Observations of Moisture Distribution in *Fraxinus mandshurica* var. *japonica* Maxim. and *Kalopanax pictus* Nakai with Soft X-ray Photography.*

By

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軟X線透視によるヤチダモ (*Fraxinus mandshurica* var. *japonica* Maxim.), ハリギリ (*Kalopanax pictus* NAKAI) の水分分布の観察*

佐 野 雄 三** 深 沢 和 三**

Abstract

The authors investigated the moisture distribution of *Fraxinus mandshurica* var. *japonica* and *Kalopanax pictus*. In *F. mandshurica* var. *japonica*, the heartwood contained more moisture than the sapwood. The re-wetting in the heartwood was limited at the inner layer of the sapwood-heartwood boundary. The moisture distribution in the heartwood differed between trees, and even within a tree. In *K. pictus*, the moisture content steadily decreased from the outermost area inward, without an abrupt change near the border of the heartwood. In both species, areas around dead branches, knots and wounds had considerably higher moisture levels. Each species has been grouped into different types from a point of view of their moisture content distribution in past works, but these species also share a common characteristic in their moisture distribution.

Key words: moisture distribution, moisture content, wetwood, soft X-ray photography, angiosperm species.

1. Introduction

Moisture distribution in a tree trunk varies with the species, especially among angiosperm species. In gymnosperm and many angiosperm species, dehydration occurs during the transformation of sapwood to heartwood. On the other hand, re-wetting occurs with

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the tranformation in some angiosperm species. In these species, the moisture content increases sharply at the sapwood-heartwood boundary (SMITH and GOEBLE 1952, BENIC 1957, GIBBS 1958, YAZAWA 1964, YAZAWA and ISHIDA 1965a, b, STEWART 1967, HILLIS 1987).

Although moisture content sharply increases in the heartwood at the sapwood-heartwood boundary in some angiosperm species, it is unclear whether the re-wetting completely corresponds with the heartwood transition or not, because these findings were obtained only from the measurement of wood blocks having radial width. On the other hand, it is also unclear whether the dehydration occurs corrsponding with the heartwood transition or not in angiosperm species having dry heartwood, as is the case with gymnosperm species.

Soft X-ray photography can be used to show the moisture distribution of wood (ISHIDA et al. 1967). The method has the advantage that the moisture localization at the tissue level can be ascertained by enlarging the photographs. Recently, LEE (1988), KON (1985) reported significant findings about wetwood distribution in *Poplus maximowizii* and some other species growing in Hokkaido, respectively, using soft X-ray photography. It is expected that the problem described above will be resolved and the pattern of moisture localization, which is hardly known yet, will be clarified.

Fraxinus mandshurica var. *japonica* has heartwood containing more moisture than the sapwood (YAZAWA and ISHIDA 1965a, b). On the other hand, *Kalopanax pictus* has heartwood containing less moisture than the sapwood (YAZAWA 1964). These species have different patterns of moisture content distribution although both species are ring porous wood. Thus, the authors examined the moisture distribution of these two species mainly with soft X-ray photography. Not only the typical radial distribution in trunks without defects, but also the areas around branches, knots, wounds and other defects, were examined.

2. Materials and Methods

Two *Fraxinus mandshurica* var. *japonica* trees and two *Kalopanax pictus* trees, grown in the Nakagawa Experiment Forest of Hokkaido University, were felled on December 12, 1988 and January 11, 1989, respectively. Each sample tree, except for tree No. 4, had been bored with an increment borer during the last growing season for an other purpose. Heights and diameter of the sample trees are shown in Table.

Immediately after felling, each tree was cut into logs having one meter lengths, and the cutting surfaces were coated with vaseline. After freezing the logs, disks of about 3mm in thickness were serially obtained at 20 to 30cm intervals with a disc saw. In addition, some transverse or longitudinal sections of about 3mm in thickness, that included living and dead branches, knots or other defects, were also obtained from the sample trees. The

Table Sample trees used in this study

Sample trees		Height	D.B.H.	Notes
Fraxinus mandshurica var. *japonica*	No. 1	10.5m	9cm	Planted in 1954.
	No. 2	10 m	9cm	
Kalopanax pictus	No. 3	11 m	19cm	Both trees had about 60 annual rings at the butt.
	No. 4	8.5m	11cm	

green disks and sections were placed on film covered with a sheet, and irradiated at 18kV and 5mA for 210 seconds. The dried disks were also irradiated in the same manner.

At the time of the sectioning of the disks described above, wood disks and pieces that were 1cm thick, were taken from the neighbouring xylem of the disks and the sections of about 3mm in thickness. The samples were cut into small pieces of a reasonable size : the sapwood and heartwood were each divided into three pieces. The pieces were weighed immediately after the cutting and oven dried at 105℃ for 24 hours. Then, the moisture content as a percentage of oven dry weight (MCd) was determined.

Moisture content of dense wood will become lower than that of light wood even in the case that both wood contains same amount of water and have same volume, if the moisture content is expressed as a percentage of the dry weight (CHALK and BIGG 1956). Thus, moisture content as a percentage of saturated water (MCs) was also determined about wood sections, in which the density was quite variable such as those from areas around knots. After the weighing of green wood, the wood pieces were saturated with water in a deccicator using a vacuum pump to achieve a constant weight. Then, the surface water was blotted off, the samples were re-weighed and MCs was determined.

3. Results

3.1 Moisture distribution in *F. mandshurica* var. *japonica*

As a rule, heartwood contained more moisture than sapwood. MCd of the sapwood ranged from 35 to 55% and that of the heartwood was from 55 to 110%. Fig. 1 shows the moisture content distribution in the trunk of tree No. 1, from the butt to a 1.25 meter height. As a rule, the moisture content of heartwood is higher than that of sapwood. The pattern of moisture content distribution near the butt, in which heartwood did not develop, is invariable at approximately 50% as MCd.

The appearance of moisture distribution in the heartwood was variable among the tree heights. Figs. 2-5 show the moisture distributions at 0.7, 1.2, 1.8 and 2.5 meter heights, respectively. At 0.7 meter height, the soft X-ray absorbance of the green heartwood was uniformly high, signifying that the heartwood become wet evenly (Fig. 2). However, the heartwood partly became wet at higher levels and the ratio of the wetwood reduced with the increase of the tree height (Figs. 3-5). At 2.5 meter height, only the outer heartwood and the areas around internal cracks became wet (Fig. 5).

The re-wetting in the heartwood did not always correspond with the color change from the sapwood to heartwood, and was limited to a few annual rings inner layer from the sapwood-heartwood boundary in many cases. This is evident near the butt at which the heartwood did not so develop (Figs. 6, 7). Fig. 6 shows a transverse view of the moisture distribution at 45cm height of the trunk of tree No. 1. The re-wetting is limited to inner layer from the sapwood-heartwood boundary in the areas pointed out by arrows. Fig. 7 shows the longitudinal view of the moisture distribution below the transverse section shown in Fig. 6. The re-wetting is notable only in the upper area of the heartwood shown in the photograph and is not found in the lower part of the heartwood. This feature was also observed at higher parts of the trunk (Fig. 8). Fig. 8 shows an enlarged view of a part of Fig. 2. The weteood development is limited to one or two annual rings inner layer from the sapwood-heartwood boudary.

At the junction of a living branch, the moisture distribution shows the same pattern as

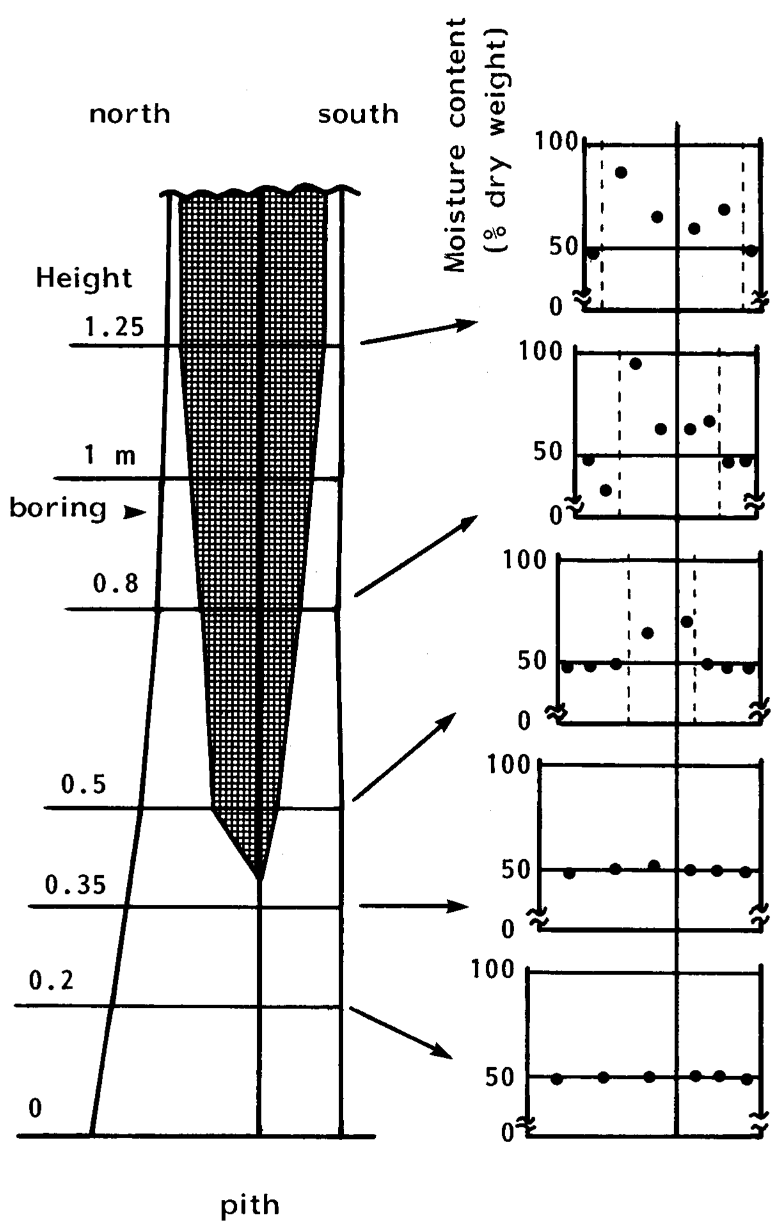

Fig. 1 Moisture content of tree No. 2 (*Fraxinus mandshurica*). Area shown by screen expresses heartwood region. In this tree, heartwood was not formed in portion below 0.4m height.

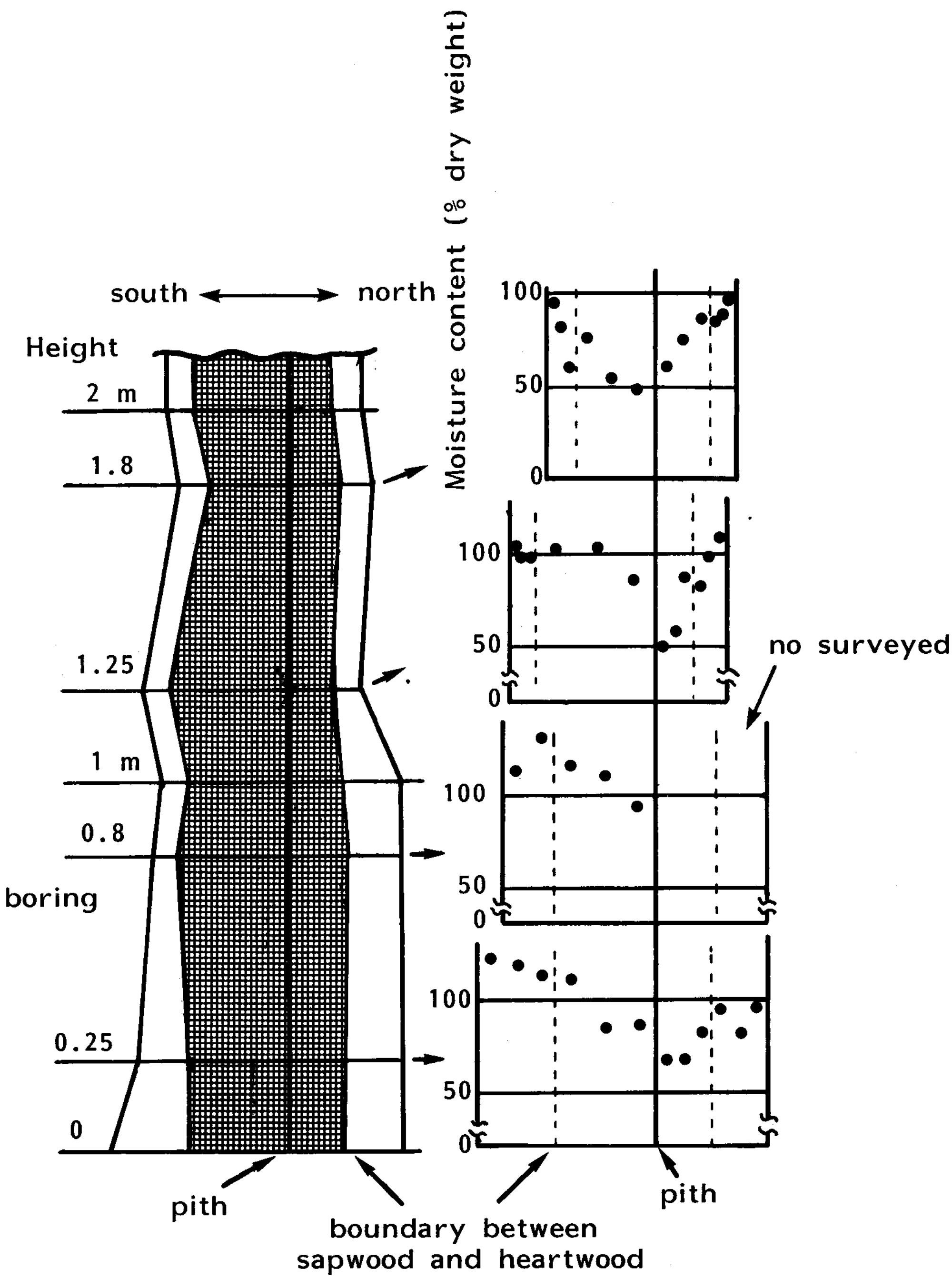

Fig. 15 Moisture content of tree No. 3 (*Kalopanax pictus*).

that in tree trunks without branches (Fig. 9). However, areas around dead branches, knots and wounds, became quite wet (Figs. 10, 11). Fig. 10 shows a longitudinal section including knots at about 6m height of tree No. 2. Areas around knots become wetter than the neighbouring area. Fig. 11 shows a transverse section including a bore hole made with an increment borer. The layer along the bore hole become wetter than the neighbouring areas.

Wetwood existed even in the sapwood below the level of about 0.7m height (Figs. 2,8, 12-14). The wetwood developed with the decrease of the tree heights. Wetwood formation in sapwood was observed only in tree No. 1, and not in tree No. 2.

3.2 Moisture distribution in *K. pictus*

In most cases, the heartwood contained less moisture than the sapwood. MCd of sapwood blocks sampled ranged from 60 to 120% and that of the heartwood was from 40 to 110%.

Dehydration did not suddenly occur with the transition from sapwood to heartwood, but rather gradually occured. Fig. 15 shows the moisture content distribution of tree No. 3. In general, the moisture content gradually decreased from the outermost layer to the innermost layers although this tendency displayed some partial irregularities. Fig. 16 shows a transverse view of a section without branches and other defects. The dehydration occurs from the outermost layer inward in a trunk independently of the distinction between sapwood and heartwood, developing from earlywood to latewood in an annual ring, as a rule. However, local re-wetting occured here and there independently of the distinction between sapwood and heartwood. At the junction of a living branch, the pattern of moisture distribution was the same as that of areas of the trunk without branches, namely dehydration steadily advanced from the outermost layer inward.

Wetwood was found in areas around dead branches, knots, wounds and other defects. Fig. 17 shows the moisture distribution of a transeverse section having a dead branch and Figs. 18, 19 show those of longitudinal ones above and below the dead branch shown in Fig. 17, respectively. Wetwood is formed around the rotted dead branch and developes in both areas above and below the dead branch. Figs. 20, 21 show the moisture content distribution of the layers adjoining the wood sections shown in Figs. 18, 19, respectively. MCs in the outer heartwood is higher than that of the sapwood transversely and increases as the area of the dead branch is approached longitudinaly, although the same tendency is not necessarily observed for MCd.

Wetwood was also found in areas around wounds. Fig. 22 shows a transverse section including a bore hole made with an increment borer. The section become wholly saturated in contrast to the section without wounds shown in Fig. 16. Earlywood vessels are filled with water in the layer along the bore hole. The opposite side of the figure shows the same pattern as the area without wounds and dead branches shown in Fig. 16. The water accumulation in the side having the bore is also noticed in Fig. 15, namely MCd in the side including bores became significantly higher than in the opposite side.

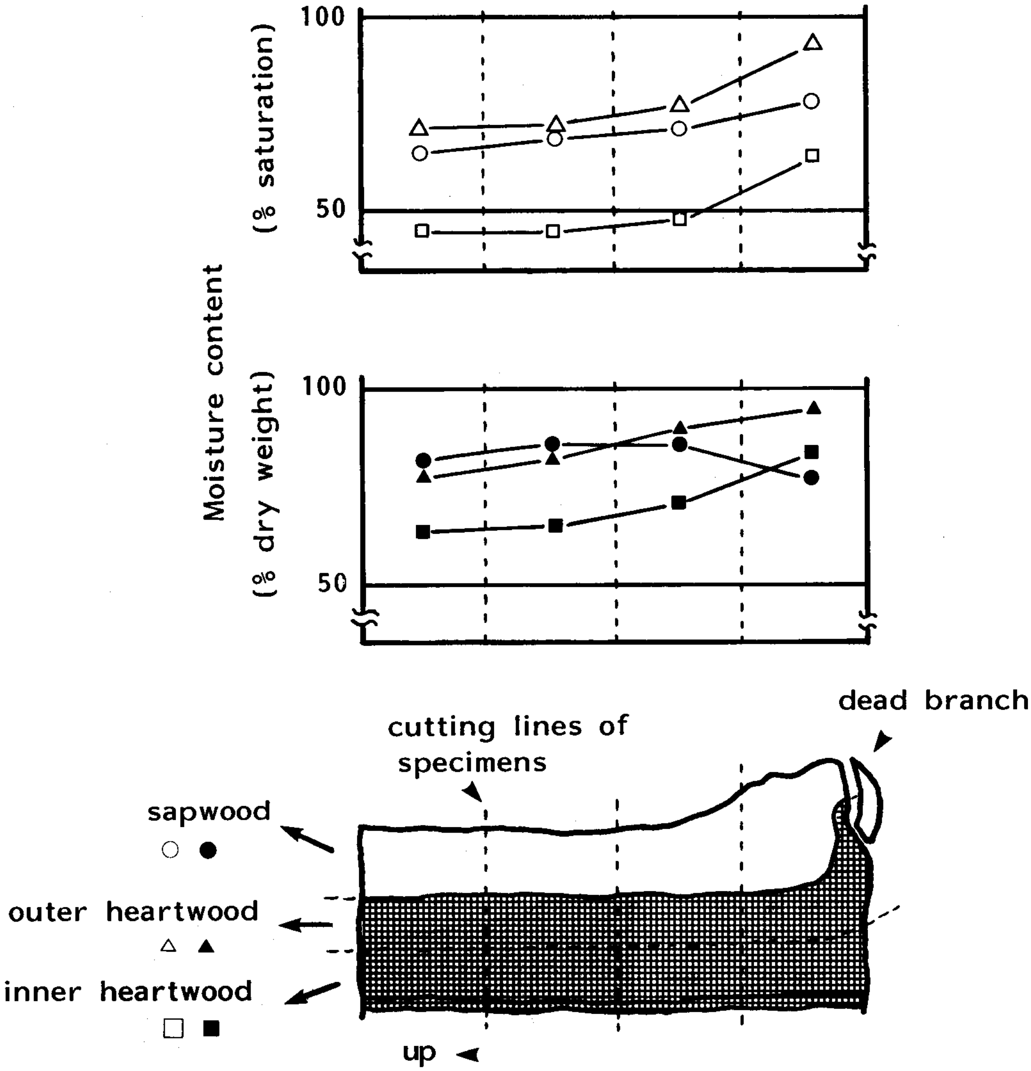

Fig. 20 Moisture content distribution in an area above a dead branch in tree No. 4 (*Kalopanax pictus*).

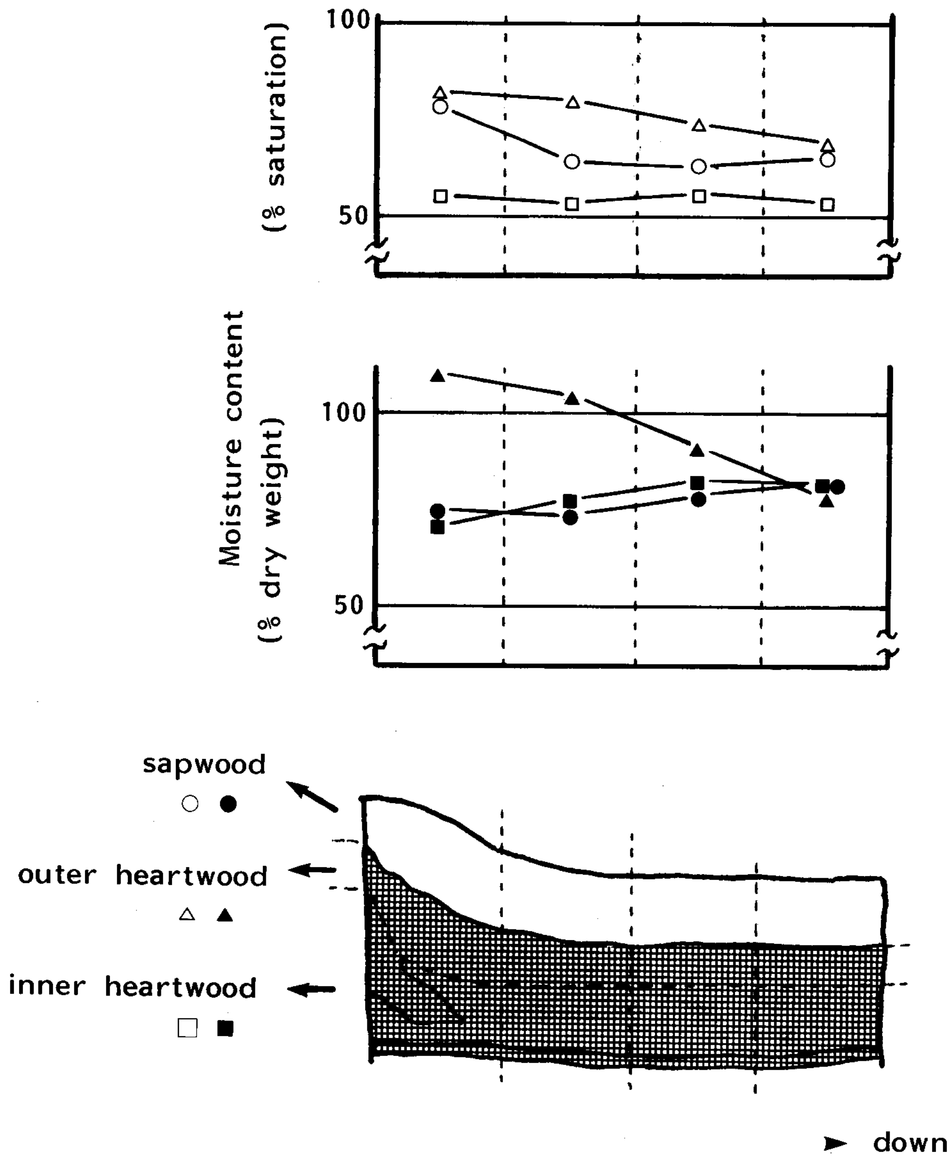

Fig. 21 Moisture content distribution in an area blow a dead branch in tree No. 4 (*Kalopanax pictus*).

4. Discussion

The result obtained in this study that the heartwood moisture content is higher than that of the sapwood in *F. mandshurica* var. *japonica*, agreed with that reported by YAZAWA and ISHIDA (1965a, b). However, the moisture contents were inconstant in the heartwood. In addition, it was shown that the moisture distribution in heartwood varied between the trees, and the amount of moisture itself decreased with the increase in the tree heights within the sample trees examined in this study. YAZAWA and ISHIDA (1965a) mentioned that there was a tendency for the values of the moisture content to decrease with increases in tree heights in some trees, and attributed the cause to the increase in specific gravity with the increases in the tree heights.

In *K. pictus*, the average moisture content of heartwood is lower than that of sapwood, as was reported by YAZAWA (1964). It was also shown that dehydration did not occur in conjunction with the heartwood transition, but steadily occured from the outermost layer to inward as a rule, which is different from the process in gymnosperm species. But the tendency is not always constant: local wet xylem existed here and there.

In *K. pictus*, wetwood was formed around knots, dead branches and wounds without exception. In *F. mandshurica*, areas around knots and wounds became wetter than the neighbouring areas without exception. ETHERIDGE and MORIN (1962), KABURAGI (1973) and BAUCH et al. (1975) suggested an association between wetwood formation and branches, knots in *Abies* species. Water accumulation around dead branches and knots may be a common phenomena in many tree species although the association has not been examined in other species.

Wetwood around dead branches, knots and wounds appeared to develop longitudinaly rahter than transversely. Wetwood may develops longitudinaly as described by *Shigo* (1986) although WARRAL and PARMETER (1982), and ISHII and FUKAZAWA (1987) suggested that wetwood developed radialy in the trunk by osmotic potential in *Abies* species. And inconstancies in moisture distribution, which were observed even in areas apparently without dead branches and knots, can possibly be ascribed to the existence of many knots in the trunk. Namely, the wet xylem possibly developed longitudinaly associated with the existence of knots or wounds. The existence of dead branches, knots and wounds, is certainly a factor in wetwood formation.

Wetwood was found to develop in areas both of above and below the junction of a dead branch. SHIGO (1985) reported that there was little or no local conduction between trunk and branch xylem at the upper part of the junction from an experiment with dye movement, and so it is suggested that the accumulated water in areas above the junction of a dead branch is not from an external source. In addition, wetwood was formed in areas around bores which was occluded with vaseline immediately after the boring. Thus, it is suggested that the accumulated water in areas around bores is also not from an external source.

It is noteworthy that wetwood formation or significant water accumulation occured in areas around dead branches, knots and other wounds in both species. Each species has been grouped into different types from the point of view of the differences in moisture content distribution (YAZAWA 1964), but both species also have a common characteristic in moisture distribution. There may be uniformity, being common in tree species, in the varieties of moisture distribution found among tree species.

Acknowledgement

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要　　約

ヤチダモ，ハリギリ樹幹の水分分布，とくにその局所的変動について，主として軟X線透視により調べた。

ヤチダモでは，全体的には樹幹の地上高とは無関係に心材の方が辺材よりも多湿であった。従って，その含水率分布は凸字型を呈する。心材での多湿材部（水食い材）の広がりは辺材から心材にかけての材色変化と概ね一致していたが，部分的にはその変色の境界部よりも数年輪内側の部分にとどまっていた。心材内は一定して均一に多湿になっているわけではなく，その水分状態は部位によって大きく変動していた。

ハリギリでは，基本的に辺心材の区分に関係なく，外部から内部へとすすむにつれて徐々に乾燥するという傾向が認められた。その含水率分布はV字型を呈する。乾燥化は，一年輪内では早材から晩材へとすすむ傾向が認められた。

両樹種ともに，枯枝，節，傷害の周辺部にとくに水分が集中していた。とくにハリギリではそれら欠点の存在により基本的な水分分布パターンが大きく損なわれていた。

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Explanation of Figures

Note; Photographs without scale bar have the size of the original.

Figures 2 to 14. *Fraxinus mandshurica* **var.** *japonica.*

Figs. 2-5. Cross sections of tree No. 1. a (dry wood) and b (green wood) - soft X-ray photographs, c- optical photograph corresponding to photos a and b. Fig. 2- 0.7m heights, Fig. 3- 1.2m, Fig. 4- 1.8m, Fig. 5- 2.5m.

Fig. 6. A cross section placed at 0.45m heights of tree No. 2. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Arrows show areas in which the wetwood development is limited to inner layer from the sapwood-heartwood boundary.

Fig. 7. A longitudinal section in the area below the cross section shown in Fig. 6. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Arrows show fine splits.

Fig. 8. An enlarged view of a part of Fig. 2. a (green wood) - soft X-ray photograph, b - optical photograph.

Fig. 9. A longitudinal section at the junction of a living branch, placed at about 6m heights of tree No. 1. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Arrows show fine splits.

Fig. 10. A longitudinal section placed at about 4.6m heights of tree No. 2. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Areas around knots become wetter than the neighbouring areas.

Fig. 11. A cross section in the area including bore made with an increment borer of tree No. 2. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph.

Figs. 12-14. Cross sections of tree No. 1. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Fig. 12- 0.5m heights, Fig. 13- 0.3m, Fig. 14- 0.2m.

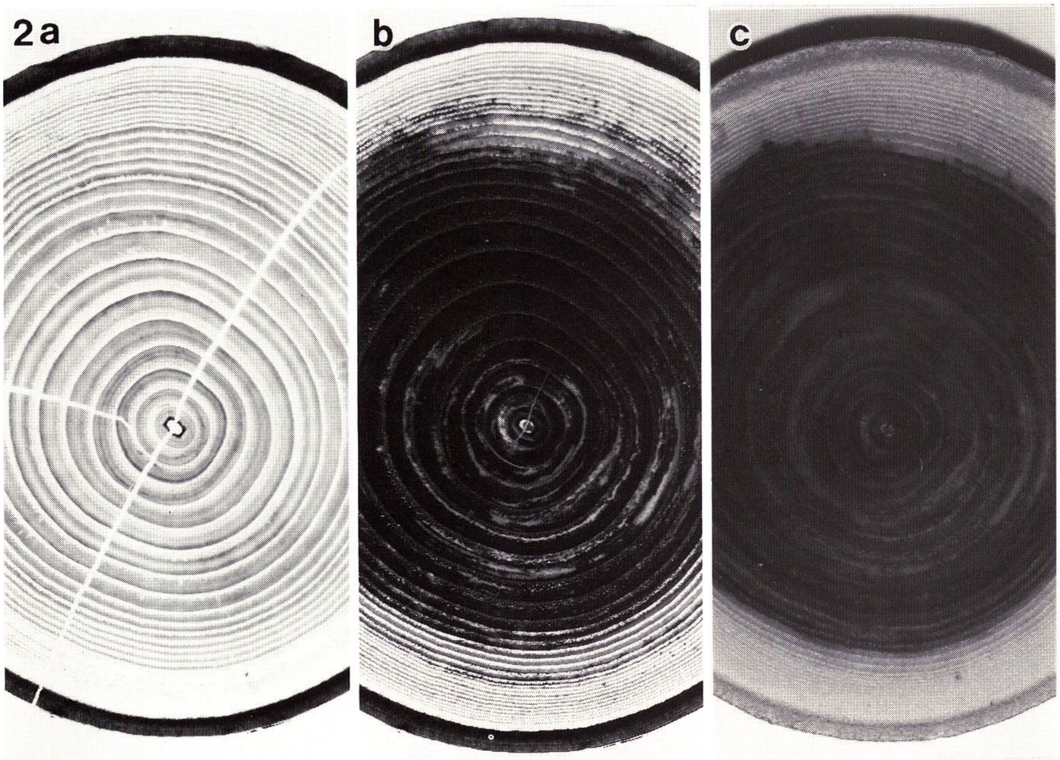
Figures 16 to 19, 22. *Kalopanax pictus.*

Fig. 16. An enlarged cross section placed at 0.8m heights of tree No. 3. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph.

Fig. 17. A cross section in the area around a dead branch placed at 6.8m heights of tree No. 4. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph. Arrow shows a layer in which the annual ring width is very narrow.

Figs. 18, 19. Longitudinal sections placed above (18) and below (19) the cross section shown in Fig. 17. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph.

Fig. 22. A cross section in the area including bore made with increment borer. a (dry wood) and b (green wood) - soft X-ray photographs, c - optical photograph.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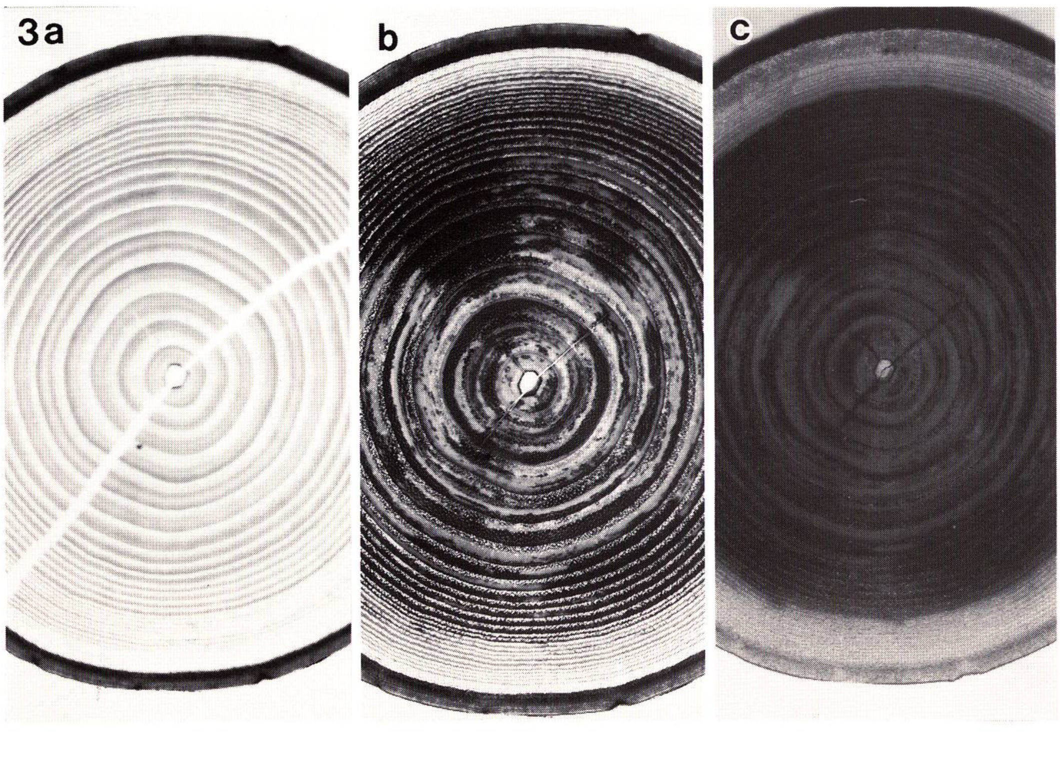
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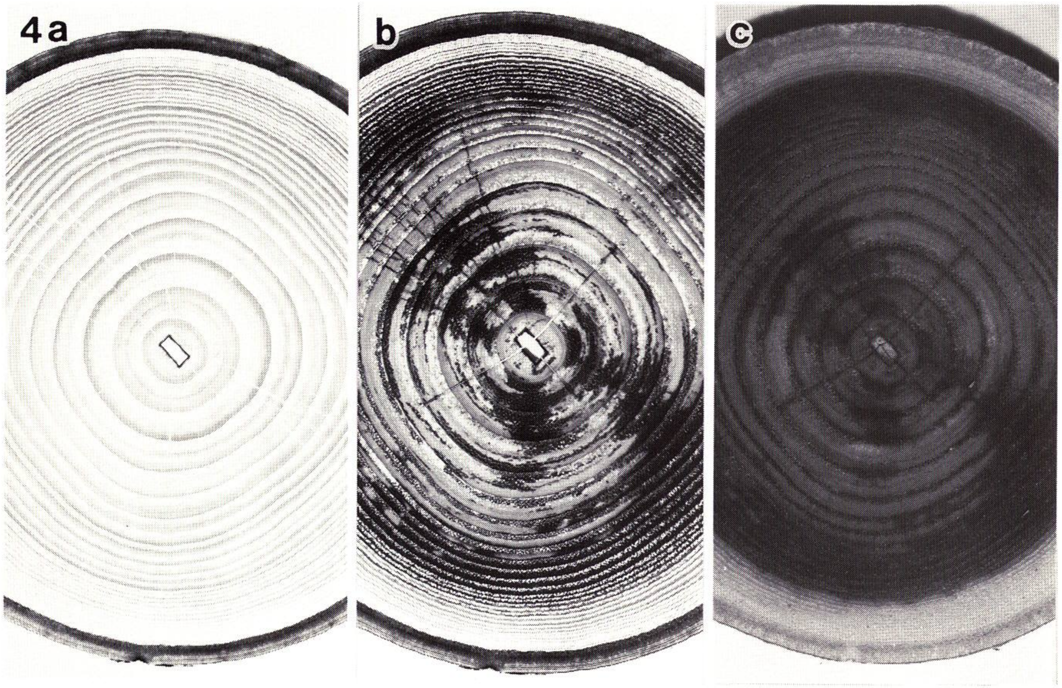
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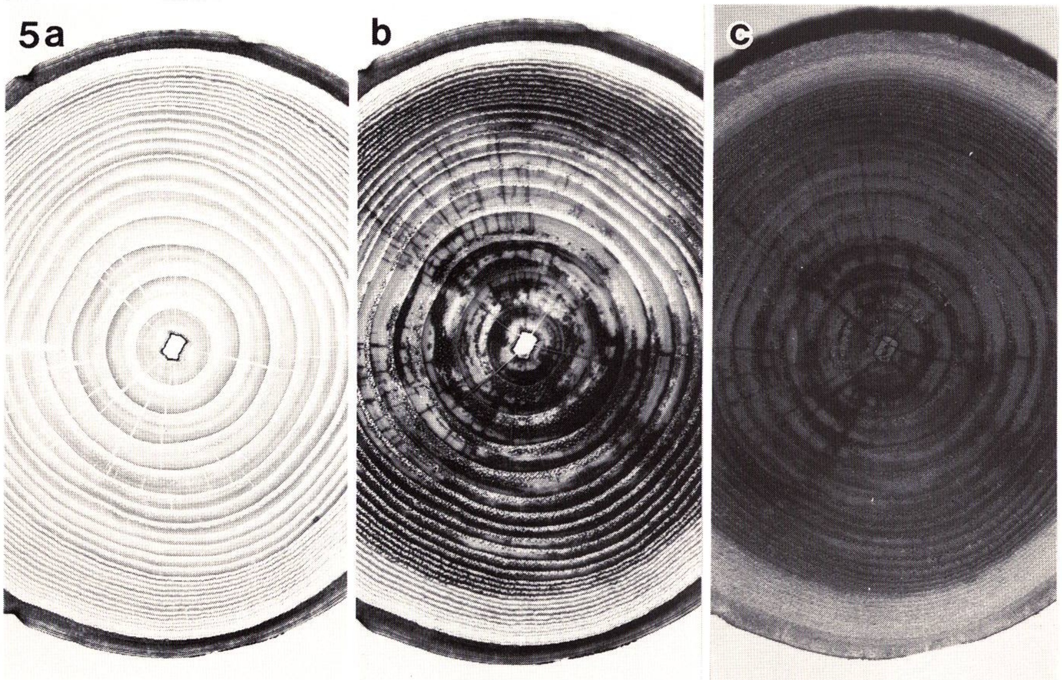
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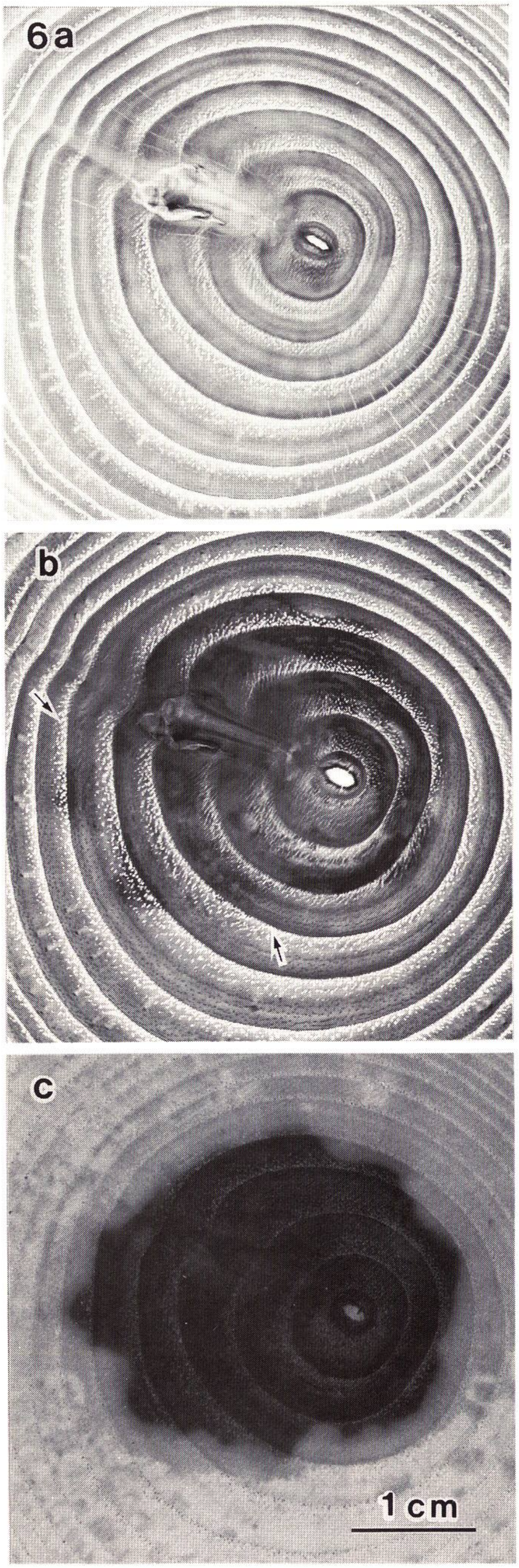
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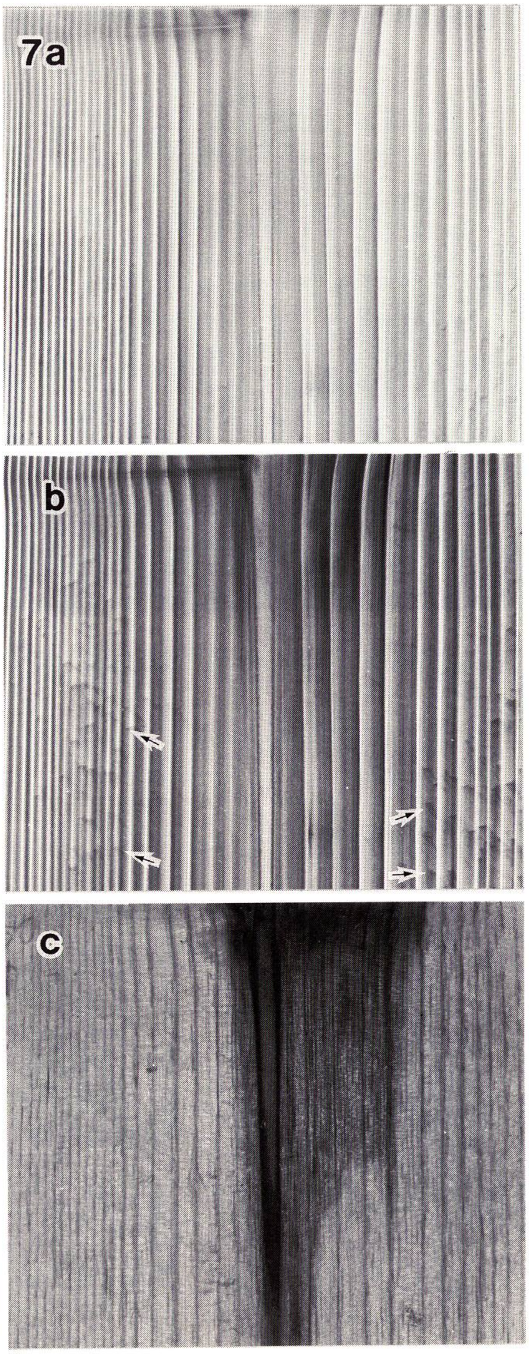
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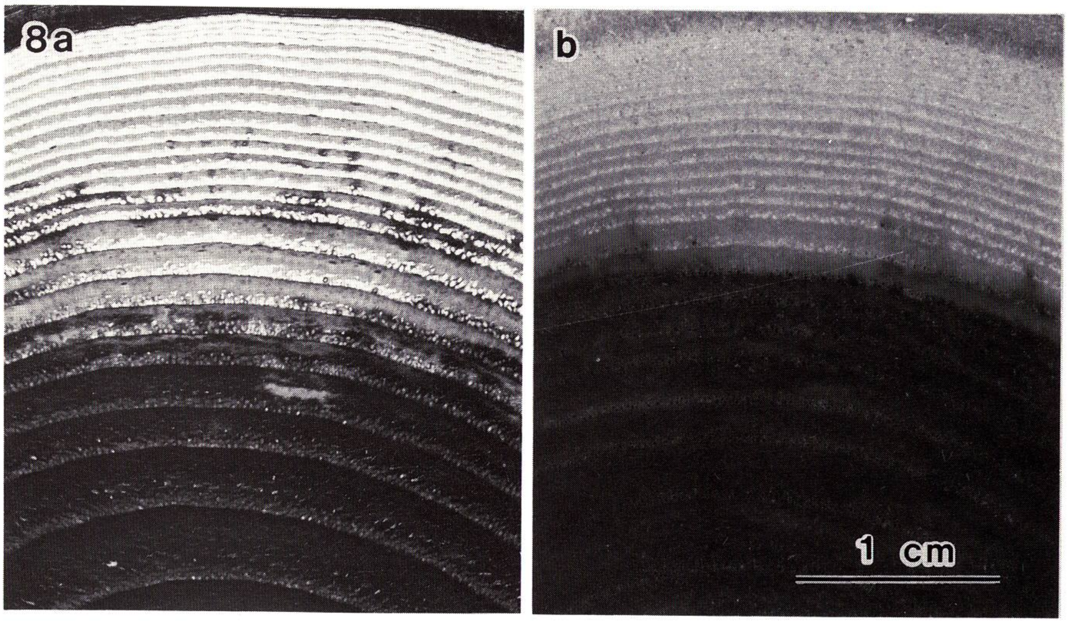
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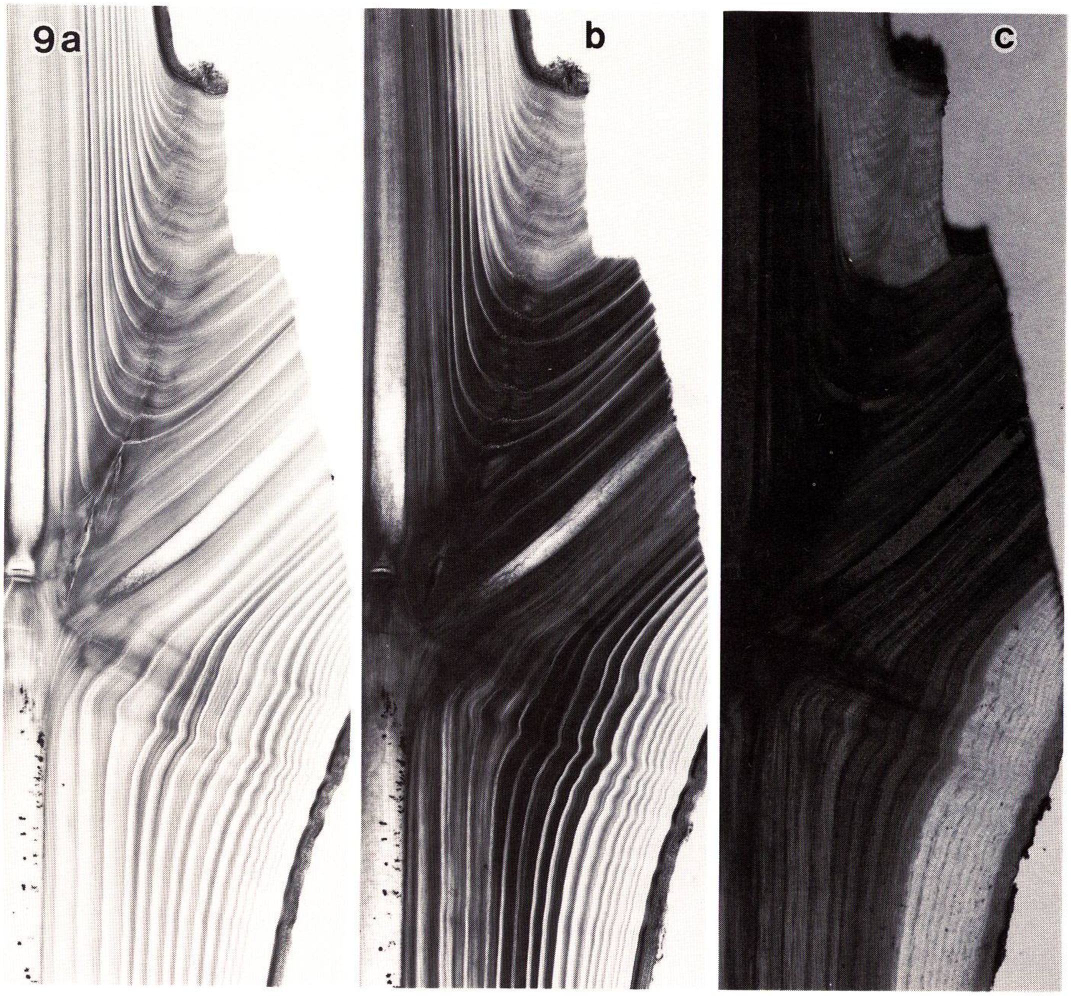
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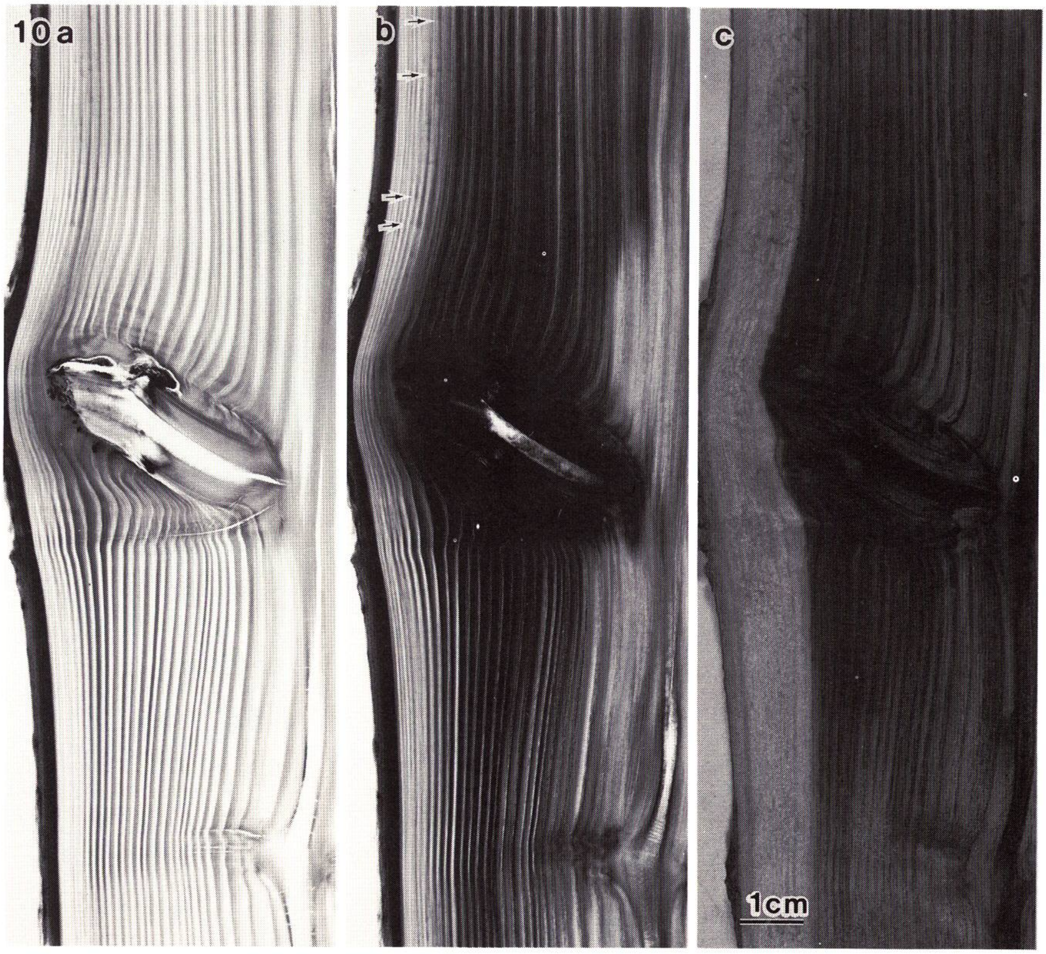
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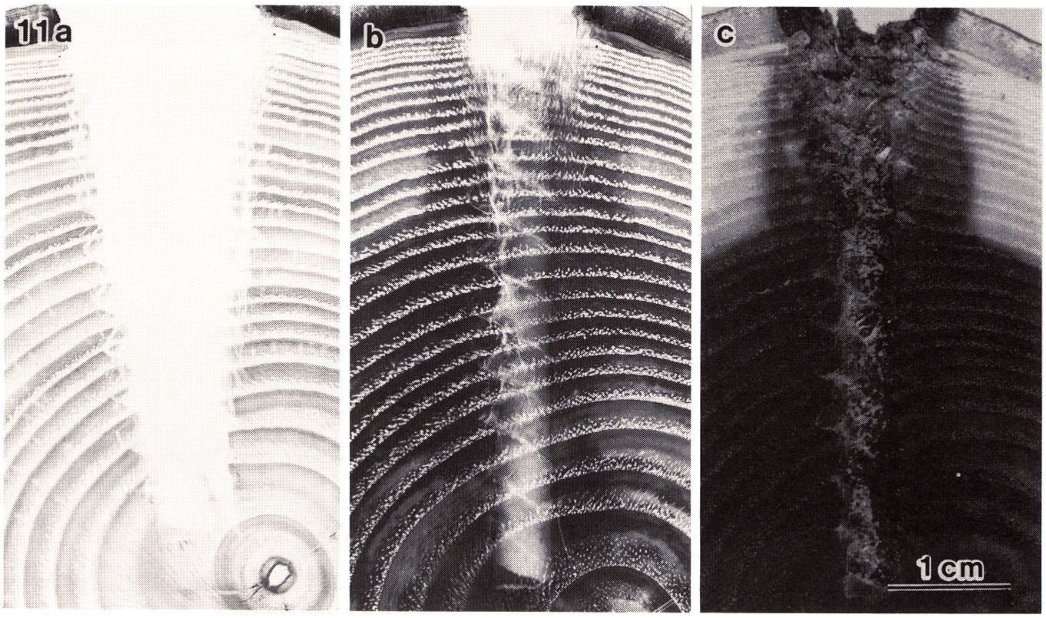
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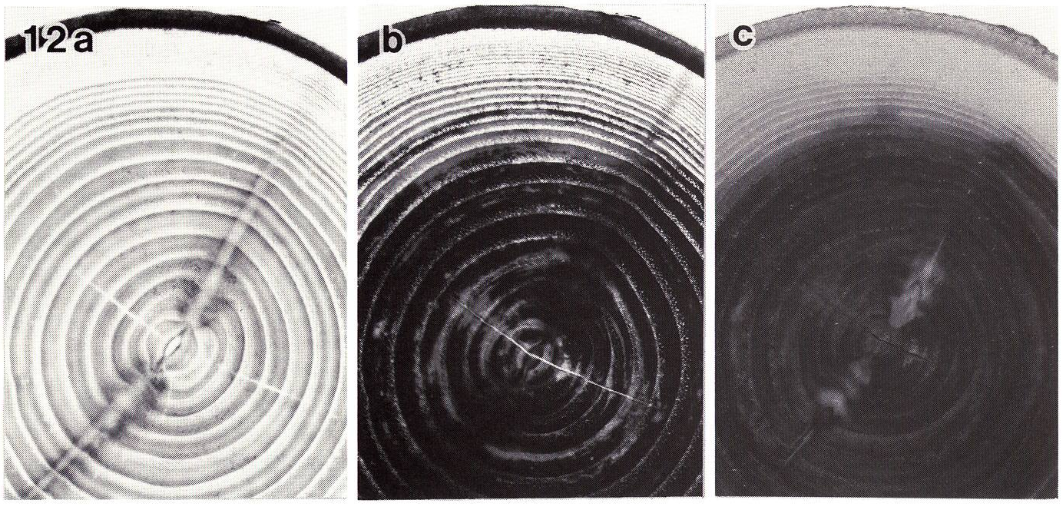
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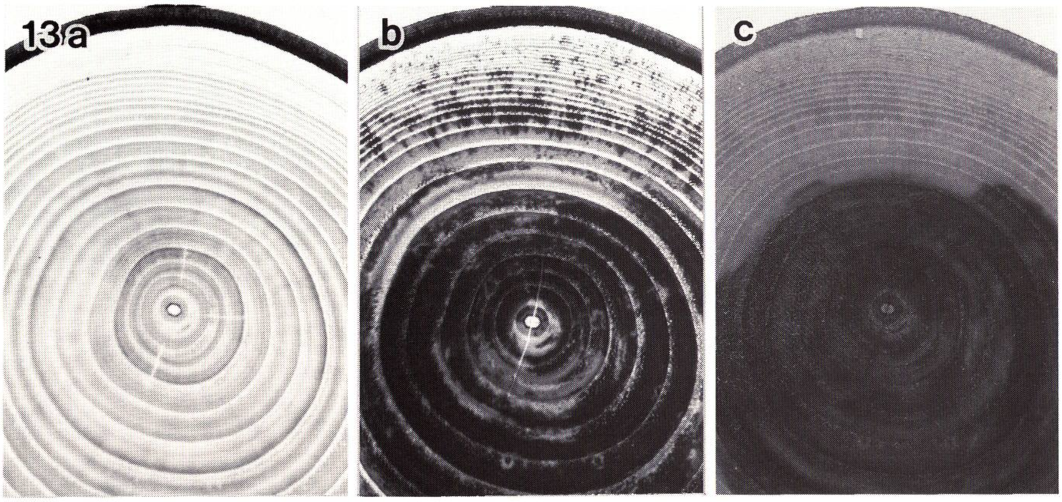
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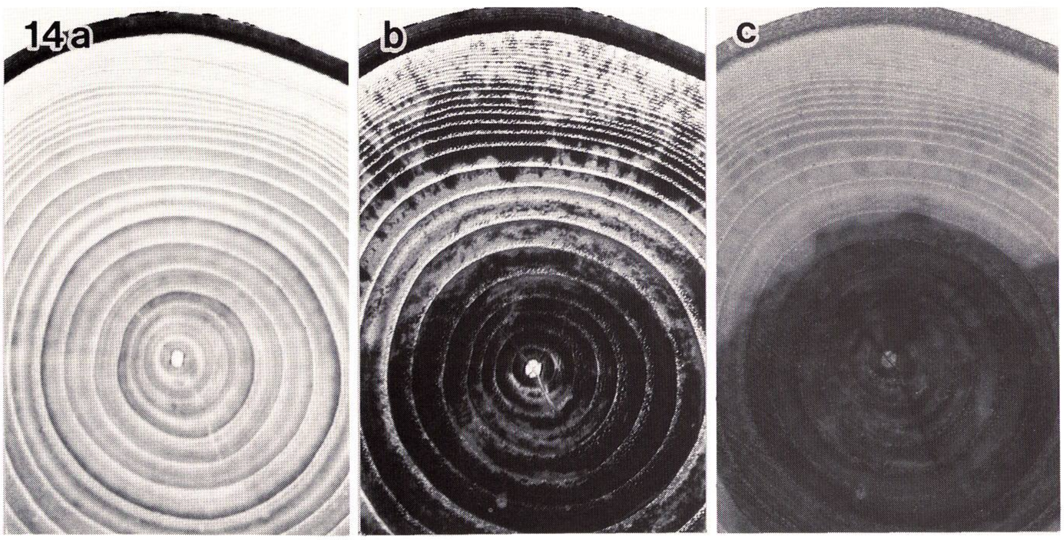
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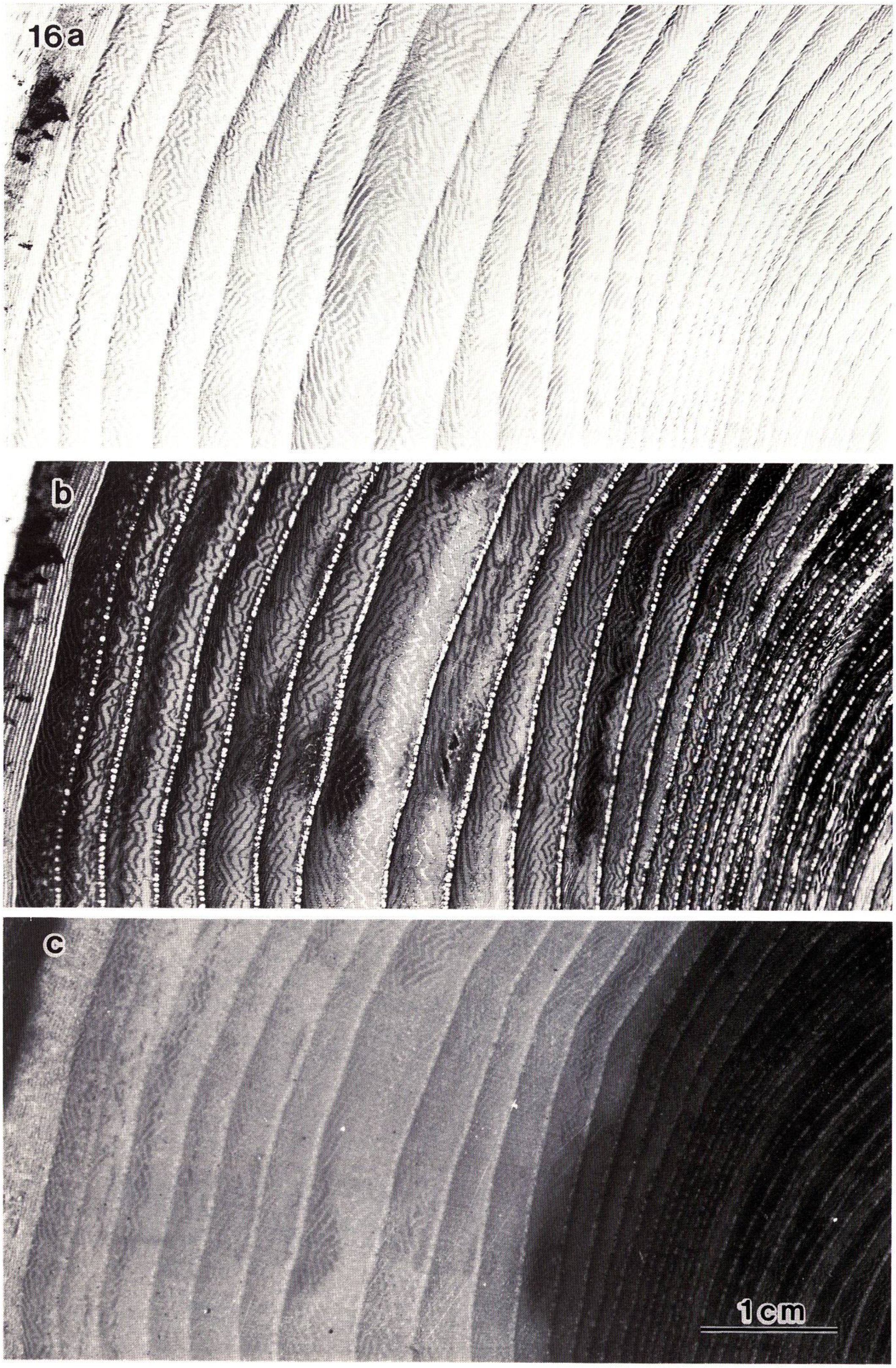
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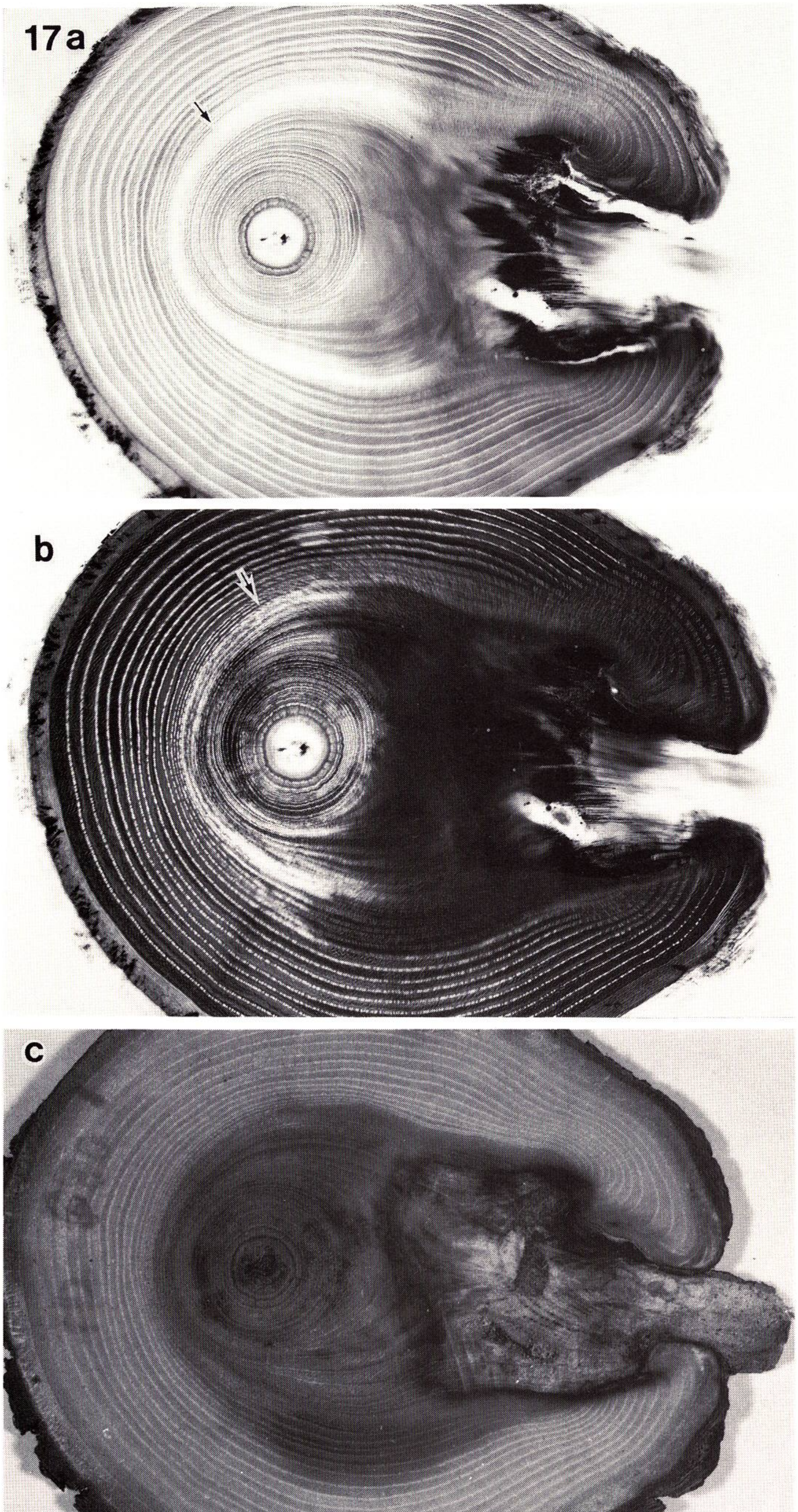
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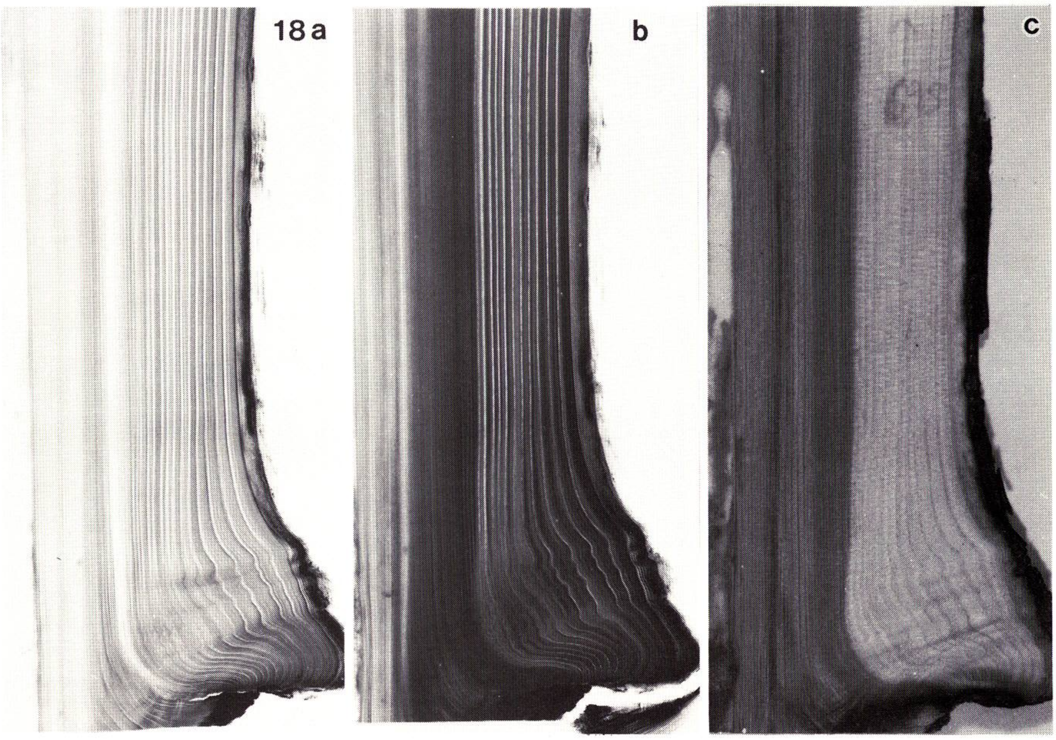
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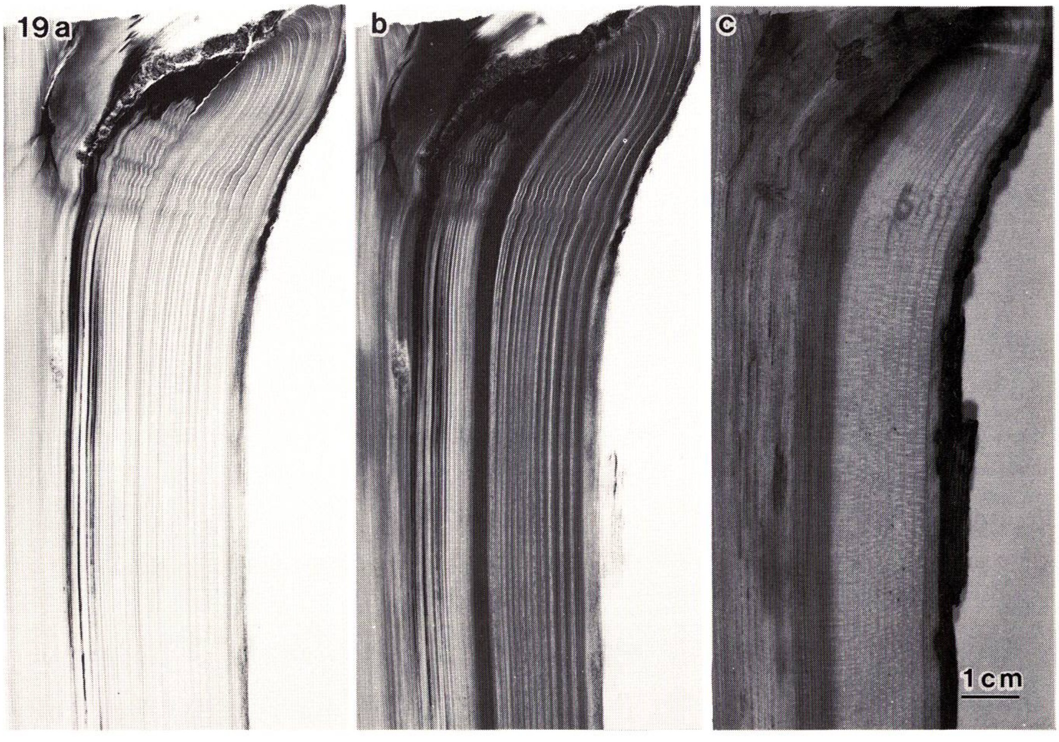
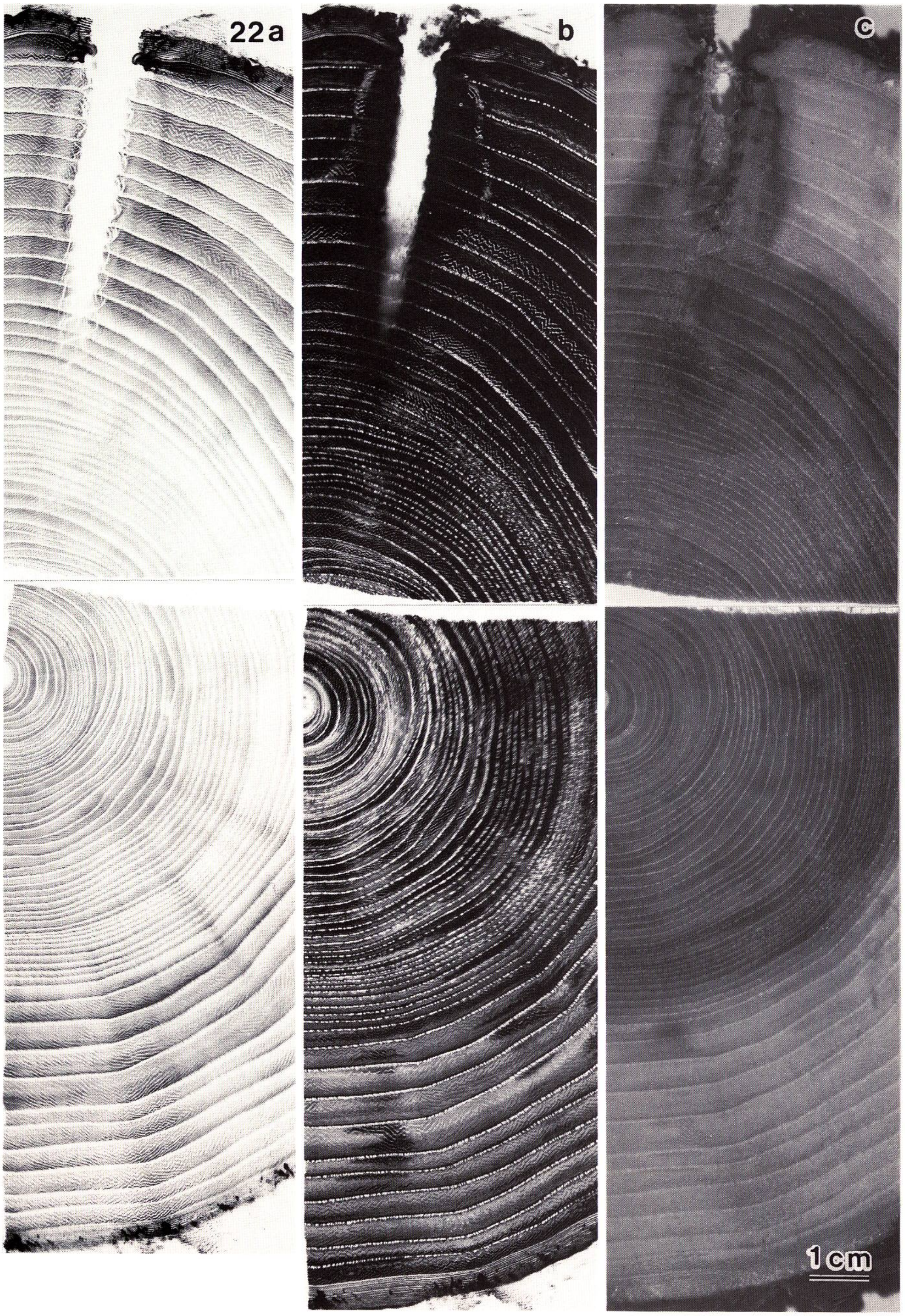
b
c


19a
b
c
1cm


22a
b
c
1 cm