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Cytology of the Ray Cells in Sapwood and Heartwood*)

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It is a generally admitted opinion that all living cells in the wood of a tree lose their vitality when the sapwood is transformed into heartwood (Büsgen/Münch 1927, p. 124; Chalk 1957). On the other hand metabolic processes have been reported in the "dead" core of trunks (Gäumann 1928) and living parenchyma cells were observed in heartwood (Good and Nelson 1951). According to Chattaway (1952) such findings are due to the existence of a band of intermediate wood between sapwood and heartwood, which, owing to its incipient coloration, is often erroneously attributed to the heartwood. Since transformation processes occur in this transition layer, it is concluded that the intermediate wood represents a zone of intensified metabolism.

With the goal of checking these findings in European timbers, a cytological study of wood parenchyma in pine, larch, yew, fir, spruce, hornbeam, linden, locust, beech, and ash has been performed. The necessary wood samples have been provided by the Winterthur Municipal Forestry Department; we should like to express our gratitude for this co-operation.

Material and Methods

Pine (*Pinus silvestris* L.), larch (*Larix decidua* Mill.), yew (*Taxus baccata* L.), Douglas fir (*Pseudotsuga taxifolia* Britt.), redwood (*Sequoia sempervirens* Endl.) and locust (*Robinia Pseudacacia* L.) display pronounced heartwood, spruce (*Picea Abies* Karsten), fir (*Abies alba* Mill.), hornbeam (*Carpinus Betulus* L.) and linden (*Tilia cordata* Mill.) are trees with uncoloured heartwood and beech (*Fagus silvatica* L.) as well as ash (*Fraxinus excelsior* L.) are timbers with facultatively coloured heartwood. Uncoloured heartwood is often referred to as "ripewood"; but we avoid this term because the cytological behaviour turned out to be the same in both cases.

The cytology of the ray cells has been studied in material obtained from the growing trees by an increment borer. This instrument permitted samples from the whole sapwood to be obtained through the band of intermediate wood deep into the heartwood. The bore cores removed were fixed in Nawashin's mixture (chromic acid 1% 10 p., formaldehyde 4% 4 p., glacial acetic acid 1 p.). For the identification of lipids in the ray cells it proved preferable to fix the samples in 10% formaldehyde only. For the observation of living cells, part of the collected material was kept in 5% saccharose solution.

On a series of radial sections the ray parenchyma could be followed through all annual rings from the cambium to approx. the 50th ring in the heartwood.

Cell Nucleus

Morphology and structure of the nuclei give the best information on the cell activity. The nuclei were stained by Feulgen or haemalum. The haemalum method provides a more pronounced contrast on photomicrographs (Figs. 1—9).

Two types of transformation of the nuclei in the aging ray cells can be observed. In the first place they change their shape, but also their structure and chemistry are modified which is revealed by their altered faculty of accumulating the haemalum stain.

Figs. 1 through 4 demonstrate the alteration of the nucleus shape in pine rays. Near the cambium (4th ring) the nucleus is oblong-elliptical, in the zone from the 9th to the 16th ring it rounds off and after the 16th ring near the heartwood boundary it displays evident pycnotic degeneration. Long before the heartwood boundary is reached (53rd ring), the ray cells have lost their nucleus. Figs. 5—7 are showing the same development in the rays of *Abies*.

Dividing the length by the width of the nucleus, its slenderness ratio λ can be calculated. As shown in Graph I (Fig. 19) this ratio can be as high as 6 in fir (Fig. 5) or 5 in larch. In the aging rings this ratio falls off and reaches a value between 1 and 2 before the nucleus is dissolved one or several years before the boundary of the coloured heartwood is reached. Graph I displays these relationships for the investigated samples of pine, larch, yew, spruce, and fir. Although less pronounced, this relation is also evident in broad-leaved trees (ash, hornbeam, linden; Graph I, Fig. 19b).

Another significant alteration of the nuclei in the transition zone between sapwood and heartwood is the loss of the nucleolus which is shown for *Sequoia sempervirens* in Figs. 8 and 9. At the same time a good deal of the chromatine disappears (Fig. 6). This denegeration of the nucleus does not occur at the same time in all ray cells of an annual ring. Fig. 6 shows three neighbouring ray

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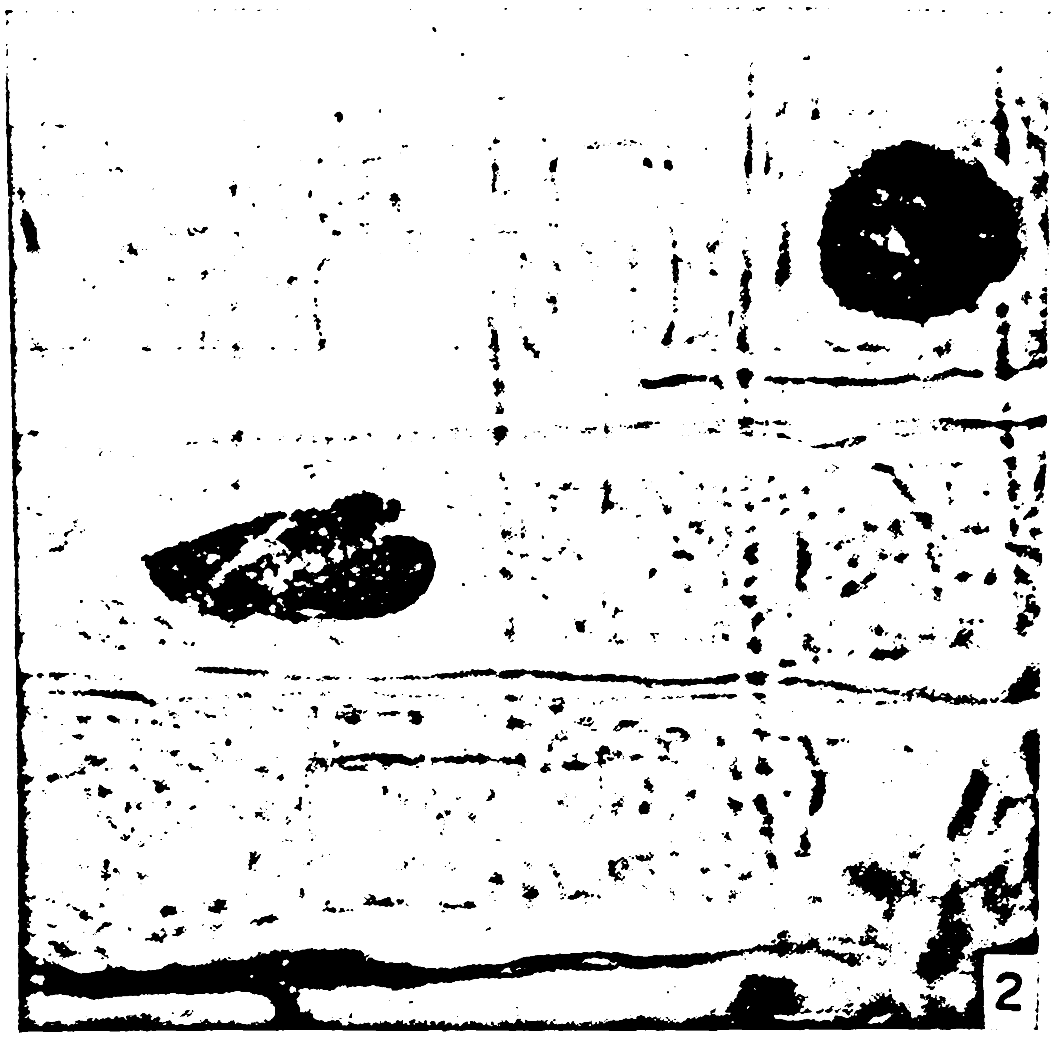

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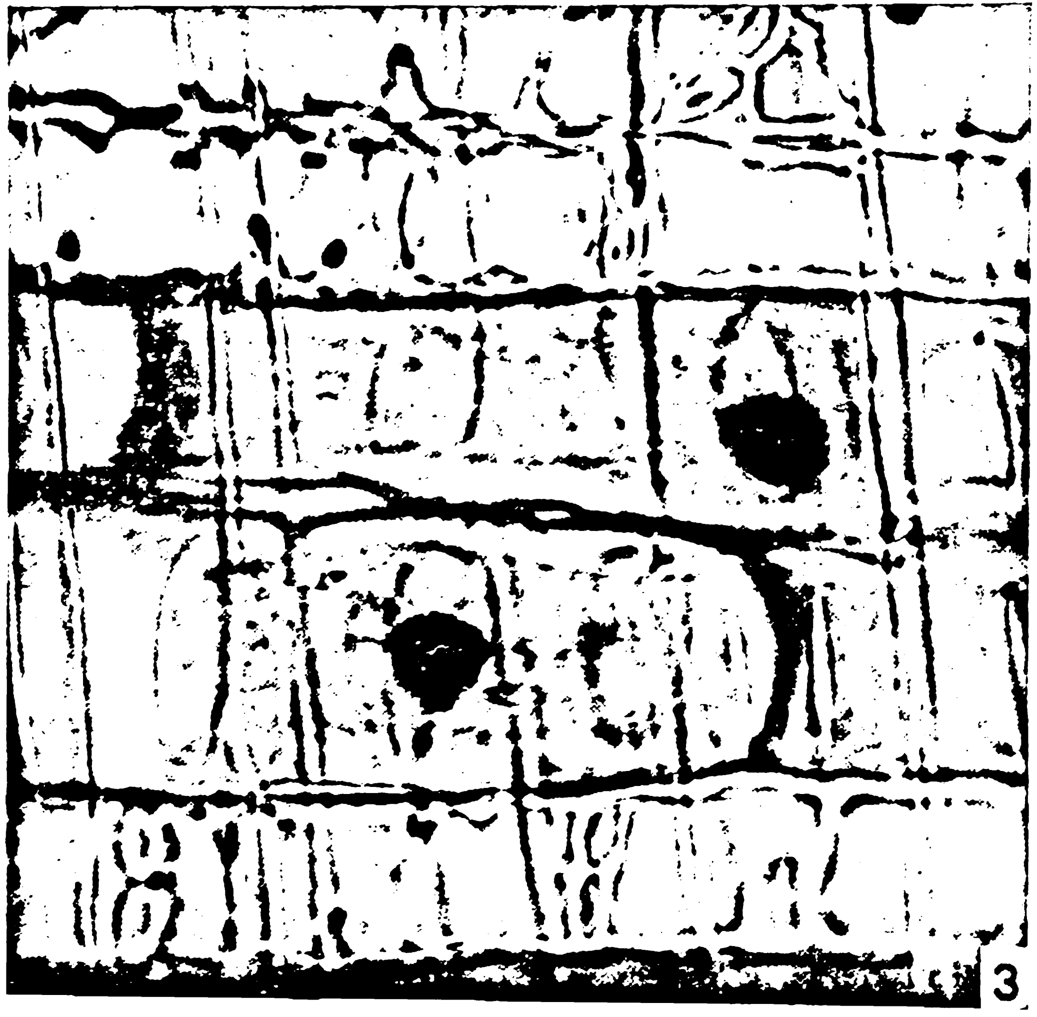

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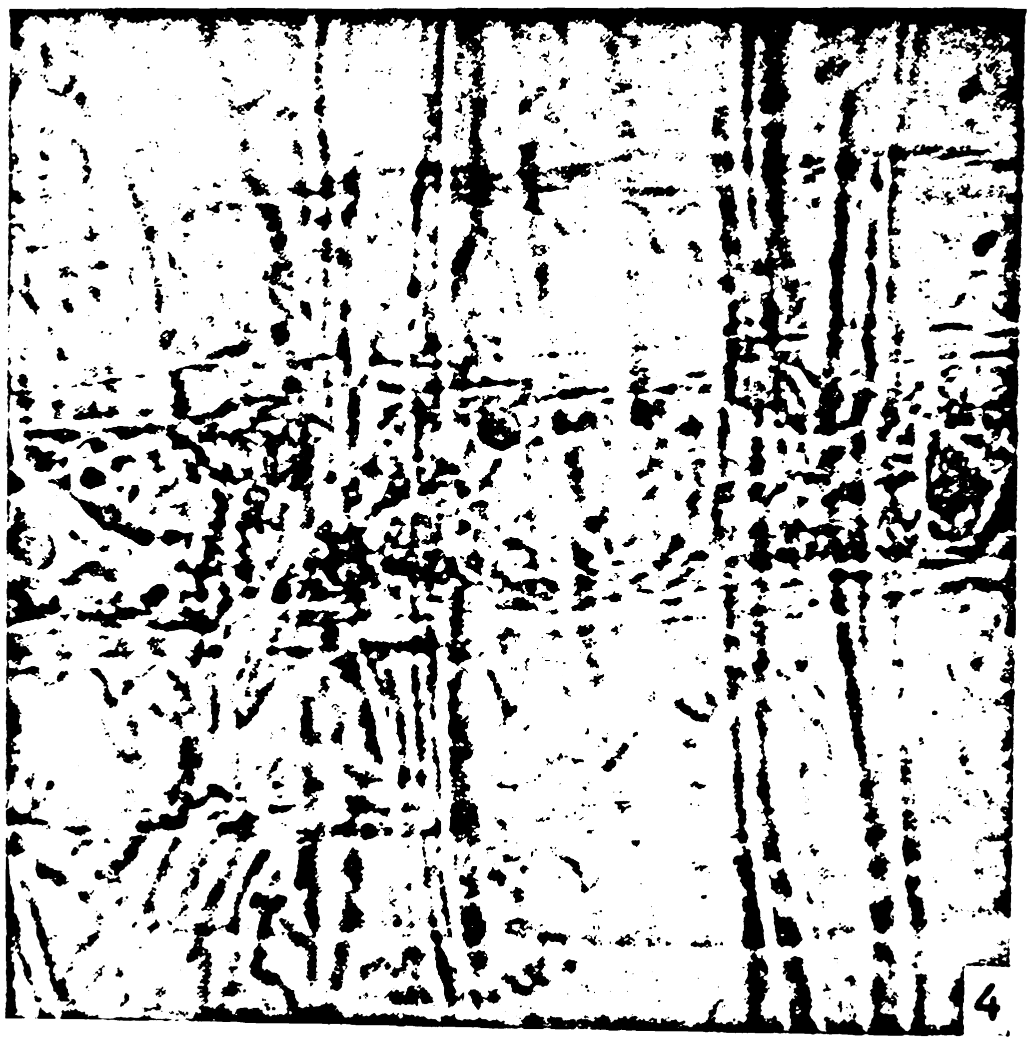

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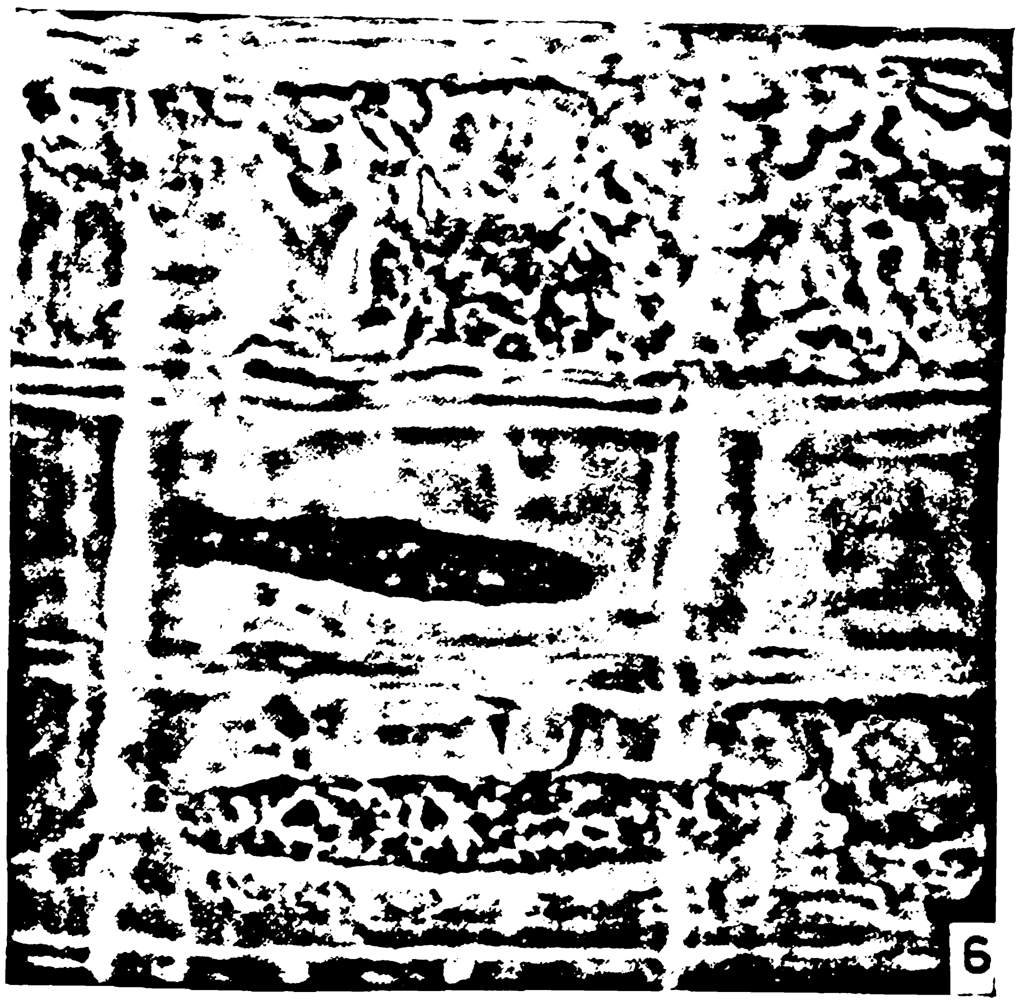

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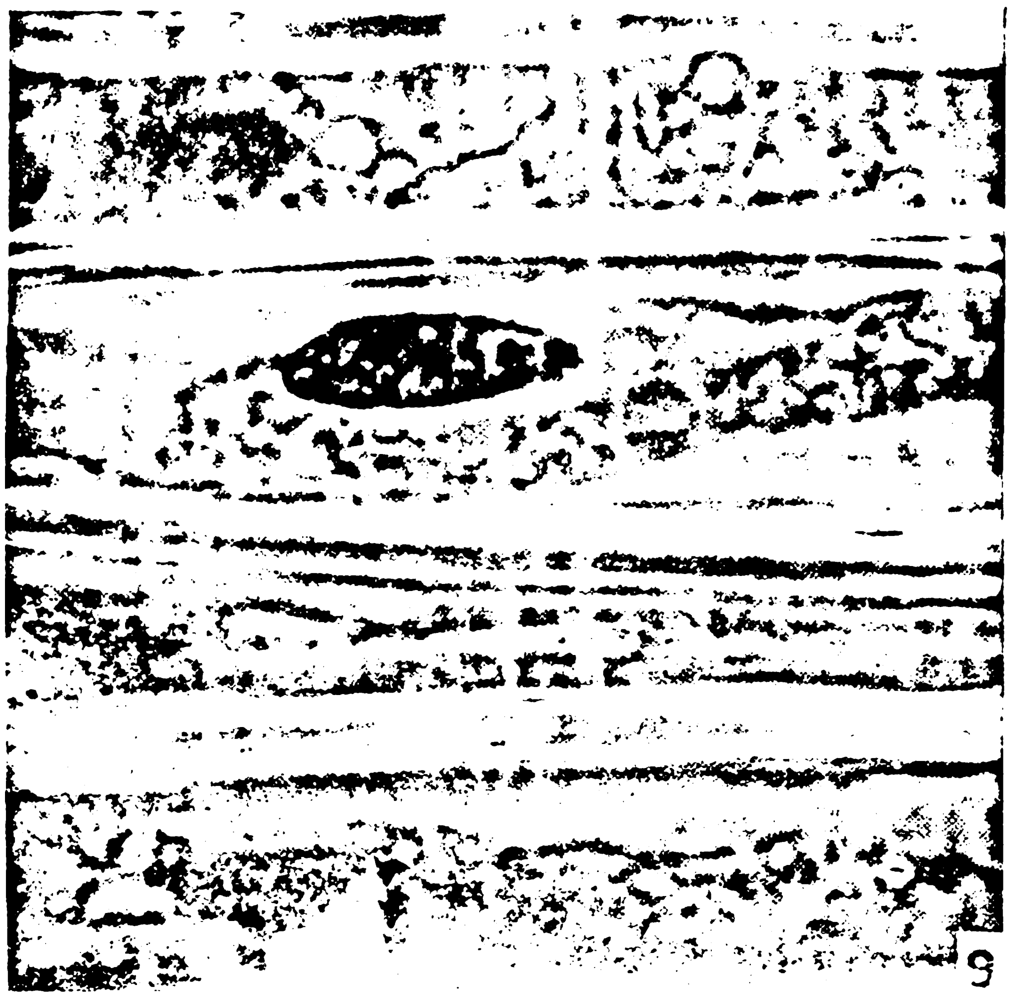
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Nuclei in the ray parenchyma of *Pinus silvestris* (Figs. 1—4):

Fig. 1 normal nucleus, 4th ring (× 260)
Fig. 2 nucleus rounding off, 9th ring (× 800)
Fig. 3 rounded off nucleus, 16th ring (× 760)
Fig. 4 nucleus disappeared, 36th ring (× 1180)

Nuclei in the ray parenchyma of *Abies alba* (Figs. 5—7):

Fig. 5 normal nuclei, 2nd ring (× 1400)
Fig. 6 nuclei losing their stainability, 9th ring (× 1480)
Fig. 7 pycnotic nucleus and starch granules, 5th ring (× 1480)

Nuclei in the ray parenchyma of *Sequoia sempervirens* (Figs. 8—9):

Fig. 8 Nucleus with nucleolus, 2nd ring (× 2150)
Fig. 9 Nucleoli disappeared, 20th ring (× 1400)

Fig. 10 Mitochondria, reducing Janus Green B, in the vertical parenchyma of *Pinus silvestris*, 2nd ring (× 830) cells in the 9th ring, of which one contains a well-stained nucleus, another a poorly stained nucleus and a third an unstained rounded-off nucleus. In the heartwood, the nuclei have disappeared (Fig. 4).

The decomposition and decay of the nuclei in the transition zone seem to contradict the statement of Chattaway (1952), that there is an increased physiological activity in the intermediate band in front of the heartwood boundary. This would require an enhanced metabolism and sound nuclei of, according to their raised activity, an increased size. We have therefore calculated the volume of the nuclei in the ray cells in sapwood and transition zone. For this calculation the shape of the nuclei was assumed to represent a rotation ellipsoid, which assumption comes near enough the truth. In Graph II (Fig. 20), the results are reproduced for five investigated samples. It is clearly seen that the volume of the nuclei diminishes gradually in the direction from the sapwood to the heartwood. Before they disappear in the transition zone, their volume is at a minimum. These findings do not favour the supposition of a raised metabolism in the intermediate band.

Mitochondria

Mitochondria of living cells have the faculty to accumulate the vital dye Janus green B and to transform it after a while, by their reduction capacity, into a colourless leucodye. Therefore, sections of recently bored cores preserved in 5% saccharose solution were stained with this reagent (50 cm^3 8% saccharose solution + 1 drop aqueous 1% Janus green B dye).

In the ray cells and the vertical wood parenchyma, two types of particles fixing Janus green B are found. One category remains stained for hours and days, whilst the other reduces the dye and bleaches out. According to Sorokin (1938, 1941) and Lazarow and Cooperstein (1953) particles of the second category are mitochondria, whilst the particles which stay coloured for days might be sphaerosomes (Bautz 1955).

The reduction capacity of the mitochondria has been tested in rays of larch, fir, pine, ash, and beech. Near the cambium a good deal of such particles are found. They have a globular shape with 0,8 to 1.2 μ diameter; rod-shaped mitochondria with e. g. 1.2 μ length and 0.6 μ width are rare. Fig. 10 shows these particles in a cell of the vertical parenchyma of pine wood.

When proceeding along the ray through the sapwood toward the heartwood, the time needed for the reduction of the dye increases, and long before the heartwood boundary is reached, no reducing capacity of the Janus green positive particles is displayed any longer. Whether those are all sphaerosomes, or whether they include mitochondria which do no longer metabolize, is difficult to decide.

At any rate active mitochondria show up only in the outermost rings. This statement is in agreement with the theory that the transformation of sapwood into heartwood is correlated with a diminished respiration activity of the living wood parenchyma.

Reserve Materials (starch and fat)

Starch granules are abundant in the sapwood, disappear in the transition zone and lack completely in the heartwood. This oft-reported situation (e. g. Chattaway 1952) has been confirmed for fir, larch, pine, ash, and beech.

Besides starch, many trees, such as spruce, pine, birch, and linden accumulate fat in their ray parenchyma (Fischer 1891, Fabricius 1905). For the demonstration of fat, Nile blue has been used. This dye stains neutral fats in a pink colour, but free fatty acids in deep blue. In this way a distinction between the presence of intact reserve fat and of saponified, degraded fat is possible. Unfortunately this reaction is not reliable for the identification of fatty acids, since other acid lipids produce a blue colour as well.

With this method, fatty materials have been demonstrated in the rays of fir, larch, pine, ash, and beech. In contrast to the starch reserves, lipidic compounds can be found not only in the sapwood but also in the heartwood; in our fir samples they showed up through 30 annual rings, in larch through 37 rings, in ash through 77 rings etc. Fat seems to be regularly distributed in the cells (Fig. 11), whilst "fatty acids" show up in an aggregated or precipitated manner (Figs. 12 and 13). Although neutral fat can be found to deep in the heartwood, "fatty acids" seem to prevail there.

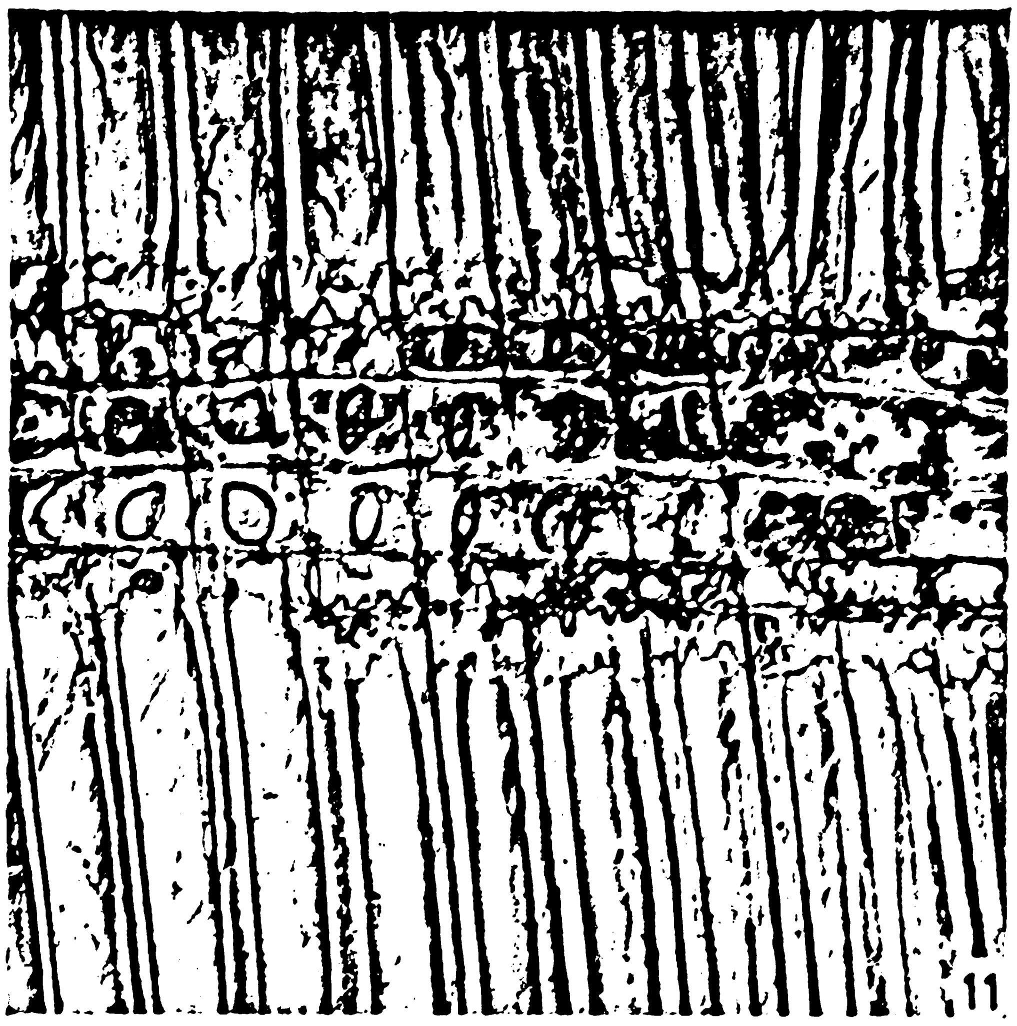
In cells which contain phenols, a greenish colour is produced. It seems that the lipids stained by Nile blue are associated with the precursors of the heartwood pigments. This would mean that they are not really fatty reserve material but, more likely, compounds which have been eliminated by the aging cells. Such a behaviour would explain why these lipids can be found in the dead cells of the heartwood.

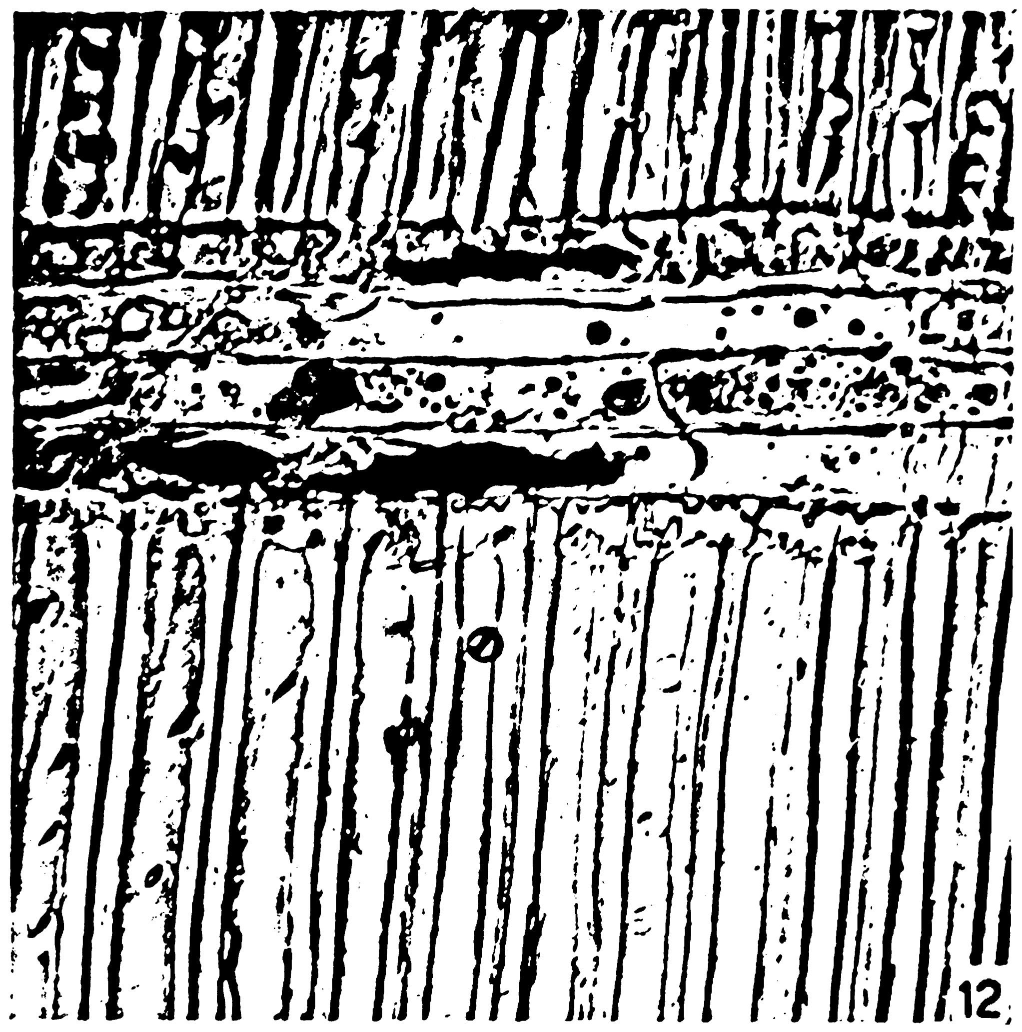
Phenols

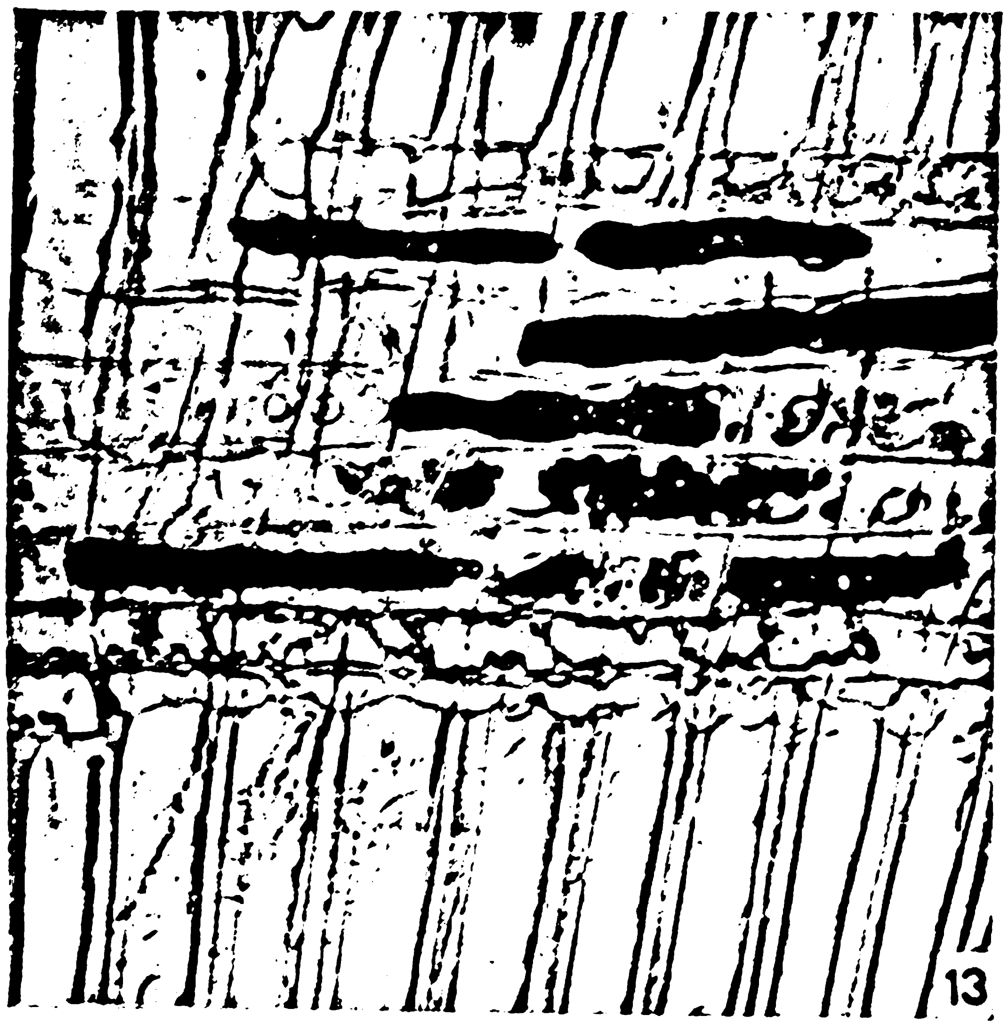
Although there is a great variety of reagents (e. g. $FeCl_3$, OsO_4 etc.) which produce dark colours with phenols, it was not possible to obtain a clear insight into their distribution along the rays and to localize the exact place where they are produced before they diffuse into the cell walls of the heartwood where they polymerize to insoluble dyestuffs.

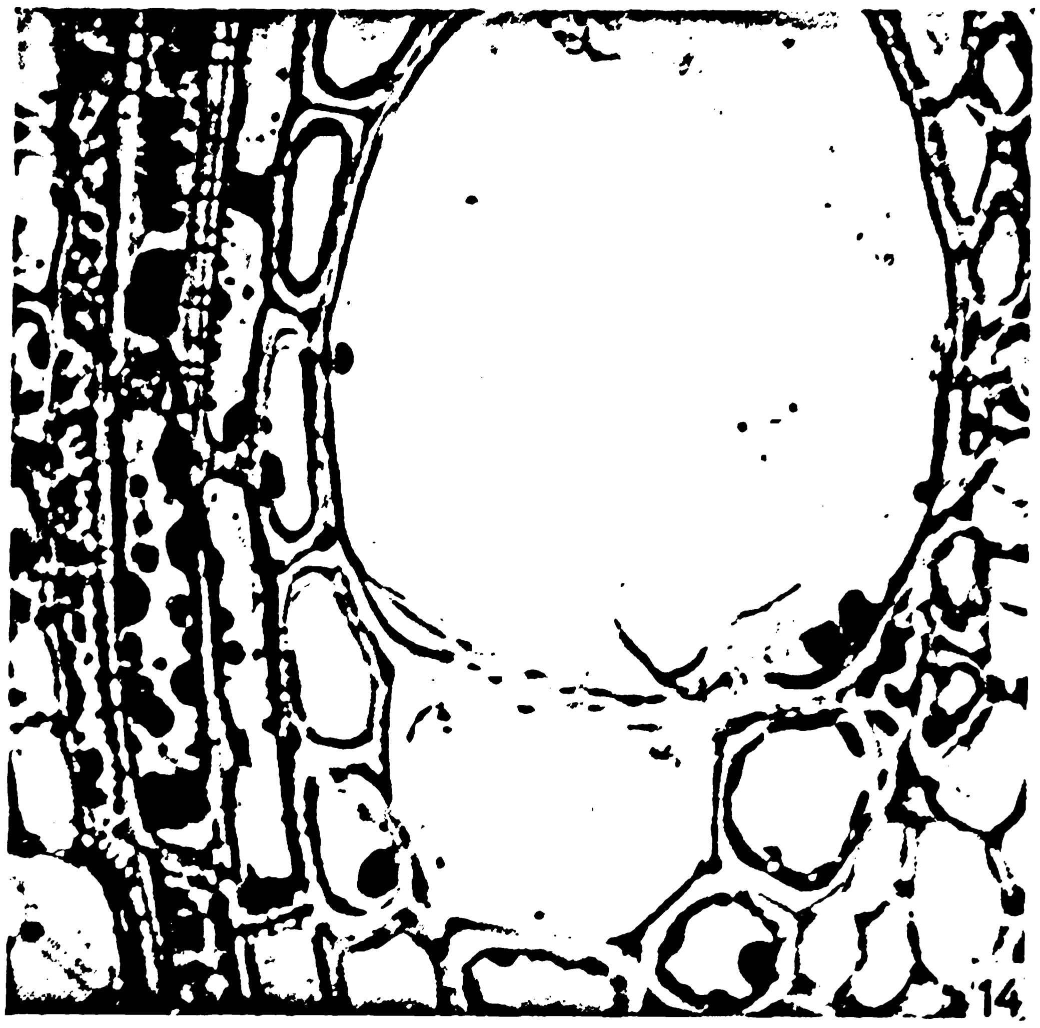
An exception to this unfavourable state of affairs is encountered in ash (*Fraxinus excelsior*). This timber produces coloured heartwood only if the moisture content of the trunk core exceeds 55% and if oxygen is present (Bosshard 1953, 1955). These conditions not being fulfilled, the ash tree produces colourless heartwood. When a coloured heartwood is lacking, the ray parenchyma of the uncoloured heartwood contains colourless droplets of phenols; in the sapwood and the transition wood, no such compounds seem to be accumulated. Sufficient moisture presupposed, those phenols will be oxidized and will polymerize to a dark-brown pigment. This dye does not diffuse into the cell walls, so that black droplets show up in the dead parenchyma cells. The facultatively coloured heartwood of ash timber is therefore unique in that not the cell walls, but the contents of the ray and the vertical parenchyma are stained. (Fig. 14.)

We consider the behaviour of the ash wood to be theoretically important, because it makes it probable that the colourless precursors of the heartwood pigments are produced by the ray cells in the dying transition zone whence they diffuse into the neighbouring cell walls where they become transformed into oxidized pigments.









Lipids in the ray parenchyma of *Pinus silvestris* stained with Nile blue (Figs 11—13):

Fig. 11 Pink coloration (fat?) 7th ring (× 230)
Fig. 12 Pink and blue coloration, 7th ring (× 230)
Fig. 13 Blue coloration (fatty acids?), 12th ring (× 230)

Fig. 14 Parenchyma cells in the facultatively coloured heartwood of *Fraxinus excelsior* filled with darkened phenol droplets (× 200)

For the synthesis of the relevant phenols an uninterrupted file of ray parenchyma with the cambial zone is necessary. If the file is interrupted, e. g. by cracks in the cambial zone due to shearing stresses caused by wind, around the attachment of branches, heartwood cannot be formed there for several years, so that an uncoloured sector is left behind such a crack (Bourquin 1938, Frey-Wyssling 1938, Erdtman und Rennerfelt 1944).

Sometimes there is enough moisture in the core of an ash tree, but it does not turn brown until the trunk is felled and sawn into pieces. This is an indication that the inner part of old trees suffers from an oxygen deficiency or even from an anaerobiotic condition (Ziegler 1957). This statement leaves the problem wherefrom the oxygen is supplied for the oxidation polymerization in timbers with compulsory formation of heartwood.

Influence of Heartwood Formation to the Water Conducting System

Tyloses are said to be one of the most characteristic features of heartwood formation (Chattaway 1949, Trendelenburg 1955). But in ring-porous timbers tyloses may appear already in the second or the third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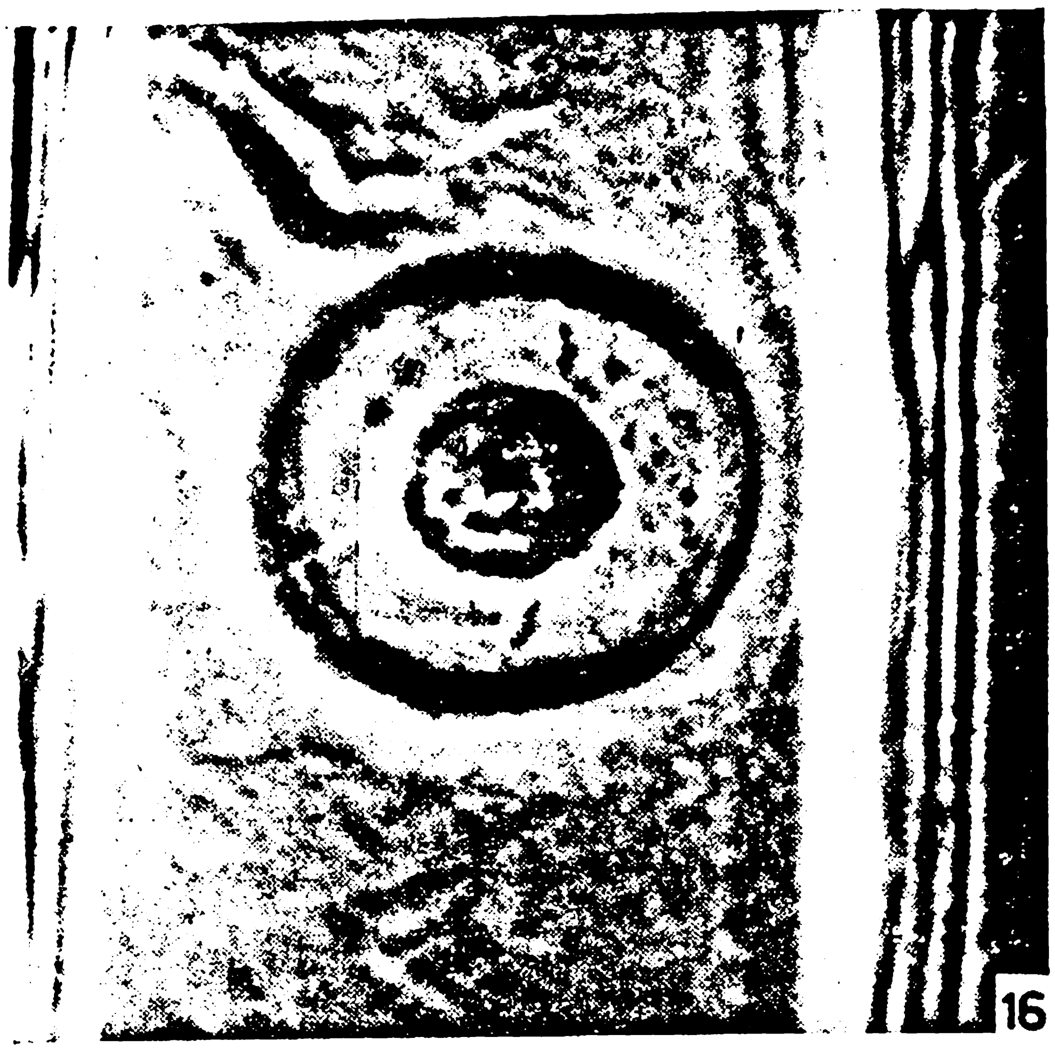
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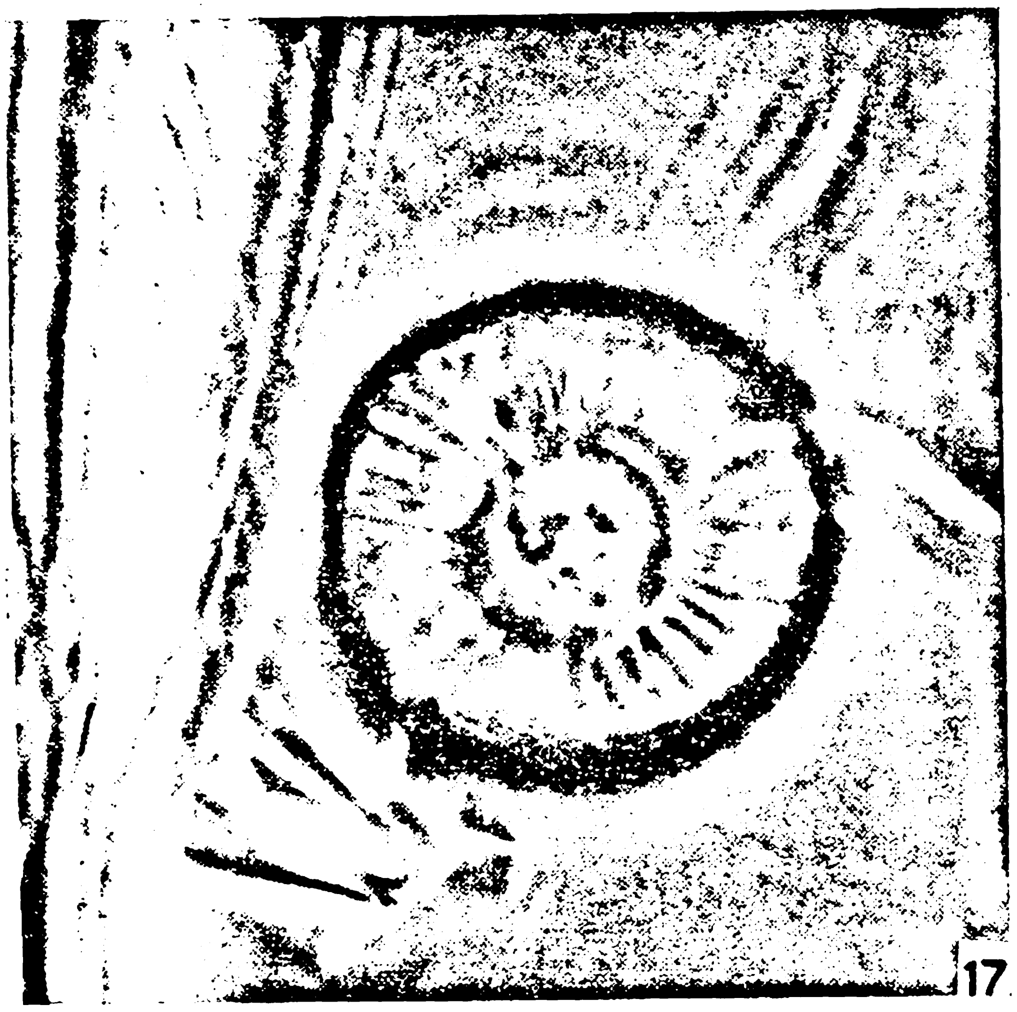
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Fig. 15 Bordered pit in a ray tracheid of *Pseudotsuga taxifolia* stained with haemalum, 18th ring (× 2300)

Bordered pits on the vertical tracheids of *Abies alba* (Figs. 16—17)

Fig. 16 Threads holding the torus submicroscopic, 4th ring (× 2280)

Fig. 17 Threads holding the torus microscopic, 11th ring (× 2280)

Fig. 18 The same as Fig. 17 in *Larix decidua*, 27th ring (× 2050)

annual ring. According to our observations it is true that tyloses are increased in the heartwood, but it cannot be said that, in the timbers under investigation, tyloses formation is a special cell activity of the intermediate band, as claimed by Chattaway (1952).

As to the bordered pits, we made some interesting findings. In the ray tracheids they seem to be functional for many years. Fig. 15 shows such a pit in the 18th ring of *Pseudotsuga*, where the torus is still in the physiologically active intermediate position.

The pit membrans of the vertical tracheids, observed in the light microscope, seem to be homogeneous in the outer rings of the sapwood (Fig. 16). Only after a certain number of years do the threads which hold the torus in its central position become visible (Figs. 17 and 18). Homogeneous pit membranes have been found to the 37th ring in pine (heartwood boundary at the 54th ring) the 14th in spruce, the 8th in fir the 19th in *Pseudotsuga*, and the 24th ring in larch (heartwood at the 30th ring). This is in accordance with the findings of Frey-Wyssling, Bosshard and Mühlethaler (1956), who showed how the radial threads, in later years, thicken heavily by incrustation, and in opposition to the claim of Jayme and Fengel (1959) that individual pits would stay unaltered to the 47th or even to the 56th ring in spruce.

Discussion

The reported cytological observations demonstrate clearly that, with increasing distance from the cambium, the living ray cells undergo a gradual transformation.

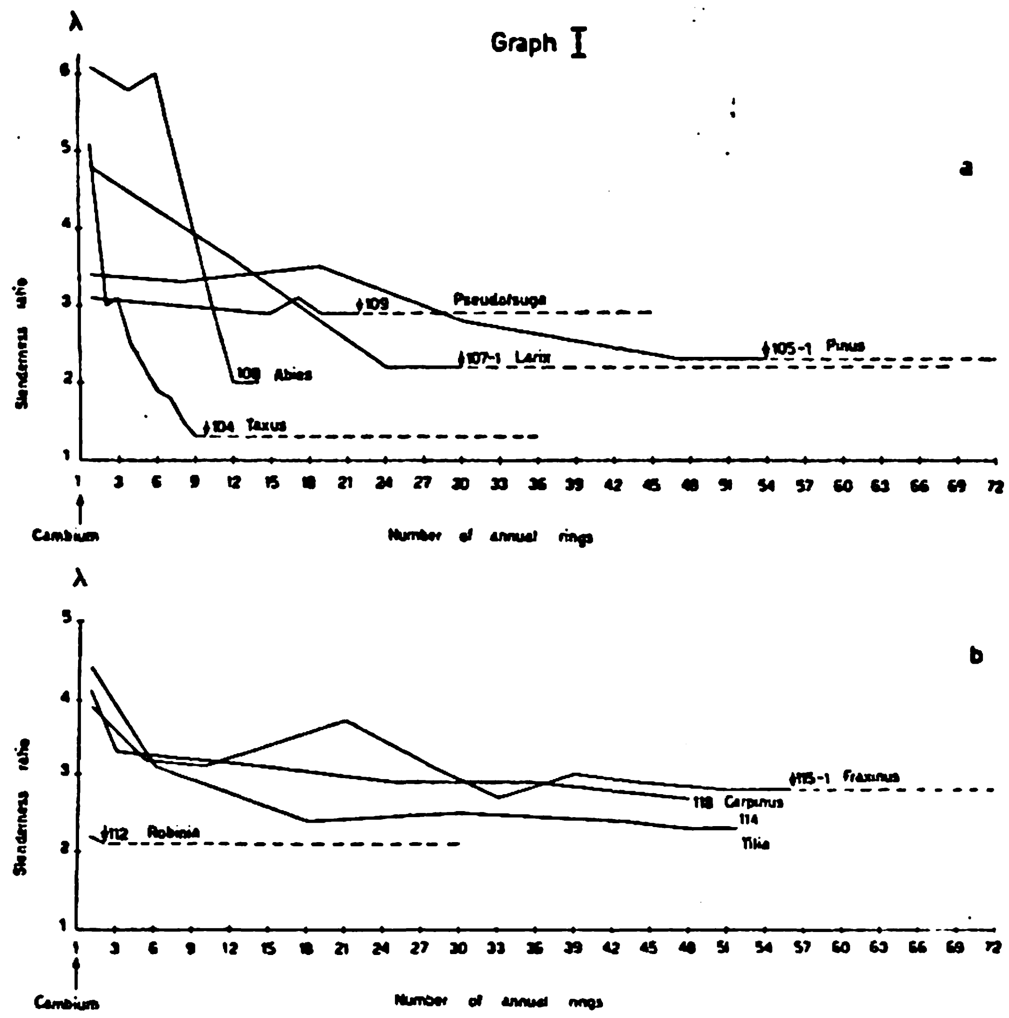

Fig. 19 Slenderness ratio λ of ray parenchyma nuclei plotted against the number of annual rings, a) for softwood species, b) for hardwood species. — The length of the curves for each species indicates the number of annual rings which has been investigated; the arrows mark the boundary between the transition zone and the heartwood region. The lineated part of the curves indicates the zones where the nuclei have disappeared.

This alteration with aging concerns the morphology as well as the metabolism of the cell constituents. The oblong nuclei round off, gradually lose their chromatine, disintegrate and disappear before the boundary of the heartwood is reached (Figs. 1—9; Graphs I and II, Figs. 19 and 20). The mitochondria (Fig. 10) have been shown to lose their reduction power towards Janus green B very early, only a few rings inwards of the cambium. Then they can no longer be distinguished from sphaerosomes. The particles stainable with Janus green B disappear before the heartwood boundary is reached. The observed cytological changes do not occur at the same time in all cells of a ring, but some of them may survive for a few years, when their neighbours in the same ray appear already to have lost their metabolizing cell content.

Starch granules are detectable throughout the sapwood. They diseappear rather abruptly in the transition zone to the heartwood boundary. In contrast to this behaviour, neutral lipids and, above all, aggregated lipids of the acid type which is stained a deep blue by Nile blue are found in the dead cells of the heartwood (Figs. 11—13). These deposits can hardly represent reserve material, but must rather be considered as excretions or transformed remnants of the disintegrated cell constituents.

According to Chattaway (1952) the ray cells of the intermediate band between sapwood and heartwood display an intensified metabolism characterized by the formation of tyloses, the production of phenols and the disappearance of starch. From a cytological point of view such a conception is hardly acceptable; because as a rule, cells with an intensified metabolism are distinguished by a large nucleus rich in chromatine and by increased respiration. However, the contrary is found in the transition zone: the nuclei disintegrate and disappear, and the lack of oxygen causes a respiration coefficient considerably larger than one (Ziegler 1957) creating an almost anaerobic environment. This is in accordance with the fact that certain colourless wood pigments remain in the reduced state as long as no oxygen is added from outside (ash, alder). Therefore it seems better not to speak of an intensified but of an altered metabolism.

Assuming that, comparable to lignin, the heartwood pigments polymerize in the cell wall by dehydrogenation of colourless phenols, the following difference between sapwood and heartwood conditions to leucodyes can be established:

$$\text{sapwood: Janus green B} \xrightarrow{+\,H_2} \text{leucodye}$$

$$\text{heartwood: phenols} \xrightarrow{-\,H_2} \text{heartwood pigments}$$

In the outer rings of the sapwood the respiratory system is intact. Oxygen functions as acceptor for the hydrogen of the dehydrogenating respiration enzymes; if Janus green B is accumulated in the mitochondria, it acts as a substitute for oxygen and is hydrogenated to a leucodye.

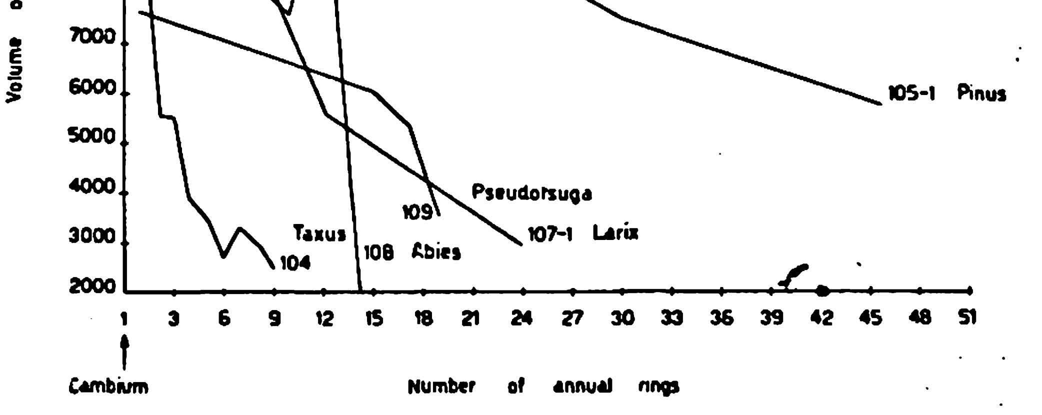

Fig. 20 Volume of ray parenchyma nuclei in function of their age expressed by the number of the annual ring for five softwood species.

In the transition zone, the aerobic respiratory system breaks down. Some metabolites of the respiration substrate serve concurrently as H_2 acceptors (fermentation), so that more CO_2 is produced than O_2 used. In this altered environment with a low oxido-reduction potential, the production of colourless phenols by dehydrogenation seems to be favoured. It is of special interest that the hydrolysis of starch is not hindered but rather stimulated by this type of anaerobiosis.

It seems that oxydation of the phenols is only possible when starch has disappeared. From studies of the formation of the brown pigments in tobacco fermentation (Birnstiel 1959) it is known that the oxydation of the relevant phenols (chlorogenic acid, rutine) is not possible as long as there is a high concentration of sugars in the leaves. Only when a good deal of this sugar is consumed, does the redox-potential rise sufficiently to allow the transfer of oxygen to the phenols. Under these conditions even a low oxygen tension (e. g. that of commercial nitrogen gas) is capable of oxidizing the phenols if enough time is available. Similar circumstances obtain in the transition zone between sapwood and heartwood: the respiratory system has broken down and starch, the purveyor of sugars, has disappeared. The available oxygen, although with a very low semianaerobic tension, is thus capable of acting as acceptor for the hydrogen transfer from the polymerizing phenols and so doing, in the long run, causes the browning of the heartwood.

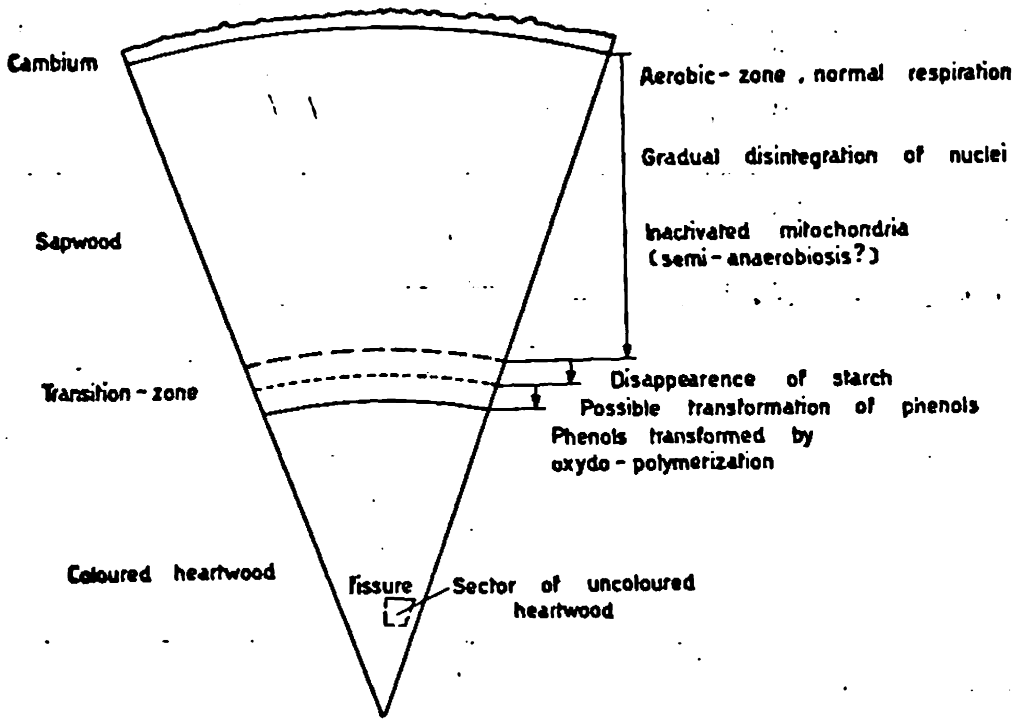

Fig. 21 Sector of a tree with heartwood showing diagrammatically the different zones between cambium and pith with their various cytological and physiological characteristics.

Erdtman (1953) finds in conifers that all the phenols of the heartwood, though in very small quantities, are already detectable in the sapwood. From this he concludes that the colourless phenols must be produced by the cambium. However, the formation of uncoloured zones behind local fissures parallel to the rings (Bourquin 1938, Frey-Wyssling 1938, Erdtman and Rennerfelt 1944) shows that the bulk of these phenols must be produced in the inner sapwood and in the outer transition zone. The depth of the mentioned uncoloured sectors in the heartwood then corresponds to the number of the innermost rings of the sapwood where phenol can be transformed by postmortal oxidation.

Fig. 21 gives a tentative survey of our findings. Under the cambium there is an aerobic zone with a normal respiratory system in the sapwood. With increasing depth there is a gradual disintegration of the nuclei and an inactivation of the mitochondria as judged from the Janus green test. Towards the transition zone the normal respiratory system seems to break down (respiration quotient > 1, semi-anaerobiosis?). In the outer part of the transition zone the starch granules are hydrolized. With the disappearance of starch, the enzyme system of the cells seems altered in some way so that the phenols which diffuse radially inwards from the inner sapwood become oxidizable.

Summary

The gradual degradation of the cell nucleus and the mitochondria in the ray cells with increasing distance from the cambium, where the oxygen supply is more and more impeded, favours the view that the transition band between sapwood and heartwood is characterized by a semi-anaerobiotic metabolism. Starch hydrolysis seems to be a feature of the transition zone. After the disappearance of starch the enzymes of the sapwood parenchyma seem to lose control over the ray cells so that, at the boundary of the coloured heartwood, an oxido-polymerization of the phenols adsorbed in the cell-walls becomes possible in that region. Oxygen is no longer used as H_2 acceptor in the respiratory cycle, and in spite of its very low tension, it can oxidize phenols if enough time is avaiblale. This explains why the formation of coloured heartwood is a slow, time consuming process.

Zusammenfassung

Es wird eine schrittweise Degeneration der Kerne und der Mitochondrien des Strahlenparenchyms mit zunehmender Tiefe des Splintholzes festgestellt. Da parallel hierzu steigende Schwierigkeiten der Sauerstoffversorgung auftreten, darf angenommen werden, daß in der Übergangszone zwischen Splint- und Kernholz ein semianaerobiontischer Stoffwechsel stattfindet. In jener Zone macht sich eine gesteigerte Stärkehydrolyse geltend. Nachdem alle Stärkekörner verschwunden sind und der entstandene Zucker aufgebraucht ist, bricht offenbar das respiratorische Enzymsystem zusammen und die oxydative Polymerisation der in den Zellwänden adsorbierten Phenole wird ermöglicht, indem das vorher durch die Gegenwart von Zucker tiefgehaltene Redoxpotential ansteigt. Der spärlich vorhandene Sauerstoff wird nicht mehr als Akzeptor für den Wasserstoff der Dehydrierungsvorgänge des Atmungszyklus verwendet, sondern er geht trotz seiner sehr geringen Dampfspannung dazu über, die anwesenden Phenole zu oxydieren, wenn hierfür genügend Zeit zur Verfügung steht. Dies erklärt, warum die Bildung eines Farbkernes im Holz ein langsamer, zeitraubender Vorgang ist.

References

Bautz, E.: Über Mitochondria-Färbungen an höheren Pilzen. Naturwiss. 42, 619 (1955).

Birnstiel, M.: Über das Redoxpotential lebender und absterbender Pflanzengewebe. Diss. E. T. H., Zürich 1959.

Bosshard, H. H.: Der braune Kern der Esche. Holz 11, 349 (1953);

— Zur Physiologie des Eschenbraunkerns. Schweiz. Z. Forstwesen 9/10 (1955).

Bourquin, A.: Quelques observations sur un phénomène accompagnant les poches résinifères du mélèze. J. Forest. Suisse 3 (1938).

Büsgen, M. u. E. Münch: Bau und Leben unserer Waldbäume. (Fischer) Jena 1927.

Chalk, L. (Pres. Comm. on Nomenclature I. A. W. A.): International Glossary of Terms Used in Wood Anatomy. Tropical Woods Nr. 107 (1957).

Chattaway, M. M.: The Development of Tyloses and Secretion of Gum in Heartwood Formation. Austral. J. Bot. B 2, 227 (1949).

— The Sapwood — Heartwood Transition. Austral. Forestry 16, 25 (1952).

Erdtman, H.: Über einige Inhaltsstoffe des Kernholzes der Coniferenordnung Pinales. Holz als Roh- u. Werkstoff 11, 245 (1953).

Erdtman, H. u. E. Rennerfelt: Der Gehalt des Kiefernholzes an Pinosylvin-Phenolen. Svensk Papperstidn. 47, 45 (1944).

Fabricius, L.: Untersuchungen über den Stärke- und Fettgehalt der Fichte auf der oberbayerischen Hochebene. Naturwiss. Z. Land- u. Forstwirtsch. 3, 137 (1905).

Fischer, A.: Beiträge zur Physiologie der Holzgewächse. Jb. wiss. Bot. 22, 73 (1891).

Frey-Wyssling, A.: Über die Entstehung von Harztaschen. Holz als Roh- und Werkstoff 1, 329 (1938).

Frey-Wyssling, A., Bosshard, H. H. u. K. Mühlethaler: Die submikroskopische Entwicklung der Hoftüpfel. Planta 47, 115 (1956).

Gäumann, E.: Die chemische Zusammensetzung des Fichten- und Tannenholzes in den verschiedenen Jahreszeiten. Flora 23, 344 (1928).

Good, H. M. and C. D. Nelson: A Histological Study of Sugar Maple Decayed by Polyporus glomeratus Peck. Canad. J. Bot. 29, 215 (1951).

Jayme, G. u. D. Fengel: Untersuchungen über den Feinbau der Hoftüpfelschließhäute in Fichtenholz unter Anwendung einer Feucht-Präparationsmethode. Holz als Roh- u. Werkstoff 17, 226 (1959).

Lazarow, H. and S. J. Cooperstein: Studies on the Mechanism of Janus Green B Staining of Mitochondria. Exp. Cell Res. 5, 56, 69, 82 (1953).

Sorokin, H.: Mitochondria and Plastids in Living Cells of Allium cepa. Amer. J. Bot. 25, 28 (1938).

— The Distinction between Mitochondria and Plastids in Living Epidermal Cells. Amer. J. Bot. 28, 476 (1941).

Trendelenburg, R. u. H. Mayer-Wegelin: Das Holz als Rohstoff. 2nd ed. (Hauser) München 1955, p. 247.

Ziegler, H.: Über den Gaswechsel verholzter Achsen. Flora 144, 229 (1957).

Chemische Studien an Tropenhölzern — 4. Mitteilung[1] [2]

Chemische Untersuchungen an Teakholz

Gewidmet dem Gedenken von Heinrich Wienhaus

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Einleitung

Teakholz (*Tectona grandis* L. fil., Familie *Verbenaceae*) findet als eines der beliebtesten und wertvollsten Importhölzer weitverbreitete Verwendung im Möbelbau, für Vertäfelungen, in der Ausstattung von Schiffen, Waggons sowie für andere hochwertige Zwecke. Das ringporige, wenig schwindende Holz mit der mittleren Wichte 0,68 hat hervorragende statische Eigenschaften. Daneben ist die Widerstandsfähigkeit dieses Edelholzes gegen Abnützung, Chemikalien und Holzzerstörer bemerkenswert. Über den anatomischen Bau gibt Abb. 1 Aufklärung.

Im Holzhandel stand Teakholz schon im Altertum an erster Stelle. Bereits im 4. Jahrtausend v. Chr. brachten orientalische Holzhändler zur Zeit der Monsune indisches Teakholz auf dem Schiffswege nach Mesopotamien und nach dem Yemen, der alten Weihrauch-Handelsmetropole. Dort diente das edle und unverwüstliche Holz für Türpfosten und Schwellen der Tempel, Paläste und Villen (1). Im Schiffsbau wurde es wegen seiner Dauerhaftigkeit vom Altertum bis zur Gegenwart für Aufbauten und Decks verwandt (2).

Im Holzhandel werden im wesentlichen drei Teakholzsorten geführt: Burma-, Siam- und Javateak. Teakholz burmesischer Herkunft wird am höchsten bewertet, jenes aus Java am niedrigsten. Hauptausfuhrland ist Burma, das bis zum letzten Krieg 85% des Weltbedarfs deckte und heute etwa die Hälfte allen Teakholzes liefert (3). Wegen seines hohen Wertes wird Teak oft durch andere Hölzer ersetzt, z. B. **Yang** („Yang-Teak"), **Angelique** („Guayana-Teak"), **Afrormosia** („Gold-Teak") und **Iroko** („Kambala-Teak"). Hinsichtlich waldbaulicher Fragen sowie der Beschreibung und Verwendung des Holzes sei auf das entsprechende Schrifttum verwiesen (4—6).

Beeinflussung der Eigenschaften des Teakholzes durch Inhaltsstoffe

Es besteht kein Zweifel, daß einige der bemerkenswertesten Eigenschaften des Teakholzes in ähnlicher Weise wie bei anderen Hölzern durch Menge und Natur der Inhaltstoffe bedingt sind (7).

Während beispielsweise der **Abnützungswiderstand** von Hölzern in engem Zusammenhang mit der Rohwichte steht, gilt dieses nach Arbeiten von **Chaplin** und **Armstrong** nicht für Teak und Jarrah (8). Die besonders günstigen Werte für Teak sollen durch den natürlichen Ölgehalt dieses Holzes bedingt sein, die weit schlechteren von Jarrah durch das wie Sand wirkende spröde Harz dieser Eucalyptusart. Zweifellos wird die Abweichung bei Teak (Abb. 2) mit Art und Menge des Inhaltstoffes zusammenhängen. Wie jedoch später noch nachgewiesen sei, wird die Verbesserung des Abnützungswiderstandes von Teak nicht durch den Gehalt an Öl, sondern an Kautschuk bewirkt. Darauf deutet auch die Tatsache, daß beim alkalischen Aufschluß von Teak die öligen Tröpfchen in den Zellen erhalten bleiben (Abb. 3).

Teak zeigt weiterhin eine für Hölzer ungewöhnliche Beständigkeit gegen starke Säuren. Das ist auch der Grund, weshalb es für Säurebehälter, Lagertanks und dgl. Verwendung findet. Nach Arbeiten von **Alliott** erwiesen sich von einer größeren Anzahl geprüfter Hölzer Teak und Pitch pine am günstigsten in ihrem Verhalten gegen Schwefel- und Salzsäure (9). **Campbell**

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[1] 3. Mitteilung: W. **Sandermann** und H. H. **Dietrichs**, Holz Roh- u. Werkstoff 17, 88 (1959).

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