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Bordered pits in spruce from old Italian violins

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SUMMARY

Spruce from a variety of old Italian musical instruments has been studied in the scanning electron microscope, to examine the membranes of bordered pits for evidence of bacterial degradation. Such degradation would be evidence in favour of a suggestion which has been made recently that the makers of such instruments may have used wood which had been immersed in water for a significant period before use. No such evidence was found—no undamaged bordered pits could be found with membranes absent or damaged in this way. Some possible sources of confusion arising from the wide range of appearances of bordered pits are illustrated and discussed.

INTRODUCTION

There has been some speculation recently that the wood used by the classical Italian violin makers may have at some stage been soaked or treated in water (Nagyvary, 1988; K. Roy, personal communication). When wood is soaked in water, or kept very wet, bacterial attack occurs, with enzymes selectively destroying parts of the wood structure. The attack is particularly severe if green wood is soaked in this way: it will show marked signs of bacterial action after only a matter of days. The commercial process, usually known as 'ponding', involves treatment for 4–12 weeks. There is a substantial body of literature on this subject—see for example the review by Rossell *et al.* (1973).

Such treatment could have been in some sense accidental: the easiest and cheapest way of transporting logs after felling is still by floating them. There is also a tradition of deliberate soaking, which may be in salt or fresh water. The effect on the properties of wood of such ponding has to some extent been studied in recent years, because among other things the process increases the permeability of wood to preservatives, and is thus of commercial significance. The relevance to violin making is unclear. Soaking in seawater was known to shipbuilders to be a way of strengthening wood, but in connection with the selection of maple for violin making Count Cozio di Salabue (Dipper & Woodrow, 1987) warned: 'Good timber can usually be bought in Venice out of Istria, but be sure to get it before it has been carried to the Arsenal and been immersed in sea water to fortify it and stop the worm'.

In this study we concentrate on Norway spruce (*Picea abies*), the wood used for soundboards of violins and other stringed instruments. There is general agreement about the major structural change brought about by freshwater ponding in softwood, and this change is readily investigated by scanning electron microscopy. We have collected samples from a variety of old instruments in the course of research on varnishes and ground layers (Barlow & Woodhouse, 1989), and we were thus able to examine spruce from thirteen different old Italian instruments.

BOTANICAL SUMMARY

The bulk of the tissue in spruce wood is made up of elongated cells which run vertically in the tree. These cells are known as tracheids, and their precise structure varies according to the season at which they are formed. Early growth, or spring wood, accounts for the softer, lighter-coloured wood in each annual ring, and consists of tracheids with very thin walls. As the growing season comes towards its end, summer wood is produced, with much thicker-walled tracheids accounting for the darker, harder portion of each annual ring. A small proportion of cells run transversely to the long axis in the growing tree, radially outwards from the centre. These constitute the medullary rays. Their mechanical significance in spruce is rather slight, although they are of course important to the lateral movement of fluids and nutrients in the living tree.

Adjacent cells may be connected together by means of perforations known as pits. In spruce, there are two types (e.g. Siau, 1971; Smith & Banks, 1971). Ray cells are connected to the tracheids which they cross by means of small piceoid pits. More significant for the present purpose, tracheids join to each other via bordered pits, so called because they have a doughnut-shaped ring around the edge. These bordered pits generally occur near the ends of tracheids, where the cells taper down and overlap with the ends of the next set of tracheids. Figure 1 illustrates these botanical details.

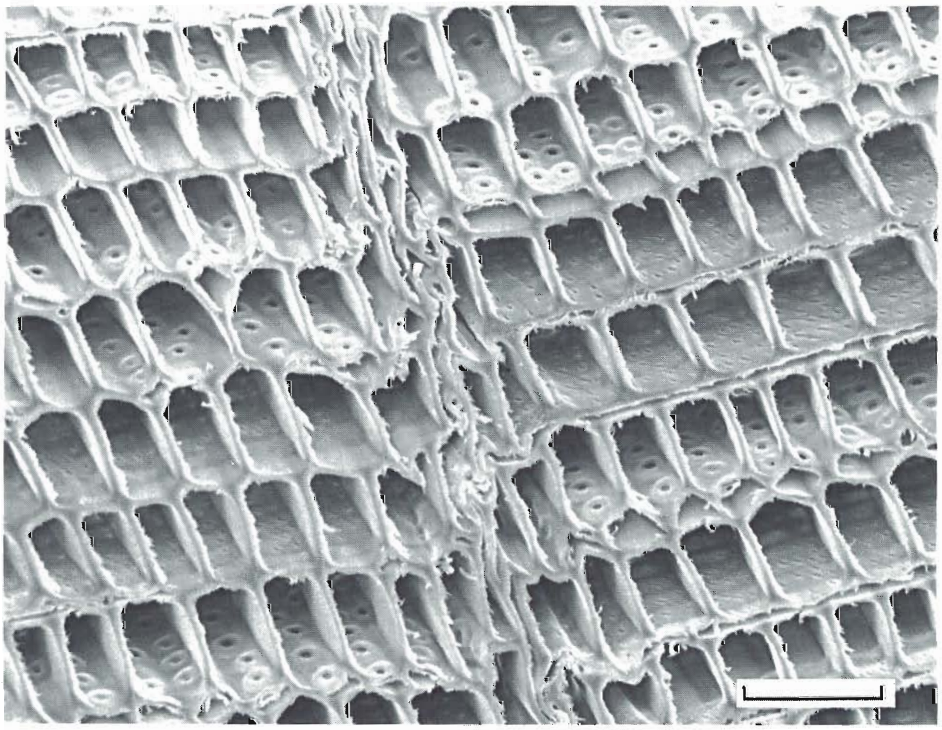


Fig. 1. Transverse section of modern air-dried spruce. Scale bar = 100 μm.

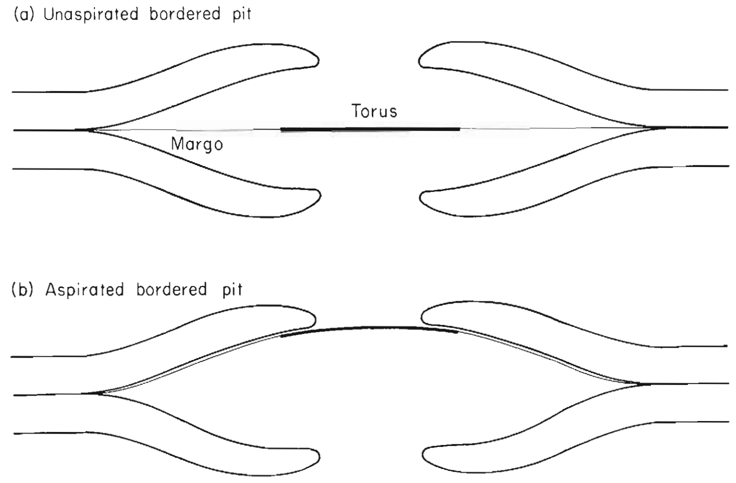


Fig. 2. Schematic diagrams of bordered pits in spruce: (a) membrane in the central position (pit permeable and open); (b) membrane drawn over to one of the pit walls, so that the pit is aspirated and impermeable.

It shows an end-grain view, corresponding to an approximately transverse section of the growing tree, of a piece of modern, air-dried spruce. Sections of many thin-walled tracheids dominate the picture. Rays with their associated pits are visible, running across the picture laterally between layers of tracheids, and many bordered pits are conspicuous at the narrow ends of rows of tracheids. This particular specimen has been crushed by clamping too hard, which accounts for the line of collapsed cells running almost vertically across the picture.

The different possible structures of bordered pits in spruce are shown in Fig. 2. Each pit consists of a pair of small circular holes in the walls of adjacent tracheid cells, with a central membrane. This membrane has an impermeable region, the torus, supported by a permeable array of filaments, the margo. When the membrane is in the centre of the pit pair as in Fig. 2(a), fluid can pass through the margo from one cell to the other, and the pit is open. A pit becomes closed, or aspirated, when the torus moves from its central position to block either of the pit apertures as in Fig. 2(b). In the sapwood of the living tree, the pits open and close like valves to control the flow of sap. When a cell dries out, the membrane is drawn away from its central position, perhaps by the surface tension of the last droplet of water in the pit, and becomes attached to one or other of the interior surfaces (Petty, 1972). Pits in the heartwood are often aspirated while the tree is still living, and may become sealed with deposits. Sapwood pits generally become aspirated during the process of air drying. There is reported to be a difference between earlywood and latewood: a greater proportion of latewood pits remain unaspirated (Petty, 1972). Once pits are aspirated, the wood becomes rather impermeable to fluids.

The first visible sign of bacterial action in softwoods is degradation of the membranes of bordered pits (Rossell *et al.*, 1973; Bolton & Petty, 1975). The response of pits to bacterial attack will vary depending upon the prior treatment of the wood, and on whether the sample is heartwood or sapwood. Rapid bacterial attack occurs in green sapwood kept under water, or in very damp conditions (e.g. under water sprays), and the pit membranes disappear. Pit membranes in heartwood are much more resistant to attack because they become lignified (Rossell *et al.*, 1973).

The purpose of this study was therefore to examine all the spruce samples available to us, looking at the structure of the bordered pits. If the pit membranes were degraded or missing entirely, this would support the theory that the wood had been wittingly or unwittingly ponded. If the membranes were intact, there would be no evidence for this theory. Of course if the pits of a particular sample had been already aspirated before soaking, either because it was heartwood or because it had been air-dried first, we would not expect to see degradation of membranes unless soaking had been very prolonged. We would not then be able to rule out the possibility that the wood had been soaked for a short time. However, the available literature seems to suggest that the degradation of pit membranes to increase permeability is the main useful function of ponding. The effects on mechanical properties have been shown to be slight (Stamm, 1964; Efransjah *et al.*, 1989) so that if the pit membranes are intact then any soaking presumably has little influence (except perhaps resulting from some loss of gums, resins, etc., the so-called extractives).

EXPERIMENTAL DETAILS

The samples which we have studied are listed in Table 1. They span nearly two centuries of Italian instrument making, and the list of makers includes some famous names. We have had no control over which samples became available because we rely entirely on the generosity and interest of restorers. In fact, though, the collection listed here seems to be quite a representative cross-section of golden-age Italian instrument making of all periods and regions.

Because the samples were fragments removed during the course of restoration, the surfaces examined had been prepared in various ways: fractured, knife-cut or planed. The most satisfactory samples for our purposes (showing most pits) were those cut in the longitudinal-radial plane of the tree, so that shavings from the interior surfaces of quarter-cut front plates were found to be ideal. Some samples were extremely minute, some were very brittle and crumbly. The combination of these factors with the different orientations and types of cut leads to a wide variety of appearances. Each of the samples was sputter-coated with the thinnest workable layer of gold and examined in a scanning electron microscope, using an accelerating voltage of 10 kV.

RESULTS AND DISCUSSION

Figure 3 is a micrograph of part of a belly shaving from a 1704 Stradivari violin. The pits visible here are all aspirated, but the two outer ones in the micrograph have membranes attached to the upper halves of the pits, close to us, and in the other two the membranes are attached to the lower halves, away from us. We have generally found that pits are not all aspirated in the same direction, and have seen no consistent pattern. Sometimes all the pits are aspirated the same way in one tracheid, and the opposite way in the adjacent tracheid; sometimes nearly all the pits are aspirated the same way in a substantial area of the sample; and on other occasions the arrangement

Table 1. Details of the samples examined in this study.

Maker	Place, date	Description of sample
Gasparo da Salo	Brescia. *c.* 1580	Interior shaving, violin
Maggini	Brescia, *c.* 1610	Interior shaving, violin
A. &. H. Amati	Cremona, 1620	Surface sliver, violin
Nicolo Amati	Cremona, early seventeenth century	Full-depth piece, violin
Seraphin	Venice, early seventeenth century	Full-depth piece, violin
Andrea Guarneri	Cremona, *c.* 1650	Full-depth piece, cello
Andrea Guarneri	Cremona, *c.* 1680	Full-depth piece, cello
Pietro Zanetto	Brescia, 1680–1692	Full-depth piece, viola
Testore	Milan, *c.* 1700	Full-depth piece, violin
Stradivari	Cremona, 1704	Interior shaving, violin
Ferdinando Gagliano	Naples, 1748	Interior shaving
J. B. Guadagnini	Milan, 1750	Interior surface, cello
Gennaro Gagliano	Naples, 1751	Interior shaving

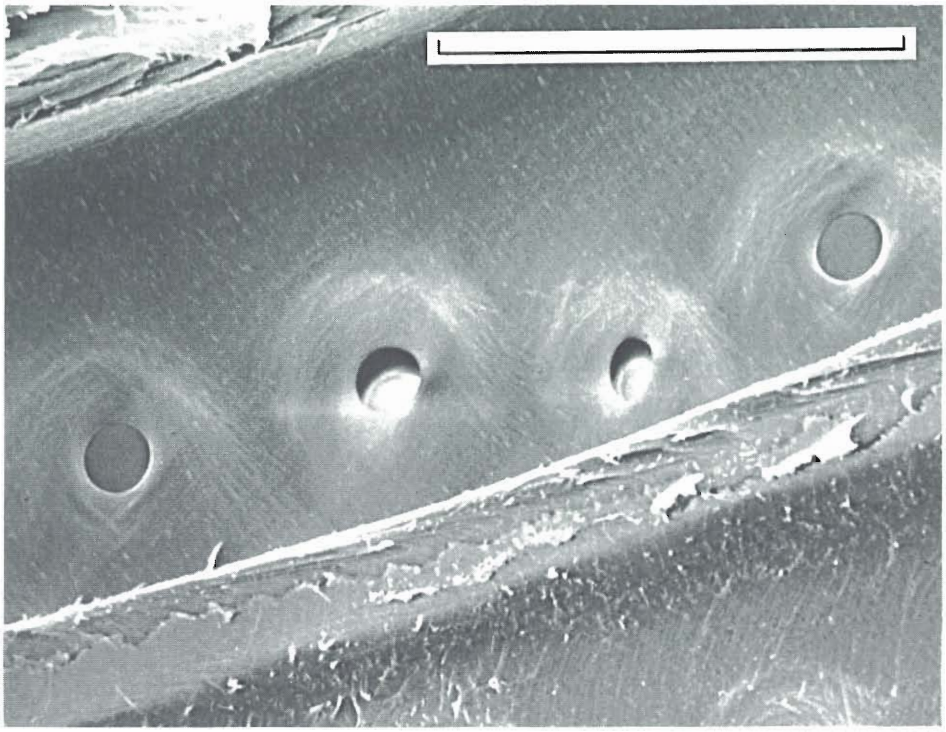


Fig. 3. Sample from a 1704 Stradivari violin. All the pits are aspirated, but the membranes in the central pair of pits are attached to the lower halves of the pits and are bright due to charging. Scale bar = 20 μm.

is random, as here. The precise way in which the tree dried probably determines the pattern of aspiration, but we are not qualified to speculate further.

A very different view of bordered pits appears in Fig. 4, showing a spruce sample from a Maggini violin of *c.* 1610. Here the exposed surface of the wood has been created by adjacent tracheids pulling apart along the middle lamella. The cell wall has thus been divided in two, revealing the interiors of bordered pits. Most of the pits were aspirated with the torus closing the bottom part of the pits, and in these the torus can be seen neatly sealing the pit opening. In some cases part of the margo is visible as fine filaments running radially between the torus and the outside of the pit. Where no such structure can be seen, the margo is presumably stuck down firmly onto the cell wall, and there may be a film of some deposit covering it, obscuring the details. Other pits show empty openings, not because the pit membrane was absent originally, but because it had been attached to the upper surface of the pit pair, which has been removed.

Damage of this sort is to be expected, whatever the method by which the surface was prepared. Wood often splits most readily within the tracheid cell walls, so that the crack runs along the middle lamella and divides the pits. Undamaged pits are found where the crack or cut reveals the interior of tracheids so that the cell walls immediately around the pits are undisturbed, as in Fig. 3. When checking whether pits still retained their membranes, or whether there was any indication of bacterial action having consumed the torus, undamaged pits are the only ones which provide definitive answers. Statistically, half of the damaged aspirated pits would be expected to have membranes and half would show no sign of a membrane. The casual observer might

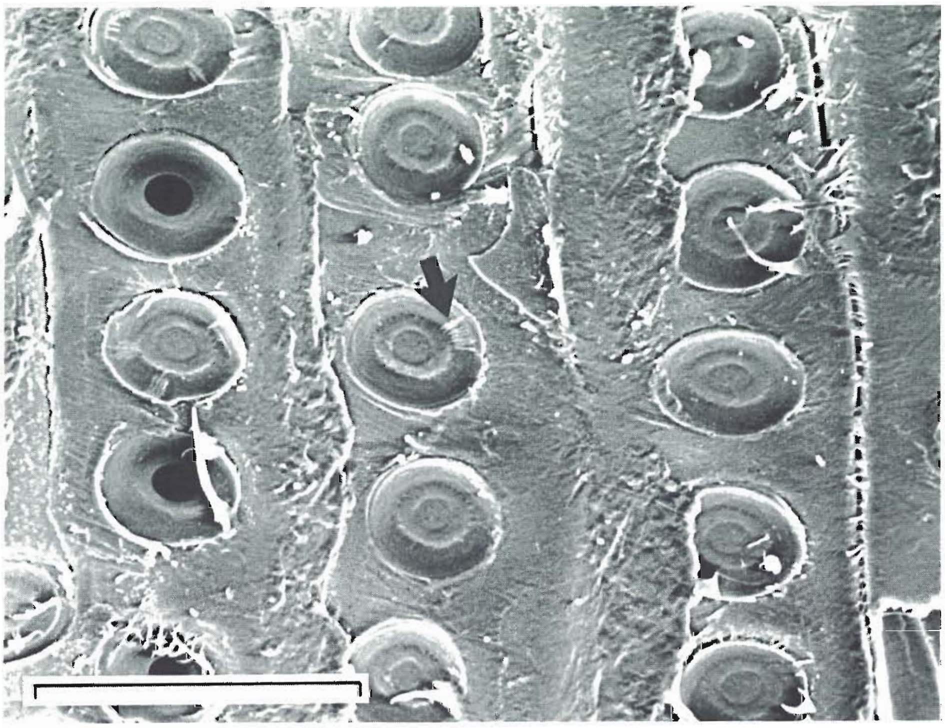


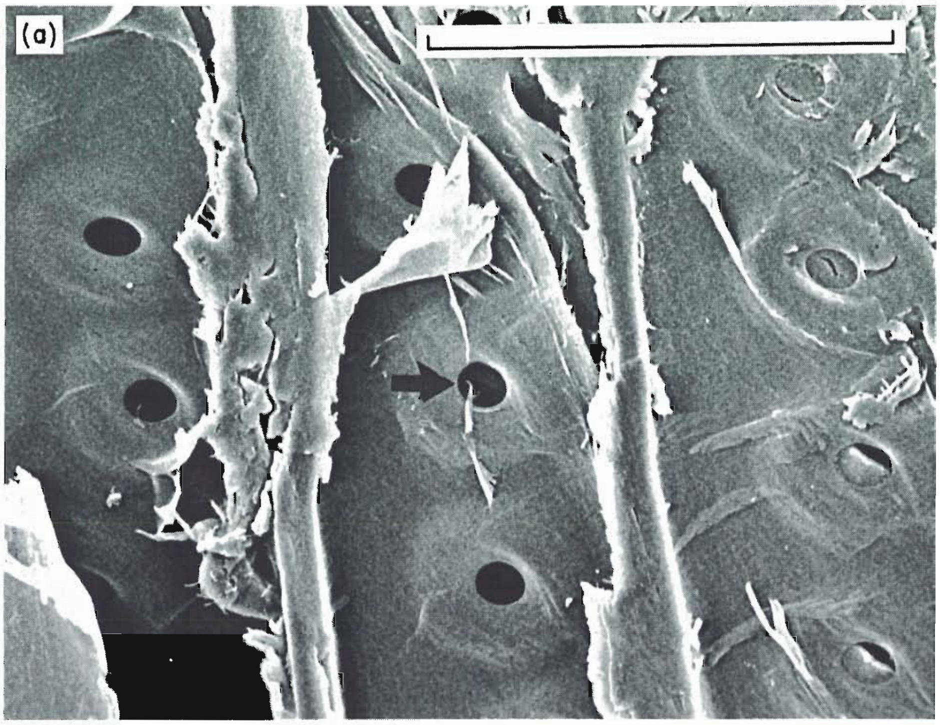
Fig. 4. Sample from a violin by Maggini, *c.* 1610. Part of the structure of the margo in some of the pits is visible as radial filaments (for example where arrowed). Scale bar = 50 μm.

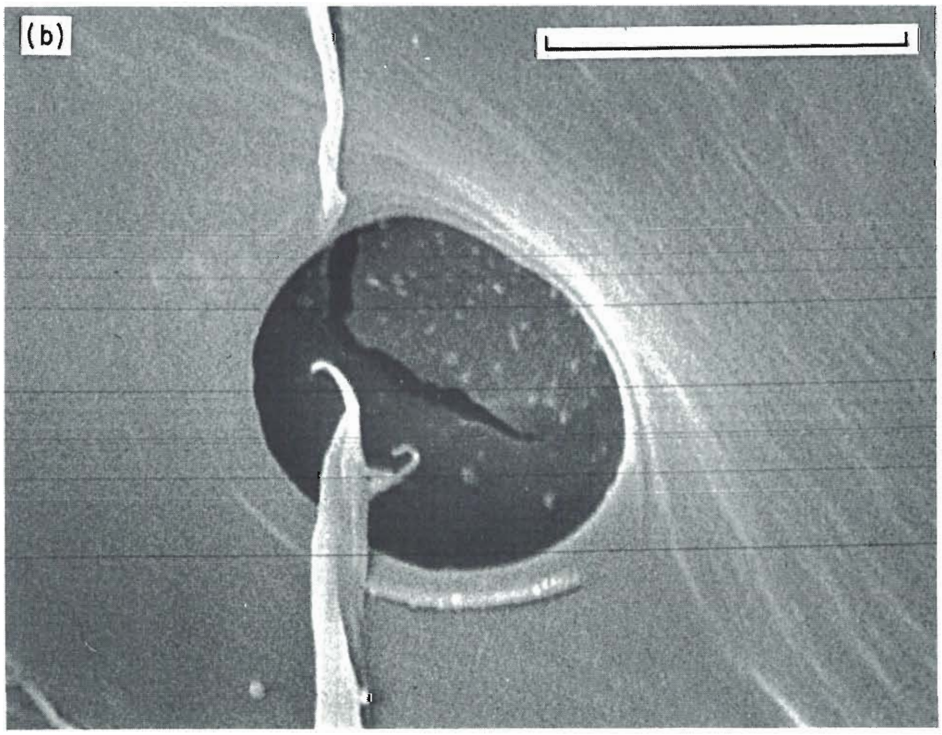
identify the latter set as candidates for bacterial degradation, but the probability is that they have merely lost their membranes through mechanical damage.

There is another class of pits which can appear to have lost their membranes, and these are aspirated pits where the membrane is attached to the lower part of the pit. We have already seen examples of this in Fig. 3, where the membranes are quite clearly present at the bottoms of the pits, but there are other occasions where the membranes are visible only with difficulty. Most of the pits in Fig. 5(a) appear to lack membranes (except for the row on the right hand side). Looking more closely, though, and tilting the specimen somewhat, the membrane at the bottom of the arrowed pit in the middle of the photograph can be seen clearly in Fig. 5(b). The membrane has split, but this has probably been caused by the conditions within the microscope: in some cases we were able to watch such splits forming. The other pits in Fig. 5(a) all proved to have their membranes attached to the lower of the two pit openings. The difference in appearance between these pits and those in Fig. 3 perhaps arises because the separation of the two pit openings was rather large in this case. This may be a difference between earlywood and latewood: the cell walls of latewood are thicker than those of earlywood, and the pit openings are therefore further apart.

A further variation on membrane positions in bordered pits is shown in Fig. 6, of a sample by Testore. This is a damaged pit, without its top half, and before being

Fig. 5. Sample from a violin by Gasparo da Salo, *c.* 1580: (a) apparently showing some pits with membranes absent (scale bar = 50 μm); (b) close-up of the arrowed pit from (a), showing membrane to be present (although damaged) (scale bar = 5 μm). The horizontal lines in (b) arise from scan faults.


(a)


(b)

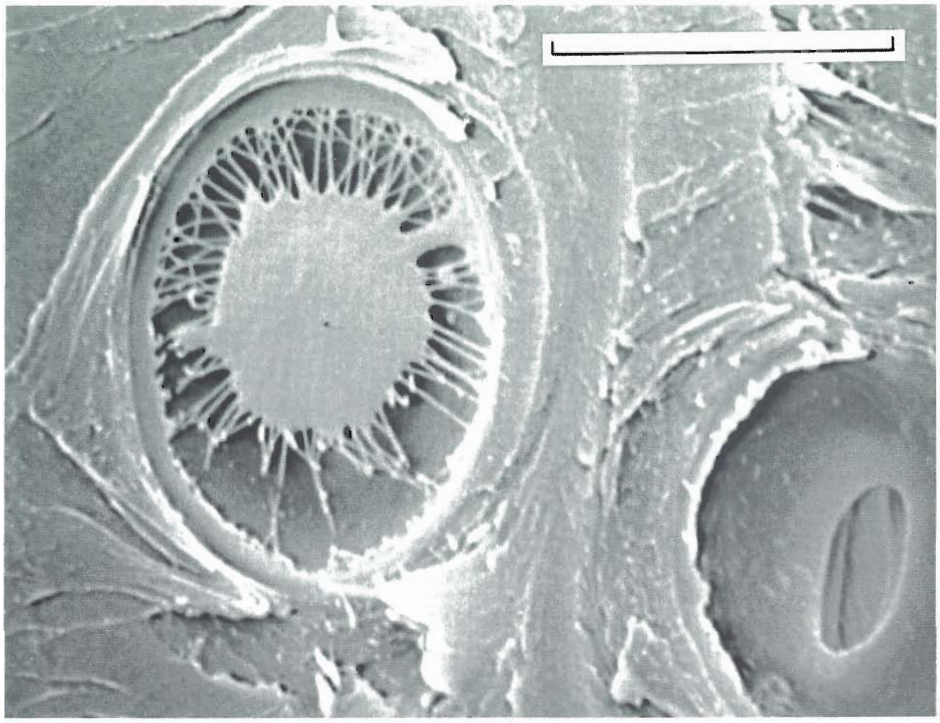


Fig. 6. Sample from a violin by Testore, *c.* 1700. Scale bar = 10 μm.

broken it appears to have been in the unaspirated configuration with the membrane in the middle of the pit chamber. The structure of the membrane, with the margo and torus, is very clear here. A small proportion of the pits in this sample were like this, the remainder being aspirated and resembling aspirated pits shown elsewhere in this article. This is the only sample in which we have found open pits. Unaspirated pits have been reported in wood samples which have been treated with solvents (e.g. alcohols) before they dried naturally (Banks, 1971), and it is possible that their presence in this sample may be an indication of the way in which the timber was treated. As the wood is rather different in its botanical details from any of the other samples we have examined, it could also be a characteristic of the type of softwood Testore used. This specimen is the only one in our collection which appears not to be *Picea abies*.

CONCLUSIONS

When we examined samples of old instruments in an earlier study of varnish and ground layers (Barlow & Woodhouse, 1989), we found great diversity. No universal generalizations could be drawn from the observations. In the present investigation, by contrast, complete unanimity was discovered among the wide range of samples studied. After a very thorough investigation of each sample, we were unable to find a single example of a bordered pit which had not been subjected to obvious mechanical damage but whose membrane was missing or partially degraded in the manner reported in the literature to be characteristic of ponded wood (Bolton & Petty, 1975). In some cases we saw evidence of slight fungal infestation, but could not tell whether this was old or modern: many of the samples had travelled the world extensively between being removed from instruments and being examined by us, so there will have been scope for recent superficial infestation. Fungal infestation is certainly not limited to wet wood (Rossell *et al.*, 1973), so it gives no particular evidence for or against ponding.

Thus our study offers no positive evidence for the theory that the classical Italian instrument makers used spruce which had been ponded to increase permeability by bacterial degradation of pit membranes. Most of the samples seemed, at least to our eyes, indistinguishable from modern, air-dried spruce of musical instrument quality. The only exceptions were those samples which had lost mechanical strength for one reason or another and become crumbly, but even there all the pits we could find had their membranes intact, so that ponding does not appear to be implicated in the process of loss of strength.

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