RELATION BETWEEN WOOD STRUCTURE AND PENETRATION

THESIS FOR DEGREE OF M. S.

PAUL CLIFFORD KITCHIN

1917

THESIS

Wood.

Botany

THE RELATION BETWEEN THE STRUCTURES OF SOME CONIFEROUS WOODS AND THEIR PENETRATION BY PRESERVATIVES.

Thesis for the Degree of Master of Science.

Paul Clifford Kitchin

1917.

THESIS

THE RELATION BETWEEN THE STRUCTURES OF SOME CONIFEROUS WOODS AND THEIR PENETRATION BY PRESERVATIVES.

The incentive for the work which I have attempted on the relation, if there be any, between the microscopic structures of some of the soft woods and the degree to which they are penetrated by creosote oil, was furnished by one of the conclusions reached by Teesdale (1) in his work on that subject. The conclusion was as follows;

"The results obtained with a given species of wood cannot always be applied to another species, however similar in structure the two may be. This fact is strikingly evident in the treatment of heartwood larch" (Larix occidentalis)"and tamarack"(L. laricina). Teesdale treated three pieces of each species under identical conditions and reported the results as follows;

L. occidentalis.	Average longitudinal penetration	3.17 ins.
	Average radial penetration	0.09 ins.
L. laricina.	Average longitudinal penetration	0.84 ins.
	Average radial penetration	0.04 ins.

Penhallow (2) describes these two species as follows;

Larix occidentalis Nutt.

"TRANSVERSE. Growth rings usually broad, the dense and prominent summer wood about one half the spring wood, from which the transition is abrupt. Tracheids of the summer wood large, squarish, in regular rows. Tracheids of the spring wood very large and thin walled, squarish hexagonal, in very regular rows, rather uniform. Medullary rays prominent, rather resinous and broad, one cell wide, distant 2-6 rows of tracheids. Resin passages few, large, without thyloses, the epithelium narrow, rather thin walled, the nutritive layer thick walled and resinous. Resin cells widely scattered on the outer surface of the summer wood, but readily recognized by their abundant resinous contents.

RADIAL. Rays conspicuously resinous thruout; the tracheids narrow and marginal, rarely interspersed. Ray cells chiefly straight thruout and equal to 3-9 spring tracheids; the upper and lower walls chiefly thick and unequal, sparingly pitted thruout, more strongly so in the summer wood; the terminal walls coarsely pitted thruout; the lateral walls with elliptical and distinctly bordered pits, with a narrow, chiefly oblong or lenticular orifice, numerous, at first 6-8 per tracheid, soon greatly reduced in size, and in the summer wood abruptly 1 per tracheid. Bordered pits conspicuously in 1-2 rows, more rarely in one row only, elliptical, the orifice very large. Pits on the tangential walls of the summer wood rather numerous but small and often obscure. Resin cells about 12.5 microns wide and 60 -150 microns long.

TANGENTIAL. Rays rather numerous, low to very high. Fusiform rays with a large resin canal without thyloses, the epithelium cells thick walled. Ordinary rays often very high, chiefly very uniform, and not contracted at the position of the rarely interspersed tracheids; the parenchyma cells rather unequal, sometimes in pairs, oval or oblong, somewhat variable.

Larix americana Michx. (*L. laricina* (Duroi) Koch).

TRANSVERSE. Growth rings rather broad and uniform, sometimes double. Summer wood rather dense, about one fourth to one half the spring wood, from which the transition is either gradual or abrupt; the tracheids small, conspicuously unequal, and not in very regular rows, distinctly rounded. Spring tracheids large, hexagonal, radially elongated, thin. Medullary rays prominent, broad, one cell wide, distant 2-8, rarely more, tracheids. Resinous passages large, equal to 2-3 tracheids, devoid of thyloses, the epithelium cells flat, rather thin walled, the nutritive parenchyma scanty, thick walled; not very numerous, chiefly in the summer wood. Resin cells few, widely scattered on the outer face of the summer wood, non resinous, distinguished by (1) their thin outer walls and advanced position, and (2) by the sieve plate structure of the terminal walls.

RADIAL. Rays somewhat resinous thruout; the tracheids prominent, numerous and marginal. Parenchyma cells straight or barely contracted in the summer wood; the upper and loser walls thick, unequal, and usually sparingly pitted; the terminal walls coarsely pitted thruout; the lateral walls with distinctly bordered pits, the narrow orifice chiefly oblong, 2-6 per tracheid, becoming distinctly smaller tward the summer wood, where they are abruptly reduced to 2 and finally 1 per tracheid. Bordered pits in 1 or 2 rows, large, elliptical, becoming smaller and round tward the summer wood. Pits often showing an equatorial band. Pits on the tangential walls of the summer wood numerous, small, approximate, on the outermost tracheids only. The outer summer tracheids often show a marked tendency tward the formation of spirals. Resin cells 15 microns wide, about 125 microns long.

TANGENTIAL. Rays numerous, medium to high, sparingly resinous. The fusiform rays with a broad central tract and a large resin canal without thyloses. The ordinary rays rather broad, sometimes 2 seriate in part; the resin cells thick walled, chiefly rather equal, uniform, oblong, more rarely oval. Rays somewhat contracted at the position of the narrow and interspersed tracheids."

A careful comparison of the foregoing descriptions shows that in the transverse sections the tracheids of the summer wood are larger in Larix occidentalis than they are in Larix laricina. It has been found to be a fact in wood preservation that the dense summer wood of some species, notably of the hard pines, is much more easily penetrated and absorbes more creosote than does the more open spring wood. The presumed cause for this difference is the presence of resin passages in the summer wood, however given resin passages in the summer wood of both L. laricina and L. occidentalis, the larger tracheids in the latter may be a contributing factor in it's easier penetration.

The radial and tangential sections, according to the descriptions, show no appreciable differences, at least no differences which would be active in assisting or retarding the penetration of preservatives.

As the wood of conifers is made up almost wholly of tracheids, some of these at least , are analagous to the tracheary system of the Angiospermous woods. The question of the penetration of preservatives into wood resolves itself into two problems; first, the structure of the conducting system of the wood, and second, the penetrability of the cell walls. Both Bailey (3) and Teesdale (4) have shown that the passage of creosote oil thru the cell wall is practically negligible. Therefore there remains to be made a detailed study of the individual tracheids of L. laricina and L. occidentalis with reference to their role as conducting structures. This, then, is the point from which the problem has been attackt, and though I consider it by no means solved, as that would take much more time than was available, the results give an indication as to what the structural differences may be which cause this seeming paradox in penetration.

The Method of Investigation.

Typical specimens of Larix laricina and L. occidentalis were secured thru the kindness of Mr. H.D. Tiemann of the Forest Products Laboratory at Madison, Wisconsin. That of L. laricina was a piece from the collection of "Commercial Woods of the United States" prepared by the Forest Service, while that of the L. occidentalis came from the collection at the Laboratory at Madison. Small pieces of each wood, about the thickness of a toothpick and 3/4" to 1" long were split from the specimens and macerated by Schultze's method*. However instead of using all nitric acid as Schultze did, I used about 1/4 water, applying more heat and lengthening the time of maceration, thus being able to control the process to a greater extent than with strong acid. After maceration the tracheids were boiled in water for a short time to expell the acid and air. The macerated material was then placed in a vial and used as needed. Small amounts of the wood from the vial were carefully separated into individual cells with two needles and using a dissecting lens. Only one tracheid was mounted on the slide at a time and was placed in just enough water to hold the cover glass down. The water gradually evaporated and it was found that the parts of the individual pits were easiest to see at the time when the water was leaving them.

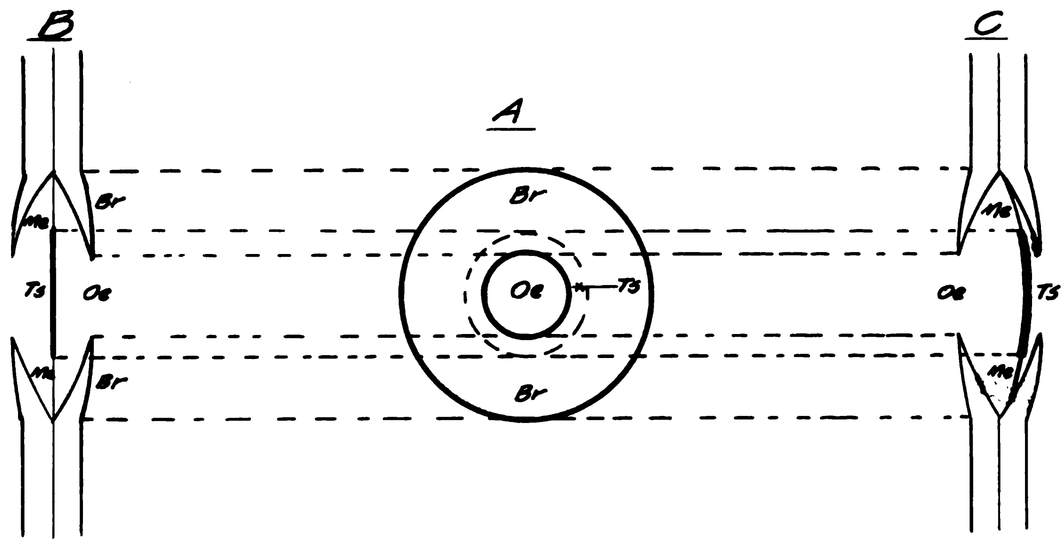
All measurements of tracheid lengths were made in spaces of the ocular micrometer using the 16 mm. objective. Such a space on the microscope employed was equal to 0.00845 millimeters. The remaining measurements were all made in spaces of the ocular micrometer using the 4 mm. objective. Such a space on the microscope used was equivalent to 0.00191 mm. At the conclusion of each set of measurements the average was secured and translated into terms of millimeters. From these measure-

*Chamberlain, C.J. Methods in Plant Histology, P. 109.

ments there were calculated the following;

(1) The penetrable bordered pit area.

According to Bailey (3) the bordered pits are the means of passage for liquids going from one tracheid to another. Not all of the bordered pit, however, is available for this purpose. The accompanying diagram shows the various parts of the bordered pit both entire and in section.



A, surface view of bordered pit. B and C, sectional views of boredred pits. Br, embossed or bordered area of secondary wall. Oe, pit or orifice (mouth) in the secondary wall. Me, membrane. Ts, thickened area of membrane, or torus. (After Bailey).

According to Bailey(3) the only part of the bordered pit structure which functions in the transmission of preservatives is the pit membrane, less the torus, which is located in the center of the same. After wood is seasoned, this membrane, from the torus to the edge, is composed of a number of radiating ribbons so shrunken that there is actual space between them. This area of radiating ribbons is what I have designated as "the penetrable bordered pit area".

In order to compare the the penetrable bordered pit area of one wood with that of another it is not enough to determine the penetrable bordered pit area of an average tracheid of each. To make this comparison the length of an average tracheid, in millimeters, was divided into the average number of bordered pits per tracheid and the penetrable bordered pit area of an average pit was then multiplied by the quotient obtained. The result was "the penetrable bordered pit area per millimeter of tracheid length". This was then directly comparable to the same length of tracheid in any other species.

(2) The simple pit area.

Here the average area of a simple pit was determined, and then multiplied by the average number of simple pits in a tracheid. Then, by the same method as described for the penetrable bordered pit area, "the simple pit area per millimeter of tracheid length" was ascertained.

The preliminary tables of measurements on Larix laricina and L. occidentalis are as follows; (See next page).

TABLE I.

Larix laricina(heartwood) Forest Service spécimen.

	1	2	3	4	5	6	7	8	9	10	av.	mm.
Length	500	390	500	455	510	590	440	485	440	440	470	8.97150
Diameter	43	32	40	45	35	40	40	40	42	38	40	0.07640
No. bord. pits.	185	188	2;27	195	200	158	216	206	128	166	187	
Pit diam.	12	12	12	12	12	12	12	12	12	12	12	0.02292
Torus diam.	8	8	8	8	8	8	8	8	8	8	8	0.08528
Mouth diam.	4	4	4	4	4	4	4	4	4	4	4	0.00764
No, simple pits.	325	330	269	197	225	281	246	250	283	234	264	
Av. simple pit area.	2	2	2	2	2	2	2	2	2	2	2	0.000007
No. rays crossed.	8	8	8	5	7	10	6	4	7	7	7	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00038 sq. mm.*
Av. area of torus	*0.00019*
Penetrable area of 1 av. pit	*0.00019 sq. mm.*
Av. no. pits per tracheid	*187*
Penetrable area of 1 av. tracheid	*0.03553 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.000007 sq. mm.*
Av. no. pits per tracheid	*264*
Simple pit area per av. tracheid	*0.001848 sq. mm.*

The penetrable bordered pit area per mm. of tracheid is 0.00912 sq.mm
The simple pit area for the same unit is 0.000462 sq. mm.

TABLE II.

Larix occidentalis (heartwood) Forest Service specimen.

	1	2	3	4	5	6	7	8	9	10	av.	mm.
Length	650	510	530	620	510	450	520	620	600	600	561	4.74045
Diameter	35	30	40	40	45	40	45	40	40	40	40	0.07640
No. bord. pits.	215	250	260	283	220	220	250	233	250	300	248	
Pit diam.	13	13	13	13	13	13	13	13	13	13	13	0.02483
Torus diam.	7	7	7	7	7	7	7	7	7	7	7	0.01337
Mouth diam.	5	5	5	5	5	5	5	5	5	5	5	0.00955
No. simple pits.	268	202	306	330	171	149	326	321	546	540	325	
Av. simple pit area.	2	3	3	1	1	2	3	3	1	1	2	0.000007
No. rays crossed.	11	8	10	13	3	6	10	12	12	13	10	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00048 sq. mm.*
Av. area of torus	*0.00014*
Penetrable area of 1 av. pit	*0.00034 sq. mm.*
Av. no. pits per tracheid	*248*
Penetrable area of 1 av. tracheid	*0.08527 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.000007 sq. mm.*
Av. no. pits per tracheid	*325*
Simple pit area per av. tracheid	*0.002371 sq. mm.*

The penetrable bordered pit area per mm. of tracheid length is 0.01804 sq. mm.

The simple pit area for thes same unit is 0.000490 sq. mm.

A comparison of the figures given in Tables I and II shows that the simple pit area is not directly connected with the penetrance figures as given by Teesdale (1). However the penetrable bordered pit areas show enough of a correlation to the figures of Teesdale to warrant a more critical study of a large number of bordered pits in order to further test and verify the results of the preliminary survey. Therefore I abandoned any close study of the simple pit areas and concentrated on measurements of the penetrable areas of bordered pits. The rest of the measurements, on the fresh material, were taken merely to check the first ones and establish their accuracy as far as possible.

Table III shows the measurements of 100 bordered pits, selected from 10 average tracheids, 10 pits per tracheid, of Larix laricina. The averages of each 10 pits are incorporated in Table IV under the headings of Pit diameter; Torus diameter, and Mouth diameter.

Tables V and VI show the corresponding measurements for Larix occidentalis. (See following pages for tables)

TABLE III.

Measurements of 100 bordered pits

of Larix laricina, penetrance specimen from Michigan..

Diameters				Diameters			
Pit	Torus	Mouth	Av. of 10	Pit	Torus	Mouth	Av. of 10.
10.0	6.0	3.0		11.0	7.0	4.5	
11.0	7.0	5.0		11.0	7.0	4.0	
11.0	6.0	4.0		10.5	7.0	4.0	
10.0	6.0	4.0		10.5	7.0	3.5	
10.0	6.0	4.0		10.5	7.0	4.0	
10.0	6.0	4.0		11.0	7.0	4.0	
11.0	6.0	4.0		9.5	6.0	3.0	
1100	6.5	4.0	Pit 10.4	10.0	6.0	3.5	Pit 10.3
10.0	6.0	4.0	Torus 6.2	9.5	6.0	3.0	Torus 6.6
10.5	6.5	4.0	Mouth 4.0	9.0	6.0	3.0	Mouth 3.7
9.0	6.0	4.0		11.0	7.0	4.5	
11.5	6.5	4.5		11.0	7.0	4.0	
11.5	7.0	4.5		10.0	6.5	4.0	
10.0	6.0	4.0		10.0	6.5	4.0	
10.0	5.75	3.0		11.0	7.0	4.5	
10.0	6.25	4.0		11.0	7.0	4.5	
9.75	6.5	4.0		10.5	6.75	3.5	
10.0	5.25	4.0	Pit 10.3	11.0	7.0	4.0	Pit 11.0
10.0	6.75	4.0	Torus 6.4	11.0	7.0	4.0	Torus 6.8
10.5	6.5	4.0	Mouth 4.0	11.0	6.5	4.5	Mouth 4.2
11.0	6.5	3.0		8.5	5.5	3.5	
10.5	6.5	2.75		9.0	6.0	4.0	
1".0	8.5	4.0		9.5	7.0	4.5	
10.5	6.0	2.5		9.0	5.5	3.5	
10.75	6.5	3.5		10.5	6.5	3.5	
11.5	9.0	3.5		10.5	6.5	3.5	
11.0	7.0	4.5		10.5	6.5	4.5	
12.5	7.0	4.5	Pit 11.3	10.0	6.5	4.0	Pit 9.8
12.0	7.5	4.0	Torus 7.2	10.0	6.5	4.0	Torus 6.3
11.0	7.0	3.5	Mouth 3.6	10.0	6.0	3.0	Mouth 3.8
11.0	7.0	4.0		10.5	6.5	4.0	
11.5	7.0	4.5		10.0	6.5	3.5	
10.5	7.0	4.5		10.5	6.5	3.5	
11.0	7.5	4.5		89.5	5.5	3.5	
9.5	6.5	4.0		10.0	6.0	3.0	
10.0	6.0	4.0		9.5	6.0	3.0	
12.5	8.5	5.0		8.0	4.5	2.0	
12.0	8.0	4.0	Pit 11.1	9.5	6.0	3.5	Pit 9.7
11.5	8.0	5.0	Torus 7.3	9.5	6.0	3.5	Torus 6.1
11.0	8.0	4.5	Mouth 4.4	10.0	7.0	3.5	Mouth 3.3
10.5	6.0	4.0		10.5	6.5	4.5	
10.5	6.0	4.0		10.5	6.5	4.5	
11.0	6.0	4.0		11.0	6.75	4.5	
9.0	5.0	2.5		10.0	6.25	4.0	
10.0	6.0	3.0		11.0	6.5	4.5	
10.5	6.0	3.0		10.5	7.0	4.5	
10.0	7.0	3.0		9.0	5.5	3.5	
9.5	6.0	4.0	Pit 10.4	11.0	6.5	4.0	Pit 10.3
11.0	6.0	4.0	Torus 6.1	9.5	6.0	4.5	Torus 6.4
11.5	7.0	3.5	Mouth 3.5	10.0	6.0	4.5	Mouth 4.3

The average of the ten previous averages is as follows;

10.4	6.2	4.0	10.2	6.3	4.0	
11.3	7.2	3.6	11.1	7.3	4.4	
10.4	6.1	3.5	10.3	6.6	3.7	
11.0	6.8	4.2	9.8	6.3	3.8	
9.7	6.1	3.3	10.3	6.4	4.3	Pit 10.5
						Torus 6.5
						Mouth 3.9

The previous measurements are all in units of 0.00191 mm. Translating to millimeters then, the measurements are as follows;

Pit diameter	0.02006 mm.
Torus diameter	0.01242 mm.
Mouth diameter	0.00745 mm.

Using the formula Radius squared x 3.1416 to obtain the area, the results are;

Pit area	0.00032 sq. mm.
Torus area	0.00012 sq. mm.
Mouth area	0.00004 sq. mm.

TABLE IV.

Larix laricina(heartwood) Penetrance specimen.

	1	2	3	4	5	6	7	8	9	10	av.	m.m.
Length	430	570	460	410	545	420	430	400	400	410	448	3.78560
Diameter	43	27	37	39	30	31	40	40	38	35	36	0.06876
No. bord. pits.	196	220	217	189	260	180	193	189	220	225	209	
Pit Diam.	10.4	10.3	11.8	11.1	10.4	10.3	11.0	9.8	9.7	10.3	10.5	0.02006
Torus Diam.	6.2	6.3	7.2	7.3	6.1	6.6	6.8	6.3	6.1	6.4	6.5	0.01242
Mopth Diam.	4.0	4.0	3.6	4.4	3.5	3.7	4.2	3.8	3.3	4.3	3.9	0.00745
No. Simple Pits.	301	427	337	368	352	257	246	317	209	268	308	
Av. Simple Pit Area.	2	3	2	4	3	2	2	2	2	2	2	0.000007
No. rays crossed.	8	8	8	5	7	10	6	4	7	7	7	

The penetrable boraered pit area is;

Average area of one pit	*0.00032 sq. m.m.*
Average area of torus	*0.00012*
Penetrable area of 1 av. pit	*0.00020 sq. mm.*
Av. no. of pits pert tracheid	*209*
Penetrable area og one av. tracheid	*0.04880 sq. mm.*

The simple pit area is;

Average area of one pit	*0.000007 sq. mm.*
Average no. pits per tracheid	***208***
Simple pit area per av. tracheid	*0.002156 sq. mm.*

The penetrable boraered pit area per mm. of tracheid length is ***0.01100*** *sq. mm.*
The simple pit area for the same unit is 0.000560 sq. mm.

TABLE V.

Measurements of 100 bordered pits

of Larix occidentalis, penetrance specimen from Montana.

	Diameters				Diameters		
Pit	Torus	Mouth	av. of 10	Pit	Torus	Mouth	Av. of 10
12.5	7.0	5.0		11.0	6.5	4.0	
10.5	7.0	4.5		12.5	7.0	4.5	
13.0	8.0	5.0		12.5	6.5	4.5	
11.5	7.5	4.5		11.0	6.0	5.0	
12.5	7.0	4.5		11.5	6.5	5.0	
13.5	7.5	4.5		12.5	6.5	5.0	
13.0	7.0	4.5		12.5	6.5	4.0	
13.0	7.5	4.5	Pit 12.6	11.5	6.5	4.0	Pit 12.1
13.5	6.5	5.0	Torus 7.2	13.0	6.0	4.0	Torus 6.5
13.0	6.5	4.5	Mouth 4.7	13.0	7.0	5.0	Mouth 4.5
12.0	7.0	4.5		11.5	6.0	4.0	
12.0	6.0	4.0		12.0	7.0	4.5	
12.5	7.0	4.5		12.5	7.0	4.5	
13.5	7.0	5.5		13.0	7.5	5.0	
13.0	7.0	5.0		11.0	6.5	4.5	
14.0	6.5	4.5		14.0	6.5	5.0	
13.5	7.0	5.0		13.5	6.0	4.0	
12.5	7.0	5.0	Pit 13.0	11.5	6.0	4.0	Pit 12.3
13.0	7.0	5.0	Torus 7.0	12.0	6.5	3.5	Torus 7.0
13.5	8.0	4.5	Mouth 4.8	12.0	6.5	4.5	Mouth 4.4
13.0	6.5	5.0		11.5	7.0	5.0	
11.5	6.5	5.0		12.0	6.5	4.5	
12.0	6.0	4.5		12.0	7.0	4.5	
13.5	7.5	4.5		13.0	7.5	5.0	
13.5	7.5	5.0		13.5	7.5	5.0	
13.0	7.0	5.0		13.5	7.5	5.0	
11.0	6.5	4.0		13.5	6.5	5.0	
13.0	6.5	3.5	Pit 12.7	11.5	6.5	4.0	Pit 12.6
13.0	6.0	5.0	Torus 6.7	11.5	5.5	3.0	Torus 6.9
13.5	6.0	5.0	Mouth 4.7	14.0	7.0	5.0	Mouth 4.6
12.5	6.5	5.0		10.0	6.0	3.5	
13.0	7.0	5.0		13.0	7.0	4.0	
11.0	6.0	4.5		12.5	7.5	4.0	
11.5	6.5	4.5		13.0	7.0	5.0	
11.0	6.0	4.5		13.0	6.5	5.0	
12.0	6.0	5.0		12.0	6.0	4.0	
12.0	6.0	5.0		12.0	6.5	3.5	
12.5	6.0	5.0	Pit 12.1	11.5	6.0	4.0	Pit 12.2
14.0	7.0	5.0	Torus 6.3	11.5	5.5	3.5	Torus 6.4
11.0	6.0	4.0	Mouth 4.8	13.0	6.0	4.5	Mouth 3.6
11.0	7.0	5.0		11.0	6.5	4.5	
11.0	7.0	5.0		13.5	8.0	5.5	
12.0	6.5	5.5		13.5	7.5	5.0	
12.0	6.5	5.0		12.0	6.5	4.5	
12.0	6.0	4.5		12.5	7.0	5.0	
12.5	6.0	4.5		12.0	7.0	4.0	
13.5	7.0	4.5		14.0	7.5	5.5	
12.5	6.5	4.5	Pit 12.0	12.0	7.0	5.0	Pit 12.9
13.5	8.5	5.0	Torus 6.6	14.0	8.0	5.5	Torus 7.3
10.0	6.0	4.0	Mouth 4.8	14.0	7.5	5.5	Mouth 5.0

The average of the ten foregoing averages is as follows;

12.6	7.2	4.7	
13.0	7.0	4.8	
12.7	6.7	4.7	
12.1	6.3	4.8	
12.1	6.5	4.5	
12.3	7.0	4.4	
12.6	6.9	4.6	
12.2	6.4	3.6	Pit 12.5
12.0	6.6	4.8	Torus 6.8
12.0	7.3	5.0	Mouth 4.6

The previous measurements are all in units equivalent to 0.00191 mm. Translating to millimeters then, the averages are as follows;

Pit diameter	*0.02388 mm.*
Torus diameter	*0.01299 mm.*
Mouth diameter	*0.00879 mm.*

Using the formula, radius squared x 3.1416, to obtain the areas, the resulta are;

Pit area	*0.00044 sq. mm.*
Torus area	*0.00013 sq. mm.*
Mouth area	*0.00006 sq. mm.*

TABLE VI.

Larix occidentalis (heartwood) Penetrance specimen.

	1	2	3	4	5	6	7	8	9	10	av.	mm.
Length	400	450	590	410	420	510	480	460	455	620	486	4.10670
Diameter	38	42	55	47	35	55	46	55	44	55	47	0.08977
No. bord. pits.	179	208	340	240	221	240	270	216	186	262	236	
Pit diam.	12.6	13.0	12.7	12.1	12.1	12.3	12.6	12.2	12.0	12.9	12.5	0.023875
Torus diam.	7.2	7.0	6.7	6.3	6.5	7.0	6.9	6.4	6.6	7.3	6.8	0.012988
Mouth diam.	4.7	4.8	4.7	4.8	4.5	4.4	4.6	3.6	4.8	5.0	4.6	0.008786
No. simple pits.	338	292	569	230	243	259	424	305	312	666	368	
Av. simple pit area.	2	2	2	2	2	2	2	2	2	2	2	0.000007
No. rays crossed	10	8	10	8	4	10	10	8	9	17	9	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00044 sq. mm.*
Av. area of torus	*0.00013*
Penetrable area of 1 av. pit	*0.00031 sq. mm.*
Av. no. pits per tracheid	*236*
Penetrable area of 1 av. tracheid	*0.07316 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.000007 sq. mm.*
Av. no. pits per tracheid	*366*
Simple pit area per av. tracheid	*0.002576 sq. mm.*

The penetrable bordered pit area per mm. of tracheid length is 0.01798 sq. mm.

The simple pit area for the same unit is 0.000630 sq. mm.

The figuees given in Tables III, IV, V, and VI verify the preliminary figures of Tables I and II. The penetrable bordered pit areas seem to be the only factors which show a consistant relation to the penetration figures. The simple pit areas vary from 0.000462 sq. mm. to 0.000560 sq. mm. in the same species, and there is no evidence elsewhere that the simple pit area is a factor in the penetration of preservatives into wood.

Summary of Results.

In the case of Larix laricina and Larix occidentalis we have two species very similar in most of their characters but dissimilar in those structures most concerned in the passage of creosote oil into wood. Thus the seeming paradox in penetration, upon close examination of the bordered pit structures, is explained by a difference in "penetrable bordered pit areas". Whether the figures which I have obtained in the careful measyrements of one hundred bordered pits will be found true in all cases remains to be proven.

It would be interesting to pursue this question of "penetrable bordered pit areas" thru all the woods which are treated commercially in order to see whether the relationship between penetration and penetrable areas will hold in other cases besides the one investigated. In the appendix I have included studies of several other kinds of wood, different species of Pinus, and one of Abies. The penetrance figures for all of these have not been ascertained. Their main value lies in the penetrable bordered pit areas per millimeter of tracheid length which is given for each. Of course a comparison between two species with several points of structural difference will necessatate a careful differentiation between each pair of points involved. In the case of the two species of Larix discussed the specimens were very similar excepting in bordered pit area which was penetrable by preservatives. In comparing Abies to Pinus it would be necessary to allow for the fact that most forms of Abies have no resin passages while they are frequent in Pinus. Thus for purposes of comparison species should be associated which have only one or a few points that are not common to both. In many cases the heartwood of a species is harder to penetrate than the sapwood. Since in the higher conifers the tracheids, which are the passage ways, are seldom found to contain resin, the cause of this difference can scarcely be assumed as a clogged condition of tracheids. Here then is a case where there are no, or few, structural differences, and still a difference in penetration.

The appendix also contains a table showing the results of a few penetrance tests which I have conducted in an endeavor to check the figures on L. laricina and L. occidentalis given by Teesdale (1). Where they vary from his, the error, if there be one, is perhaps due to the imperfections of my apparatus, a picture of which will be found in PLATE XII.

Literature cited.

(1) Teesdale, C.H. Relative resistance of various conifers to injection with creosote. U.S. Dept. of Agr. Bul. 101. Washington. Sept. 1914.

(2) Penhallow, D.P. A manual of the North American Gymnosperms. Ginn and Co. Boston. 1907.

(3) Bailey, I.W. The preservative treatment of wood. Forestry Quarterly. Vol. 11. 1913.

(4) Teesdale, C.H. The absorption of creosote by the cell walls of wood. U.S. Forest Service Cir. 200.

APPENDIX

Containing tables of measurements on eight species of Pinus and one species of Abies. Also penetrance figures on Larix laricina, L. occidentalis, and several miscellaneous species.

Pinus strobus, specimen from Michigan.

	1	2	3	4	5	6	7	8	9	10	av.	mm.
Length	454	537	300	585	550	285	312	325	350	410	412	3.48140
Diameter	26	27	19	21	22	20	25	20	20	30	23	0.04392
No. bord. pits	118	153	91	120	117	52	61	56	35	50	85	
Pit diam.	8	8	10	10	10	9	10	10	10	11	10	0.01910
Torus diam.	4	4	6	5	5	6	6	6	6	6	5	0.00955
Mouth diam.	2	2	3	3	3	3	4	5	4	4	3	0.00573
No. simple pits.	15	18	4	14	13	10	7	8	7	20	12	
Av. simple pit area.	81	60	70	90	90	70	100	90	100	100	85	0.00031
No. rays crossed.	5	7	2	5	4	2	3	3	3	6	5	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00029 sq. mm.*
Av. area of torus	*0.00007 sq. mm.*
Penetrable area of 1 av. pit	*0.00022 sq. mm.*
Av. no. pits per tracheid	*85*
Penetrable area of an av. tracheid	*0.01827 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.00031 sq. mm.*
Av. no. pits per tracheid	*12*
Simple pit area per av. tracheid	*0.00372 sq. mm.*

The penetrable bordered pit area per mm. of tracheid length is 0.00504 sq. mm.

The simple pit area for the same unit is 0.00107 sq. mm.

Pinus lambertiana, specimen from California.

	1	2	3	4	5	6	7	8	9	10	av.	mm.
Length	650	670	610	800	770	910	690	680	640	640	707	5.97415
Diameter	38	34	50	37	41	38	35	40	40	21	37	0.07067
No. bord. pits	215	245	245	296	283	322	300	250	210	102	239	
Pit diam.	11	11	12	12	12	12	12	12	12	12	12	0.02292
Torus diam.	6	6	7	6	6	6	6	7	6	6	6	0.01146
Mouth diam.	3	4	5	4	4	4	4	5	4	4	4	0.00764
No. simple pits.	70	51	52	86	54	51	49	49	74	43	59	
Av. simple pit area.	45	45	43	55	45	30	40	40	40	40	42	0.00015
No. rays crossed.	7	7	8	13	11	13	7	8	8	6	9	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00038 sq. mm.*
Av. area of toeus	*0.00011 sq. mm.*
Penetrable area of 1 av. pit	*0.00027 sq. mm.*
Av. no. pits per tracheid	239
Penetrable area of an av, tracheid	*0.06382 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.00015 sq. mm.*
Avl. no. pits per tracheid	*59*
Simple pit area per av. tracheid	*0.00904 sq. mm.*

The penetrable bordered pit area per millimeter of tracheid length is 0.01080s sq. mm.

The simple pit area for the same length is 0.00150 sq. mm.

Pinus monticola, specimen from Com. Woods of U.S.

	1	2	3	4	5	6	7	8	9	10	av	mm
Length	700	705	710	710	720	685	610	600	860	450	675	5.70375
Diameter	31	35	30	29	45	37	25	25	30	30	32	0.06112
No. bord. pits.	121	125	115	140	240	140	173	155	193	146	155	
Pit diam.	12	13	12	13	12	12	11	12	13	12	12	0.02292
Torus diam.	6	6	6	6	6	6	6	6	7	6	6	0.01146
Mouth diam.	4	4	4	4	4	4	4	4	5	4	4	0.00764
No. simple pits	40	43	39	42	80	60	46	40	81	44	54	
Av. simple pit area.	28	28	30	30	50	30	40	40	50	60	39	0.00014
No. rays crossed	9	9	8	8	9	7	9	8	13	6	9	

The penetrable bordered pit area is;

Av. area of 1 pit	0.00038 sq. mm.
Av. area of torus	0.00011 sq. mm.
Penetrable area of an av. pit	0.00027 sq. mm.
Av. no. pits per tracheid	155
Penetrable area of an av. tracheid	0.04139 sq. mm.

The simple pit area is;

Av. area of 1 pit	0.00014 sq. mm.
Av. no. pits per tracheid	54
Simple pit area per av. tracheid	0.00768 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00729 sq. mm.

The simple pit area for the sma length is 0.00133 sq. mm.

Pinus resinosa, specimen from Com. Woods of U.S.

	1	2	3	4	5	6	7	8	9	10	av	mm.
Length	500	450	400	360	410	365	350	420	360	355	397	3.35465
Diameter	28	32	22	21	25	23	25	21	24	26	25	0.04775
No. bord. pits	87	84	71	76	101	67	63	73	60	107	79	
Pit diam.	10	10	10	10	12	10	10	10	10	11	10	0.01910
Torus diam.	6	5	5	5	6	6	6	6	5	6	6	0.01146
Mouth diam.	3	3	3	3	4	4	4	4	3	4	4	0.00764
No. simple pits.	15	14	14	14	7	19	22	7	17	10	14	
Av. simple pit area.	50	50	50	50	50	50	60	60	40	70	50	0.00018
No. rays crossed	5	4	3	3	2	6	6	2	6	3	4	

The penetrable bordered pit area is;

Av. area of 1 pit 0.00031 sq. mm.

Av. area of torus 0.00011 sq. mm.

Penetrable area of 1 av. pit 0.00020 sq. mm.

Av. no. pits per tracheid 79

Penetrable area of an av. tracheid 0.01588 sq. mm.

The simple pit area is;

Av. area of 1 pit 0.00018 sq. mm.

Av. no. pits per tracheid 14

Simple pit area per av. tracheid 0.00255 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00460 sq. mm.

The simple pit area for the same length is 0.00074 sq. mm.

Pinus divaricata, sapwood; specimen from Madison Laboratory.

	1	2	3	4	5	6	7	8	9	10	av	mm
Length	350	260	290	240	370	290	310	290	330	410	314	2.65330
Diameter	20	20	17	25	23	20	20	20	20	20	20	0.03820
No. bord. pits.	50	41	42	48	98	48	72	69	83	69	61	
Pit diam.	10	10	10	10	10	10	10	10	10	10	10	0.01910
Torus diam.	6	6	6	6	6	6	6	6	6	6	6	0.01146
Mouth diam.	4	4	4	4	4	4	4	4	4	4	4	0.00764
No. simple pits.	46	37	19	48	24	43	22	38	17	76	37	
Av. simple pit area.	10	8	8	8	10	10	8	6	8	8	8	0.00003
No. rays crossed	5	3	3	5	5	4	4	3	3	9	4	

The penetrable bordered pit area is;

Av. area of 1 pit	*0.00029 sq. mm.*
Av. area of torus	*0.00011 sq. mm.*
Penetrable area of 1 av. pit	*0.00018 sq. mm.*
Av. no. pits per tracheid	*61*
Penetrable area of 1 av. tracheid	*0.01098 sq. mm.*

The simple pit area is;

Av. area of 1 pit	*0.00003 sq. mm.*
Av. no. pits per tracheid	*37*
Simple pit area per av. tracheid	*0.00107 sq. mm.*

The penetrable bordered pit area per millimeter of tracheid length is 0.00396 sq. mm.

The simple pit area for the same length is 0.00042 sq. mm.

Pinus palustris, heartwood; specimen from Com. Woods of U.S.

	1	2	3	4	5	6	7	8	9	10	av	mm.
Length	700	510	700	720	650	740	710	680	700	800	691	5.88895
Diameter	35	35	35	37	28	35	30	30	32	42	34	0.06494
No. bord. pits.	208	205	190	280	108	152	180	208	188	187	190	
Pit diam.	12	14	12	12	12	12	12	12	12	12	12	0.02292
Torus diam.	7	7	7	7	7	7	7	7	7	7	7	0.01337
Mouth diam.	5	5	5	5	5	5	5	5	5	5	5	0.00955
No. simple pits.	82	20	99	56	64	129	79	54	35	83	70	
Av. simple pit area	45	45	45	40	30	45	30	35	50	45	41	0.00015
No. rays crossed	8	3	8	8	7	12	8	6	4	9	7	

The penetrable bordered pit area is;

Av. area of 1 pit	0.00038 sq. mm.
Av. area of torus	0.00014 sq. mm.
Penetrable area of 1 av. pit	0.00024 sq. mm.
No. of pits per av. tracheid	190
Penetrable area of 1 av. tracheid	0.04560 sq. mm.

Simple pit area is;

Av. area of 1 pit	0.00015 sq. mm.
Av. no. pits per tracheid	70
Simple pit area per av. tracheid	0.01050 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00792 sq. mm.

The simple pit area for the same length is 0.00180 sq. mm.

Pinus glabra, sapwood(?) , specimen from Madison Laboratory.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*av*	*mmm*
Length	440	435	425	350	340	550	290	390	390	570	418	3.53210
Diameter	26	27	27	30	30	28	25	25	22	27	27	0.05157
No. bord. pits.	74	73	67	81	68	88	70	51	55	44	67	
Pit diam.	12	12	12	12	12	10	12	10	10	12	13	0.02292
Torus diam	6	6	6	6	6	6	6	6	6	6	6	0.01146
Mouth diam.	4	4	4	4	4	4	4	4	4	4	4	0.00764
No. simple pits	31	28	27	23	17	43	24	36	33	57	32	
Av. simple pit area	15	20	20	18	7	10	10	10	10	15	13	0.00005
No. rays crossed	4	4	4	2	2	8	4	6	5	6	5	

The penetrable bordered pit area is;

Av. area of 1 pit 0.00038 sq. mm.

Av. area of torus 0.00011 sq mm.

Penetrable area of 1 av. pit 0.00027 sq. mm.

Av. no. pits per tracheid 67

Penetrable area of 1 av. tracheid 0.01809 sq. mm.

The simple pit area is;

Av. area of 1 pit 0.00005 sq. mm.

Av. no. pits per tracheid 32

Simple pit area per av. tracheid 0.00160 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00513 sq. mm.

The simple pit area for the same length is 0.00045 sq. mm.

Pinus taeda, sapwood(?), specimen from Com. Woods of U.S.

	1	2	3	4	5	6	7	8	9	10	av	mm
Length	590	530	600	420	510	530	410	490	500	510	509	4.30105
Diameter	36	34	40	35	37	26	23	30	28	32	32	0.06112
No. bord. pits.	97	82	112	110	77	75	66	74	72	117	88	
Pit diam.	12	12	12	12	15	10	10	12	12	12	12	0.02292
Torus diam.	7	7	7	7	7	6	6	7	7	7	7	0.01837
Mouth diam.	5	5	5	5	5	4	4	5	5	5	5	0.00955
No. simple pits	49	81	64	54	81	25	37	37	27	44	50	
Av. simple pit area	35	20	20	25	20	20	20	20	20	20	20	0.00007
No. rays crossed	7	10	9	8	10	4	6	5	5	6	7	

The penetrable bordered pit area is;

Av. area of 1 pit	0.00038 sq. mm.
Av. area of torus	0.00014 sq. mm.
Penetrable area of 1 av. pit	0.00024 sq. mm.
Av. no. pits per tracheid	88
Penetrable area of 1 av. tracheid	0.02112 sq. mm.

The simple pit area is;

Av. area of 1 pit	0.00007sq. mm.
Av. no. pits per tracheid	50
Simple pit area per av. tracheid	0.00350 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00480 sq. mm.

The simple pit area for the same length is 0.00081 sq. mm.

Abies grandis, sapwood; specimen from Madison Laboratory.

	1	2	3	4	5	6	7	8	9	10	av	mm
Length	270	450	550	420	520	460	500	430	400	410	441	3.72645
Diameter	26	35	33	35	50	27	27	40	30	53	36	0.06876
No. bord. pits	75	212	260	195	270	95	186	164	128	230	182	
Pit diam.	10	10	10	10	10	10	10	10	10	10	10	0.01910
Torus diam	6	6	6	6	6	6	6	6	6	6	6	0.01146
Mouth diam.	4	4	4	4	4	4	4	4	4	4	4	0.00764
No. simple pits.	112	105	140	135	184	35	81	215	101	194	130	
Av. area of simple pit.	10	10	10	10	10	10	8	8	6	5	9	0.00003
No. rays crossed	3	7	7	8	8	5	6	8	5	5	6	

The penetrable borderea pit area is;

Av. area of 1 pit 0.00029 sq. mm.

Av. area of torus 0.00011 sq. mm.

Penetrable area of 1 av. pit 0.00018 sq. mm.

Av, no. pits per tracheid 182

Penetrable area of 1 av. tracheid 0.03276 sq. mm.

The simple pit area is;

Av. area of 1 pit 0.00003 sq. mm.

Av. no. pits per tracheid 130

Simple pit area per av. tracheid 0.00390 sq. mm.

The penetrable bordered pit area per millimeter of tracheid length is 0.00882 sq. mm.

The simple pit area for the same length is 0.00105 sq. mm.

The following table gives the penetrations in inches (according to Teesdale), and the penetrable bordered pit and simple pit areas per millimeter of tracheid length, in sq. mm. (according to my calculations).

Species	Penetration long.	rad.	P.B.P.A.	S.P.A.
Pinus taeda	12.0	2.0	0.00480	0.00081
" palustris	12.0	2.0	0.00792	0.00180
" glabra	12.0	2.0	0.00513	0.00045
Larix occidentalis	3.17	0.09	0.01798	0.00063
" laricina	0.87	0.04	0.01100	0.00056
Abies grandis	9.00	0.18	0.00882	0.00105

The following are penetrations which I have made, using one specimen only, with a pressure of 100 pounds per sq. in. continued for 30 minutes. The oil temperature was 20°C. The apparatus used was that shown in PLATE XII. The penetrable bordered pit and simple pit areas were not determined for Tsuga canadensis or Picea excelsa.

Species	Penetration (ins.) long.	rad.	tan.	P.B.P.A.	S.P.A.
Tsuga canadensis	2.62	0.05	0.20		
Picea excelsa	2.93	0.05	0.15		
Pinus taeda	7.31	0.50	0.80	0.00480	0.00081
Pinus lambertiana	7.31	0.30	0.20	0.01080	0.00150

The following tables show the penetrations in Larix laricina and L. occidentalis as caused by a pressure of 100 pounds per sq. in. continued for 30 minutes. In all my penetrations the oil used was a commercial product from the Barrett Co., Chicago, known as "Carbosota, Grade One, Liquid Creosote Oil". In all cases, unless otherwise noted, the wood was in pieces 24 x 2 x 4 inches. It was first dried in an electric oven for 48 hours at a constant temperature of 100°C to remove as much moisture as possible. The oil temperature at the time of treatment was about 20°C.

LARIX LARICINA Pen. bor. pit area 0.01100 sq. mm
Simple pit area 0.00056 " "

Specimen no.	Penetration in inches. long.	rad.	tan.
I (12 ins. long)	0.15	0.05	0.15
II (do)	6.00*	0.20	0.10
III	0.15	0.05	0.15
IV (do)	6.00**	0.20	0.10
V (do)	4.30	0.15	0.05
VI (do)	6.00	0.20	0.05

* At the end of 10 minutes.

** Almost instantaneously.

Due to an oversight Specimens II, IV, V, and VI, which were cut from the same piece of wood, remained in the oven about 60 hours instead of the usual 48 hours. This, coupled with the fact, that other pieces shipped in the same lot were so season checked as to be worthless for experimental purposes, seems to indicate poor seasoning of the entire lot and perhaps accounts for the excessive and variable longitudinal penetrations in those cases. Numbers I and III were from a different source than the foregoing and presumably were cut from the same piece.. They show a more normal penetration. In view of Teesdale's figures these last are the ones to be compared to the corresponding penetrations in Larix occidentalis.

LARIX OCCIDENTALIS Pen. bord. pit A. 0.01798
Simple pit A. 0.00063

Specimen no.	Penetration in inches. long..	rad..	tang.	
I	0.54	0.20	0.10	
II	0.43	0.20	0.10	
III	0.30	0.20	0.10	
IV	0.33	0.20	0.10	
V	0.30	0.15	0.05	
VI	0.30	0.20	0.05	(long. occasionally to 1.15 ins.)
VII	0.30	0.10	0.05	
VIII	0.35	0.20	0.20	
IX	0.15	0.15	0.10	
X	0.17	0.20	0.20	
XI	0.25	0.10	0.20	
Average	0.31	0.17	0.11	

The specimens of L. laricina were obtained from the R. Hansen Co. and came from northern Michigan. They were of poor quality for experimental work, generally, and only about one third of the lot could be utilized at all.

The specimens of L. occidentalis were secured from Montana thru the kindness of Mr. C.N. Whitney, the then (June 1917) Acting Forester of District I. The material was first class in every respect, giving evidence of having been carefully seasoned and selected.

PLATE I.

Larix laricina, radial section, showing the perforated pit membranes and the relatively large pit torus. Magnification about 697 diameters.

PLATE II.

Larix occidentalis, radial section, showing the perforated pit membrane and the relatively small pit torus. Magnification as above.

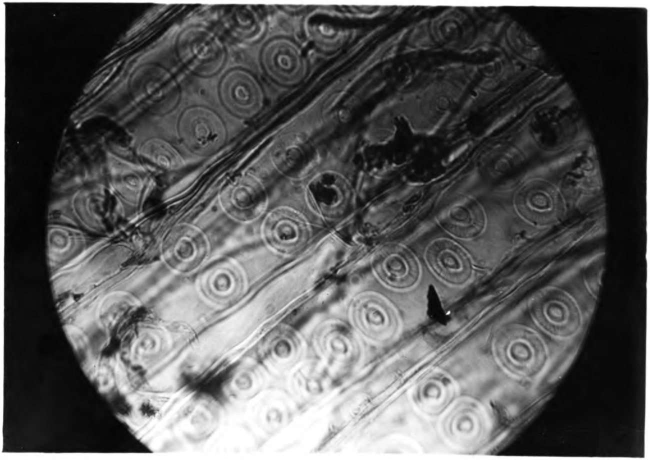


PLATE I

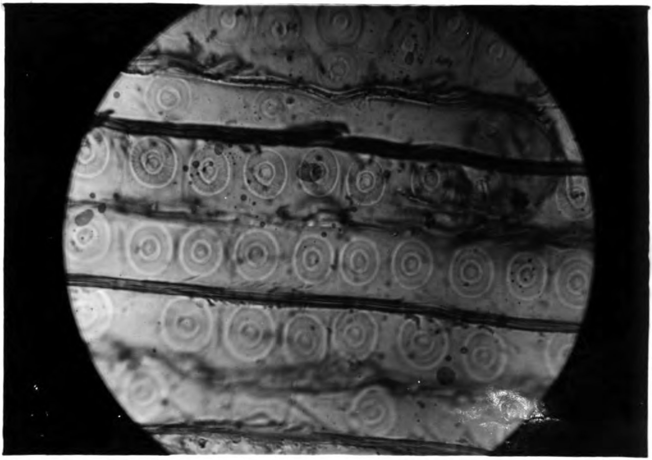


PLATE II.

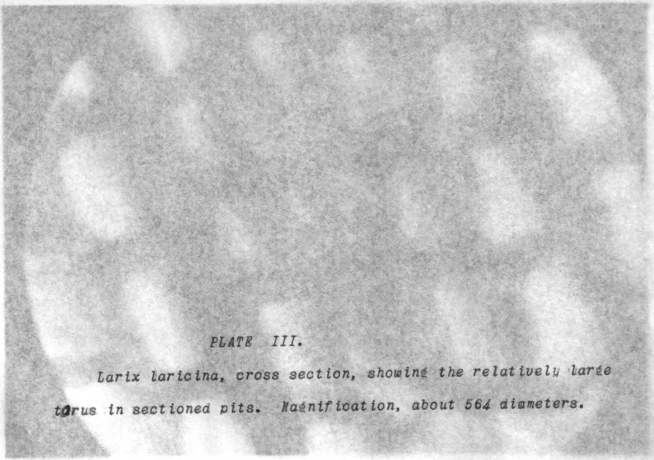


PLATE III.

Larix laricina, cross section, showing the relatively large torus in sectioned pits. Magnification, about 564 diameters.

PLATE IV.

Larix occidentalis, cross section, showing the relatively small torus in sectioned pits. Magnification as above.

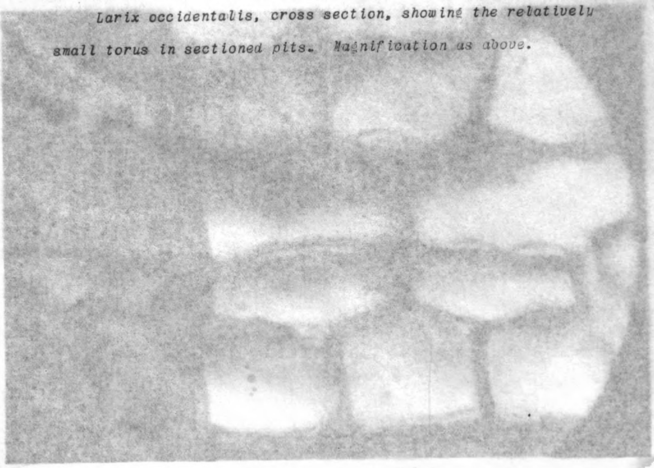


Plate IV.

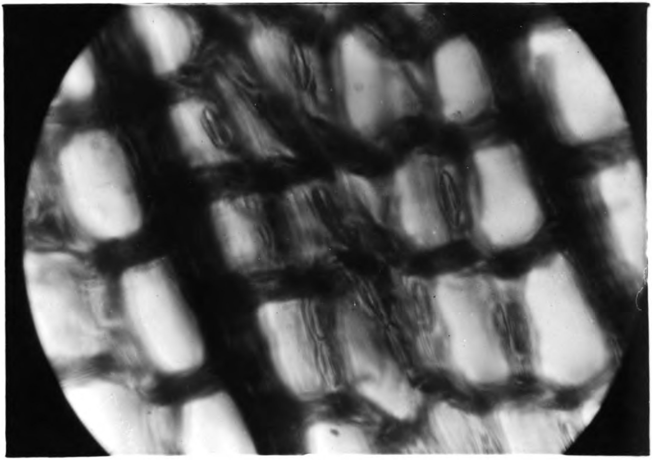


Plate III

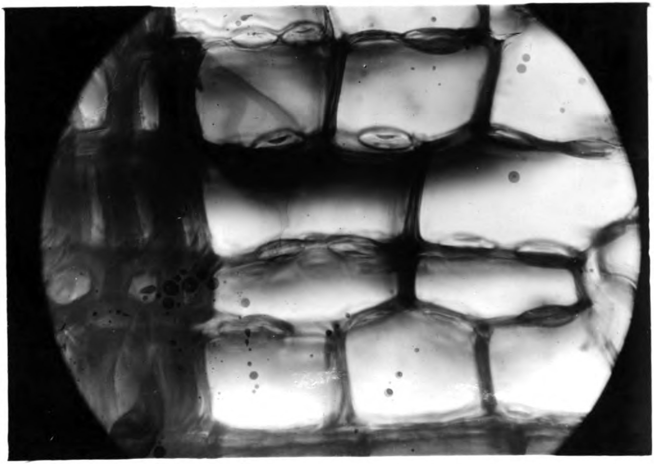


Plate IV.

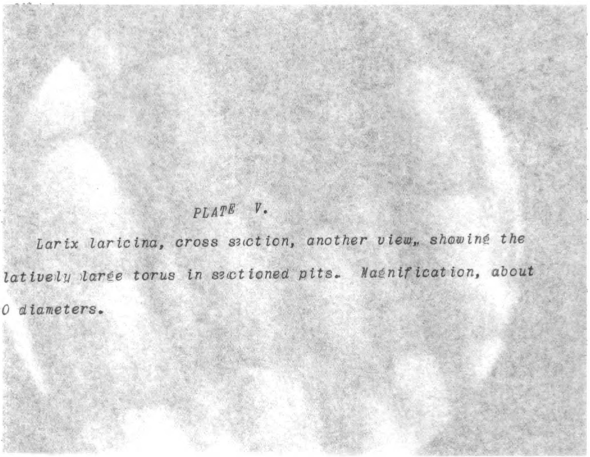


PLATE V.

Larix laricina, cross section, another view, showing the relatively large torus in sectioned pits. Magnification, about 590 diameters.

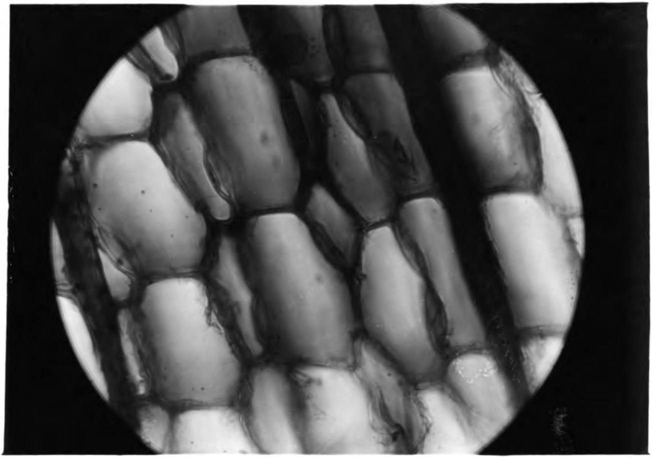


Plate V.

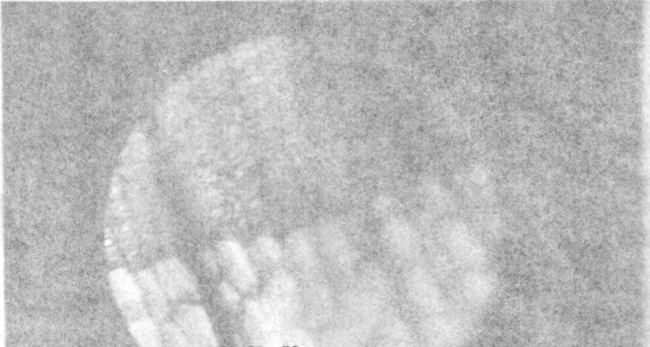


PLATE VI.

Larix laricina, cross section, showing the general nature of the wood structure. The dense part is the summer wood and the more open section is the spring wood. Magnification, about 218 diameters.

PLATE VII.

Larix occidentalis, cross section, showing the similarity to *L. laricina*. Magnification as above.

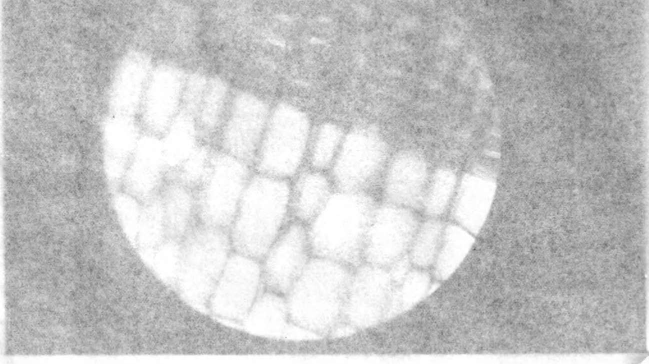


Plate VII.

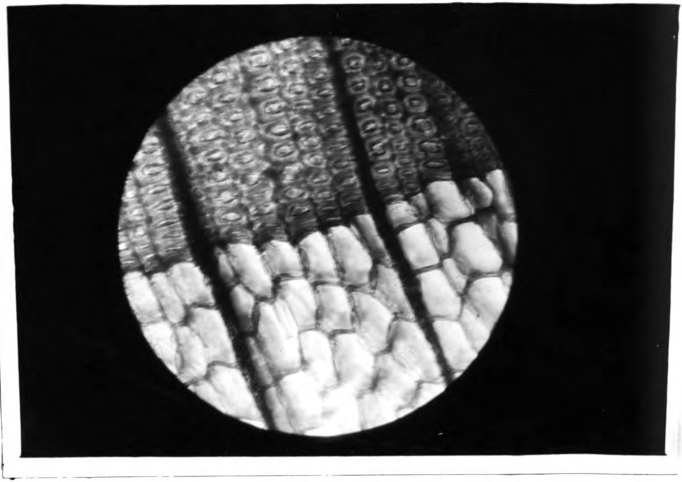


Plate VI.

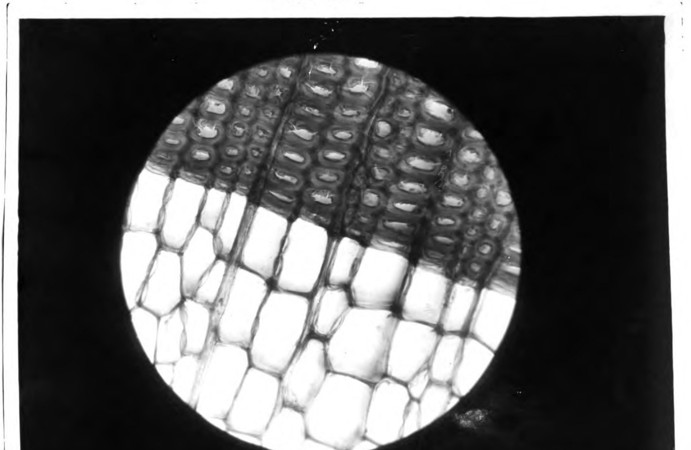


Plate VII.

PLATE VIII.

Larix laricina, radial section, spring wood only, showing medullary ray, simple pits, and bordered pits. Magnification about 237 diameters.

PLATE IX.

Larix occidentalis, radial section, both spring and summer wood, showing medullary ray, simple pits, and bordered pits. Magnification as above.

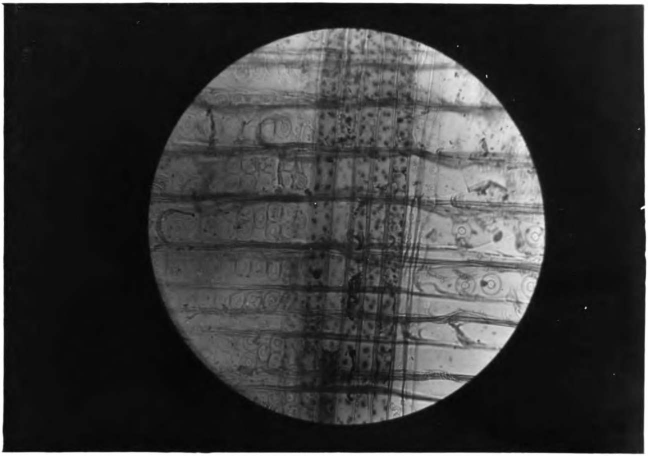


Plate VIII.

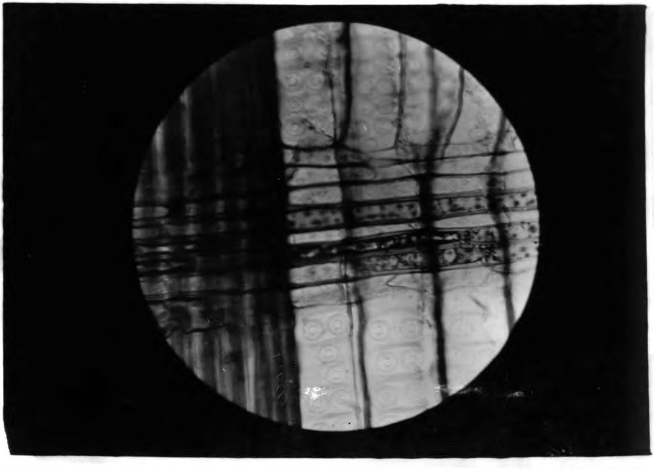


Plate IX.

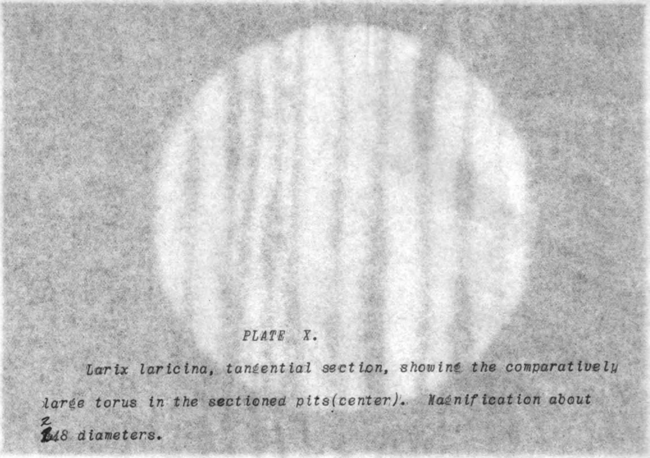


PLATE X.

Larix laricina, tangential section, showing the comparatively large torus in the sectioned pits(center). Magnification about 248 diameters.

PLATE XI.

Larix occidentalis, tangential section, showing the comparatively small torus in the sectioned pits (bottom row). Magnification about 483 diameters.

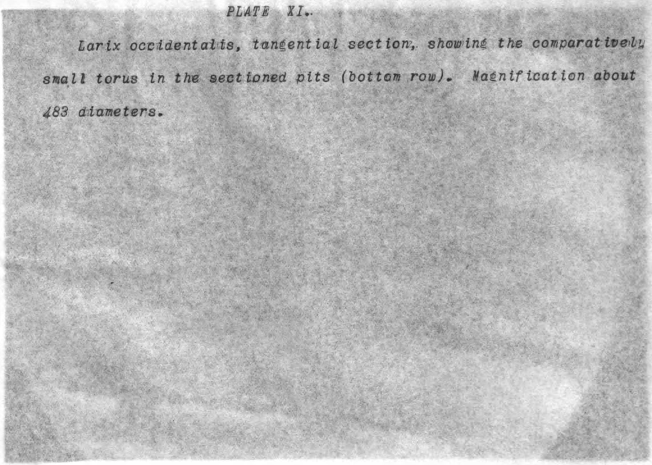


Plate XI.

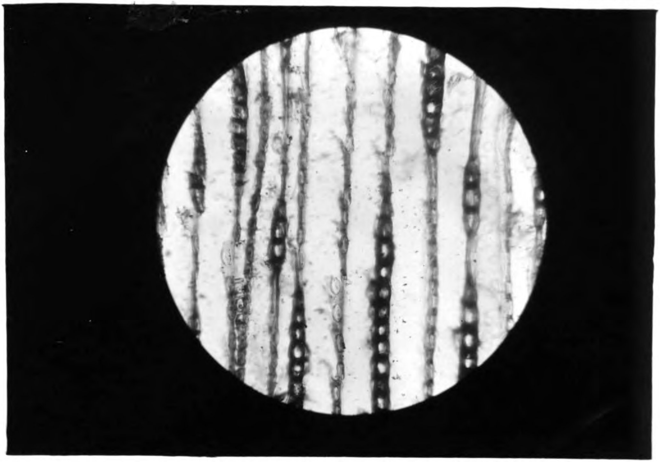


Plate X.

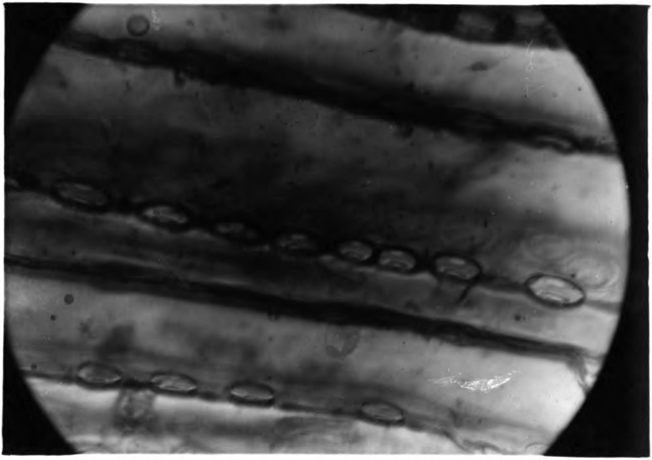


Plate XI.

PLATE XII.

The apparatus used in the penetrance experiments, consisting of a reserve cylinder above for use in case vacuum is first desired, and the pressure cylinder below. A piece of wood is shown in position between the metal plates which hold it to the pipe leading from the pressure cylinder. The wood has a hole bored in the face which fits over the tip of the pipe coming thru the plate from the cylinder. This hole affords the penetrance surface. Apparatus modeled somewhat after that of Teesdale. (see U.S.D.A. Bul. 101).

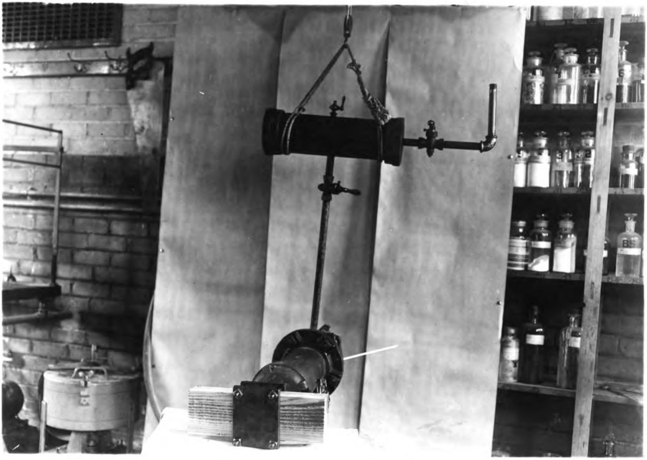


Plate XII.