ACTA SOCIETATIS
BOTANICORUM POLONIAE
Vol. XLII — nr 3
1973

Anatomical studies on the development of *Metasequoia glyptostroboides* Hu et Cheng wood

ALINA HEJNOWICZ

Institute of Dendrology and Kórnik Arboretum, Polish Academy of Sciences

(Received; March 9, 1973)

Abstract

Variability of anatomical characters within a 15 year old stem is presented by the method of contour lines, where against a schematic longitudinal section of a stem points corresponding to the same values for a character are joined by lines, similarly as altitudes in cartography. The method permits prediction of future trends in character changes. It was thus established that tracheid dimensions and diameter of bordered pits in early wood tracheids increase with age of tree and do not reach maximal values before the 15th year. The annual ring width and the height of the rays attain maximal values before the 15th year while the dimensions of ray cells and the percentage of late wood reach almost constant values during the first year or two.

INTRODUCTION

Since a living specimen of the genus *Metasequoia* has been first found in China an interest in the anatomy of its wood has started. The first information on the microscopic structure of the wood has been provided by Chinese scientists (Li 1948; Yu 1948; Liang Chow and Au — after Zalewska 1952). Studies of other authors have not added much more information (Hida 1953, 1962; Zalewska 1952; Greguss 1955; Brazier 1963; Jaroslavtsyev and Vishnyakova 1965). In all these papers very little attention is paid to the problem of ontogenic changes of various anatomical characters, though Yu (1948) has pointed out that wood from the central part of the trunk near the pith differs from that in the outer part of the trunk and Brazier (1963) has established the existence of directional changes of the average tracheid length at one level in the trunk.

One of the reasons why I have undertaken the study of some anatomical characters of wood of *Metasequoia* has been the fact that I had at my disposal samples of wood coming from one 15 years old stem felled in the Kórnik Arboretum. From the studies of other tree species it is known that in the 15th year from seedling the structure of wood is not fixed yet, and many characters undergo further changes in later years. However most of the characters undergo rapid changes in the first few years of tree life which permits the determination of the character and direction of these changes in the stem. One has to be aware of the fact however that this is not a sufficient age for the characterization of the quality of mature wood.

MATERIALS AND METHODS

The specimen on which the observations and measurements of microscopic characters have been made is a 15 year old rooted cutting propagated from a 10 years old Metasequoia seedling growing in the Kórnik Arboretum. Wood samples have been investigated from 8 levels in trunk at 1 m intervals. At each of the 8 levels all the consecutive growth rings have been investigated, avoiding those only in which the arrangement of cells was very irregular indicating that they were produced by cambium that was aberrant at the time (Fig. 1 e and 1 f). Such irregularities occurred primarily at the beginning of the growing season in the last year of the life of the tree.

Microscopic sections, transverse, radial and tangential have been made on a sliding microtome, and the maceration was performed on a water bath at 80°C in a mixture of glacial acetic acid and commercial hydrogen peroxide (30%) in a ratio 1:1.

Microphotographs have been made on a Zeiss "Lumipan" microscope with an "Exacta" camera on an ORWO NP-15 film. In order to demonstrate the nature of changes in the various characters within one stem use was made of the contour line method adapted from cartography, which facilitates the interpretation of the obtained results.

QUALITATIVE DESCRIPTION OF THE WOOD

The wood of *Metasequoia* has a distinct heartwood and the sapwood region in the studied stem covers 3—5 growth rings only. The wood consists of tracheids and a small number of scattered parenchyma cells (metatracheal parenchyma Fig. 1 a,b,c,d, and Fig. 2 f,g). The xylem rays are also parenchymatous. In the wood of *Metasequoia* there are no resin ducts. Resin fills the lumen of the parenchyma cells (Fig. 1 a,b,c,d). Annual rings are distinct, with a very narrow zone of the late wood, which is not distinctly cut off from the early wood in the same growth ring. Bordered pits in the tracheids are to be found on radial and

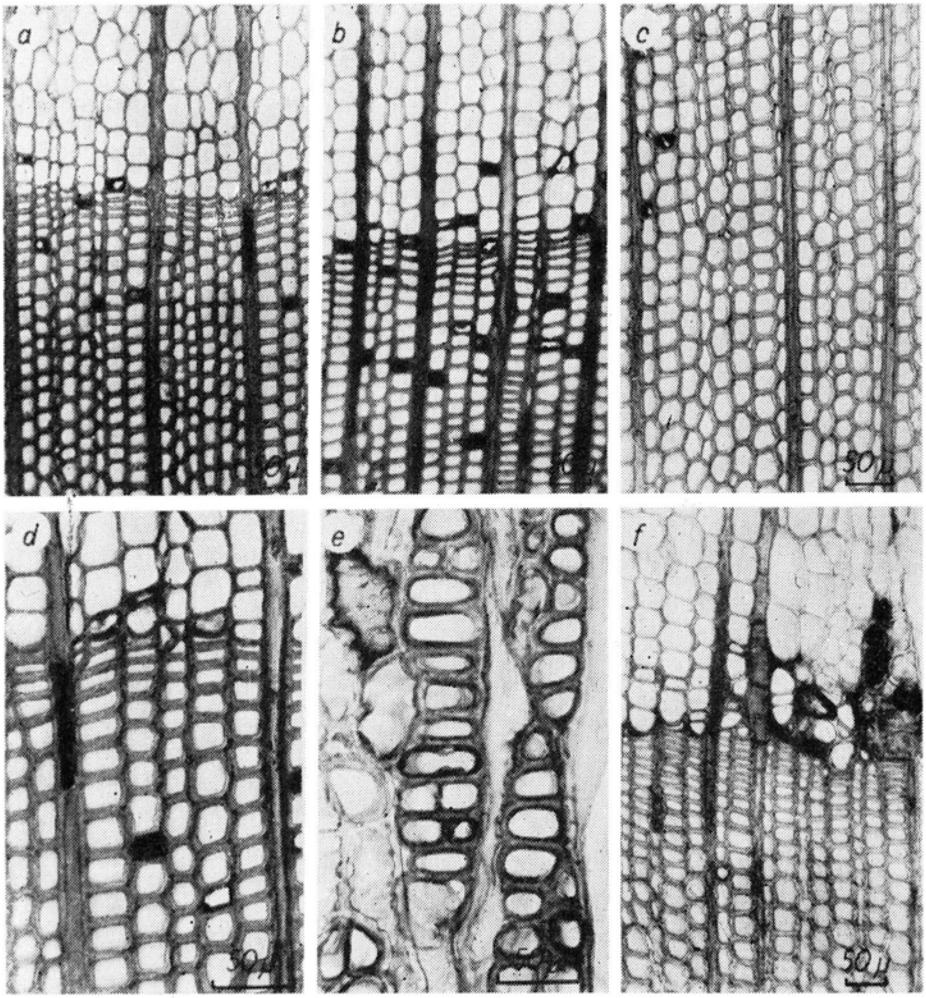

Fig. 1. Structure of wood at the root collar (a-e) and from the level 1m from the ground (f):

a — transverse section between 8th and 9th growth ring
b — ,, ,, between 10th and 11th growth ring
c — ,, ,, through central part of the 8th growth ring
d — ,, ,, between 8th and 9th growth ring
e — tangential section through the 13th growth ring
f — transverse section between 12th and 13th growth ring.

In fig. a-d it can be seen that the metatracheal parenchyma cells are filled with resin. In fig. e-f aberrations in early spring arrangement of cells are visible.

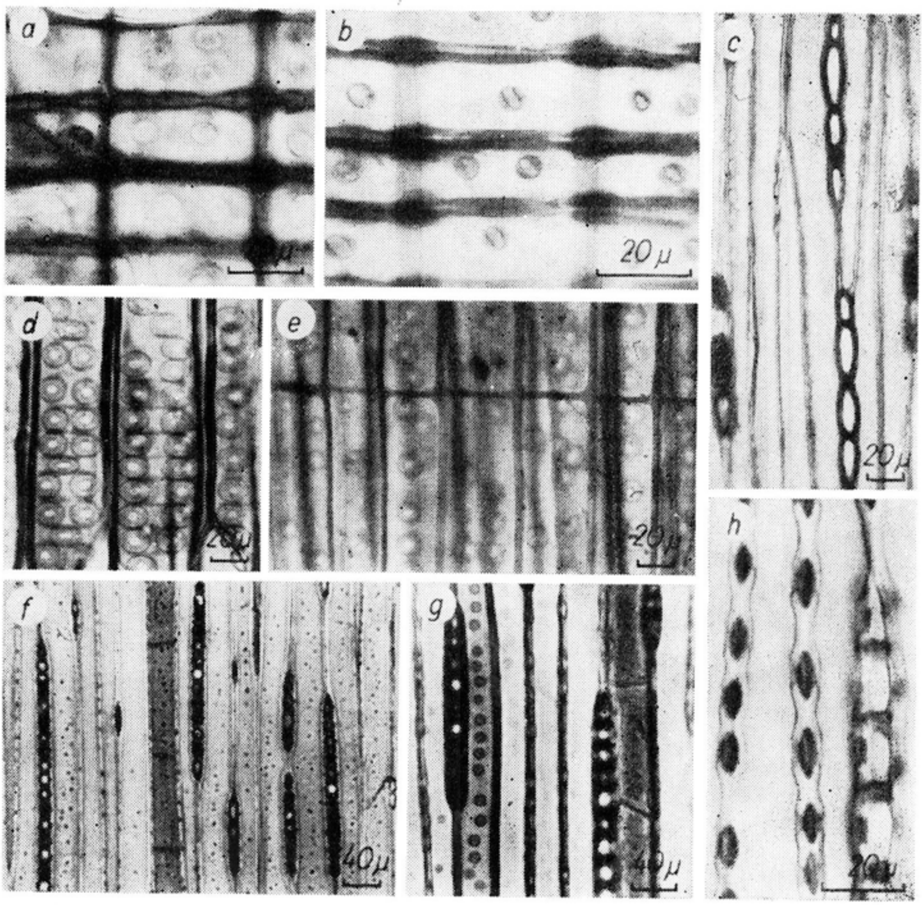

Fig. 2. Wood structure in radial (a,b,d,e) and tangential (c,f,h) sections:

a — cupressoid pits in cross-fields and the primary pit fields on transverse walls of parenchyma cells in a xylem ray

b — taxodioid pits in a cross-field

c — ray cells of various sizes in the first growth ring at 2m from the ground level

d — bi- and uniseriate bordered pits with crassulae in early wood

e — trabeculae passing through a row of neighbouring tracheids

f — ray cells of various sizes, tracheids with bordered pits in the tangential walls and columns of xylem parenchyma cells in the late wood of 5th growth ring at 4m from the ground

g — as in f but in early wood; there are no crassulae between the bordered pits on tangential walls

h — bordered pits in radial tracheid walls in the 2nd growth ring at 4m from the ground; tori are visible.

tangential walls. The torus is distinct (Fig. 2 h). On the radial walls one can observe crassulae between the primary pit-fields (Fig. 2 d), which are not visible on the tangential walls (Fig. 2 f,g). A large number of pits can be found on the tangential walls of the tracheids in the late wood. The pits are arranged singly or in pairs (Fig. 2 d). In the wood of *Metasequoia* trabeculae occur frequently (Fig. 2 e).

The xylem rays are uniseriate (Fig. 2 f,g) though some of them have two rows of cells along some parts of the ray. Traumatic rays on the other hand are multiseriate (Fig. 1 f). These form as a result of aberrations in the cambium. The rays are homogenous as a rule, and there are no tracheids in them. The edge cells of the rays are sometimes similar in shape to tracheids but they do not have the characteristic feature of tracheids, namely the bordered pits.

On the transverse and tangential walls of the parenchyma cells tubercles occur (Fig. 2 a). They are local thickenings of the primary cell wall, since there is no typical secondary wall in the wood parenchyma nor in the ray parenchyma of *Metasequoia* (Chavchavadzye 1965). The same seems to be true for other representatives of the *Taxodiaceae* (Bailey and Faull 1934). Thus there are also no typical simple pits, and the constrictions in the wall are the primary pit-fields.

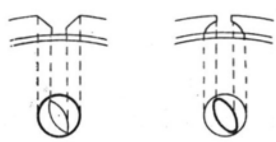

Fig. 3. Drawing of a cupressoid (a) and a toxodioid (b) pit in cross section and in vertical projection.

At the cross section of a tracheid with a ray in the wall of the tracheid there occur bordered pits that have no equivalents in the wall of the ray cell. In one cross-field there may be 1—3 pits. In *Metasequoia* two types of pits can be found, cupressoid, with a lens-like outline of the chamber and a larger, round outline of the opening (Fig. 2 a and 3 a) and taxodioid in which the outline of the opening is elliptical and has a diameter smaller than the diameter of the chamber (Fig. 2 b and 3 b). The cupressoid pits occur primarily in the first growth ring near the pith frequently mixed with the taxodioid pits that are typical for the rest of the stem.

In the studied tree there occur considerable quantities of compression wood. Greatest quantities of it formed in the first year of the life of the tree, and in the other years it formed in the middle of the vegetative period usually occupying the central part of each growth ring.

STUDIES ON THE INTERNAL VARIATION IN WOOD CHARACTERS

The width of an annual ring at one level in the tree increases to a certain age and then declines (Fig. 4). An annual ring formed in one and the same year is wider at base of the tree than in the upper parts. The arrangement of lines in Fig. 4 suggests that there is a general tendency for a decline of the growth ring width that would have continued had the tree remained alive. This was the result of the tree growing suppressed in a dense group. This was the reason why the tree was cut.

The percentage of late wood besides being occasionally very high near the pith (if section went through the apical portion of the annual increment) and near the root collar (due to presence of reaction wood) was very low and generally not subject to ontogenic changes (Fig. 5).

Transverse dimensions of a tracheid, that is their radial and tangential diameters and their cross-sectional area increase with tree age (Fig. 6—11). In the part of the tree near the pith these changes are very rapid and further away they are slower. It can be well seen however that generally the diameter of a tracheid in the 15th year has not attained its maximal value yet except the radial diameter of late wood where maximal values seem to have been reached (Fig. 9). In one and the same vegetative season the diameters of the tracheids at the top and bottom of the tree were smaller than at middle heights.

The average length of a tracheid grows with tree age (Fig. 12—14). Initially the increase in tracheid length is considerable, later however it declines, but as can be seen from the arrangement of curves in Fig. 13—14 the increase does not terminate even in the 15th year of the life of the tree. In early wood it appears that maximal values are almost attained (Fig. 12). In one and the same year at the base of the tree and at the top shorter tracheids develop than at the central part of the stem.

In one growth ring the lowest mean tracheid length is to be found in the early wood, particularly in the upper part of the stem (Fig. 16 and 17). On the other hand there are no major differences between the layer from the central part of the growth ring and the late wood in the given growth ring (Fig. 16). Analysing the change in this character in one growth ring divided into 33 layers (Fig. 17) it can be seen that towards the very end of the season the average length of the tracheid falls to a value that is typical for the cells in the layer of early wood in the next adjacent growth ring.

Diameter of a bordered pit in the earliest wood increases at one level in the tree from the pith towards the outside (Fig. 15). This increment is rapid in the first years, then ceases off but as can be seen from Fig. 15 it does not terminate in the 15th year. In one and the

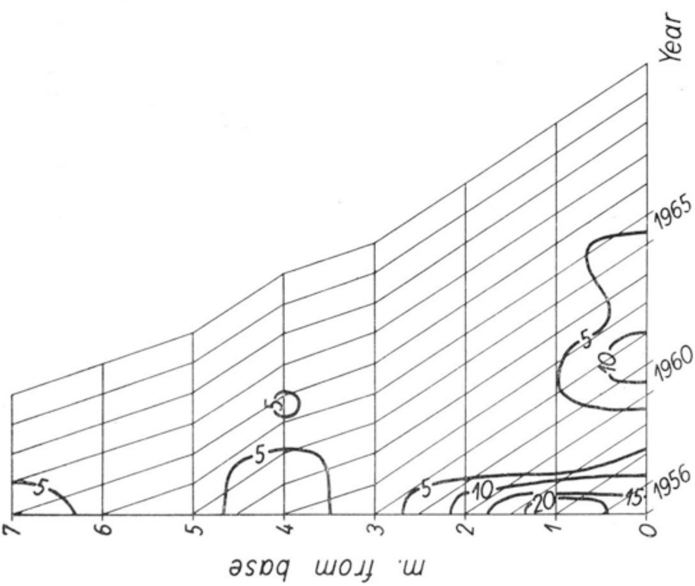

Fig. 5. Variation of late wood percentage within the tree, presented in the form of contour lines (isolines) drawn against a schematic outline of a radial section of the whole stem.

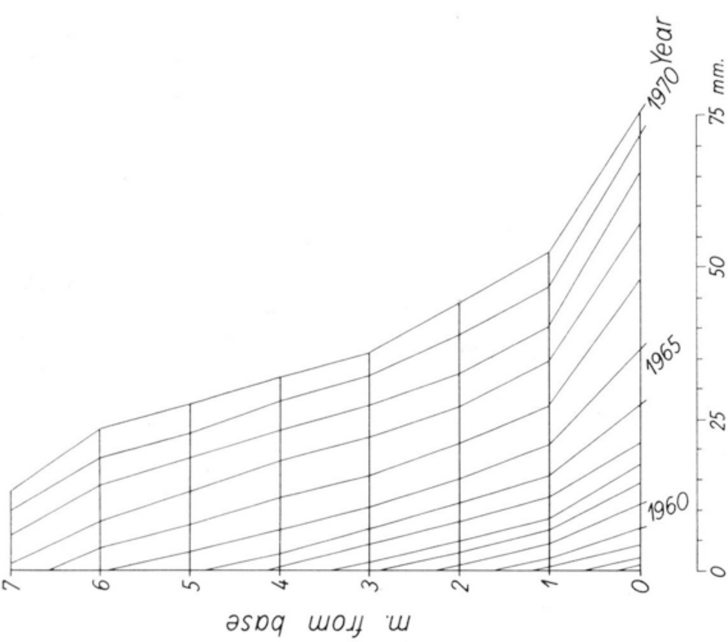

Fig. 4. Variation of growth increment in mm within the stem.

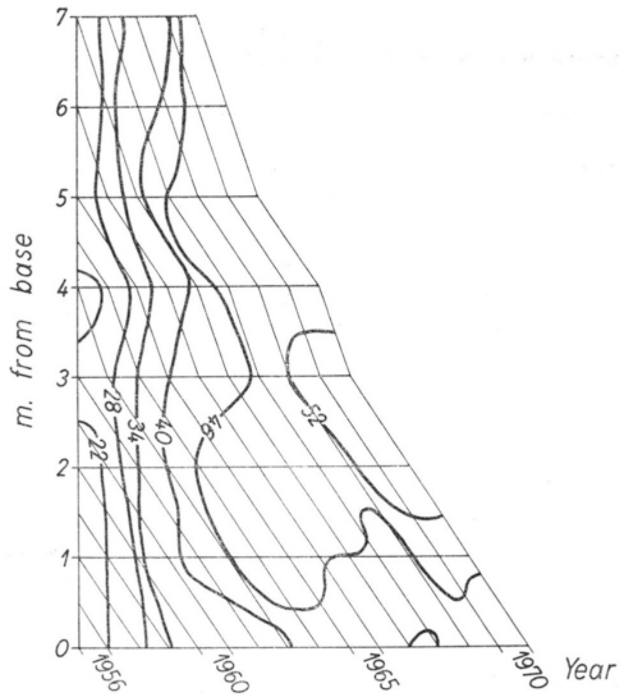

Fig. 6. Variation of the average radial diameter in microns of an early wood tracheid. Explanation as in fig. 5.

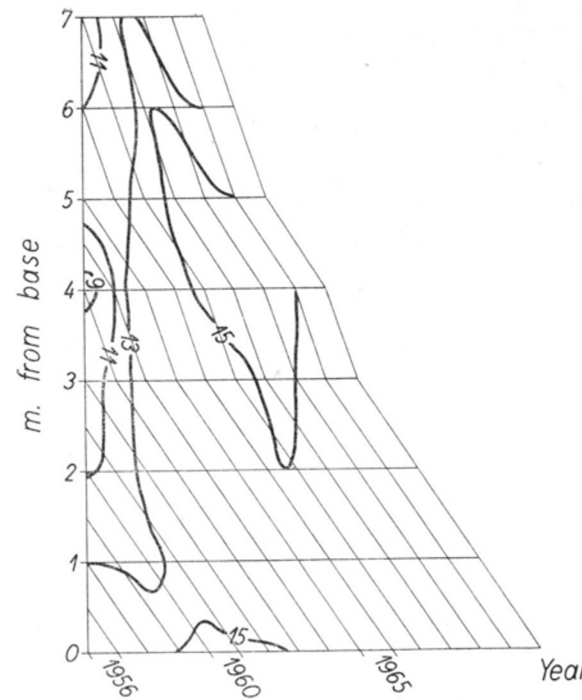

Fig. 7. Same as in fig. 6 but in late wood.

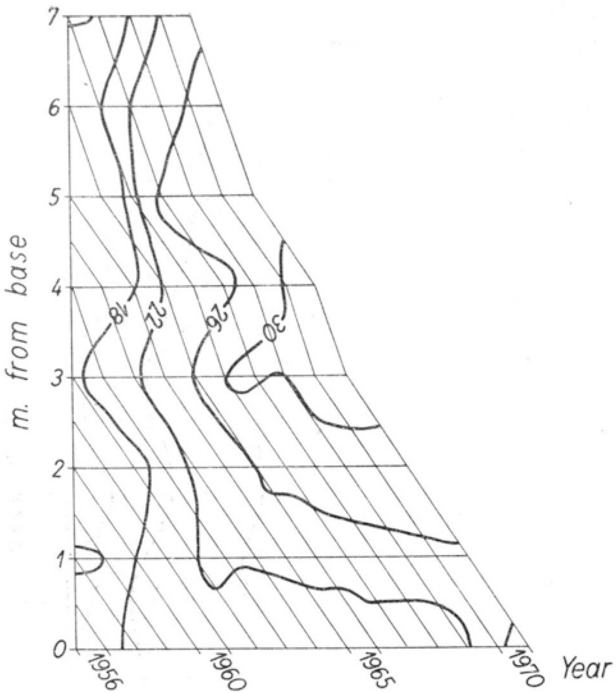

Fig. 8. Variation of the average tangential diameter in microns of an early wood tracheid. Explanation as in fig. 5.

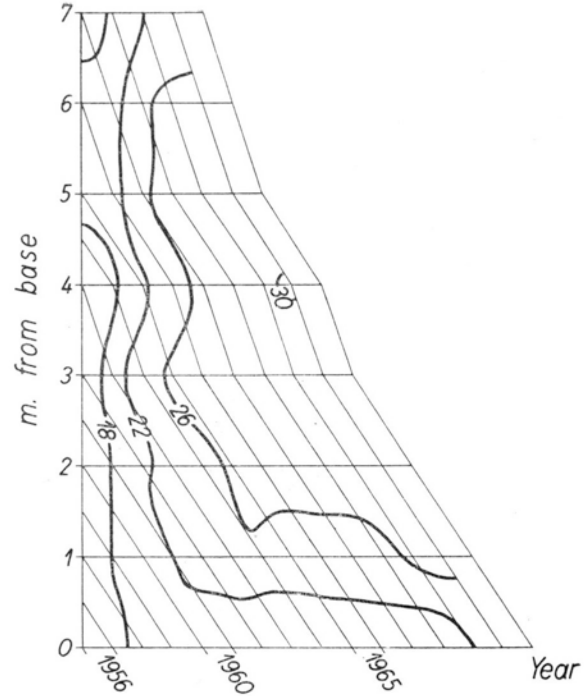

Fig. 9. Same as in fig. 8 but in late wood.

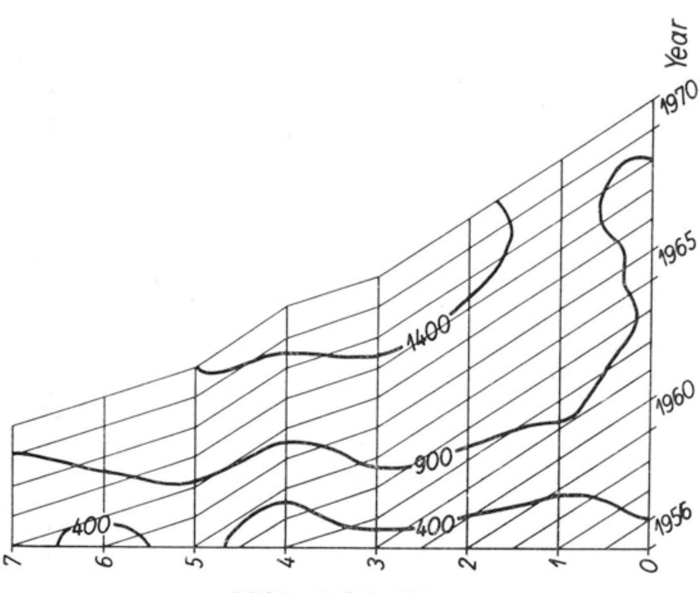

Fig. 10. Variation of the average cross-sectional area of an early wood tracheid in microns. Explanation as in fig. 5.

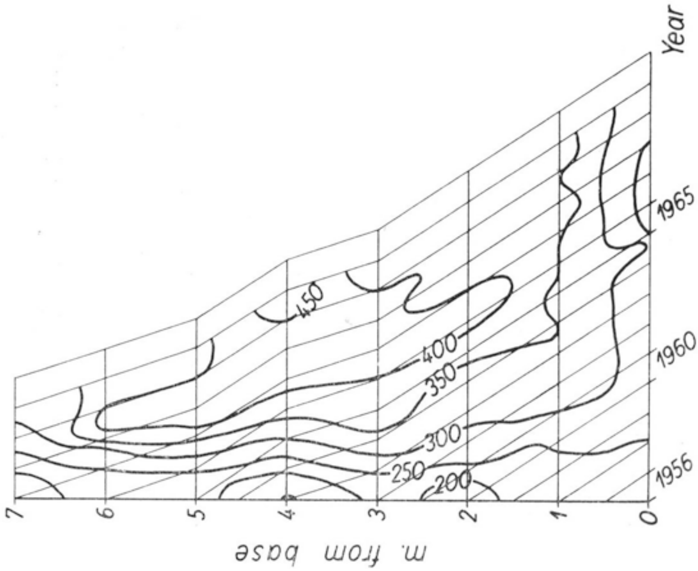

Fig. 11. Same as in fig. 10 but in late wood.

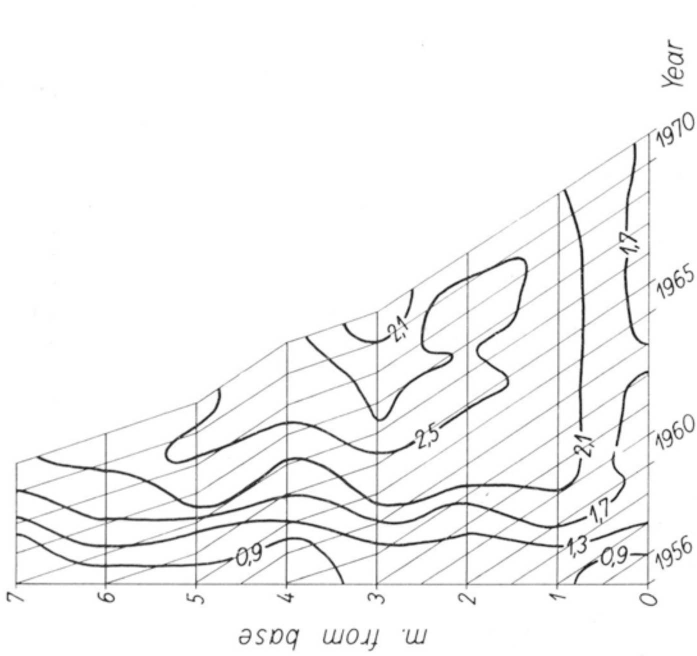

Fig. 12. Variation of the average tracheid length in microns in an early wood. Explanation as in fig. 5.

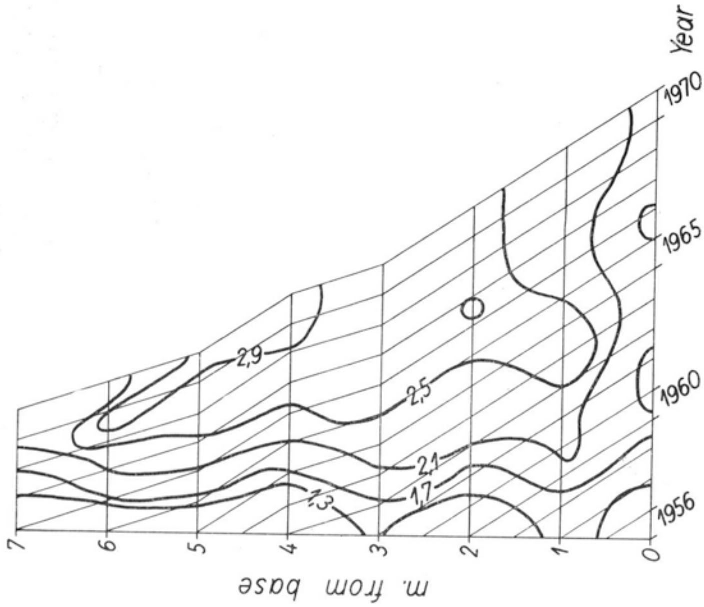

Fig. 13. Same as in fig. 12 but from the central part of the growth ring.

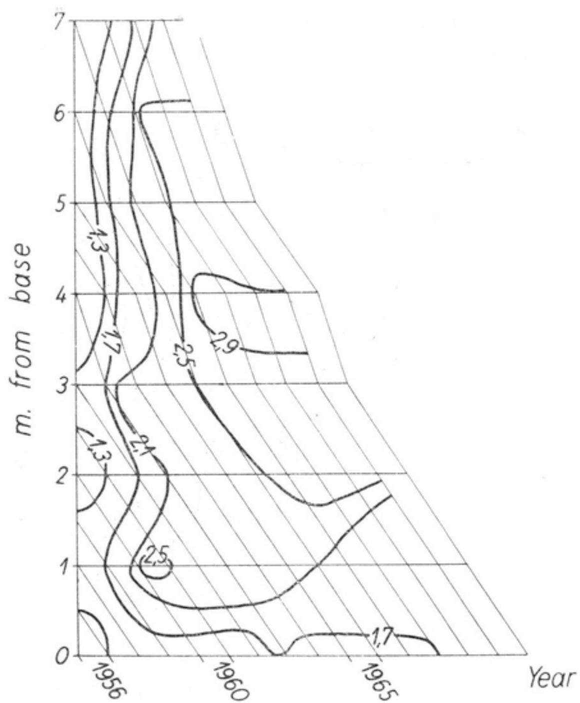

Fig. 14. Same as in fig. 12 but in late wood.

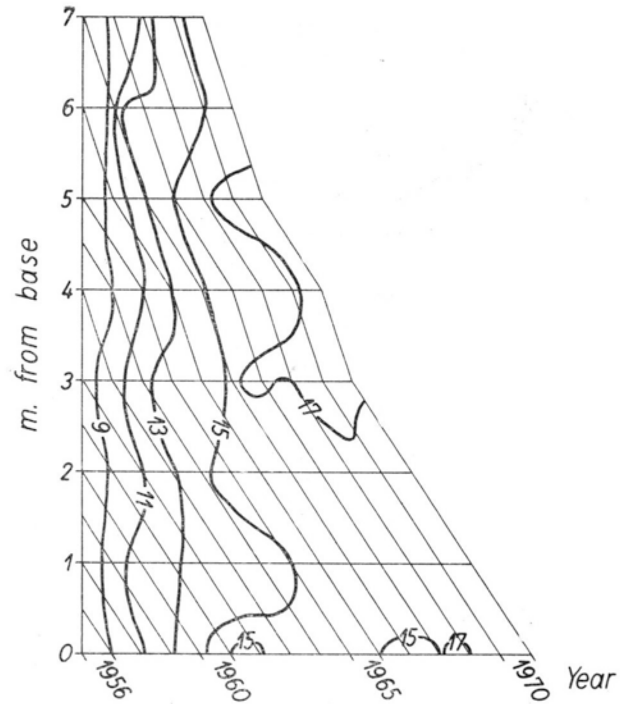

Fig. 15. Variation of the average diameter of a bordered pit in microns in an early wood tracheid. Explanation as in fig. 5.

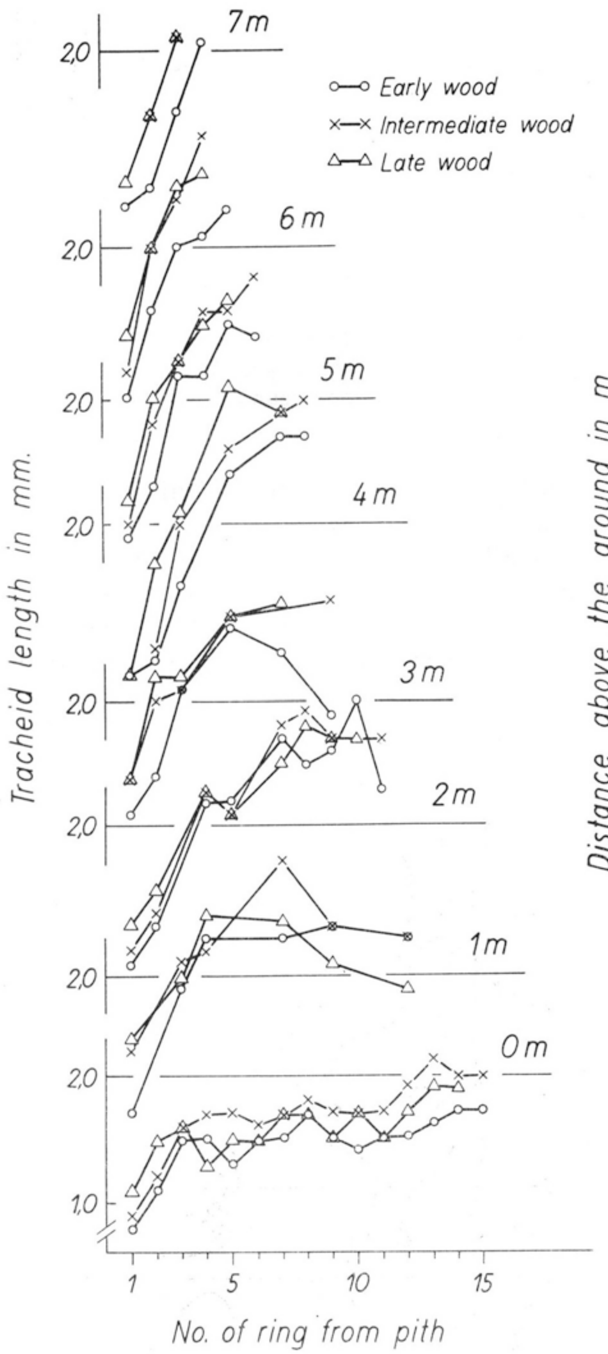

Fig. 16. Comparison of the average tracheid length in three layers of one growth ring at various levels in the stem.

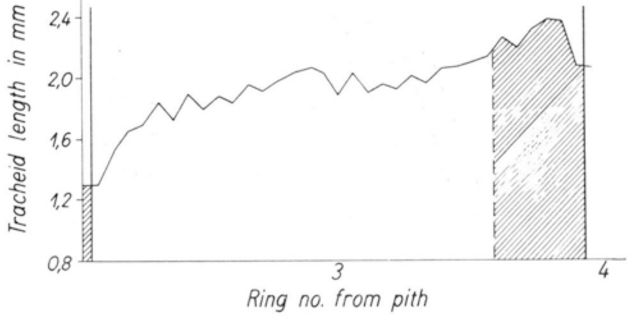

Fig. 17. Comparison of the average tracheid length in 33 layers of xylem in the 3rd growth ring and in two layers of the adjacent 2nd and 4th ring at 7m from the ground.

same year the largest pits form in the central part of the stem and the smallest at the base and near the top.

Xylem rays usually consist of 5—11 cells. Also 1 and 2 celled rays can be found in *Metasequoia*, and the largest ray found consisted of 34 cells. In spite of the great variability of this character even in a small sample it can be seen that the direction of change of this character is

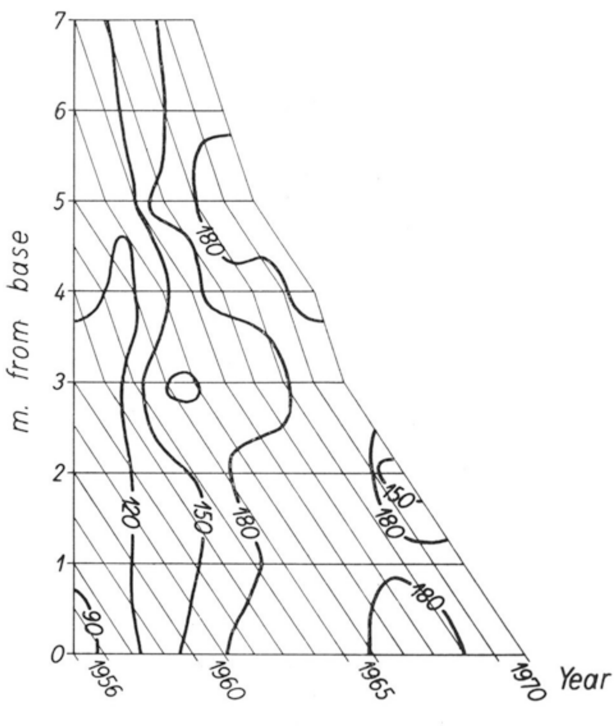

Fig. 18. Variation of the average ray height in microns. Explanation as in fig. 5.

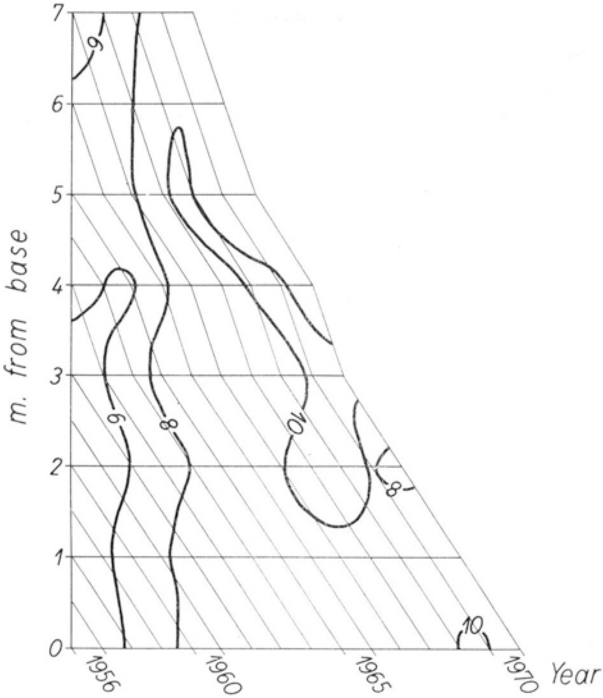

Fig. 19. Variation of the average numbers of cells in one xylem ray. Explanation as in fig. 5.

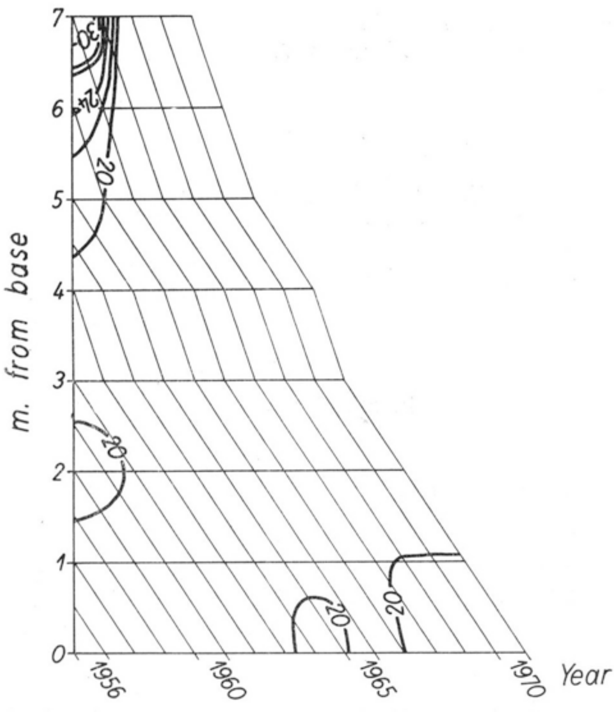

Fig. 20. Variation of the average height of a ray cell in one xylem ray. Explanation as in fig. 5.

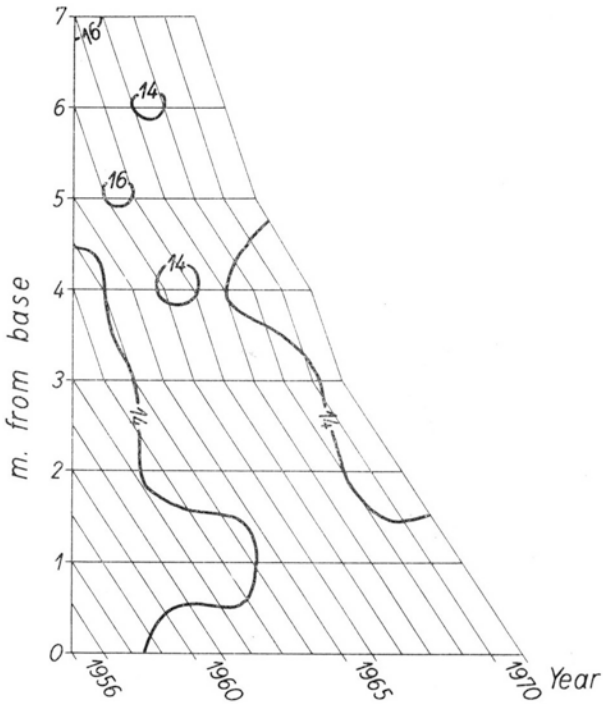

Fig. 21. Variation of the average width of a ray cell in microns. Explanation as in fig. 5.

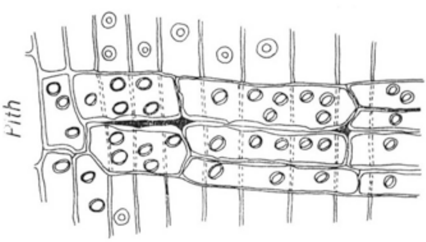

Fig. 22. A fragment of a xylem ray in the first annual ring at 4m from the ground in radial section.

very definite (Fig. 18 and 19). The tallest rays occur in the central part of the stem while the shortest in the part of wood near the pith. One can expect that after the 15th year of life an increase in the average number of cells per ray is unlikely.

Diameters of the individual ray cells are more or less the same throughout the whole stem (Fig. 20 and 21). Generally the dimensions of cells in a multicelled ray are also even. Near the pith there are some differences. Besides small cells there are some in the same ray which are several times larger (Fig. 2 c). Such great variability is associated with the method in which the number of tiers of cells in a xylem ray increases. In the region of wood near pith this takes place by means of transverse divisions of ray cell initials (Fig. 22). In the region distant from the pith the phenomenon of transverse splitting of rays occurs very rarely.

DISCUSSION

The anatomical characters in the studied stem of *Metasequoia* are juvenile in nature. Annual rings are very wide (up to 10 mm and at the base of the stem they are even wider), consisting primarily of thin-walled tracheids of the early wood, with numerous parenchyma cells scattered evenly throughout the whole ring. The greatest amounts of parenchyma are to be found in the first and second growth ring, while in the later ones their number declines. A boundary between the early and late wood in the same ring is not clearcut. The traumatic resin ducts mentioned by Liang (after Zalewska 1952) and the resin pockets described by Greguss (1955) have not been encountered.

The values for several characters change in the stem very rapidly, however most of them have not attained a maximum by the 15th year. As a rule the values obtained for the studied stem were lower than those reported by other authors for wood samples from older stems (Yu 1948; Li 1948; Zalewska 1952; Greguss 1955). The radial diameter of a tracheid has rarely exceeded in the studied stem a value of 50 microns (Fig. 8 and 9). This was the value reported by Yu (1948) in a part of the wood close to the pith, and in the outer parts of the wood the tracheids had much larger diameters, reaching even 75 microns (the average was 55 microns). Zalewska (1952) has found in an old stem tracheids that have a diameter reaching 100 microns.

The average tracheid length in the studied stem was 1.5 to 3.0 mm (Fig. 12—14). In the first few years of life a very rapid increase in the tracheid length was observed. During the first 10 years it was about 100%. The increase does not terminate by the 15th year. Brazier (1963) has observed in a 38 years old specimen a fourfold increase in the tracheid length.

Diameter of a bordered pit in an early wood tracheid of the studied stem was on the average 15.5 microns (Fig. 15). In mature wood Zalewska (1953) and Greguss (1955) have found higher values (16—22 microns).

The xylem rays consisted on the average of 5—11 cells (Fig. 19) and during the 15 years of the life of the tree they have attained the same height as was reported for old stems by other authors (Zalewska 1952; Yu 1948; Greguss 1955).

The height of one ray cell in the studied stem was 18—21 microns (Fig. 20), the same as in older stems (16—22 microns according to Zalewska 1952 and 20—22 microns according to Greguss 1955). This character is correlated with the height of the whole ray. The correlation coefficient $r = -0.33$. The taller the ray the smaller are the cells constituting it.

In the part of the stem close to the pith large variation in the size of individual cells in one ray was observed. A similar variability has been also noted in other representatives of the class *Coniferae* (*Larix polonica* — Hejnowicz 1964, *Picea abies* — Hejnowicz 1969 and *Pseudotsuga menziesii* — Hejnowicz 1971). This variability has been caused by the characteristic for this part of the stem mode of division in the ray initials — depending on the transverse splitting of cells as a result of which the number of tiers of cells in a ray increases.

The majority of the anatomical characters of wood have not attained constant values by the 15th year. This concerns primarily the dimensions of the tracheids (Figs 6, 7, 8, 10, 11, 13, 14), except perhaps the radial diameter in late wood and length in early wood, and also the diameter of the bordered pits in an early wood tracheid (Fig. 15). The same nature of variation is shown by these characters in the stems of other coniferous species studied by me (*Larix polonica, Picea abies, Pseudotsuga menziesii*). The dimensions of rays in all these species including *Metasequoia* reach constant values by the 15th year (Fig. 18 and 19) while the dimensions of individual cells in a ray (Figs 20—21) and the percentage of late wood (Fig. 5) stabilize even earlier, during the first or second year.

At about 4 meters from the ground in the studied stem a depression was observed in the values for all the studied characters with a directional change of the average dimensions (Figs 6—15 and 18—19). At this level in the tree there devoloped a greater agglomeration of lateral branches possibly associated with an inhibition of shoot growth when the tree was 4 or 5 meters tall.

CONCLUSIONS

A 15 year old stem of *Metasequoia glyptostroboides* from the collection in Kórnik Arboretum has been subjected to an anatomical investigation. On the basis of information from over 70 wood samples from various growth rings and from 8 different levels above the ground the structure of the wood in the stem was described and the nature of ontogenic changes in several characters was determined. When discussing the direction of changes of individual characters use was made of the contour method adopted from cartography. It permitted a visual presentation of results, facilitated their interpretation and helped in predicting the further course of these changes in future years had not the stem been felled.

On the basis of the microscopic structure of the wood it has to be considered as juvenile. It is characterized by wide growth rings, a small percentage of late wood, an indistinct transition from early to late wood within the same growth ring and an abundant xylem parenchyma scattered evenly throughout the whole wood.

Metasequoia lacks resin ducts, however resin containing cells are common. The xylem rays are homogenous and usually uniseriate. Only traumatic xylem rays consist of more rows of cells. It is a characteristic feature of the ray cells that they do not have a secondary cell wall and typical simple pits. Apparent simple pits occur here. These are primary pit-fields in the irregularily thickened primary wall.

Three groups of characters were recognized on the basis of the nature and direction of ontogenic changes within the stem. The first group consists of characters that change regularily within the stem. Their average values grow from the pith towards the outside, and from the base of the stem to a certain height and then start declining. These characters have not attained maximal values by the 15th year. In this group the dimensions of the tracheids and the diameter of bordered pits belong.

The second group consists of characters the maximal values of which appear to have been attained by the 15th year. In this group belong such characters as width of the annual ring, and the height on the xylem rays.

In the third group are included the characters that have reached almost constant values already in first or second growth ring near the pith. This group includes the vertical and tangential dimensions of ray cells and the late wood percentage.

Acknowledgements

The author wish to express her thanks to Professor Henryk Teleżyński for his critical review of the paper, and Dr. Maciej Giertych for his help in finding a graphical method for the presentation of results.

REFERENCES

Bailey I. W., Faull A. F. 1934. The cambium and its derivative tissues, IX. Structural variability in the redwood, *Sequoia sempervirens*, and its significance in the identification of fossil woods. Journ. Arnold Arb. 15: 233—54.

Brazier J. D. 1963. The timber of young plantation grown *Metasequoia*. Quarterly Journal of Forestry 57 (2): 151—3.

Chavchavadzye Ye. S. 1965. Morfologiya gorizontal'nykh i tangental'nykh styenok klyetok syerdtsevinnykh luchei khvoinykh. Nomenklatura i klassifikatsiya. Bot. Zhurn. 50(4): 558—63.

Greguss P. 1955. Xylotomische Bestimmung der heute lebenden Gymnospermen, Budapest.

Hejnowicz A. 1964. Badania anatomiczne drewna modrzewia polskiego (*Larix polonica* Racib.), Arboretum Kórnickie 9: 97—174.

Hejnowicz A. 1969. Badania nad zmiennością cech anatomicznych drewna *Picea abies* (L.) Karst., Arboretum Kórnickie 14: 89—132.

Hejnowicz A. 1971. Anatomical studies on the wood of *Pseudotsuga menziesii* (Mirb.) Franco. Arboretum Kórnickie 16: 169—97.

Hida M. 1953. The affinity of *Metasequoia* to other conifers as shown by the form of the tracheid. Bot. Mag. Tokyo 66: 239—44.

Hida M. 1962. The systematic position of *Metasequoia*. Bot. Mag. Tokyo 75: 316—23.

Jaroslavtsyev G. D., Vishnyakova T. N. 1965. Dryevyesina metasyekvoi, Bull. Glav. Bot. Sada 59: 97—9.

Li J. Y. 1948. Anatomical study of the wood of "Shuisha" (*Metasequoia glyptostroboides* Hu et Cheng). Tropical Woods 94: 28—9.

Zalewska Z. 1952. Budowa anatomiczna drewna *Metasequoia glyptostroboides* Hu et Cheng. Rocznik Sekcji Dendr. PTB 8: 99—112.

Yu C. H. 1948. The wood structure of *Metasequoia disticha*. Bot. Bull. Acad. Sinica 2 (4): 227—30.

Author's address:
Dr. A. Hejnowicz
Institute of Dendrology and Kórnik Arboretum
Polish Academy of Sciences
63-120 Kórnik near Poznań
Poland

Badania anatomiczne nad rozwojem drewna Metasequoia glyptostroboides Hu et Cheng

Streszczenie

Przedmiotem badań był 15-letni pień pochodzący z sadzonek kolekcji Arboretum Kórnickiego uzyskanych z siewki wyhodowanej w Arboretum. W oparciu o dane sponad 70 próbek drewna odpowiadających różnym słojom rocznym lub poszczególnym warstwom jednego słoja na 8 poziomach pnia, została opisana budowa drewna i został ustalony charakter zmiany kilkunastu jego cech w obrębie jednego pnia. Przy omawianiu kierunku zmiany poszczególnych cech została wykorzystana adaptowana z kartografii metoda izolinii. Umożliwiła ona dokładną interpretację uzyskanych wyników i pozwoliła na przewidywanie, jak analizowane cechy zmieniałyby się w następnych latach życia zbadanego drzewa.

Pod względem struktury mikroskopowej drewno zbadanego pnia należy zaliczyć do typu młodocianego. Charakteryzuje się ono szerokimi słojami rocznymi, niewielkim procentem drewna późnego, słabo zaznaczoną granicą pomiędzy drewnem wczesnym i późnym w tym samym słoju i obfitym miękiszem drzewnym rozproszonym równomiernie po całym drewnie.

U *Metasequoia* brak jest przewodów żywicznych. Powszechne są natomiast komórki żywiczne. Promienie drzewne są homogeniczne i przeważnie jednorzędowe. Zdarzają się odcinki dwurzędowe w promieniu jednorzędowym, ale z większej liczby rzędów składają się tylko traumatyczne promienie drzewne. Cechą charakterystyczną komórek promieni jest brak wtórnej ściany komórkowej i typowych

jamek prostych. Ściana pierwotna jest nierównomiernie zgrubiała (gruzełkowata), a występujące w niej przewężenia są pierwotnymi polami jamkowymi.

Wyróżnione zostały trzy grupy cech. Za podstawę podziału przyjęto charakter i kierunek zmiany danej cechy w pniu. Pierwsza grupa obejmuje cechy zmieniające się w pniu bardzo regularnie. Ich przeciętne wartości rosną od rdzenia na zewnątrz, od podstawy pnia ku wierzchołkowi do pewnej wysokości, a następnie maleją, a w piętnastym roku życia drzewa nie uzyskują wartości ostatecznych. Do tej grupy cech należą wszystkie trzy wymiary cewki i średnica jamki lejkowatej w cewce drewna wczesnego.

Druga grupa cech obejmuje te z nich, których wielkości ostateczne albo zostały osiągnięte już w piętnastym roku życia drzewa, albo ustaliłyby się w ciągu kilku następnych lat jego życia. Cechy zaliczone do tej grupy to szerokość słoja rocznego, oraz wysokość promienia drzewnego i liczba wchodzących w jego skład komórek.

Do trzeciej grupy zaliczono cechy osiągające stałe wartości już w pierwszym lub drugim przyrdzeniowym słoju rocznym. Ta grupa jest najmniej liczna i obejmuje oba styczne wymiary jednej komórki w promieniu drzewnym i procent drewna późnego w słoju rocznym.