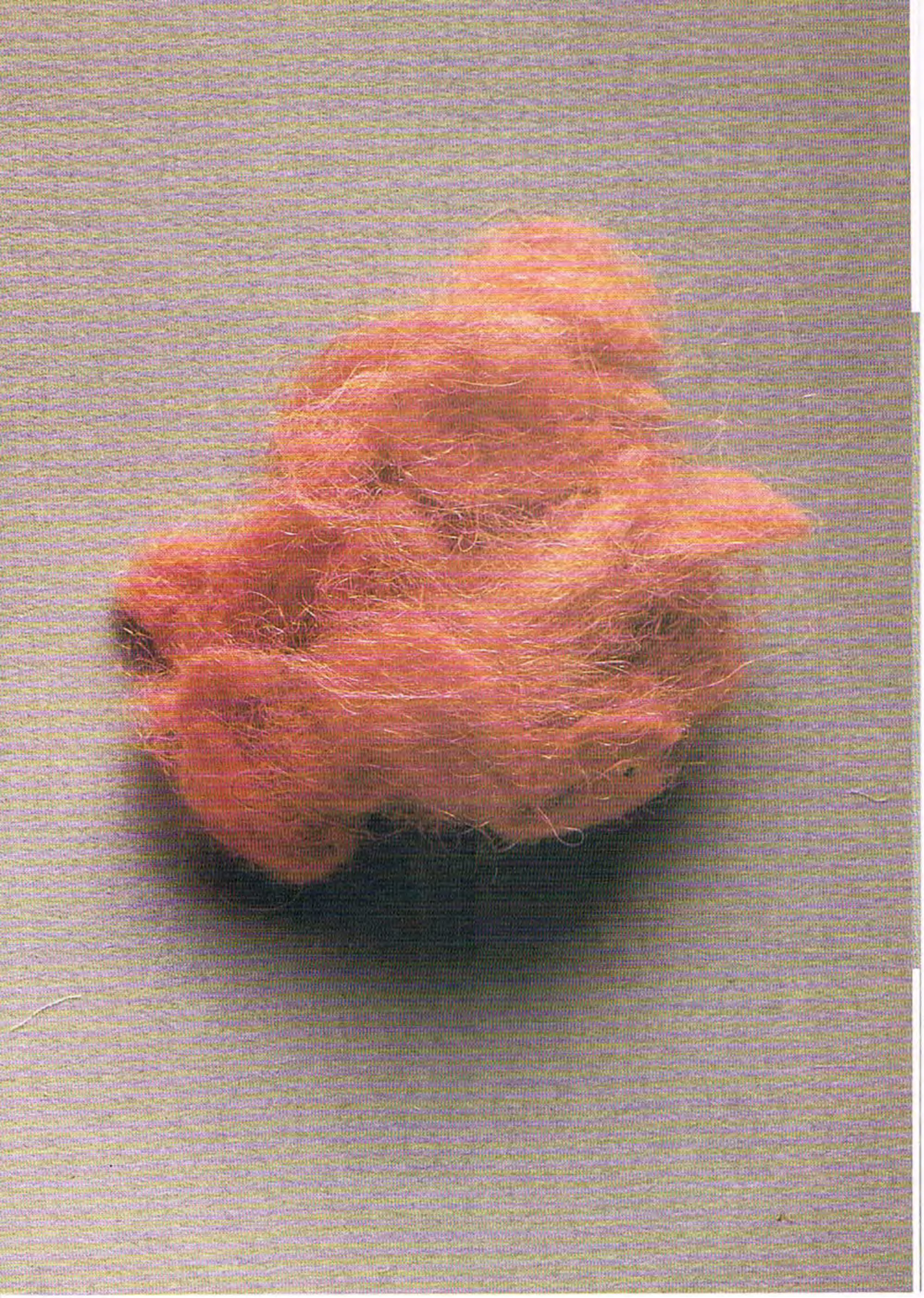


Plate XII

Échantillon du produit
colorant concentré par dissolution
au milieu alcalin
avec l'hydrosulfite de sodium.
Le produit après filtration
de la solution a été précipité par
l'acide acétique.

Sample of the coloring product
concentrated by dissolution in alkaline
medium with sodium hydrosulfite.
The bath is filtered
and the dye is precipitated
with acetic acid.

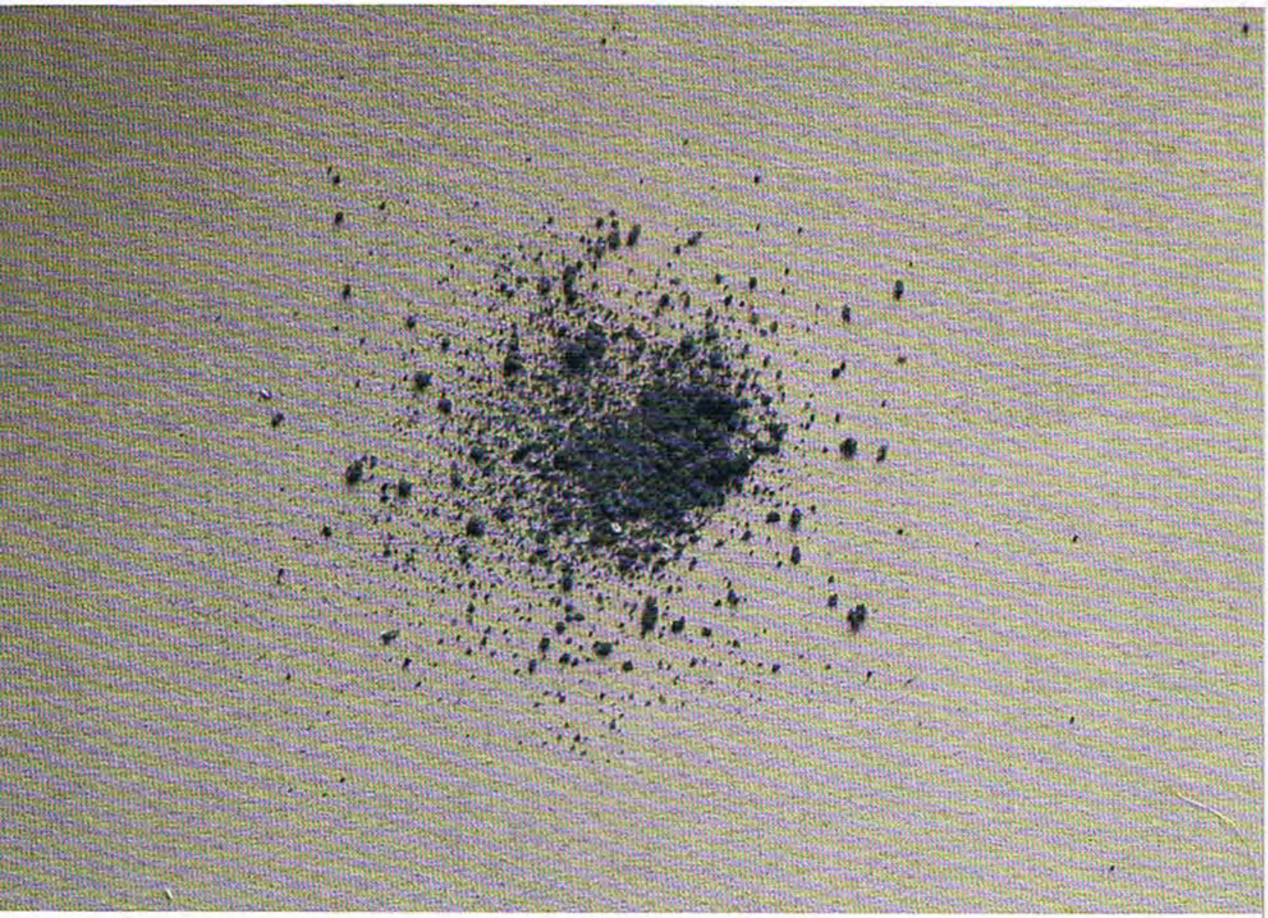
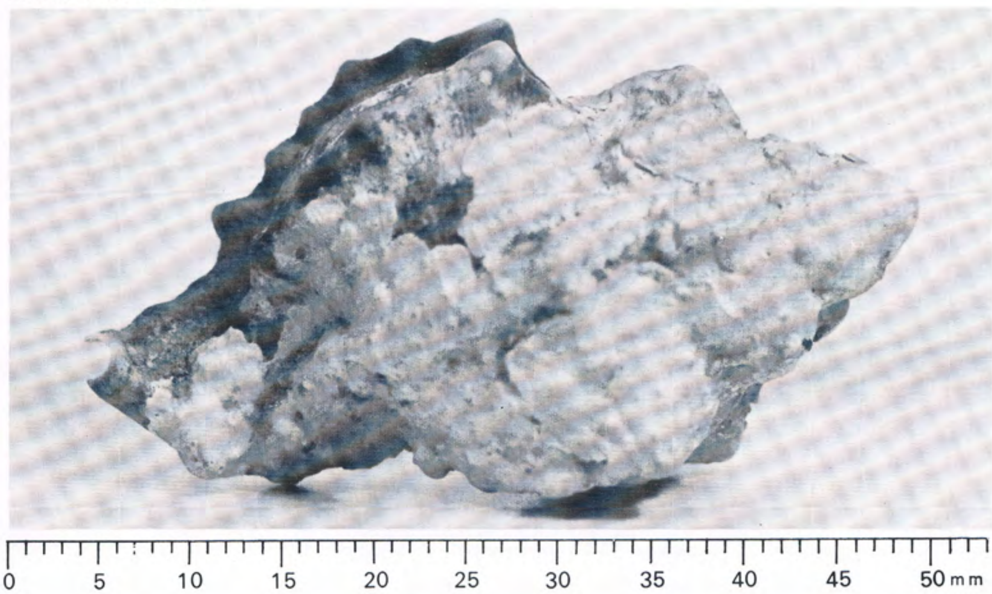


Planche XIII

Photographies de face et de dos d'un Murex identifié comme une sorte de Murex Trunculus[10].

Picture of both sides of a Murex known as Murex Trunculus[10].



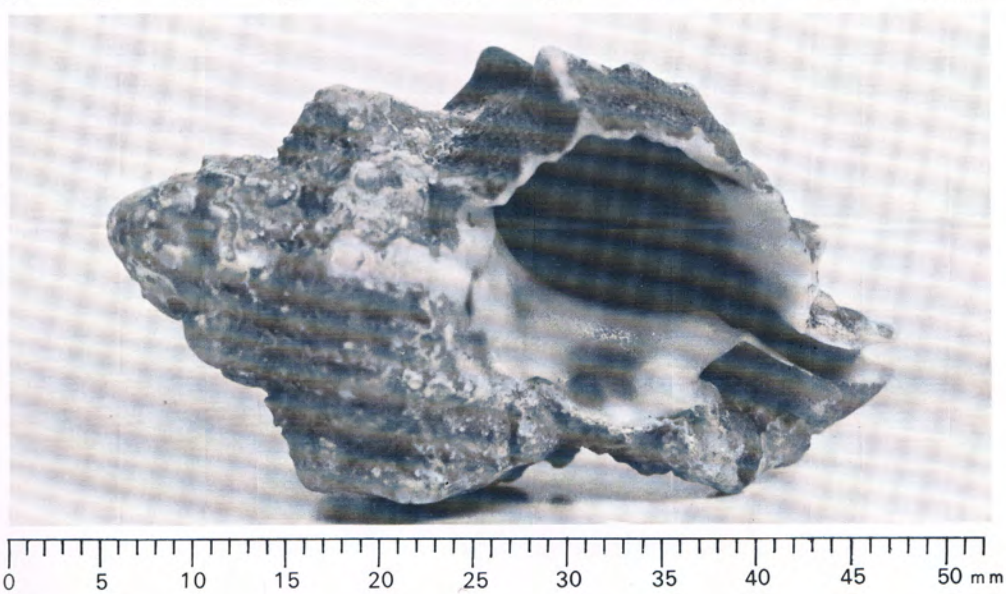
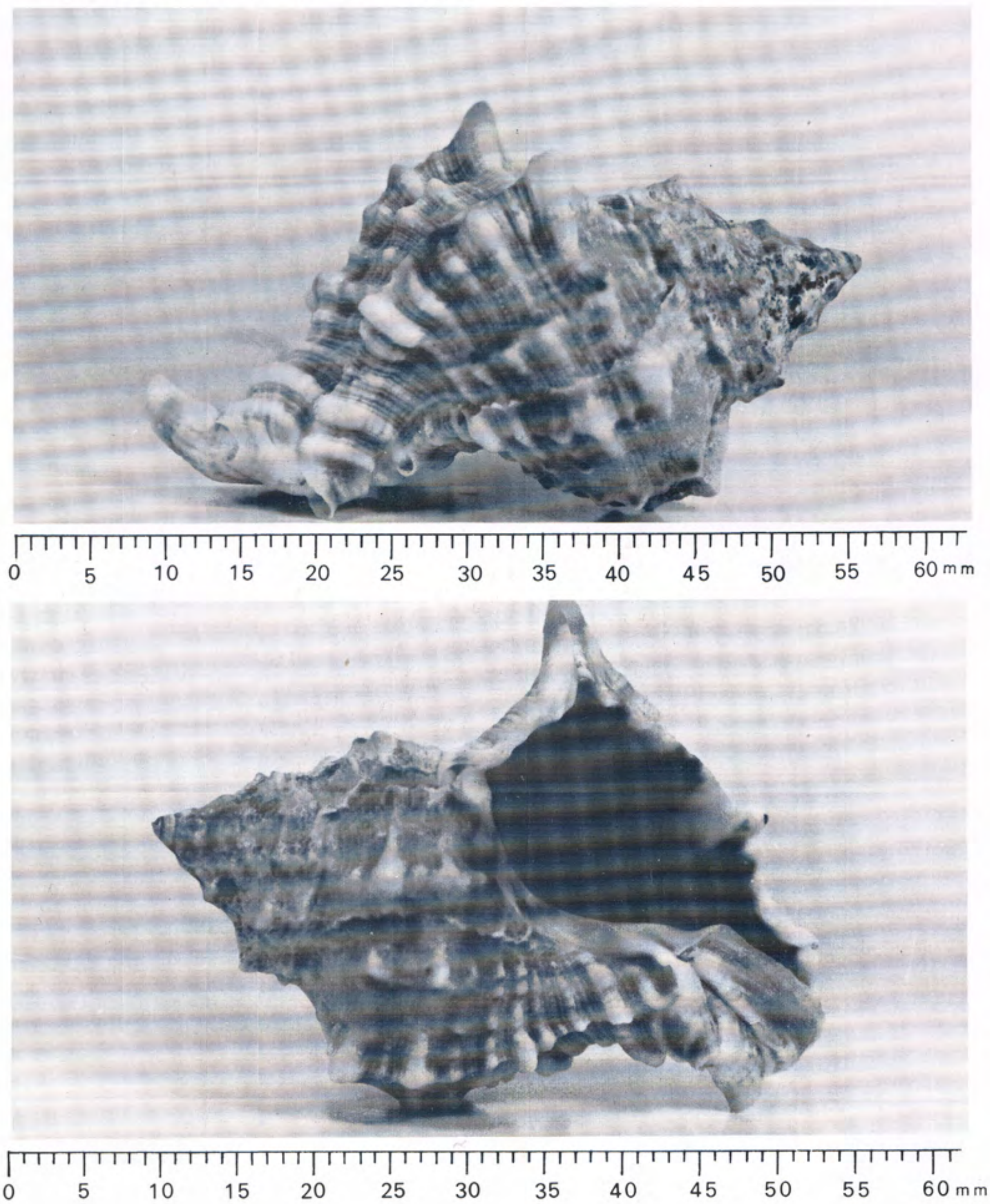


Planche XIV

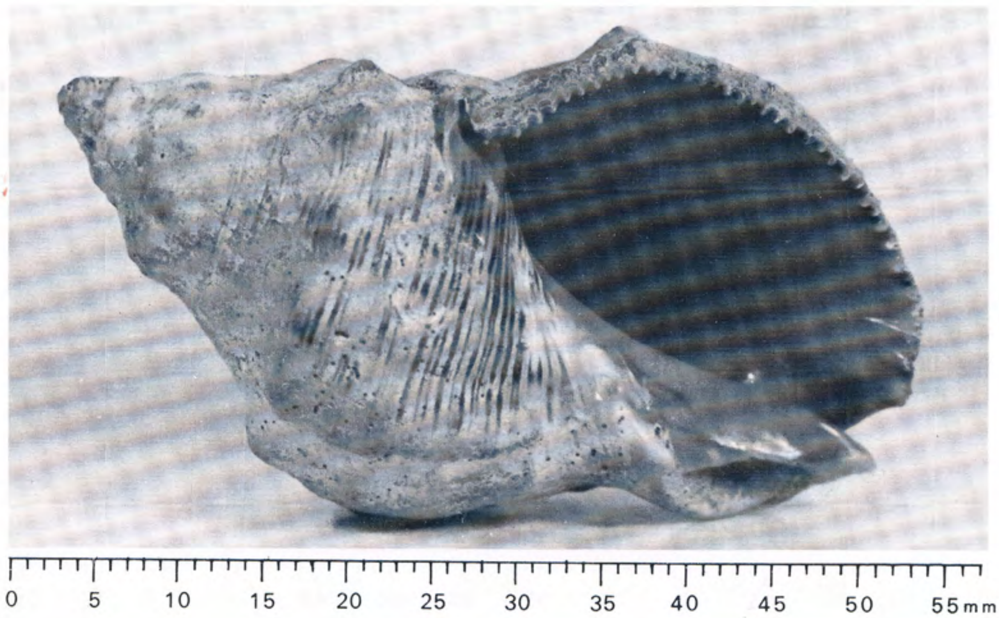
Photographies de face et de dos d'un Murex
identifié comme une sorte de Murex Trunculus[10]. («la pourpre» selon Pline)

Picture of both sides of a Murex known as
Murex Trunculus[10]. ("the purple" according to Pliny)



Photographies de face et de dos d'un coquillage identifié comme le Purpura Haemastoma[10].

Picture of both sides of a shellfish known as Purpura Haemastoma[10].



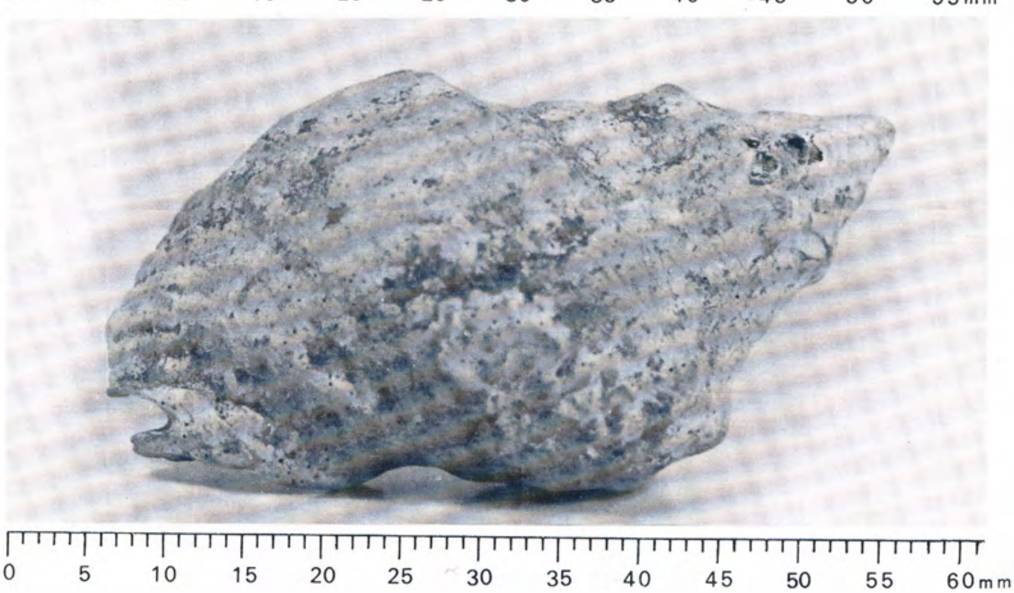


Planche XVI

Photographies de face et de dos du Murex Brandaris[10].

Picture of both sides of a Murex Brandaris.