ON THE EXISTENCE OF THE INTERMEDIATE WOOD IN SOME BROAD-LEAVED TREES GROWN IN HOKKAIDO, JAPAN*

By

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Introduction

It is well known that there often appears a pale colour zone between ordinary sapwood and the heartwood of newly-felled tree trunks. NÖRDLINGER (1860)[1] noted an *Ulmus* species as a "Reifholzkernbaum", with a special flesh-red zone between the ordinary white or yellow sapwood and the brown-red or brown heartwood. No data, however, was given on the moisture content by him. CRAIB (1923)[2] clearly pointed out in *Taxus* that in the cross section of a newly-felled tree, three distinct areas could be recognized—central heartwood, sapwood on the periphery, and separating these two areas, a narrow pale zone. He also suggested that the narrow zone (white zone, white band) was some intermediate stage or the primary stage of the conversion of the sapwood into heartwood. MIYOSHI (1951)[3] reported the existence of such a pale colour zone in Hi-no-ki, *Chamaecyparis obtusa* SIEB. et ZUCC. ap. Endl., in Japan, and named it "Haku-sen-tai" meaning "white band". OHSAWA and HIRAI (1948)[4] studied Kara-matsu wood, Japanese larch, *Larix leptolepis* GORDON, regarding the effect of moisture change on the colouration of the wood. They also recognized a special colour zone between the ordinary sapwood and heartwood in newly-felled trunks of this species, and called the zone "Juku-tai", ripe zone. There are other reports on the white zonal wood in conifers in Japan. KUROTORI (1954)[5] reported the existence of white rings at the boundary part between the sapwood and the heartwood of Sugi, *Cryptomeria japonica* D. DON, as well as the results of study on its characteristics in comparison to that of the sapwood and the heartwood. YAZAWA & FUKAZAWA (and NAKASHIMA) (1956,

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'57)[6,7,8] also studied the white zone in Sugi and Hi-no-ki trunks regarding its width, moisture content, number of growth rings involved.

No studies have been reported about the existence of such a colour zone in broad-leaved trees. The present authors, therefore, began to study the boundary zone of sapwood and heartwood where the white zone, if any, was involved in living broad-leaved trees, with particular reference to its significance in the study of heartwood formation.

Methods

To carry out a general survey for this study the authors chiefly visited the College Experimental Forest in Tomakomai, Hokkaido, where the cutting of several species of broad-leaved trees had been going on from late summer to early winter. A large number of fresh cross sections of trunks and branches as well of several different species were examined carefully and minutely from just after cutting to some hours later, with particular attention to the boundary part of sapwood and heartwood.

Many photographs in colour or black and white were taken when necessary. Discs were cut out from the newly-felled trunks and measured for green moisture content distribution in regard to sap-, heartwood and white zone. The width of the white zone and the number of growth rings included within the zone were determined. Special attention was paid to upper (top) part of trunk where heartwood disappeared. In the laboratory moisture content distribution at the boundary part and in the adjacent sap- and heartwood was minutely determined by the use of test pieces of 250 to 500 μ thickness in radial direction. Wood tissues of the typical white zone were observed under the microscope compared with the ordinary sap- and heartwood.

Results obtained

Through the course of the survey from summer to early winter it was found that several species of broad-leaved trees had white zones or recognizable intermediate wood with the naked eye, although there were marked morphological variations between species or even within species.

Species which had typical or nearly typical white zones were as follows:

Ezo-yama-zakura*	*Prunus sargentii* REHD**.	Fam. Rosaceae	(photo 1)
Mi-yama-zakura	" *maximowiczii* RUPR.	" "	
Shiuri-zakura	" *ssiori* FR. SCHM.	" "	(" 2)

* Japanese name.
** Scientific name.

Azuki-nashi	*Sorbus alnifolia* C. KOCH	Fam. Rosaceae	(Photo 3, 4)
Nana-kamado	" *comixta* Hedl.	" "	(" 5)
Hashi-doi	*Syringa reticulata* HARA	" Oleaceae	(" 6)
Ezo-itaya	*Acer mono* MAXIM. var. *glabrum* HARA	" Aceraceae	(" 7.8)
Katsura	*Cercidiphyllum japonicum* SIEB. et ZUCC.	Fam. Cercidiphyllaceae	(" 9)

Species which usually showed rather typical white zones in the upper part of the trunk were:

Mizu-ki	*Cornus Controversa* HEMSLEY	Fam. Cornaceae	(Photo 10)
Asada	*Ostrya japonica* SARG.	" Betulaceae	(" 11, 12, 13)

Species in which the intermediate wood part had somewhat complicated aspects, but with a pale colour zones were:

Ho-no-ki	*Magnolia obovata* THUNB.	Fam. Magnoliaceae
Koshi-abura	*Acanthopanax sciadophylloides* FRANCH. et SAVAT.	Fam. Araliaceae

Mizu-nara, *Quercus crispula* BL., Fagaceae, often showed a clear white zone at the boundary part of cross sectional surfaces, after short time, some 30–60 min. from the cutting, not immediately after that (photo 14). A sort of intermediate wood in Haru-niru, *Ulmus davidiana* PLANCH. var. *japonica* NAKAI, Ulmaceae, appearing at the houndary of the sap- and heartwood with one or two growth rings in width, were occassionally found. A species of *Tilia*, T. *japonica* SIMONKAI, Tiliaceae, showed a characteristic variation from the sap to the heart as shown in photo 15. Fresh cross sections of sample trees of 40 to 50 cm diameter at the breast height were studied. They all had normal heartwood and at the outermost part of xylem of their trunk there was typical sapwood, of 1 to 2 cm in width and about 10 to 15 growth rings. Between the sapwood and the heartwood there was a transitional part, 5 to 10 cm or more in width, as shown in photo 15, and this should not be called "white zone" but must be considered as a sort of intermediate wood clearly visible to the naked eye. Sawa-shiba, *Carpinus cordata* BL., Betulaceae, had multiple transition layers showing different tones of colour, generally light to dark from the outer to the pith of the trunk as shown in photo 16.

The average moisture content in green of the intermediate wood, including typical white zone, if any, of some broad-leaved trees are summarized in table 1. The species illustrated here are in order of the pattern of the moisture content distribution in stemwood, the first to the third[10]. Species from Katsura to Azuki-nashi belong to the first type of the pattern, where sapwood moisture

TABLE 1. Average* moisture content of sapwood, visible intermediate wood and heartwood of some broad-leaved trees grown in Hokkaido

Japanese name and genus name	Moisture content					Season when surveyed
	Sapwood	Intermediate wood			Heartwood	
	%	M.C. (%)	Width (mm)	Ring number	%	
Katsura, *Cercidiphyllum*	119.5	61.5	1~ 3	1~ 3	54.3	Nov
Ezo-yama-zakura, *Prunus*	76.8	50.3	2~10	2~ 5	48.3	July
Shiuri-zakura, *Prunus*	66.4	59.3	2~ 6	2~ 3	45.7	July
Azuki-nashi, *Sorbus*	85.8	46.0	2~10	2~ 7	52.2	Sept
Haru-nire, *Ulmus*	64.8	75.9	3~ 5	1~ 2	97.6	Sept
Ezo-itaya, *Acer*	60.7	45.8	3~15	2~15	117.2	Nov
Mizu-ki, *Cornus*	107.1	88.7	5~15	3~10	127.2	Nov
Ho-no-ki, *Magnolia*	93.3	85.8	1~ 3	1~ 3	119.5	Nov
Koshi-abura, *Acanthopanax*	97.6	90.7	1~ 3	1~ 3	96.1	Nov
Asada, *Ostrya*	85.2	65.7	3~15	2~10	82.7	Nov
Shina-no-ki, *Tilia*	101.8	71.3**			98.8	Nov
Mizu-nara, *Quercus*	77.0	57.1	3~ 6	2~ 3	66.3	July

* Average of all measured values of a sample tree for each species, resp.

** Moisture content of wood between typical sapwood and heartwood of this species. Refer to page 139 in the text.

Diameter at breast height of those sample trees illustrated here ranged 15~25 cm with exception of a Shina-no-ki of rd. 50 cm.

content is higher than that of the heartwood, while Haru-nire to Ho-no-ki belong to the second and the rest of them fall into the third, according to the values of average moisture content tabulated in table 1.

The first group, (Katsura to Azuki-nashi) has a moisture content in the intermediate wood of closer values to that in the heartwood than to the sapwood, with the exception of Shiuri-zakura where the value is closer to the sapwood. In the second group, on the contrary, the moisture content in the intermediate wood is closer to the sapwood, and with the exception of Haru-nire they show the lowest values compared with both the sapwood and the heartwood. In the third group (Koshi-abura to Mizu-nara) the intermediate wood moisture content is lowest in comparison to both their sap- and heartwood.

Some detailed examples of lateral moisture distribution from sapwood to heartwood, particularly at the boundary zones of the sap- and heartwood, are shown in figures 1 to 6 with an example of conifers, Kara-matsu, Japanese larch. The moisture content of Mizu-nara in figure 2, Azuki-nashi in fig. 3

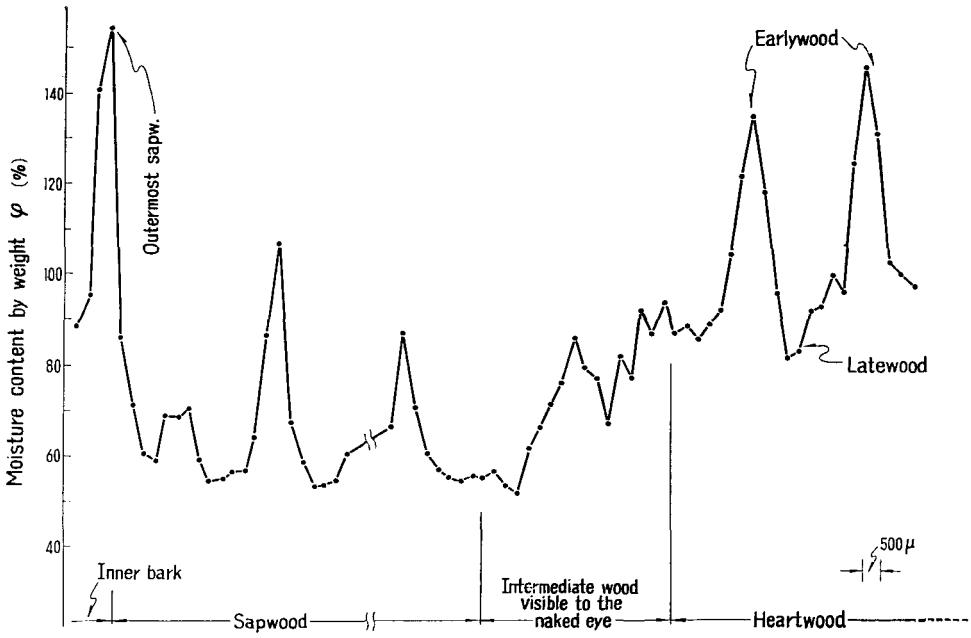

Figure. 1. Moisture distribution from the outermost sapwood to heartwood with attention to the intermediate wood in Haru-nire, *Ulmus davidiana* PLANCH var. *japonica* NAKAI.

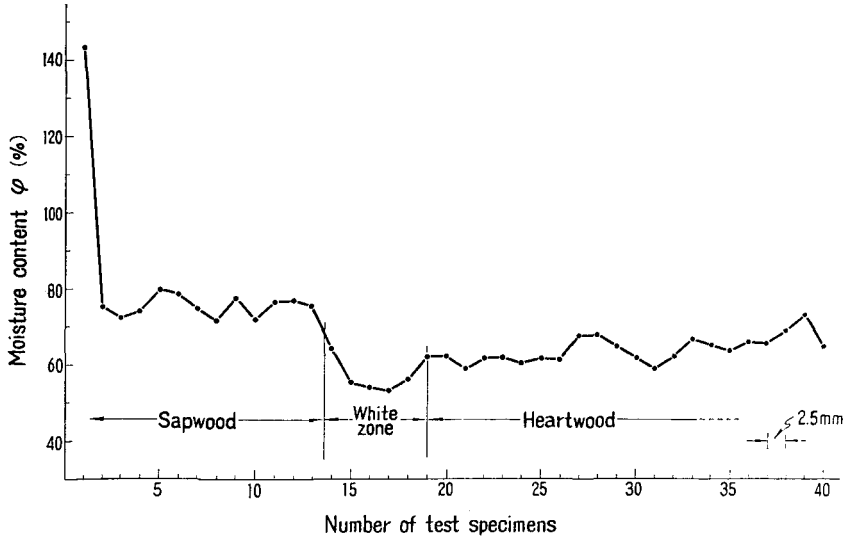

Figure. 2. Moisture distribution from the outermost sapwood to heartwood with a particular interest in the intermediate wood, a white zone, in Mizu-nara, *Quercus crispula* BL.

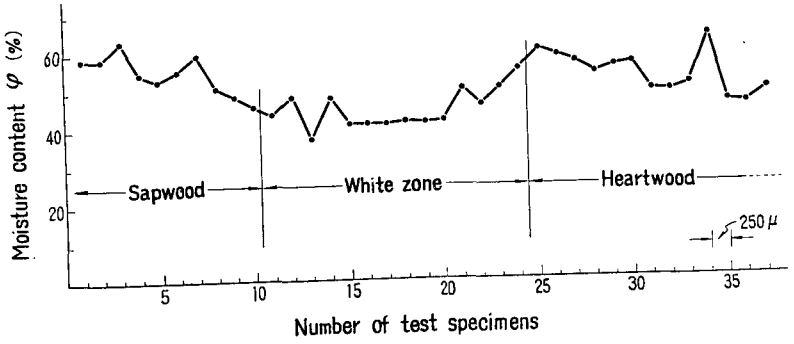

Figure. 3. Moisture distribution from sapwood to heartwood with a particular interest in moisture content in the typical white zone in Azuki-nashi, *Sorbus alnifolia* C. KOCH. Thickness of the test pieces for determining moisture content: 250μ.

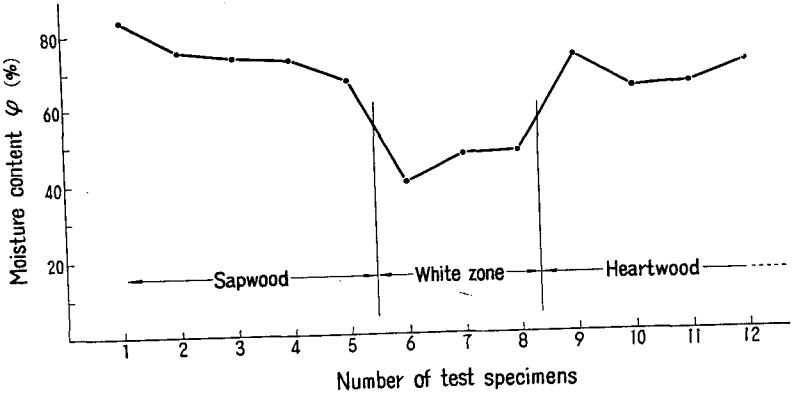

Figure. 4. Moisture content distribution from sapwood to heartwood in Azuki-nashi. Test piece thickness: 1 mm.

and Kara-matsu in fig. 5 were obtained from test specimens of thickness of 250~500 μ. They give more detailed values of moisture distribution. Figure 1 shows the intermediate state of moisture content from sapwood to heartwood in Haru-nire, corresponding to values in table 1. In fig. 2 the intermediate zone of Mizu-nara shows the lowest values of moisture content compared to the adjacent sap- and heartwood. Figures 3 and 4 show the Azuki-nashi also has a lower moisture value in the intermediate wood compared with the sap- and heartwood. Figure 5 shows the Kara-matsu intermediate wood, a typical white zone, is similar to the heartwood in regard to moisture. Figure 6 is a sketch showing a longitudinal section of a young stem of Ezo-yama-zakura showing

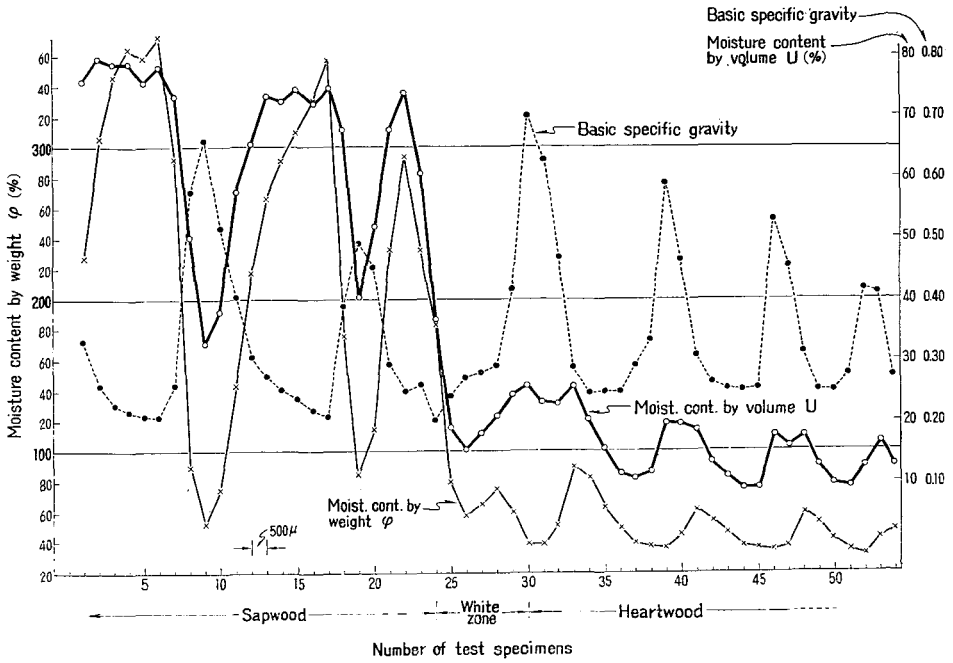

Figure. 5. Distribution of moisture content by weight (φ) and by volume (U) from sapwood to heartwood through a typical white zone, and basic specific gravity of Kara-matsu, *Larix leptolepis* GORD.

the process of disappearance of heartwood and intermediate wood, and the corresponding moisture distribution.

Discussion and conclusion

There are a number of broad-leaved tree species with an intermediate wood recognizable by the naked eye, between the sapwood and heartwood in newly-felled tree trunk, although the morphological aspect of the wood part varied widely between or within species. It should be emphasized that the species which showed the existence of a typical or nearly typical white zone belong to the diffuse-porous wood species (excluding Mizu-nara, a ring-porous wood species). Some with most typical white zone belong to Family Rosaceae.

In most of the ring-porous wood species surveyed, such as Yachi-damo (*Fraxinus* sp.), Haru-nire (*Ulmus* sp.) Hari-giri (*Kalopanax* sp.), Kihada (*Phellodendron* sp.) and Yama-guwa (*Morus* sp.) very few were provided for finding the visible intermediate wood. In Germany "Ulme" has been described as one of species named "Reifholzkernbaum" (or Kern-Reifholz-Baum)[1,11], which have

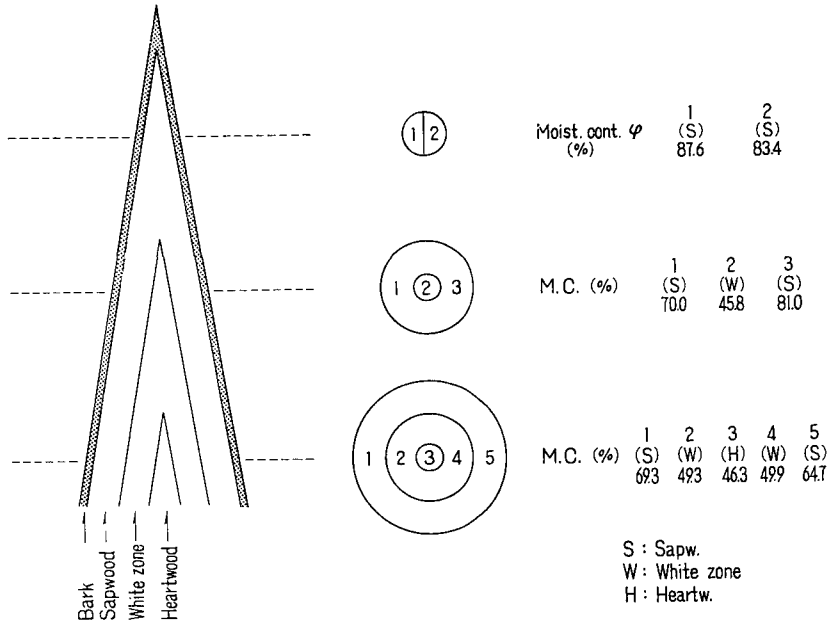

Figure. 6. Moisture content distribution at the top portion of an Ezo-yama-zakura young stem, where the heartwood disappears, with attention to sapwood, heartwood and intermediate wood.

an uncoloured dry wood layer surrounding the heartwood. In Haru-nire, a representative species of *Ulmus* in Japan, a transitional colour zone having 1~2 growth layers between sap- and heartwood can be seen, but very seldom. Its moisture content appears to have a transitional value from the sapwood to the heartwood in which a higher percentage of moisture is obtainable than in the sapwood at any season of the year[10] (table 1, figure 1).

Many researchers have been interested in the moisture of the intermediate wood and therefore there are some data available for coniferous tree species[4,6,7,8]. The intermediate wood has been reported to have a somewhat transitional value of moisture from sapwood to heartwood in general. In Katsura, one of typical species with dry-heart wood in broad-leaved trees in Japan, and in Ezo-yama-zakura which also appears to belong the same category, the moisture content of the intermediate wood was found to have nearly the same value as that of the heartwood. This fact is comparable to that in some conifers, e. g., in Kara-matsu shown in figure 5, drawn by the measurements obtained by the use of 500 μ thick test specimens. There was no transitional moisture value in the white zone in Kara-matsu, but about the same value as that of the heartwood

as shown. As stated above and also as will be seen in table 1, the moisture content of the intermediate wood in most of the species illustrated, showed a lowest value in comparison to that of both the sapwood and the heartwood, or about the same value as either one (of sapwood or heartwood) which was lower than the other.

Although on a cross sectional surface of a newly-felled trunk of some species such as Azuki-nashi, Ezo-yama-zakura, three distinct areas (sap-, heartwood and white zone) are clearly recognized by differences in colour, the aspect of the surface usually changes with the lapse of time, depending on the surface condition (such as roughness), temperature and relative humidity of air, whether the specimen is exposed to the sun or not, etc. Because of these variables, the white zone on the surface becomes sometimes easier to recognize with the naked eye or sometimes inversely more difficult, with the lapse of time. In Mizu-nara, although it is usually difficult or impossible to recognize the white zone immediately after cutting, it gradually becomes visible to the naked eye.

In a frozen state a clearer white zone can sometimes be obtained in Kara-matsu, Ichi-i (*Taxus cuspidata*, photo 17), or Azuki-nashi (photo 18), but this might depend on the moisture amount. As illustrated in figure 5, the average moisture content of sapwood in Kara-matsu markedly exceeds the white zone. This difference of moisture offers a difference in colour to the sapwood and the white zone, especially in frozen state. On the other hand, the white zone and the heartwood are distinctly separated because of clear differences of their ordinary colour. This is the main reason why the white zone is recognizable with the naked eye in Kara-matsu or Ichi-i in newly-felled trunks at least.

Although in broad-leaved trees, however, phenomenon seems to be more complicated than conifers, an experimental work is on the way to make clear the mechanism of occurrence of the recognizable intermediate wood by the naked eye. Small lateral holes were made by boring through sapwood in standing tree trunks of Azuki-nashi, Katsura, etc., to get heartwood-like colouration in the sapwood—artificial heartwood[12]. The white wood part apparently appeared near the darkly coloured wood, i.e., artificial heartwood, as the result of the boring within the sapwood of Azuki-nashi, shown in photo 18. The moisture content of the white wood was between both the artificial heartwood and the ordinary sapwood. Photo 19 shows the white zone and the artificial heartwood in Sugi.

Summary

A number of cross sectional surfaces in newly-felled broad-leaved tree trunks

were observed with particular attention to their transitional colour characteristics at the boundary of the sapwood and the heartwood. The moisture content of wood was then determined at the boundary of the sap- and the heartwood as well.

It was found that several species of broad-leaved trees had intermediate wood recognizable by the naked eye according to their special tone of colour, although there were marked varieties in outer morphology between or within species. Ezo-yama-zakura (photo 1), Mi-yama-zakura, Shiuri-zakura (ph. 2, Azuki-nashi (phs. 3, 4), Nana-kamado (ph. 5) and Hashi-doi (ph. 6) were found to have a typical white zone at any season of year. Ezo-itaya (phs. 7, 8), Katsura (ph. 9), Mizu-ki (ph. 10) and Asada (phs. 11, 12, 13) also showed typical or nearly typical white zone. Ho-no-ki and Koshi-abura were sometimes found to have a whitish zonal wood between the sap- and heartwood, although it was usually complicated by the existence of the other zonal wood in the neighbour of it. Mizu-nara (ph. 14) had also a pale zone, but it usually took a half or an hour till to become visible to the naked eye. A transitional colour zone between sap- and heartwood in Haru-nire seldom appeared.

The moisture content in the intermediate wood of some broad-leaved trees is summarized in table 1, with comparisons of the sapwood and heartwood. Figures 1~5 also illustrate moisture contents, but show the distribution from the sapwood to the heartwood in detail. In the Katsura moisture content of the white zonal wood was very close to the heartwood, just as in Kara-matsu, added as an example from conifers which have dry heartwood. With some exceptions, in those species illustrated in table 1, the moisture content of the intermediate wood is more closer to the heartwood than in the sapwood, or lower than both the sap- and heartwood. It must be noted here that species which had typical or nearly typical white zones belong to diffuse-porous wood species with the exception of Mizu-nara, a ring-porous wood species. It is also pointed out that most of those species with a typical white zone belong to Family Rosaceae.

To be recognized with the naked eye, the intermediate zone must be separated from the neighbouring sap- and heartwoood, by its colour tone. The colouration of trunk wood depends not only on its ordinary colour, but also its moisture content, surface conditions, time lapse after cutting, temperature and relative humidity of air and so on. Therefore for the intermediate wood to become visible to the naked eye depends, on one hand, upon the ordinary characteristics of the intact trunk wood, and on the other, upon the method of treatment of the materials investigated.

Acknowledgement

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Literatures cited

1) NÖRDLINGER, H.: Die technischen Eigenschaften der Hölzer. J. G. COTTA'scher Verlag (1860).
2) CRAIB, W. G.: Notes from the Royal Botanic Garden, Vol. XIV, No. LXVI, Jan. 1923.
3) MIYOSHI, T.: Bulletin of The Tokyo University Forests, No. 40, 1~216 (1951).
4) OHSAWA, M. and HIRAI, S.: Journal of The Sapporo Society of Agriculture and Forestry, Vol. 37, No. 4, July 1948.
5) KUROTORI, S.: The Journal of The Japanese Forestry Society, Vol. 36, No. 1, Jan. 1954.
6) YAZAWA, K., FUKAZAWA, K. and NAKASHIMA, S.: Research Bulletin of The Faculty of Agriculture, Gifu University, No. 6, 73~84 (1956).
7) YAZAWA, K. and FUKAZAWA, K.: Journal of The Japan Wood Research Society, Vol. 2, No. 5, Oct. 1956.
8) ibid: Research Bulletin of The Faculty of Agriculture, Gifu University, No. 8, 67~74 (1957).
9) International Association of Wood Anatomists: International Glossary of Terms used in Wood Anatomy. Tropical Wood, 107, 1~36 (1957).
10) YAZAWA, K., ISHIDA, S. and MIYAJIMA, H.: Journal of The Japan Wood Research Society, Vol. 11, No. 3, June 1965.
11) TRENDELENBURG, R. and MAYER-WEGELIN, H.: Das Holz als Rohstoff. Carl Hanser Verlag (1955).
12) YAZAWA, K., ISHIDA, S. and OHTANI, J.: Report at the 15th Meeting of The Japan Wood Research Society, April 1965.

Explanation of plates

Photo 1. Ezo-yama-zakura, *Prunus sargentii*, shows a typical white zone, pale yellowish brown, in broad-leaved tree trunks. The photograph was taken some hours after cutting the surface and it partially shows a colouration of the white band by diffusion of sap from the neighbouring sapwood.

Photo 2. Shiuri-zakura, *Prunus ssiori*. There also appears a typical white zone in this species from the butt to the upper part of trunk, similar to the ph. 1, but the zone is usually a little paler in the sapwood than in Ezo-yama-zakura in the fresh cross section. The photograph shows cross sections at 2.4, 4.8 and 7.2 meter height above the ground.

Photo 3. Azuki-nashi, *Sorbus alnifolia*, also has a typical white zone, a little more whitish than Ezo-yama-zakura. At the butt part of the trunk of this species there often appears a white zone with irregular border lines between the adjacent sap- and heartwood.

Photo 4. Do. at about a 5 meter height above the ground. A very clear white zone, surrounding small heartwood. The sapwood was darker when the photograph was taken, than when fresh. At about 1 meter higher this heartwood disappeared entirely, leaving the sapwood and the white zone, and the latter also disappeared a little further up, leaving only the sapwood.

Photo 5. Nana-kamado, *Sorbus comixta*. A photograph showing two fresh cross sections exposed to the sun, one with heartwood in the center, white zone and sapwood. The other, however, has only the sapwood and the white part in the center. The sapwood of the disk, left, was more strongly coloured by the exposure, like the disk in photo 4.

Photo 6. Hashi-doi, *Syringa reticulata*, shows a typical white zone at any season of the year, although it is not so clear in this photograph. The zone is usually narrow, 1~2 mm, having 2~3 growth layers.

Photo 7. Ezo-itaya, *Acer mono* var. *glabrum*. There often appears a typical white zone, wider than photo 6, a little higher up the trunk.

Photo 8. Do. Sapwood and white zone only, at about a 15 meter height where no heartwood exists. About 2 meter higher sapwood only was found.

Photo 9. Katsura, *Cercidiphyllum japonicum*, shows a narrow, clear white band between the ordinary sap- and heartwood. A very wide band,

10~15 mm in width rarely is found as seen in this photograph where a longitudinal radial surface is shown.

Phtoo 10. Mizu-ki, *Cornus controversa.* Photo taken about one hour after cutting the surface of the section shows a wide, typical white zone. A black part of wood in the very center might be a slight rot.

Photo 11, 12 and **13.** Asada, *Ostrya japonica.* An indistinct aspect of the band is shown at the butt of trunk of this species, as shown in photo 11. The upper part of trunk gives, however, a rather clear reddish white band as in photo 12, although this was taken some hours after cutting the surface. The diffusion of sap solution on to the surface of the pale intermediate wood can be seen. About the same thing will be seen in the photographs 4 of Azuki-nashi, 5 of Nana-kamado.

Photo 14. Mizu-nara, *Quercus crispula.* A photograph showing a very clear white zone in a newly-felled trunk, about one hour after cutting the surface. The white zone of this species is very difficult or impossible to recognize by the naked eye just after cutting the surface.

Photo 15. Shina-no-ki, *Tilia japonica.* The photograph shows three distinct wood parts of a cross section, the sapwood is indicated with S, heartwood with H, and intermediate wood part between the hoth, with I. This situation does not usually occur in the upper part of trunk even if there still is heartwood.

Photo 16. Sawa-shiba, *Carpinus cordata,* often has multiple coloured zonal wood from the sap- and to the center. The cross section shown in the photo was considerably wet due to exudation of sap-solution.

Photo 17. Ichi-i, *Taxus cuspidata,* usually gives a typical white zone like *Taxus* in Europe, as reported by CRAIB[2]. The photograph shows the white zone in a longitudinal radial section under the microscope of low magnitude 24×.; the inner bark is marked with B, very moistened sapwood with S, white zone with I in very dry condition compared to the sapwood, and a very dark heartwood with H wohse moisture content was a little higher than that of the white zone.

Photo 18. Photograph shows an artificially developed white wood part within sapwood in an Azuki-nashi living trunk as mentioned in the text (page 145). The artificial white zone indicated by an arrow was developed in the sapwood surrounding the darkly coloured wood, i. e. artificial heartwood, developed as a result of boring through the sapwood.

Photo 19. Sugi, *Cryptomeria japonica.* As mentioned in the introduction to

this paper, Sugi shows a typical white wood part as seen in the photograph which also shows artificial heartwood developed by the lateral boring, three in each disks, 4 years before felling the sample tree trunk.

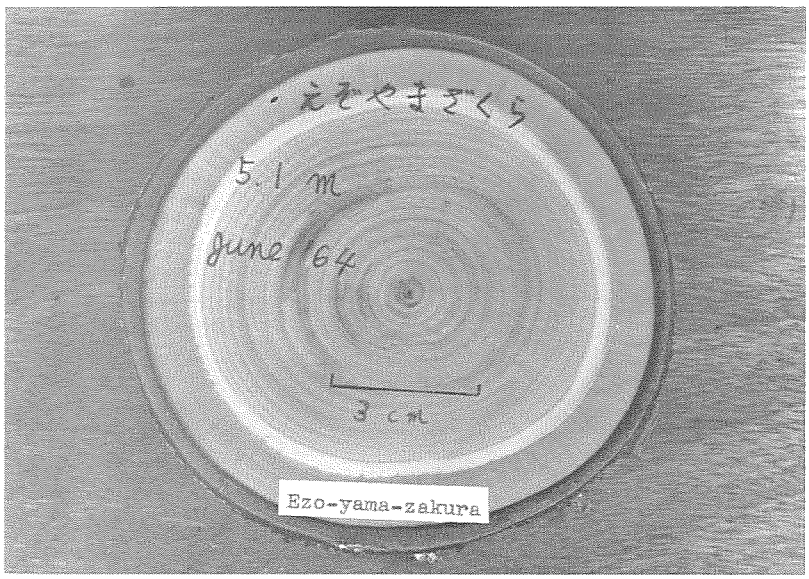
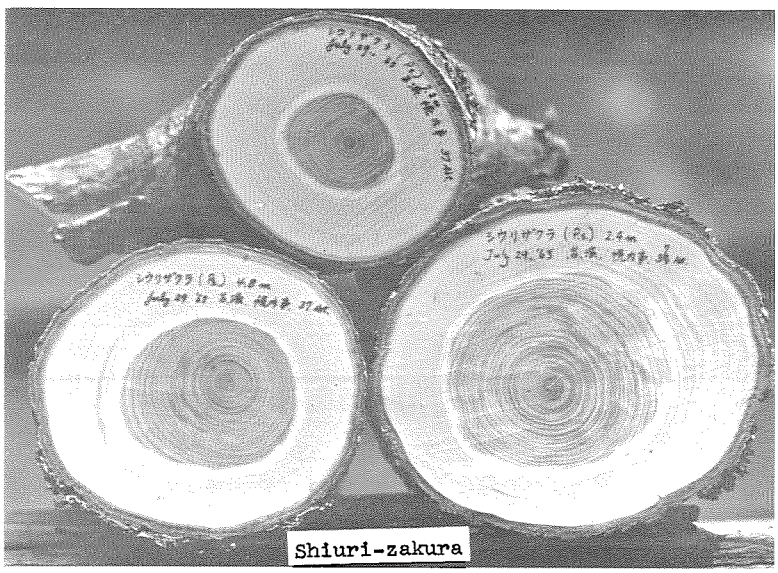


Photo 1



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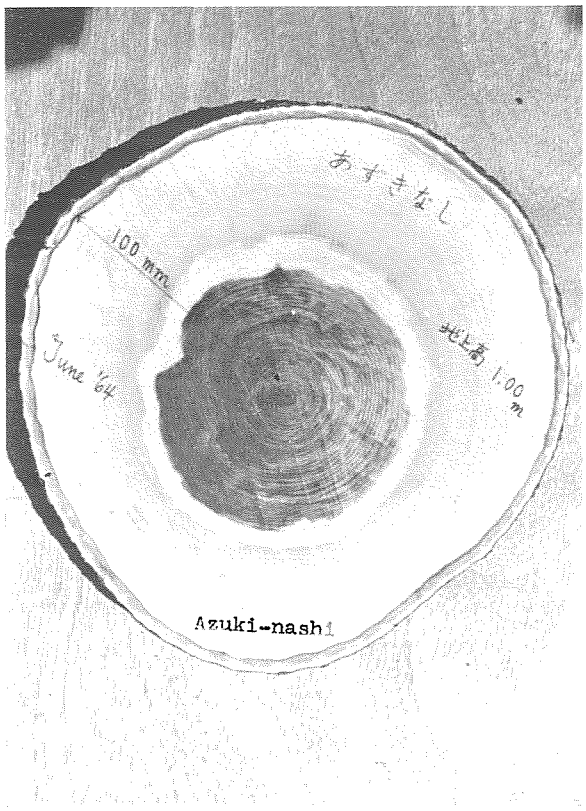

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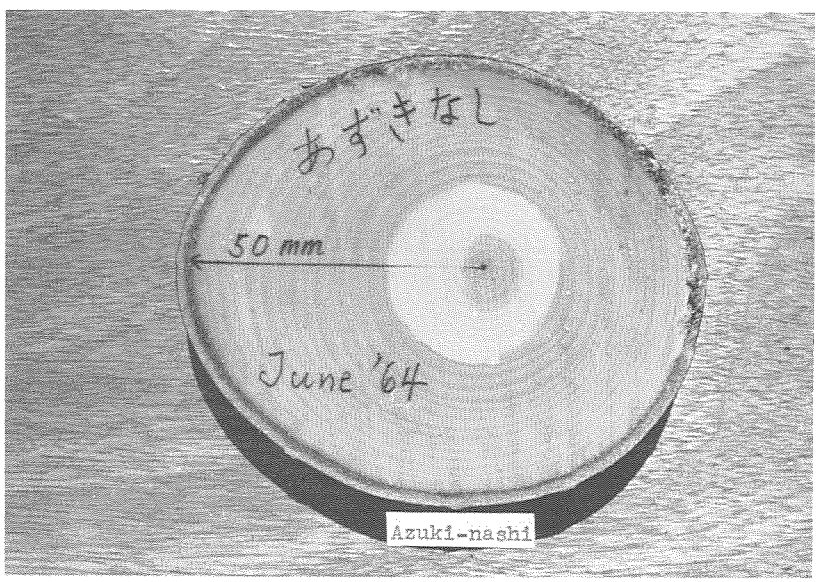

Photo 4

Photo 5

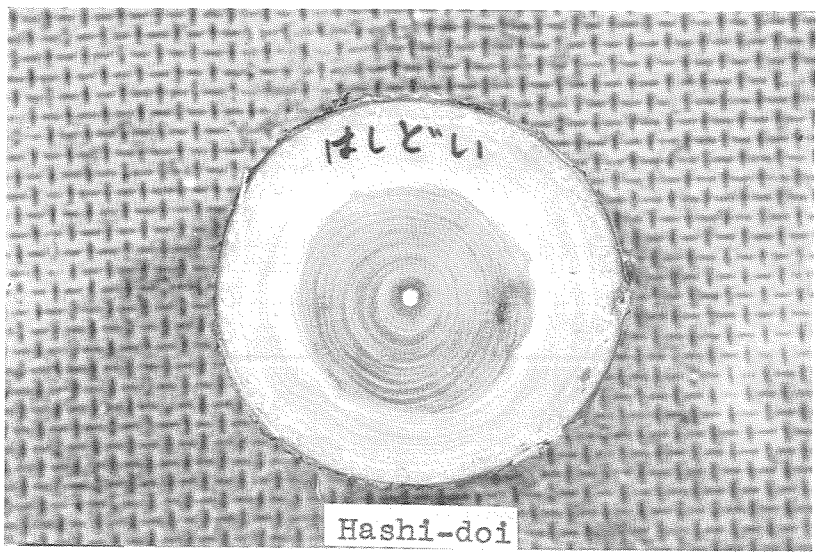

Photo 6

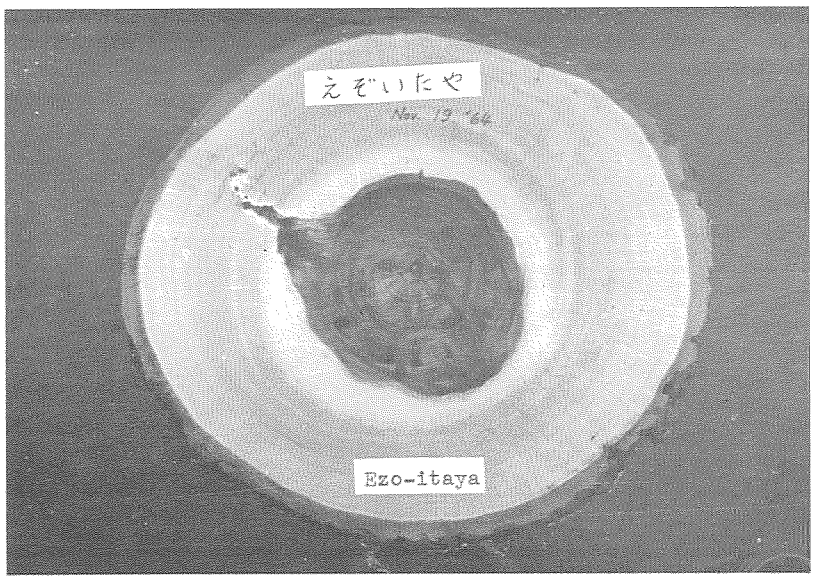

Photo 7

Photo 8

Photo 9

Photo 10

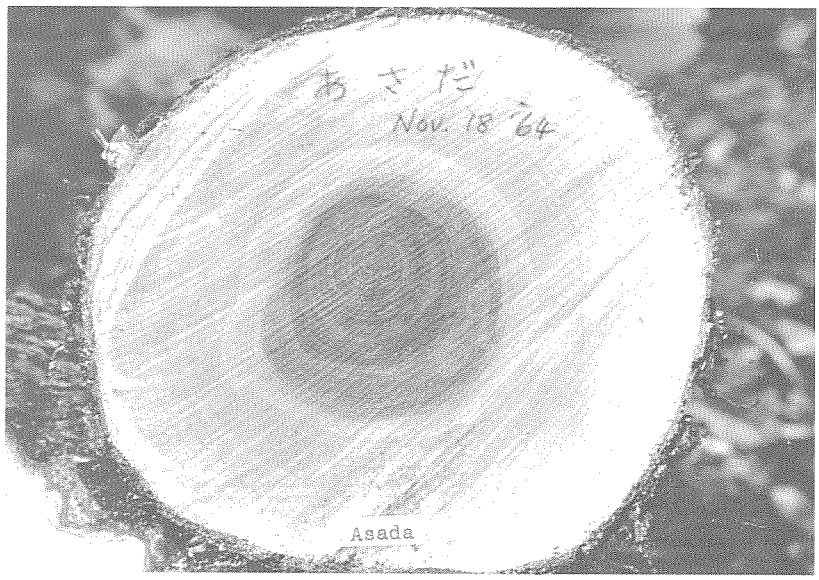

Photo 11

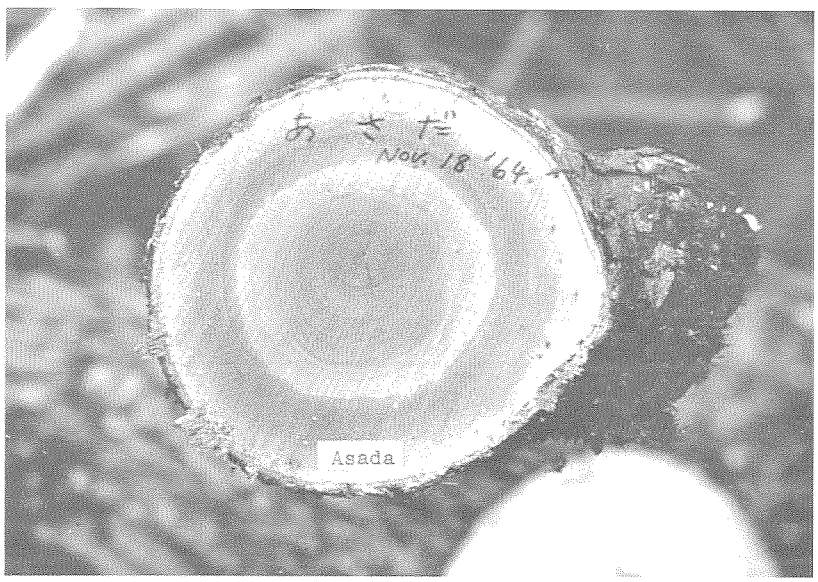

Photo 12

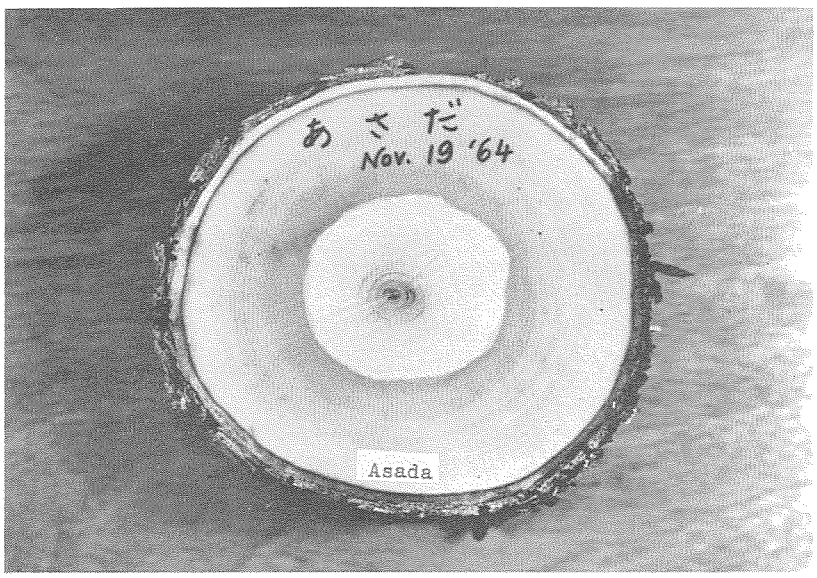

Photo 13

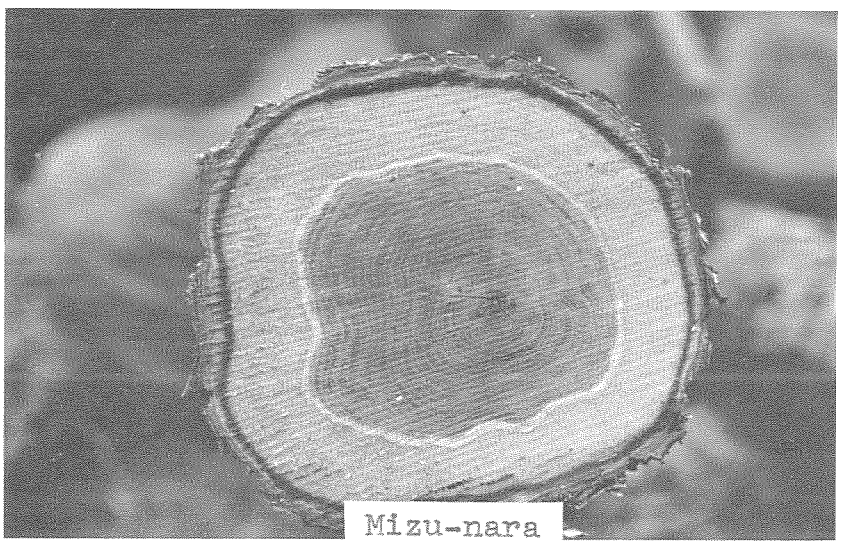

Photo 14

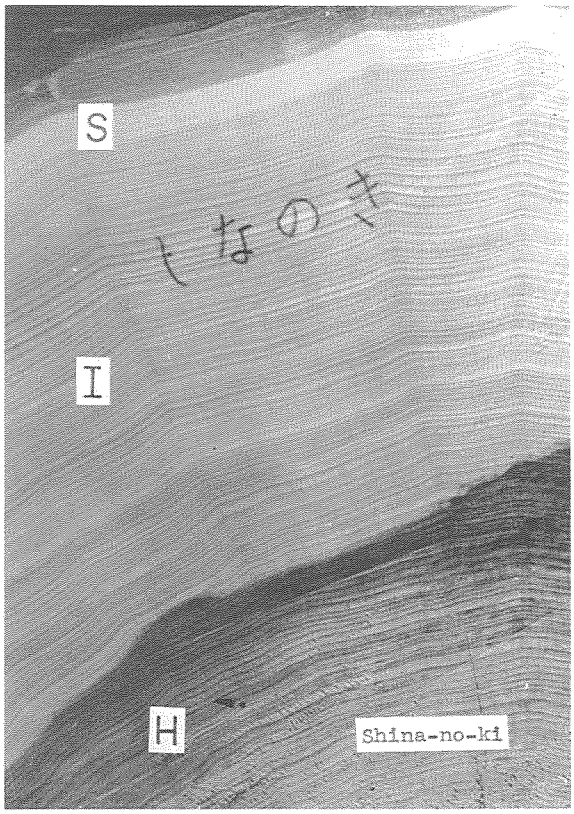

Photo 15

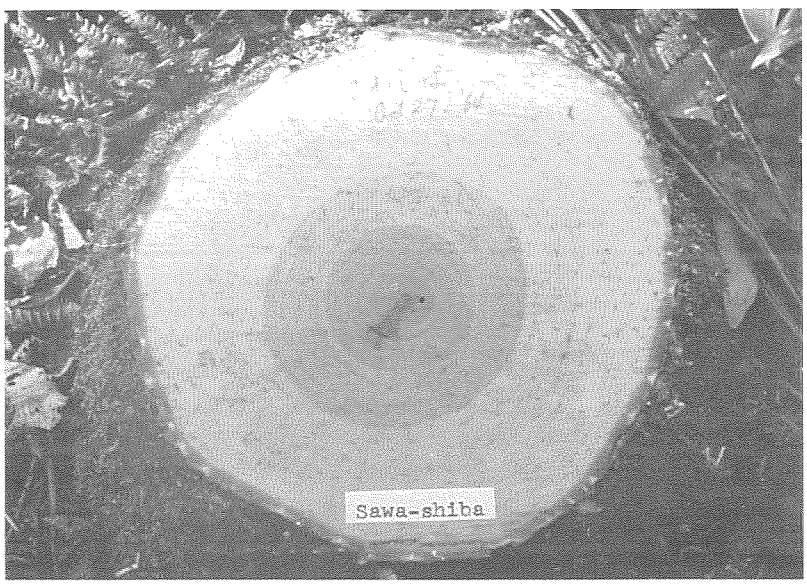

Photo 16

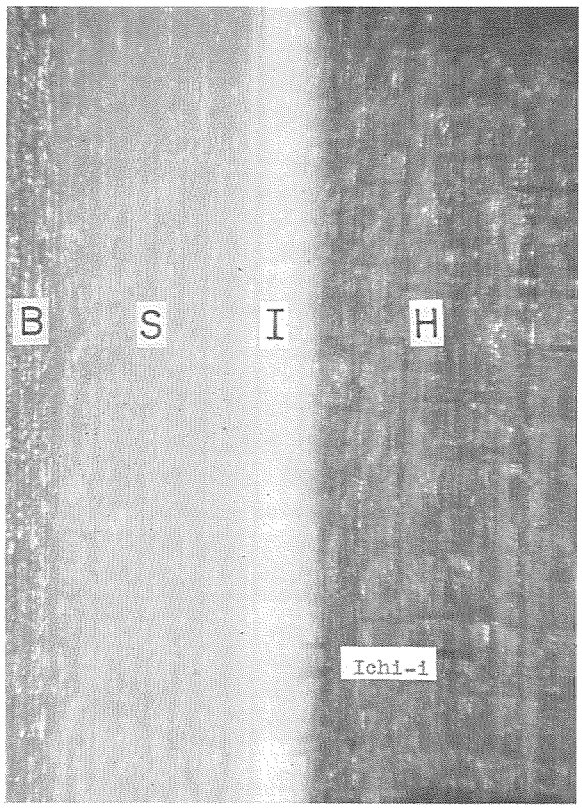

Photo 17

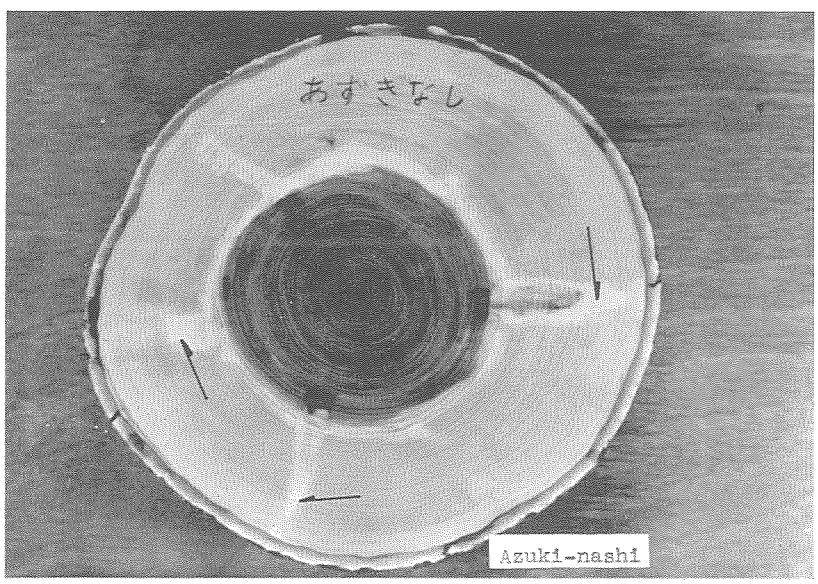

Photo 18

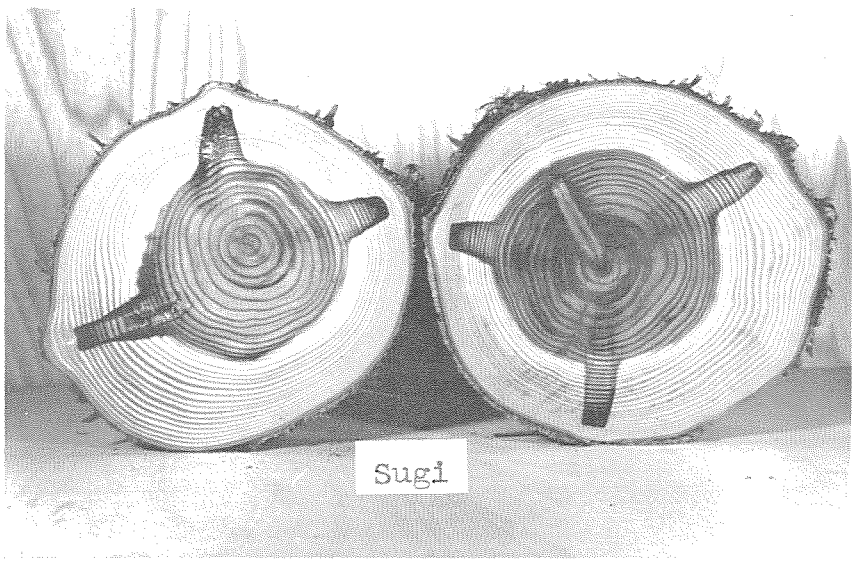

Photo 19