THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report
of
Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Leland Leonard de Flon for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

J.B. Whiting
Chairman

Clarence A. Morrow

J. H. Allison

Date May 27, 1922.

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THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Leland Leonard de Flon final oral examination for the degree of Master of Science. We recommend that the degree of Master of Science be conferred upon the candidate.

Minneapolis, Minnesota
May 27 1922

J. B. Whiting
Chairman

Clarence A. Morrow.

J. H. Allison

MOM
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THE WOOD OF THE WALNUTS AND HICKORIES OF MINNESOTA

A Study of Its Structure and of Certain
Physical Properties

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A THESIS
SUBMITTED TO THE GRADUATE FACULTY
OF THE
UNIVERSITY OF MINNESOTA
BY
LELAND L. DE FLON

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

June 1922

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Foreword

I wish to acknowledge my appreciation to Prof. J. P. Wentling, at whose suggestion this work was undertaken in this thesis, for his valuable helps and suggestions in this work, and also for the photographing of the wood sections. I wish also to thank Dr. C. A. Morrow and Mr. T. S. Hansen for helpful suggestions, and Prof. C. O. Rosendahl for help in the range and distribution of Juglans and Hicoria in Minnesota, and Prof. H. B. Roe for suggestions in the graphs.

Leland L. de Flon

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INTRODUCTION

Since the beginning of the history of the human race, wood has always played an important part in the development of civilization. It has been used for shelter, for instruments of utility and warfare, for transportation, for fuel, and in fact for almost everything to which it could be shaped. Without wood men could not have made progress, for it has been, and still is, at the base of our civilization. It has become a mother to our industrial progress. We can think of but very few things with which wood does not play a part. The paper upon which this thesis is written is made from wood. In other words, it has been an integral part of the human race and no doubt always will be an important factor in its further development as new and varied uses are found awaiting it.

For centuries men worked with wood and without investigating its properties knew it to be suited to their purposes. While it was present in apparently inexhaustible quantities, men neglected to search out its qualities and to investigate its structure. But as history points out, with an impending shortage of timber, investigations of wood were made. We, ourselves, are, in the not far distant future, facing a timber famine, and we must conserve our supply of wood by close utilization of the wood product itself as well as by reforesting our timber lands. To effect close utilization we must know wood itself, its structure, physical and mechanical properties.

HISTORY AND DEVELOPMENT OF WOOD INVESTIGATIONS. Even as early as 1505 investigations on wood were conducted when Leonardo da Vinci *(1) indicated that the number of rings shown upon the cross section of the tree corresponds to its age. He was also a pioneer in the art of testing materials for construction. French scientists *(2) especially from the beginning of the 18th century to the middle of the present century gave more or less attention to investigations on the strength of wood. The methods used were crude and the scale of the work limited so the results were contradictory and unsatisfactory. Chevandier and Wertheim *in 1848 published their results on tests of timbers in the Vosges Mountains. Their results are still in use. This was the first time a fairly good history and description of the test material was given.

Varenne de Fenille *(1) a professor at the Forest School of Nancy, about 1807, was the first to employ the lens for the examination of the transverse section of wood for its determination.

Des Etangs, *(1) in 1845-1844 also used the lens to distinguish the oak from the chestnut, and both from the elm during a discussion of the use of chestnut in Ecclesiastical architecture. Guibort *(1) in 1869 may be regarded as the founder of the method of using the structure of wood as an aid to classification. To Noerdlinger *(1852) (1) and (2) is attributed the idea that the annual ring may be used as a basis for a method of identification.

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* The works of these men were not directly consulted

He may be regarded as the one who first worked out the idea in a comprehensive manner. Most of the modern work in timber testing is founded upon the work done by Noerdlinger,*who was chief forester at Hohenheim, Wurtemburg. The results of his investigations were published in 1860. In 1883 and 1887 Bauschinger *(2) published at Munich the results of timber tests on Scotch pine and spruce from the Black Forest, giving special attention to the conditions under which the timber grew, his main object being to determine the influence of forest conditions and the time of felling on the strength of wood. He found that the density and the strength of timber is greatly affected by its moisture content, the strength decreasing rapidly as the moisture increases.

In the United States the work done in connection with the Tenth Census, by T. P. Sharples, (5a) under the direction of C. S. Sargent is outstanding and valuable, covering 412 species. Sharples says, "The results are not conclusive but valuable as to what lines of research should be followed in a more thorough study of this subject." Timber tests were made by The Division of Forestry (2) from 1891 to 1896. The laboratory work was carried on under J. B. Johnson at St Louis. The material was collected from the forest without any special reference to the conditions under which it was grown. Thirty-seven species were used, in all 308 trees, giving 6000 test pieces, and material for over 45,000 tests, 20,000 pieces being used for physical examination. Tests were made to determine structure, character of growth, specific

* The works of these men were not directly consulted.

gravity, moisture conditions, and other properties. The tests were made under the direction of Dr. B. E. Fernow. Tests were also made by Prof. G. Lanza (2) at the Massachusetts Institute of Technology and published in 1894. Other numerous tests have been made on a small scale in the United States, but as yet an engineer does not feel fully justified in applying figures on strength and durability of American woods to his practical work. Recently, (3 and 4) especially within the past 11 years, the major investigations along forest products have been conducted at the Forest Products Laboratory maintained by the U. S. Forest Service in cooperation with the University of Wisconsin, at Madison, Wis., where very complete investigations are being made of all of the native woods of the United States. Branch laboratories are conducting investigations at Wausau, Wis., Seattle, Wash., Washington, D. C., San Francisco, Cal., and Portland, Ore.

THE PRESENT STUDY OF THE JUGLANDACEAE IN MINNESOTA

A study of the wood of the walnuts and hickories of Minnesota was undertaken as a basis for this paper, covering its structure and certain physical properties. These two genera contain important species in Minnesota and a knowledge of these properties is essential for intelligent application of its uses:

The species studied were:

Juglans cinerea, L. Butternut
Juglans nigra, L. Black Walnut
Hicoria minima, Britt. Bitternut
Hicoria ovata, Britt. Shagbark Hickory

RANGE AND DISTRIBUTION. (5, 6) Two genera of trees in North America make up the Juglandaceae, Juglans (the Walnuts) and Hicoria (the Hickories). Hicoria is principally an American genus, being found in the eastern United States and in Mexico (Sargent[5] gives a hickory in China). Juglans is found in temperate North America, the West Indies, South America from Venzuela to Peru, Western and North China, Korea, Manchuria, Japan, and Formosa.

Juglans. Juglans in North America is found in the eastern and southwestern United States, and in California. Sargent (5) describes six species in North America. The species found in Minnesota are Juglans cinerea, Butternut or White Walnut, and Juglans nigra, Black Walnut.

Juglans cinerea extends from Southern New Brunswick and the valley of the St. Lawrence river in Ontario, to southern Minnesota, eastern South Dakota, eastern Iowa, south to northern Arkansas, Delaware and eastern Virginia, south on the Appalachians to northern Georgia and Alabama.

In Minnesota it is found in rich woods and hillsides, common southward and southeastward, but not in the southwest. It runs north as far as in Cass County and near the Snake river in Pine County. The northern boundary is still indefinite but apparently keeps in the latitude of Duluth. Its western limit is practically that of the Big Woods. See Map, Fig. 1.

Juglans nigra extends from western Massachusetts to southwestern and southern Minnesota, south to Texas and western Florida.

Its range in Minnesota is rather small, being found in rich woods, abundant in the southwest, distributed to Nininger, Dakota County, into southern Scott and Carver Counties. From there it follows well along the Minnesota river and into Nicollet, Redwood, Murray, and Nobles Counties. In the south and southwest it is found only along stream banks or in scattered groves as in Walnut Grove in Redwood County. See Map, Fig. 1.

Hicoria. Hicoria is confined to the eastern half of this country and to the highlands of Mexico. Sargent (5) recognizes fifteen species in the United States. In Minnesota, Hicoria minima, Bitternut or Swamp Hickory, and Hicoria ovata, Shagbark hickory are found.

Hicoria minima extends from southern Maine to Quebec, Ontario, to northern Minnesota, south to eastern Texas and northwestern Florida.

In Minnesota it occurs in rich woods common southward apparently as far west as Martin County in the south following fairly closely the Big Woods, but going farther north than the butternut to Cut Foot Sioux north of Winnibigoshish Lake, to Rush Lake and Mille Lacs, infrequently to the upper Mississippi and to the tributaries of the St Louis river. See Map, Fig. 1.

Hicoria ovata occurs from southern Maine to southeastern Minnesota, south to eastern Texas and western Florida.

In Minnesota it abounds in rich woods or drier hillsides common in Houston County, extending north to Weaver and Kellogg in Wabasha County, near Chatfield in Olmsted County, and found infrequently as far west as Moscow and Freeborn County. Its range is the smallest of the Juglandaceae in this state. See Map, Fig.1.

RANGE OF JUGLANS AND HICORIA

FIG. 1.

DENDROLOGICAL CHARACTERISTICS. The Juglandaceae contains trees with commercially valuable wood, with unequally compound leaves, with conspicuous leaf scars and superposed lateral buds. The flowers are monoecious, with the staminate in lateral aments and the pistillate in small spikelike clusters from the current terminal bud. The fruit is thin or thick husked, dehiscent, or indehiscent, containing a smooth or furrowed nut. The bark is furrowed, ridged, scaly, or shaggy.

The walnuts have chambered pith, furrowed nuts, indehiscent fruit, stout branchlets, durable, dark colored wood valuable for interior finish, furniture and cabinet work. Some trees produce nuts for commercial use.

The hickories have solid pith, smooth nuts, four valved dehiscent fruit, tough flexible branchlets, tough, heavy strong heartwood and pale sapwood, very valuable for agricultural implements, carriages, wagons, axehandles and fuel. A few trees produce valuable nuts of commerce.

SYLVICS OF THE SPECIES (7, 8, 9, 10) Juglans cinerea, the Butternut is found more or less along streams and in rich, moist soil, also on lower hill slopes and in valley bottoms. When young it is a rapid grower, but it is apt to decay readily when older. It is not a very prolific seed producer. It is 100 feet high to 2-3 feet in diameter. In Minnesota it is 45-90 feet.

Juglans nigra, the Black Walnut, is dependent upon soil and climatic factors, demanding generally a rich, moist, but well-drained soil. This dependence upon good soil is quite marked, especially in regions of light rainfall. It is intolerant and reproduces by seed and sprout although more commonly by the former. Under good conditions, it is a rapid grower. It is frequently 100 feet and sometimes over 150 feet high, and 4-6 feet in diameter. In Minnesota it grows from 60-125 feet high.

Hicoria minima, the Bitternut Hickory, prefers low, wet, fertile soils as along streams, or away from streams on high uplands in woodlots. It is not very tolerant. It is often 100 feet high and 2-3 feet in diameter, though usually smaller in Minnesota (35-75 feet high).

Hicoria ovata, the Shagbark Hickory, prefers fresh, fertile soils, although it grows very often in fairly dry situations. Next to Pignut Hickory, it is the most tolerant of the hickories. It is a prolific seed producer and good sprouter. Under good conditions it will grow fairly fast. It is from 90-120 feet high and 3-4 feet in diameter. In this state it reaches 50-90 feet.

The Butternuts, Walnuts, and Bitternut Hickories which were cut down for their structural and physical tests were found in valley bottoms under good soil and moisture conditions, while the Shagbark Hickories were found on drier hillsides with a southern exposure.

SOURCE OF MATERIAL. The trees were selected from the regions of their best development in Minnesota. Typical specimens were selected and used. These trees from which the specimen blocks were obtained for the data used in this thesis were thrifty and were cut when in the live and green condition in winter, in two localities in the southeastern part of the state. The trees had to be cut where it was convenient and satisfactory to obtain them. Two regions were chosen because of their different soil types, one near Rollingstone, Minn., in Winona County, and the other near Caledonia, Minn., in Houston County. (Plates 1, II, and III) Around Rollingstone, the soil is of glacial origin, while Caledonia is in the driftless area and loess soil prevails. Since soil has considerable influence on tree growth, it would be interesting from a practical standpoint to know if there is any difference in the quality of wood produced in the two regions. A great deal of emphasis has been placed in the tests on shrinkage and to density and specific gravity. The density and specific gravity of a wood bears a direct relation to its strength values. Since only a few tress were studied in each region, no definite conclusion can be drawn, but from some of the tests made it is evident that there is sufficient difference to warrant further investigations covering more trees.

From the Rollingstone region six trees were cut as follows:

Butternut *(Juglans cinerea) 2 trees
Walnut *(Juglans nigra) 1 tree
Bitternut Hickory *(Hicoria minima)1 tree
Shagbark Hickory *(Hicoria ovata) 2 trees

The first four trees were cut in Straight valley from 2 to 3 miles west of Rollingstone. The two shagbarks were on a side hill with south exposure, a mile northwest of Rollingstone, and grew in a mixture of oaks and other hardwoods.

From the Caledonia region, the trees were all obtained from Crystal Creek valley about 6 miles north of Caledonia, 4 trees being cut:

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* Throughout the remainder of this paper the common or trade name of the wood will be used.

HARDWOOD SLOPE
NEAR
ROLLINGSTONE

STRAIGHT VALLEY NEAR ROLLINGSTONE
BUTTERNUT, WALNUT AND BITTERNUT CUT HERE

BLACK WALNUT
CRYSTAL CREEK VALLEY NEAR CALEDONIA

Butternut *(Juglans cinerea) 1 tree
Walnut, *(Juglans nigra) 1 tree
Bitternut Hickory *Hicoria minima) 1 tree
Shagbark Hickory *(Hicoria ovata) 1 tree

The trees were cut so as to get 3 blocks about 8 inches in length at 10 foot intervals up the tree. The following diagram (Fig. 2, a) explains the position of the blocks in the tree. These blocks were at once shipped to University Farm, where the test specimens were worked out before any appreciable loss of moisture or shrinkage could take place.

PREPARATION OF MATERIAL. From each of these blocks, 3 small test pieces were taken, one for radial shrinkage, one for tangential shrinkage, and one for specific gravity. The radial and tangent blocks varied from 2-1/8 inches to 4-1/4 inches in width, and from 3/8 inches to 1 inch in thickness, and were 2 inches in width. These were cut, a tangent block as far from the pith as possible, tangent to the annual rings, a radial block, cut on a line through the pith or along the radius, and a specific gravity block 1-5/8 inches square and 4 inches long. The tangent and radial blocks were also used in loss of weight determination, while the specific gravity blocks were used to determine the specific gravity of the wood, water content, loss of moisture in drying and volumetric shrinkage. It will be seen from the diagram (Fig. 2,b) that the specific gravity block was taken out at a place where the best representative sample could be obtained. In the hickories it was sometimes impossible to avoid discolorations caused by woodpecker marks. Some blocks contained all sap, some

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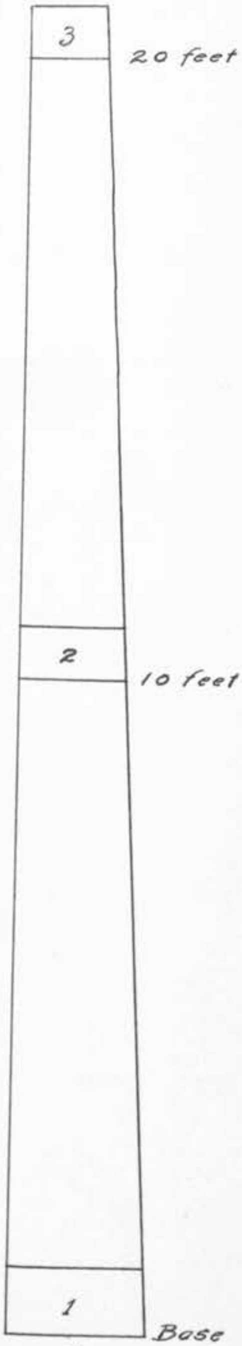
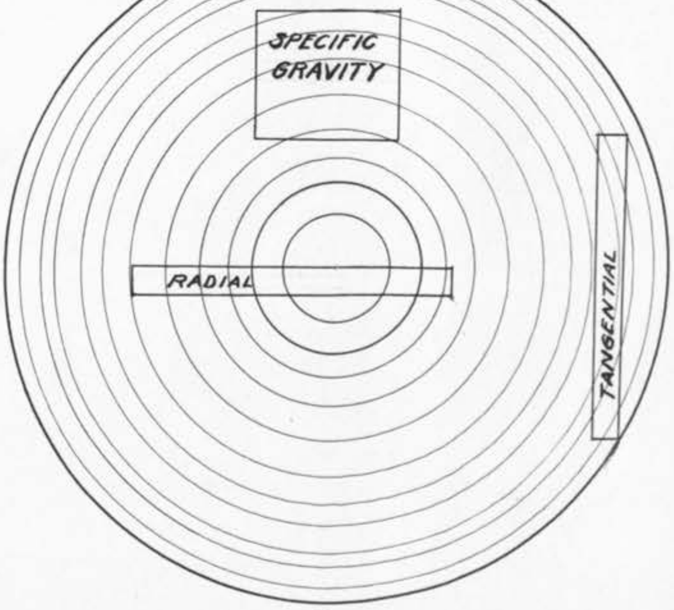
* Throughout the remainder of this paper the common or trade name of the wood will be used.



a.
POSITION OF BLOCKS IN TREE



b.
POSITION OF RADIAL, TANGENTIAL AND SPECIFIC GRAVITY BLOCKS

FIG. 2.

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all heart and some parts of both heartwood and sapwood.

ROUTINE METHODS. For the weighing of these blocks, and for the making of moisture determinations, a balance weighing to the hundredth of a gram was used. Three Starrett micrometer calipers (2-3 inches, 3-4 inches, and 4-5 inches) were used to measure the blocks for shrinkage. The tangent and radial blocks were measured and weighed each day (excepting Sundays).

The three tangent and three radial blocks of each tree were measured and weighed in the same order each day so as to prevent any great cumulative errors. The scales were balanced and adjusted each day. The specimens were considered as air dry when their weight began to fluctuate with the relative humidity of the air. When air dry, they were put into the oven at 100°C. (The Rollingstone butternut and bitternut blocks were heated to 90° for the first three days) Oven-dry was determined by the constant weight of the specimens over two or three days. Fluctuation occurred here as when air dry.

The specific gravity blocks were weighed only, each day, and their air and oven-dry weights determined as with the tangent and radial blocks. The volume and specific gravity of each block was determined by the method given below which is used at the Forest Products Laboratory at Madison, Wis.

Method of Determining Volume and Specific Gravity of Wood.

1. Weigh the green block. Then obtain its volume by displacement in water:

a. Balance scales and completely immerse green block attached to point of rod.

b. Rebalance scales. The difference in grams being the weight of the water displaced by the block. A cubic centimeter of water weighs one gram and therefore the weight in grams required to rebalance the scales is the volume of the block in cubic centimeters.

c. Weigh oven-dry block and determine its volume.

2. Divide the weight of the oven-dry block by its oven dry volume and the result is the specific gravity based on oven-dry volume. $\frac{W}{V}$ equals specific gravity.

3. Oven-dry weight green volume equals specific gravity based on green volume.

The relative humidity of the air was determined each day using an egg beater type wet and dry bulb thermometer, and also a double Fahrenheit wet and dry bulb type which was read in breeze produced by an electric fan. The speed and distance from the fan was the same each day. The two types checked closely.

Remarks on changes in the wood were noted each day as checking, warping, etc.. The following sheets show the daily routine of weighing and measuring a tangent block and of weighing a specific block (Figs. 3 and 4).

STRUCTURE OF WOOD. The structure of wood refers to the character and arrangement of the cells or wood elements of which the wood is made, also to their form and development. Upon structure depends the physical and mechanical properties of wood, for without a thorough knowledge of the anatomy of wood one can not determine or judge results when wood is put to its various uses. In trying to compare the strength of cedar and hickory

Tree No. A - Butternut
Locality where grown - Caledonia
Height from ground - 10 feet

Radial
Tangent
Volume

Specimen No. Cal.AJC 2 T

Date	Measurement In.	Shrinkage In.	Weight Gms	Gain or Loss Gms	Humidity Per Ct	Remarks
April 4	4.329		95.15		37	Green
" 5	.324	.005	79.81	15.34	41 & 34	No ck. No wp.
" 6	.320	.004	72.67	7.14	39	" "
" 7	.308	.016	63.74	8.93	36	" "
" 8	.303	.005	59.02	4.02	40	" "
" 9						
" 10	.253	.050	53.09	5.93	36	" "
" 11	.228	.025	51.50	1.59	31	" "
" 12	.203	.025	50.29	1.21	27	" "
" 13	.185	.018	49.38	0.91	28	" "
" 14	.182	.003	49.28	0.10	30 & 34	" "
" 15	.179	.003	49.16	0.22	27	" "
" 16						
" 17	.175	.004	48.97	.19	33	" "
" 18	.169	.006	48.70	.27	21	" "
" 19	.168	.001	48.64	.06	21	" "
" 20	.168	.000	48.67	-.03	29	" "
" 21*	.167	.002	48.63	.04	27	" "
" 22	.115	.052	45.47	3.16		" "
" 23						
" 24	.115	.000	45.40	.07		" "
" 25#	.109	.006	45.44	-.04		" "
" 26	.112	-.003	45.31	.13		" "
" 27	.112	.000	45.30	.01		" "
" 28	.111	.001	45.34	-.14		" "
" 29	.113	-.002	46.03	-.69	31	" "
" 30						
May 1						
" 2	.131	-.018	47.05	1.02	56	" "

*Air dry
#Oven dry

Fig. 3. Shrinkage record.

Tree No. A - Butternut
Locality where grown - Caledonia
Height from ground - 20 feet

Vol.(Green) 178.62 cc.
Vol.(Oven dry) 162.0cc.

Specimen No. Cal. AJC 3 Sp.

Date		Weight Gms	Loss Gms	Gain Gms	Humidity Per Cent	Remarks
April	4	113.36			37	Green
"	5	98.95	14.41		41 & 34	No ck. No wp.
"	6	91.33	7.62		39	" "
"	7	84.93	6.40		36	1 ring ck. No wp.
"	8	80.57	4.36		40	" " "
"	9					"
"	10	75.64	4.93		36	" " "
"	11	73.74	1.90		31	" " V.sl.wp.
"	12	72.28	1.46		27	" " "
"	13	70.40	1.88		28	" " "
"	14	69.41	0.99		30 & 34	" " "
"	15	68.93	0.48		27	" " "
"	16					
"	17	67.91	2.02		33	" " "
"	18	67.35	0.56		21	" " "
"	19	66.99	0.36		21	" " "
"	20	66.93	0.06		29	" " "
"	21	66.70	0.23		27	" " "
"	22	66.59	0.11		35	" " "
"	23					
"	24	66.87		0.28	46	" " "
"	25	67.09		0.22	39	Closing
"	26				24	"
"	27	66.54	0.55		29	"
"	28					
"	29	66.39	0.15		31	"
"	30					
May	1	66.34	0.05		34	"
"	2	66.72		0.38	56	"
"	3	61.76		0.04		Closed
"	4	61.67	0.09			"
"	5	61.64	0.03			"
"	6	61.60	0.04			"
"	7					
"	8	61.60	0.00			"
"	9	61.58	0.02			"

Fig. 4. Specific gravity record.

without knowledge of the make-up of those woods is like a doctor trying to diagnose a case without knowledge of the anatomy and physiology of the human body. It is fundamental without question.

Wood is a non-homogeneous substance unlike our homogeneous structural materials, as iron, steel and concrete. See Plates IV - XV. It is made up of small cells, placed side by side, sometimes more or less uniform and sometimes of several types, some with thin walls and large lumens, others with very thick walls and very narrow lumens. These cells are, with the exception of true vessels in hardwoods or angiosperms, closed at both ends and more or less pointed or oblique. The cells for the greater part run parallel to the main axis of the tree or vertically, while others start at the pith or at a point in the radius of the tree and run radially in small or large bands to the bark or edge of the wood. Thus we find two sets of cells at right angles to each other. These bands are spoken of as medullary rays, pith rays, or as rays. These rays serve partly as specialized food or storage cells, as carriers or storers of food coming down the trunk by the way of the phloem or inner bark. These food cells, called ray parenchyma, are usually thin-walled and help distribute the food throughout the stem or trunk of the tree.

Wood in a tree is formed in two places, at the growing point of the stem and just beneath the bark all around the stem. In temperate climates where there is a distinct rest period of no growth, or very slight growth, the additions each year form concentric bands or layers of wood just beneath the bark, formed by a layer of cells between the inner bark and the wood called the cambium. This cambium each year adds a new layer of wood on the outside of that of the previous year and a new layer of bark inside of that of the previous year. These wood layers are called annual rings and are best observed upon the transverse or cross section. Therefore each annual ring is a section of a cone placed over the layer of growth of the year before. A tree is not then a true cylinder, but a series of cones one on top of the other. Each ring consists of two parts - soft wood formed in the early spring, consisting of large thin-walled cells and called springwood, and harder, denser wood formed in the summer, consisting of smaller thick-walled cells and called summerwood. The amount of summerwood in a ring is a good indication of its strength. See Table 1. There may be a sharp division between springwood and summerwood, or it may be gradual.

SAPWOOD AND HEARTWOOD. The living, functioning cells of the wood which comprise the outer layer of growth of a tree are spoken of as the sapwood. Usually the sapwood is light in color. The usually darker colored portion of the wood inside the sapwood is made up of non-living cells which have ceased to function as living cells, but still serve as mechanical support for the tree. This portion is called the heartwood. There usually is a sharp line of demarcation between sapwood and heartwood. Some genera, as Hicoria, tend toward thick sapwood. The bitternut and shagbark hickories in the tests showed 34 per cent and 66 per cent sapwood respectively, while butternut showed 9 per cent and walnut 19 per cent. The average was raised for the walnut by one tree which showed 33 per cent sapwood.

Sapwood is greater in younger trees and also in the upper parts of older trees. The trees tested clearly show this.

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Table 1. General Table of Structural and Physical Properties.

Species	Locality	Wt.per Cu.Ft. When Green	Sp.Gr. Oven Dry Based on Green Vol.	Shrinkage Green and Oven on Vol.	Tang.	Rad.	Av. Age	Av. Height Ft.	Av. Diam. D.B.H. In.	Per Ct. Sap-wood	Per Ct Summer wood	Rings per Inch
Butternut	Minn.	46	.36	9.6	5.2	3.9	71	65	10	9		15.3
Butternut*	Wis.	45	.35	9.4	5.7	3.6						
Walnut	Minn.	58	.51	13.4	7.5	5.5	40	51	10.7	19		8.7
Walnut*	Ky.	58	.51	11.3	7.1	5.2						
Bitternut		65	.60	16.6	9.5	7.7	57	50	6.7	34	74	16.5
Bitternut*	Ohio	64	.60								70	
Shagbark		66	.68	19.3	12.0	8.2	48	49	8.5	66	78	11.8
Shagbark*	O.,Miss. Pa.,W.Va.	64	.64	16.7	10.5	7.0					66	

*Taken from Betts "Timber - Its strength, Seasoning and Grading" and from U. S. D. A. Bul. 556, Mechanical Properties of Wood Grown in the United States.

It would be possible to determine roughly the height of heartwood in a tree by the species in question, for a given height and a given diameter. Shagbark B from Rollingstone and Shagbark A from Caledonia clearly show this.

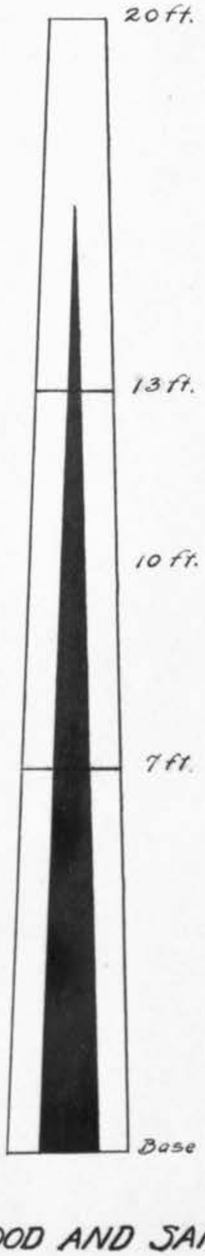
	Sapwood Per Cent		
	Base	10 Feet	20 Feet
Rollingstone Shagbark B	58	100	100
Caledonia Shagbark A	47	60	100

It is evident that in the first tree the heartwood stops somewhere in the first ten feet, while the heartwood in the second tree stops within the ten and twenty foot sections.

The Rollingstone tree is 42 years old, 6.5 inches in diameter and 45 feet high, while the Caledonia tree is 56 years old, 9.0 inches in diameter and 56 feet high. Fig. 5 shows diagramatically the approximate height of heartwood in the Caledonia tree.

GENERAL STRUCTURE OF THE WOOD OF WALNUTS AND HICKORIES. The wood of these genera, as well as other hardwoods, is made up of pores and vessels, wood fibres, wood and ray parenchyma, and of wood tracheids.

Pores or Vessels. The pores are hollow tubes of joined cells placed one above the other, large or small, and continuous sometimes throughout the height of the tree. They may be entirely clear and open, or nearly so, as in red oak, or full of intrusions from adjacent cells (mainly parenchyma). These "growths" clog the cells and prevent rapid passage of liquids. In some hard-



HEARTWOOD AND SAPWOOD
IN CALEDONIA SHAGBARK

FIG. 5.

woods the pores are much larger in the spring growth or springwood and rather abruptly become smaller in the summerwood, thus forming a porous band or ring. Such woods are known as ring-porous woods. Hickories are a good example of this class, as well as ash and elm. Another group seems to have the pores scattered fairly evenly throughout the rings. Such woods are classed as diffuse-porous. The walnuts are good examples of this group, as are also the birches and maples.

Wood Fibres. Wood fibres make up the denser, harder part of the annual ring, and to their arrangement and occurrence is due the variation in the density and specific gravity of a wood. They are small cells, thick-walled with narrow lumens, and are found mostly in the summerwood. They are slender, spindle shaped, and sharppointed (11). They contain in their walls simple or bordered pits, which are thin places in the walls to facilitate the the passage of the cell contents. The simple pits are usually associated with the distribution of elaborated food materials, while the bordered pits are associated with the passage of water.

Wood and Ray Parenchyma. Wood parenchyma cells may be distinguished from wood fibres by their thin walls, the light colored tissue they form, and by their transverse or oblique end walls and by their septate character. They serve as distributors and storers of elaborated food materials. Ray parenchyma have the same function, but are horizontally disposed. According to Jeffrey (17) pp. 50-52, wood parenchyma frequently occurs as scattered throughout the wood cells and is known as diffuse parenchyma. This is typical of the Juglandaceae. See Plate Xa for this arrangement of wood parenchyma as shown in Hicoria minima.

The parenchyma cells were stained before photographing as follows:

1. Dehydrated in 95 per cent alcohol
2. Starch in wood parenchyma stained by placing in a weak solution of potassium iodide and iodine
3. Cleared in xylol
4. Mounted in xylol balsam

Crystals of calcium oxalate frequently appear in the parenchyma of Juglans nigra. (Plate IX)

STRUCTURE OF JUGLANS CINEREA. (11, 19, 20, 21, 22) (Plates IV, V, VI)

Wood. Lighter and more porous than walnut.

Sapwood. Narrow, usually less than one inch wide, white in color or nearly so. The three trees tested showed an average amount of sapwood of 9 per cent.

Heartwood. Light brown, lighter in color than walnut. Average amount for three trees 91 per cent.

Annual rings. Usually broad, especially when young. The average rings per inch observed was 15.3. The first few years, varying up to 10 or 15 years, produced wider rings.

Cross Section (Plate IV). Pores comparatively large and visible to the naked eye, especially in the springwood. Larger in the springwood. Tyloses are present, but do not plug the vessels entirely. Wood fibres comparatively thin-walled. Rays inconspicuous to the naked eye. Yearly divisions represented by fine dark lines. Wood parenchyma in tangential lines independent of vessels.

Tangential Section. (Plate V) Rays 1-4 seriate and from few to 30 cells or more high, more often 2 cells wide, sometimes spatulate in outline.

Radial Section (Plate VI). Rays homogeneous. There are no crystals in the parenchyma cells in butternut.

STRUCTURE OF JUGLANS NIGRA. (Plates VII, VIII, IX). Wood denser and harder than in butternut.

Sapwood. Wider usually than in butternut. Sometimes 3 inches, white, or slightly yellowish. Average of two trees 19 per cent.

Heartwood. Dark rich chocolate brown color. Average for two trees 81 per cent.

Annual Rings. Fairly broad, ordinarily not as fast a grower as butternut. However, it was observed that the Rollingstone walnut obtained a diameter of 11 inches in 25 years, or an average of about 4.8 rings per inch. The Caledonia tree averaged 12.6 rings per inch.

Cross Section. (Plate VII) Pores comparatively large and visible to the naked eye, especially in the springwood. Tyloses present but not plugging the vessels. Year's growth closed by several rows of flattened thick-walled fibres. Wood fibres thicker-walled than in butternut. Rays inconspicuous. Wood parenchyma in more or less tangential bands.

Tangential Section. (Plate VIII) Rays usually 3-5 cells wide, usually not as high as butternut (few to 25 cells).

Radial Section. (Plate IX) Rays homogeneous. Calcium oxalate crystals are indicated in longitudinal sections. The crystals are quite large as will be observed in Plate IX.

USES AND VALUE OF JUGLANS. The wood of Juglans is not as tough as that of hickory, is often straight-grained and sometimes curly. It seasons under well controlled conditions very well and it holds its shape. Black walnut is highly prized for furniture and panel veneer work, because of the beautiful grain produced from walnut burls or from stumps. It is the premier gunstock wood and no wood has ever taken its place in this respect. It resists shock well, seasons well, and holds its shape, besides attaining a rich brown color and a high, beautiful polish.

STRUCTURE OF HICORIA (11,20,21) Plates X - XV). The hickories are divided into two groups, commercially, based upon weight, hardness, and toughness - the first group, the true hickories, which are much harder, heavier and tougher than the second group, pecan hickories. The Shagbark is typical of the first group and the Bitternut of the second group. The minute structure of the hickories is practically the same (except for the water hickory), so that the structure of the genus will be representative for the two species.

Sapwood. Usually fairly wide, especially in young trees, white in color. It was observed to have an average width of 34 per cent in Hicoria minima, the bitternut, and of 66 per cent in Hicoria ovata, the shagbark.

Heartwood. Dark brown, average width in bitternut 66 per cent, in shagbark 34 per cent.

Annual Rings. The wood is ring-porous and each year's growth is easily determined by the contrast between the large pores in the springwood and the very small ones in the summerwood abutting it. Average rings per inch in shagbark 11.8, and in bitternut 16.5.

Cross Section. (Plates X, XIII) Pores of springwood easily visible to the naked eye, forming a distinct band and becoming smaller in the summerwood. Wood parenchyma in distinct tangential lines, See Plate Xa Pores partly or nearly closed by tyloses.

Tangential Section. (Plates XI, XIV) Rays 1-5 cells wide and not uniform in height and shape.

Radial Section. (Plates XII, XV) Rays somewhat heterogeneous. Crystals are found in the parenchyma.

USES AND VALUE OF HICORIA. The wood of the hickories is tough, strong, and hard, unlike that of Juglans. Because it has these special features it is not used as a construction or furniture wood. It is mainly used for axe handles, agricultural implements, wheels, and spokes, where great strength, together with toughness and ability to withstand shock, are needed. No substitute for hickory has ever been found and this country is indeed fortunate to have the world's supply.

PHYSICAL PROPERTIES. Physical properties of wood are those properties which have to do with the molecular composition of the wood elements, as density, weight, color, taste, resonance, water content, shrinkage, warping, checking, etc. They are basic to the mechanical properties of wood, such as strength, bending, and resistance to stresses of various kinds. To know what wood will do under different conditions, one must know something of its physical properties as well as its structure. Strength for example, is greatly dependent upon the moisture content at time of test. The properties considered in this thesis are principally weight, density, specific gravity, water content, seasoning, shrinkage, warping, and checking.

WEIGHT, DENSITY, AND SPECIFIC GRAVITY. Weight is the downward force of a body. Density is the weight of a unit of volume, as 20 lbs. per cubic foot. The two terms are interchangable. The weight of wood substance itself is heavier than water, having a specific gravity of about 1.6. Wood does not ordinarily sink in water because the cell cavities are filled with air which buoy it up. One wood has greater density than another wood simply because it has more actual wood substance in a unit of space or volume. Therefore hickory is denser than basswood or butternut. It necessarily follows then that it is heavier or has more weight. This increase in density or weight is occasioned by thicker-walled cells with smaller lumens or cavities as compared with the larger lumens in the thinner-walled cells of butternut. As a measure of strength and hardness then, weight or density is a good indicator. This is but natural, for in lifting two pieces of wood of equal size but of different weight, it is naturally concluded that the heavier is the stronger and harder. As a general rule the denser the wood the greater its shrinkage. (14) This was well borne out in the shrinkage of the hickories and the walnuts, the hickories shrinking the most and the butternuts the least.

Specific gravity is a direct ratio between the density of a piece of oven-dry wood and the density of water at 4 degrees Centigrade, which is 62.43 lbs. per cu.ft. By dividing the weight in lbs. per cu.ft. by 62.43 the result is the specific gravity of the wood, as $\frac{20}{62.43} = 3.2$. The specific gravity of water is standard at 1.0. Specific gravity may be expressed as based upon volume when green, air-dry or overn-dry. Since wood shrinks in volume in drying the specific gravity is not the same when oven-dry as when green.

The woods tested for specific gravity compare favorably with the figures in tests published in U.S.D.A. Bulletin 556 (18) by Newlin and Wilson on "Mechanical Properties of Woods Grown in The United States. See Table 1. Table 2 represents the specific gravity of the sections in each tree giving the averages for each species as a whole, as well as for the two localities, and also giving the weight per cubic foot when green and when oven-dry. Weight per cubic foot means more to the average person perhaps, because of its immediate practical meaning. The weight per cubic foot when green was based upon the specific gravity of green weight and green volume, while that when even-dry is based on oven-dry weight and oven-dry volume. In some instances it will be noticed that the higher the block in the tree the less the specific gravity, as for example, Tree A, Rollingstone butternut, specific gravity 1st block .44, specific gravity 2nd block .42 and specific gravity 3rd block .41. However, it will also be seen that there is great variation in this respect. There is also chance for error in computing the volume of the specific gravity blocks. Record on p. 42 states that in ring-porous woods such as hickory, the growth in the spring forms later at the base of the tree than at the top, and therefore the base contains more summerwood, which is denser, and therefore the base has the greatest specific gravity. It can hardly be expected that the last block cut at 20 feet would show any great decrease in density. The table merely indicates that there is a slight and sometimes considerable variation for short distances. Specific gravity

4-22-6M

Table 2. Showing Weight per Cubic Foot and Specific Gravity.

Species	Tree	Locality Where Cut	Weight per cubic foot								Sp.Gr.Oven Dry Based on Green Vol.				Sp.Gr.Oven Dry Based on Oven Dry Vol.			
			Green				Oven Dry											
			1 Lb.	2 Lb.	3 Lb.	Av. Lb.	1 Lb.	2 Lb.	3 Lb.	Av. Lb.	1	2	3	Av.	1	2	3	Av.
Butternut	A	Rollingstone	58	47	43	49	27	26	26	26	.39	.37	.37	.38	.44	.42	.41	.42
Butternut	B	Rollingstone	52	42	37	44	24	26	25	25	.35	.36	.37	.36	.39	.41	.40	.40
Butternut	Av.	Rollingstone	55	44	40	46	25	26	25	25	.37	.37	.37	.37	.42	.42	.41	.41
Butternut	A	Caledonia	54	42	41	46	25	24	24	24	.36	.35	.34	.35	.40	.39	.38	.39
Butternut	Av.	Rs.and Cal.	54	43	40	46	25	25	24	24	.36	.36	.36	.36	.41	.40	.39	.40
Black Walnut	A	Rollingstone	60	59	56	58	41	39	37	39	.54	.54	.51	.53	.65	.62	.59	.62
Black Walnut	A	Caledonia	64	57	57	59	35	37	32	35	.49	.51	.46	.49	.56	.59	.51	.55
Black Walnut	Av.	Rs.and Cal.	62	58	56	58	38	38	34	37	.51	.52	.48	.51	.60	.60	.55	.58
Bitternut	A	Rollingstone	67	67	61	65	47	47	45	46	.63	.62	.60	.62	.75	.75	.72	.74
Bitternut	B	Caledonia	68	64	63	65	46	41	46	44	.61	.56	.61	.59	.74	.66	.74	.71
Bitternut	Av.	Rs.and Cal.	67	65	62	65	46	44	45	45	.62	.59	.60	.60	.74	.70	.73	.72
Shagbark	A	Rollingstone	72	68	64	68	57	54	54	55	.73	.71	.70	.71	.91	.86	.86	.88
Shagbark	B	Rollingstone	65	62	62	63	54	51	53	53	.68	.68	.66	.67	.87	.82	.81	.83
Shagbark	Av.	Rollingstone	68	65	63	65	55	52	53	54	.70	.69	.68	.69	.89	.84	.83	.85
Shagbark	A	Caledonia	69	65	66	67	56	54	56	55	.71	.61	.72	.68	.89	.86	.90	.88
Shagbark	Av.	Rs.and Cal.	68	65	64	66	55	53	54	54	.70	.65	.70	.68	.89	.85	.86	.86

again varies as to its position in the block, whether it be taken at the pith, 4 inches from it, or near the periphery. Betts p. 124 shows by graphs that in hickory, tests indicated that from 3-6 inches from the pith gave the highest specific gravity. All specific gravity tests were made regardless of position with the Minnesota trees. As will be pointed out in shrinkage and water loss, specific gravity plays an important part. It is quite evident from this table that the Caledonia trees except the shagbarks have a lower specific gravity than the Rollingstone trees. In the ring-porous bitternut hickory, the greater number of rings per inch in the Caledonia tree can readily be associated with a lesser specific gravity, because the narrower the rings the less the amount of summerwood. It is hard to tell just where the summerwood begins and the springwood leaves off in Juglans.

WATER CONTENT. Water is found in wood in two conditions (1) that which is contained in the cell and vessel cavities and known as free water, and (2) that which is intimately associated with the substance of the cell walls and known as hygroscopic water. Water is also found in the protoplasmic contents of the cells. Hygroscopic water, which occupies the small spaces between the molecules which go to make up the cell walls, is the water which affects shrinkage in wood, for wood does not shrink until the hygroscopic moisture begins to leave the wood or until the fibre-saturation point is reached. The "fibre-saturation point", according to Tiemann (14), is that point at which the cell walls are completely saturated. Any additional water is free water and no increase in strength occurs until the hygroscopic moisture begins to leave the wood. This fibre saturation point varies from20-30 per cent of the dry weight of the wood. (14) This fibre-saturation point is calculated by mechanical methods in strength tests, since wood does not increase in strength until this point has been passed, or in other words, until the hygroscopic moisture begins to leave the cell walls. The moisture content of the blocks was not determined, since there is wide variation in the moisture content of the tree as to sapwood, heartwood, and position in the block. In some cases the heartwood contains more moisture than the sapwood. Moisture determinations tried out with both the specific gravity blocks and the tangent and radial blocks gave results that were unsatisfactory and misleading. For correct moisture determinations, borings into the green wood are made, then weighed and oven-dried, and the amount of water lost computed in percentage of the dry-weight. The water content of green wood may vary from about 33-1/3 per cent to 250 per cent of its oven-dry weight. The following table shows roughly the per cent moisture content of specific gravity blocks from four trees based on oven-dry weight.

	Moisture Per cent	Average Specific Gravity
Caledonia Butternut A	106	.35
Rollingstone Walnut A	82	.53
Caledonia Bitternut A	76	.59
Rollingstone Shagbark B	50	.67

This relationship between specific gravity and moisture content seems to be constant enough from observations made to say that the higher the specific gravity of a wood the lower its total water loss from green to oven-dry condition. This will be further discussed under shrinkage. Air-dry wood contains from 12-15 per cent of moisture, kiln-dry wood about 8 per cent, and oven-dry wood at a temperature of 100° C. from 2-3 per cent moisture. For practical purposes, either air-dry or kiln-dry wood is used. For scientific purposes, oven-dry weight is used. The boiling point of water is the standard temperature (100° C.) for oven-drying. Higher temperatures tend to break down the structure and char the wood. At standard temperature, the wood blocks turned a light or dark brown color, especially noticeable in white sapwood.

SEASONING. Seasoning of wood ordinarily means its drying in air, but seasoning may be accomplished by soaking in water. It is apparent then that the term seasoning refers not only to the drying of the wood cells but to changes in the chemical contents of the cells, such as albumens, resins, tannins, sugars, etc. (16). The carbohydrate substances such as sugars and starch contained in the living cells have great attraction for water and tend to hold the moisture to a great extent. When heat is applied to wood the water passes from cell to cell, the free water leaving first and the hygroscopic water from between the cell wall molecules last. The heat, besides increasing the absorptive power of the wood, apparently destroys the carbohydrate materials which lose their absorptive power, and when wood is thoroughly dried it does not take up as much moisture from the air as it originally contained. Within a reasonable limit, wood contains from 12-15 per cent or slightly more moisture after it has been air-dried. A bitternut hickory radial block after three weeks' exposure to the air weighed 99 grams, or about three more grams than when thoroughly air-dry. This shows that hygroscopic water is taken up by dry wood, the rate and amount depending upon the relative humidity of the air.

Wood does not begin to strengthen until the fibre saturation point is reached, which varies for different woods. As long as any free water remains in the cell cavities the strength remains the same. Upon drying, strength may increase as much as 400 per cent. In large timbers strength gained by drying is offset by weakening of the cell walls by splitting, and by unequal shrinkage.

In drying the blocks, it was observed that the heavier woods, the hickories, took longer than the lighter woods, the butternuts and walnuts.

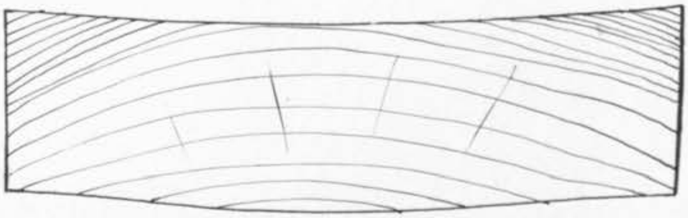
SHRINKAGE AND WEIGHT LOSS. When the fibre saturation point is passed in drying wood, the wood cells shrink or become smaller and thinner walled. Wood shrinks in 3 directions, - in the longitudinal direction, in the tangential direction, and in the radial direction. The wood cells shrink very little in length, and since the majority of cells are placed vertically in the tree this shrinkage is for practical purposes negligible. However shrinkage in the tangential direction is sometimes twice as great as that in the radial direction. The reason for this is apparent when we consider the arrangement of the wood elements. The rays run at right angles, or nearly so, to the vertical wood elements. The ray cells shrink vertically and tangentially, or in other words, in height and width. The height shrinkage tends to shrink the vertical cells in their longitudinal direction, while the latter oppose this. However the vertical cells shrink in their radial direction, thus tending to shorten the length of the ray cells. Thus we have two severe strains produced at right angles to each other, and since the vertical cells also shrink in the tangential direction as well as in the radial direction, the strains become so severe that the wood gives at the point of the easiest cleavage and greatest strains, or along the pith rays, producing checks on drying. Some of these checks which are due to greater tangential shrinkage are permanent and do not close, even becoming larger, but some are only temporary and close again as soon as the interior dries, thus restoring equilibrium to some extent. These checks are, however, a weakness in wood. Again, along the radius, the bands of springwood and summerwood are alternate, thus equalizing the shrinkage radially to a great extent, while the shrinkage in the tangent position, or around the circumference, is represented by continuous bands of summerwood which makes up the most of the wood in a tree. Thus it is evident that radial shrinkage is less than tangent shrinkage. (Figs, 6, 7)

The degree of shrinkage is plainly seen in the blocks of hickory and butternut. In the case of the radial blocks taken out of a small tree where both a radial and a tangent surface appear on the two sides of the block, the block assumes a concave shape on the tangent side, (Fig. 7a) showing the greater tangential shrinkage. The greater the degree of tangency the greater is the difference in shrinkage from the radial. In a tangent block from a good sized tree there is a less concave shape, because the block contains more nearly parallel rings and is less influenced by radial shrinkage. (Fig. 6a)

However, since heavier woods generally shrink the most because of the greater amount of thicker-walled cells, the hickory tangent shows more of a concave surface. (Fig. 6b) A normal

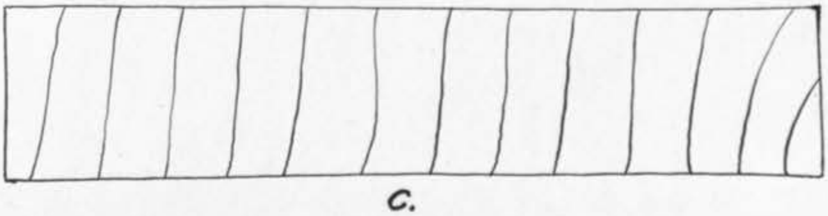
a.

ROLLINGSTONE BUTTERNUT
TANGENTIAL



b.

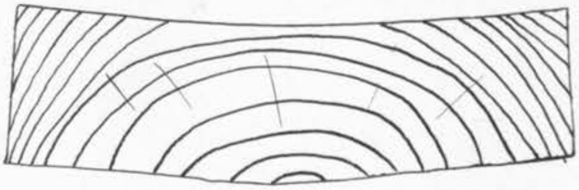
ROLLINGSTONE SHAGBARK
TANGENTIAL



c.

ROLLINGSTONE WALNUT
RADIAL

FIG. 6.



a.

ROLLINGSTONE SHAGBARK

RADIAL AND TANGENTIAL

b.

ROLLINGSTONE SHAGBARK

TANGENTIAL

c.

ROLLINGSTONE SHAGBARK

SPECIFIC GRAVITY

d.

CALEDONIA BITTERNUT

SPECIFIC GRAVITY

FIG. 7.

walnut radial block is shown in Fig. 6c with wide annual rings.

Shrinkage varies with the specific gravity of the wood. This was borne out in the tests, the average of shrinkage from greatest to least being

	Per cent Shrinkage Green to Oven-dry		
	Volume	Tangent	Radial
Shagbark Hickory	19.3	12.0	8.2
Bitternut Hickory	16.6	9.5	7.7
Walnut Hickory	13.4	7.5	5.5
Butternut Hickory	9.6	5.2	3,8

It will be observed that the tangential shrinkage is not twice as much as the radial shrinkage, but that it more nearly approaches that relation in two shagbarks. (See Table 3) This table shows that the radial shrinkage average for all the species is nearly three-fourths (73 per cent), for butternut 75 per cent, walnut 81 per cent, and shagbark 68 per cent. This proportion is held by Newlin and Wilson (16) as three-fifths. See Table 1 for comparisons with trees from other localities in the United States.

The rate of shrinkage of the woods of the walnuts and hickories is again dependent upon their specific gravity or density. The greater the amount of wood substance per unit volume the more wood there is to shrink, and therefore the rate or drop per day will be greater. One of the best ways to observe rate of shrinkage is to study the graphs(Figs. 8-12). Fig. 8 represents the shrinkage of each section, both radial and tangential, of a low specific gravity species of a butternut from the Caledonia region, while Fig. 9 represents the shrinkage of a high specific gravity species, a shagbark hickory from the Rollingstone region. The butternut shrinks less the first two days for example than does

Table 3. Per Cent Shrinkage from Green to Oven Dry.

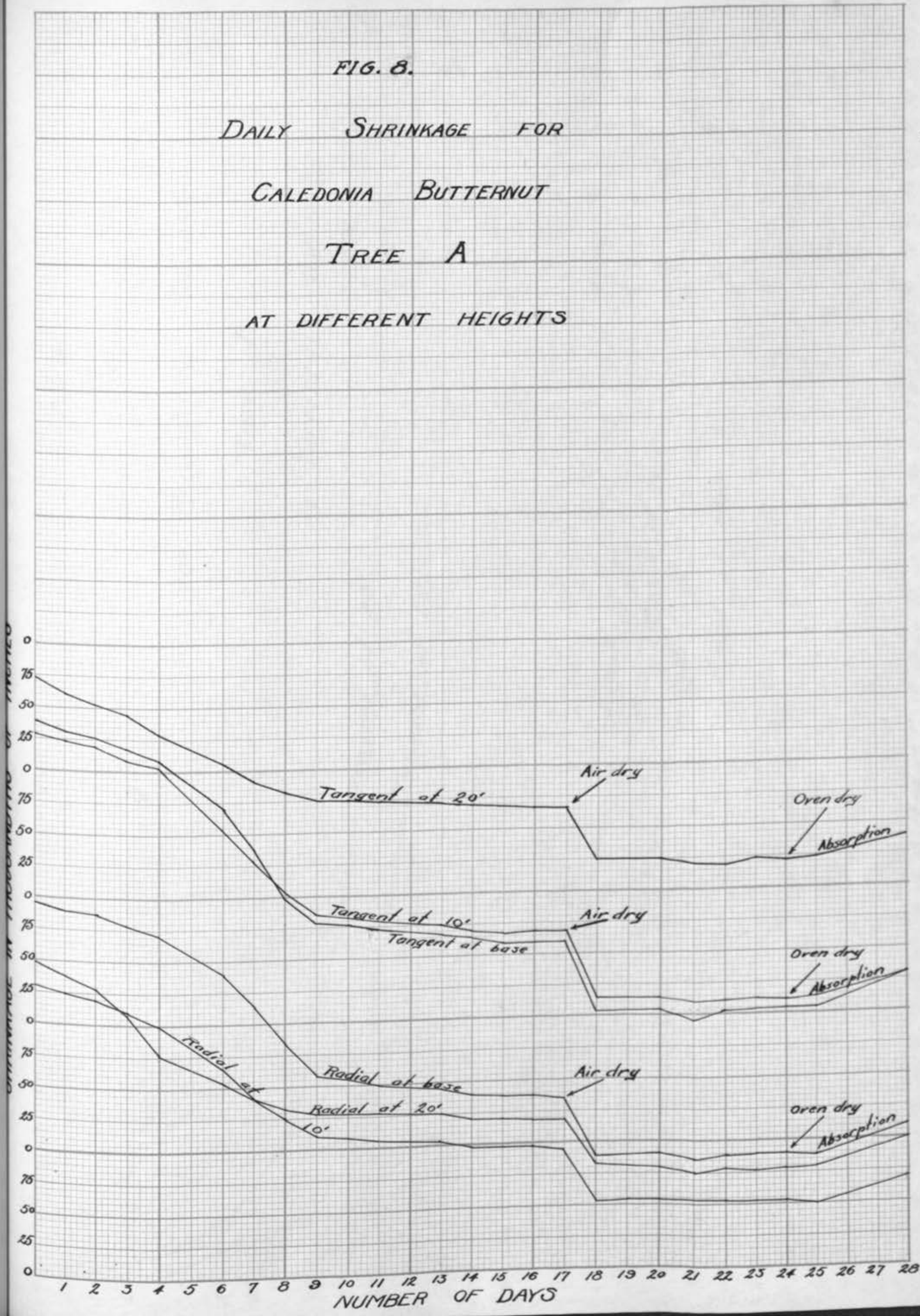
Species	Tree	Locality	Volume				Tangential				Radial			
			1	2	3	Av.	1	2	3	Av.	1	2	3	Av.
Butternut	A	Rollingstone	8.8	10.5	9.4	9.6	4.9	5.3	5.7	5.3	3.7	4.4	4.7	4.3
Butternut	B	Rollingstone	8.8	11.6	8.5	9.6	5.2	5.4	5.7	5.4	3.2	3.4	4.0	3.5
Butternut	Av.	Rollingstone	8.8	11.1	9.0	9.6	5.1	5.4	5.7	5.4	3.5	3.9	4.4	3.9
Butternut	A	Caledonia	9.6	10.0	9.3	9.6	5.0	5.1	5.0	5.0	4.2	4.0	3.8	4.0
Butternut	Av.	Rs and Cal.	9.2	10.5	9.1	9.6	5.0	5.2	5.3	5.2	3.8	3.9	4.1	3.9
Black Walnut	A	Rollingstone	16.6	13.1	13.8	14.5	9.3	7.2	8.4	8.3	5.8	4.7	5.5	5.3
Black Walnut	A	Caledonia	12.7	13.0	11.1	12.3	7.3	6.2	6.6	6.7	6.0	5.6	5.4	5.7
Black Walnut	Av.	Rs. and Cal.	14.6	13.0	12.4	13.4	8.3	6.7	7.5	7.5	5.9	5.1	5.4	5.5
Bitternut	A	Rollingstone	17.2	16.3	16.3	16.6	9.3	9.7	9.5	9.5	6.9	7.3	7.5	7.2
Bitternut	B	Caledonia	17.4	15.5	16.8	16.6	10.3	9.1	9.4	9.6	8.5	7.6	8.6	8.2
Bitternut	Av.	Rs. and Cal.	17.3	15.9	16.5	16.6	9.8	9.4	9.4	9.5	7.7	7.4	8.0	7.7
Shagbark	A	Rollingstone	20.0	17.3	18.4	18.6	12.8	10.9	11.3	11.6	6.9	7.0	8.3	7.4
Shagbark	B	Rollingstone	21.7	17.3	17.4	18.8	13.9	10.9	8.5	11.1	8.2	6.5	7.0	7.2
Shagbark	Av.	Rollingstone	20.8	17.3	17.9	18.7	13.2	15.1	9.9	11.3	7.5	6.7	7.6	7.3
Shagbark	A	Caledonia	20.9	19.1	19.9	20.0	13.3	12.1	12.8	12.7	8.8	9.2	9.4	9.1
Shagbark	Av.	Rs.and Cal.	20.8	18.2	18.9	19.3	13.2	13.6	11.3	12.0	8.1	7.9	8.5	8.2

the shagbark which drops almost vertically in comparison. It will be observed that the first two tangent blocks of the butternut shrink at about the same rate except that the first block curve crosses the second block curve at the eighth day and keeps below it. The third block curve is unlike the other two, and we find that the specific gravity of the blocks in their order from the first are .36, .35, and .34. However the specific gravity hardly seems small enough to account for so small a shrinkage rate. Its shrinkage per cent is about the same as that of the other sections since it is a small block. Examination of its cross section shows finer ringed material than from near the periphery and filled with equal sized pores. This would account satisfactorily it seems for its lesser rate of shrinkage, since there are fewer thick-walled cells to shrink. The relation between the radial curves is a little different, for the third block shrinks more than the other two from the third to the seventh days. Since the specific gravity may vary considerably from its position in the block, it follows that the specific gravity given for this block need not necessarily be a criterion for the shrinkage of the block. The specific gravity block has more uniformity in its rings than this radial block,which would perhaps account for some discrepancy. Since it is hard to ascertain the per cent of summerwood in a diffuse-porous wood, as butternut, it is difficult to account for all the discrepancies at the present state of knowledge of wood. Newlin and Wilson (16) state that the measurement of summerwood in diffuse-porous woods is not accurate and is of no practical value.

In the graph for Shagbark Hickory (Fig. 9) the first section blocks, both radial and tangential, have a greater proportion

FIG. 8.

DAILY SHRINKAGE FOR CALEDONIA BUTTERNUT TREE A AT DIFFERENT HEIGHTS



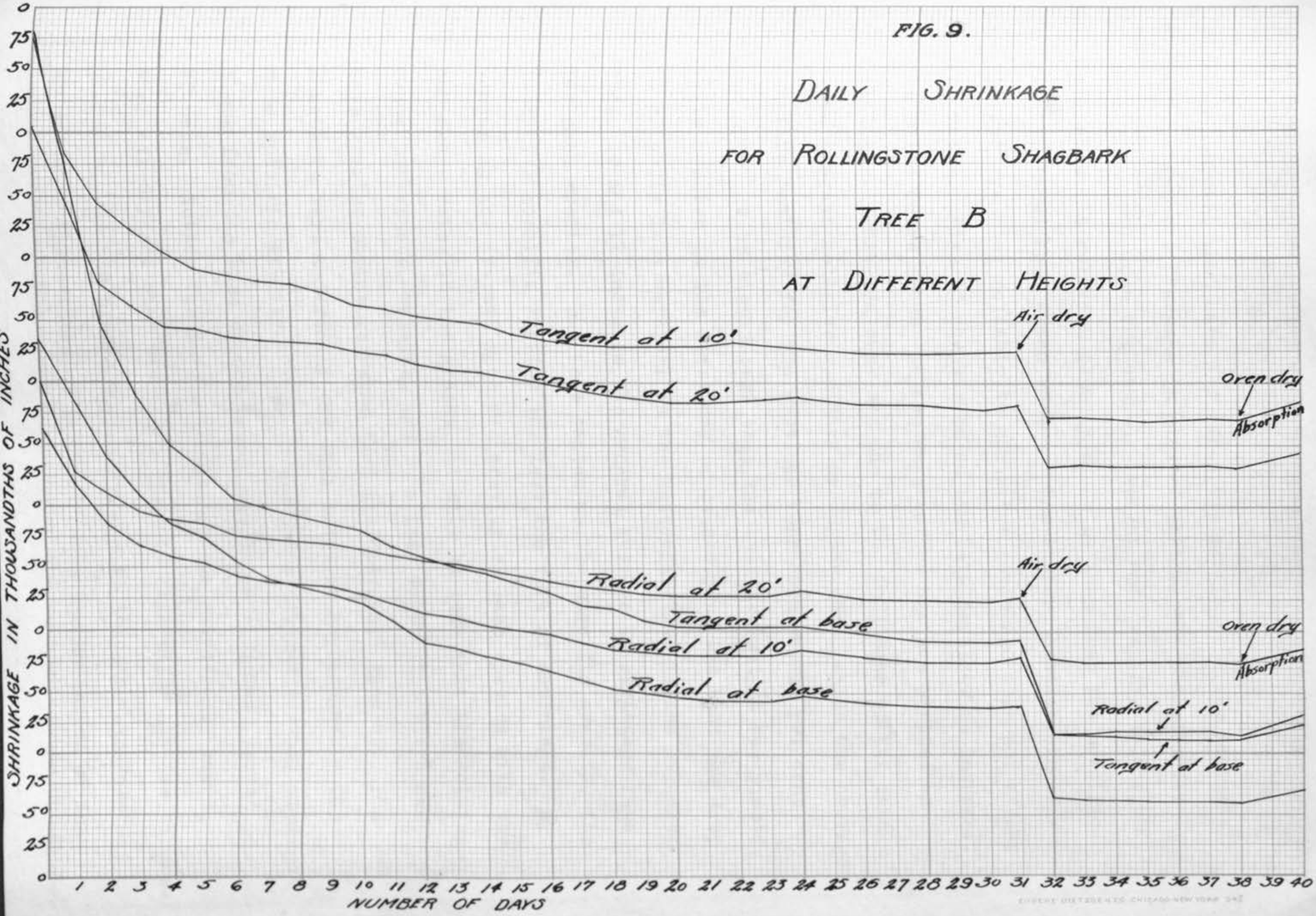


FIG. 9.

DAILY SHRINKAGE

FOR ROLLINGSTONE SHAGBARK

TREE B

AT DIFFERENT HEIGHTS

of summerwood than have the other two sections. This accounts for the great difference in rate of shrinkage. The specific gravity, based upon the oven-dry weight and oven-dry volume, indicates the relation clearly, more so than does the specific gravity based upon green volume. The latter, however, is considered the most reliable to use since shrinkage does not affect its value. Five of the curves on the 24th day show an increase. The sixth curve shows it two days before and was plotted accordingly. This increase was due to the influence of two days of an average relative humidity of 40 per cent, while the average relative humidity for the previous four days was 25 per cent.

It is significant that the oven-dry weight was practically reached in the first day of oven-drying and that the drop is slightly less vertical in the butternut than in the hickory. Figs. 10 and 11 indicate the general average in shrinkage rate for each species. The rate varies as the specific gravity, the lower the specific gravity the less the rate of shrinkage. By comparing the average specific gravity of each species with the shrinkage rates in the graphs, it will be seen that the Rollingstone butternuts, walnuts, and to a less extent the bitternut, have greater shrinkage rates than the Caledonia species. The shagbarks have apparently the same rates with practically the same specific gravity. Fig. 12 shows a bitternut hickory tangent block from the base of the tree, covering a shrinkage period of 80 days. Notice the levels it reaches and practically keeps, when air-dry and when oven-dry. This is typical of all the blocks.

All the graphs were plotted with shrinkage represented as units in thousandths of inches to show the variation of the

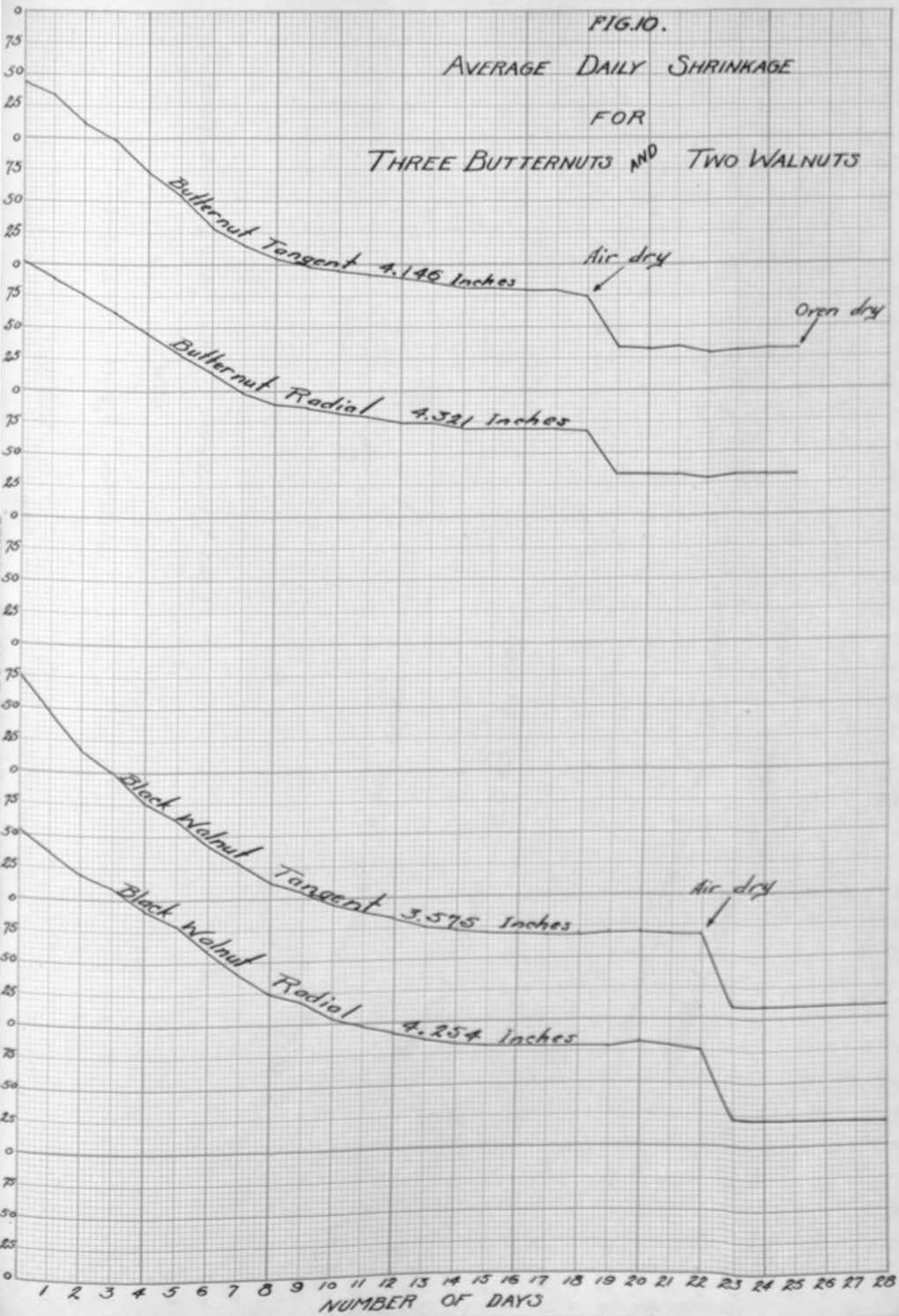
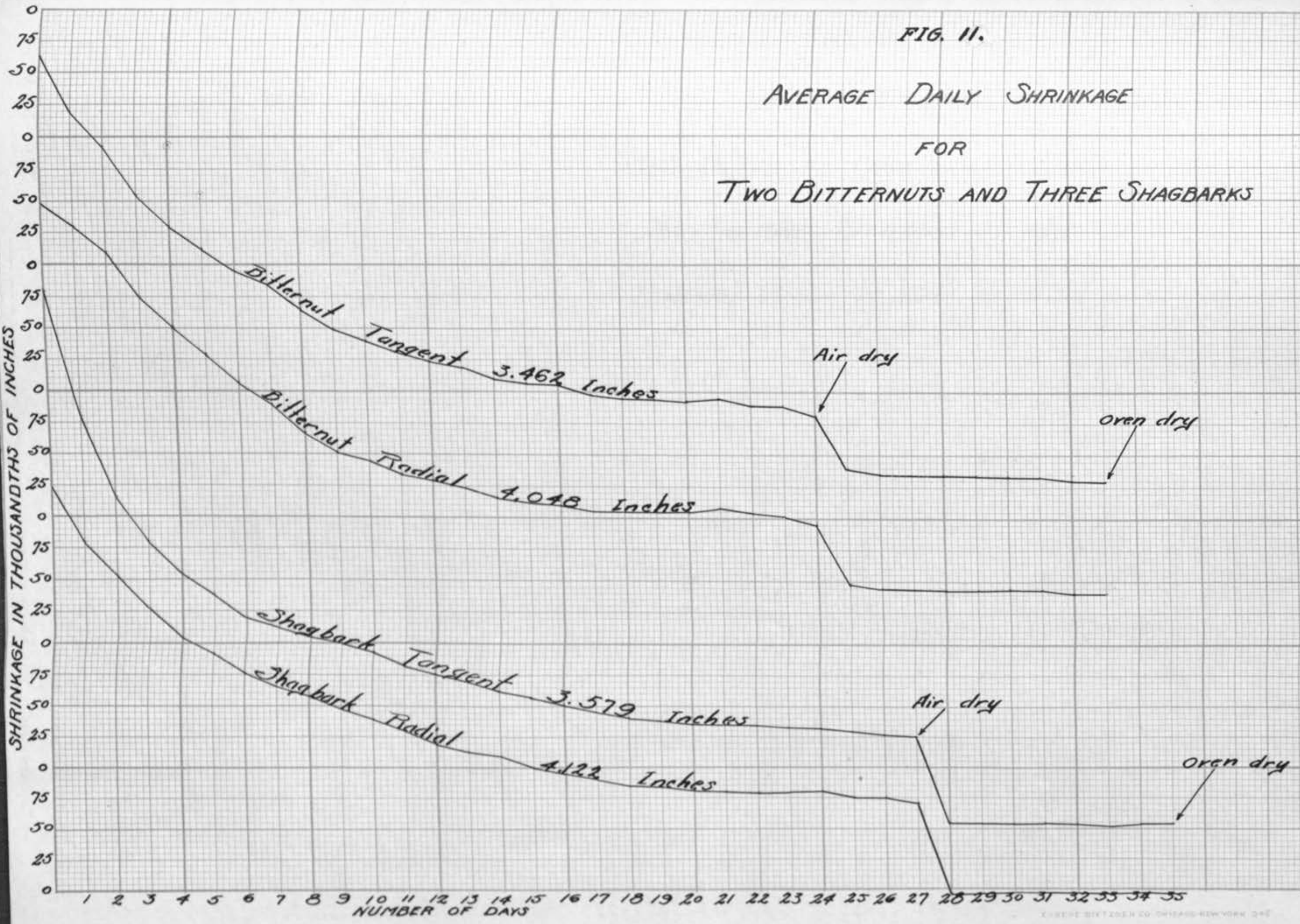


FIG. 10.

AVERAGE DAILY SHRINKAGE FOR THREE BUTTERNUTS AND TWO WALNUTS

FIG. 11.

AVERAGE DAILY SHRINKAGE
FOR
TWO BITTERNUTS AND THREE SHAGBARKS



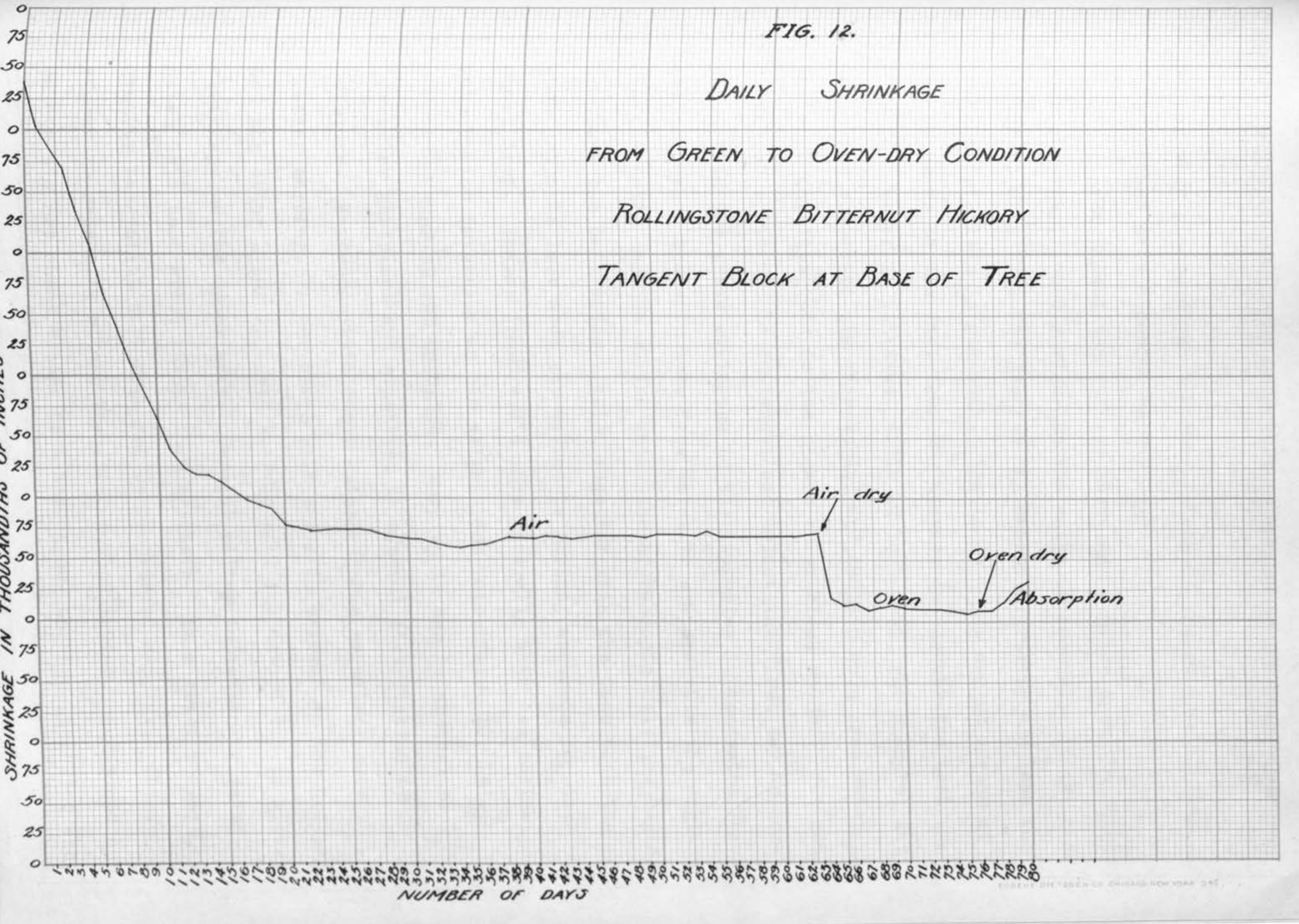


FIG. 12.

DAILY SHRINKAGE

FROM GREEN TO OVEN-DRY CONDITION

ROLLINGSTONE BITTERNUT HICKORY

TANGENT BLOCK AT BASE OF TREE

curves when placed close together. This is the same as if they were plotted with a common base-line.

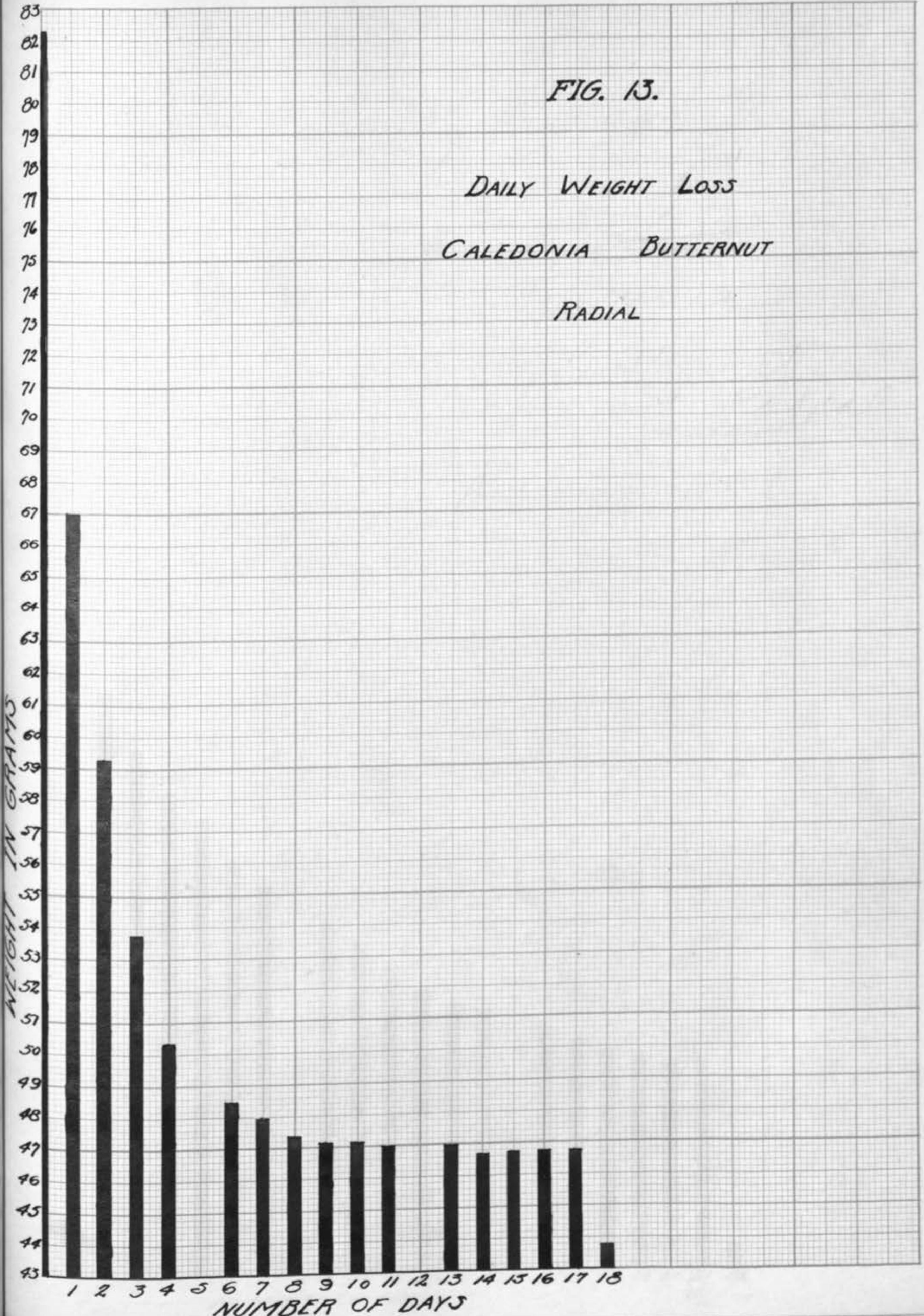
The amount and rate of shrinkage depends upon the weight lost each day. Wood shrinks as the water is removed. It is interesting to note that the greater the specific gravity the less the total weight loss in per cent. (Table 4) This can be accounted for it seems by the fact that the heavier and denser the wood the less free water it contains, while in butternut, for example, the cells are comparatively thin-walled and contain more free water in the cell cavities than do the hickories or black walnut. The small amount of shrinkage in butternut and walnut the first day as compared with the great shrinkage in the hickories is accounted for by the fact that there is more free water to evaporate in the Juglans and the cells can not shrink until the hygroscopic moisture begins to leave the cell walls. This, together with the fact that the wood contains less wood per volume to shrink, accounts for the small drop. Graphs drawn would show generally that the shrinkage rate varies inversely as the weight loss rate (Figs. 13, 14).

WARPING AND CHECKING. Warping is due to unequal or irregular shrinkage and sometimes to unequal distribution of moisture. Hardwoods with their heterogeneous structure show greater warping. A wet board with one side exposed to the hot sun and the other lying on a wet surface will cup upward due to greater shrinkage on the upper side. Careful piling in seasoning eliminates this to a great extent in many cases. In a sense perhaps, greater tangential shrinkage may be considered warping. Checks appear in seasoning within the first day of drying. Butternut and walnut did not check except in a few cases, but the hickories did.

Table 4. Per Cent Loss in Weight.

Species	Tree	Locality Where Cut	Gen. Av.	Tangential 1	Tangential 2	Tangential 3	Tangential Av.	Radial 1	Radial 2	Radial 3	Radial Av.
Butternut	A	Rollingstone	46	46	50	40	45	47	50	43	47
Butternut	B	Rollingstone	48	48	50	46	48	50	51	42	48
Butternut	Av.	Rollingstone	47								
Butternut	A	Caledonia	52	59	53	47	53	59	49	46	51
Butternut	Av.	R. S. and Cal.	49								
Black Walnut	A	Rollingstone	43	45	42	41	43	48	41	40	43
Black Walnut	A	Caledonia	49	52	51	40	48	54	50	48	51
Black Walnut	Av.	R. S. and Cal.	46								
Bitternut	A	Rollingstone	39	40	36	34	36	44	42	40	42
Bitternut	B	Caledonia	43	42	41	34	42	45	45	41	44
Bitternut	Av.	R. S. and Cal.	41				39				43
Shagbark	A	Rollingstone	33	32	31	30	31	38	36	33	36
Shagbark	B	Rollingstone	33	33	33	32	33	37	32	32	34
Shagbark	Av.	Rollingstone	33				32				35
Shagbark	A	Caledonia	33	31	30	31	31	39	34	31	35
Shagbark	Av.	R. S. and Cal.	33				31				35

FIG. 13.



DAILY WEIGHT LOSS

CALEDONIA BUTTERNUT

RADIAL

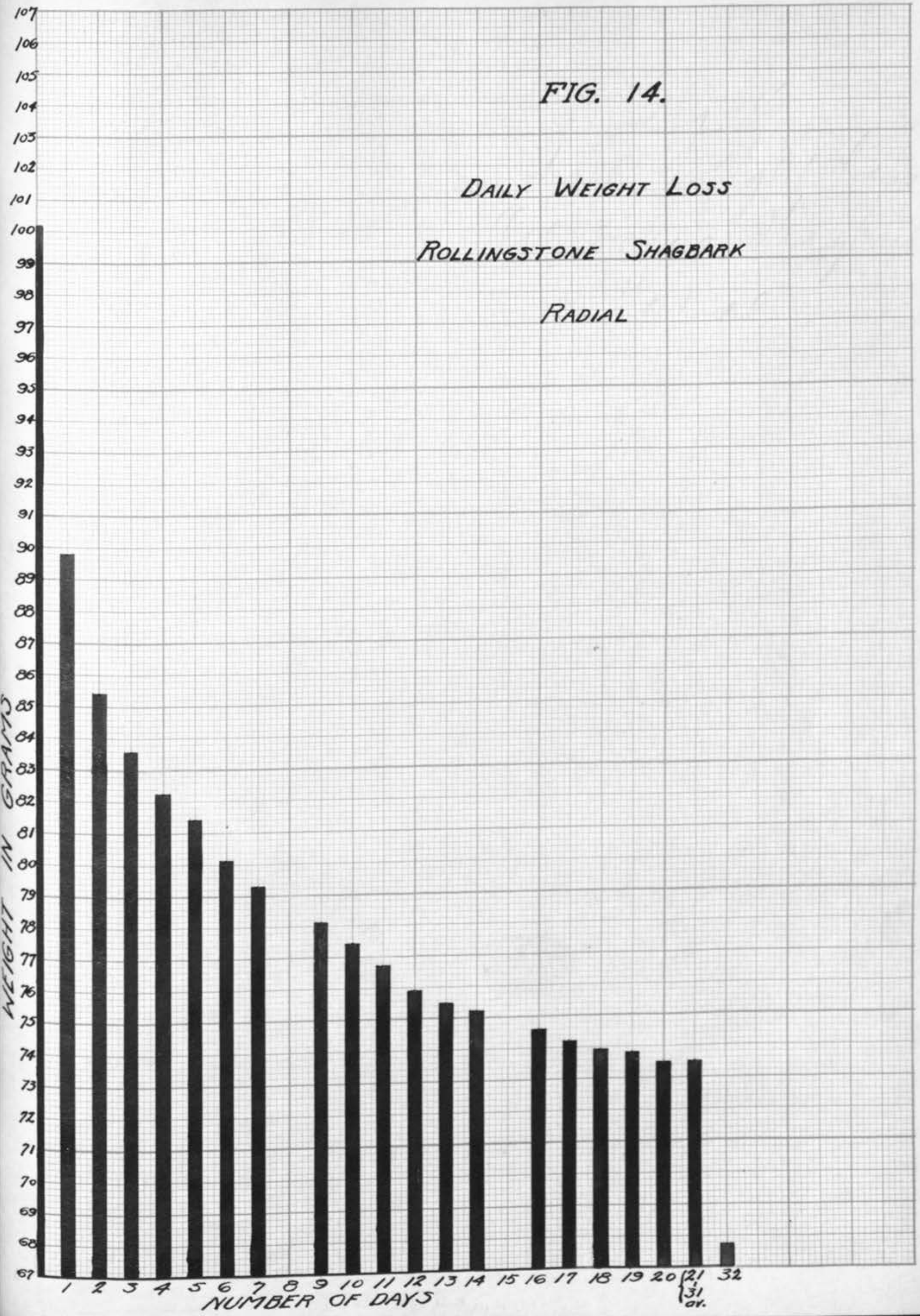


FIG. 14.

DAILY WEIGHT LOSS

ROLLINGSTONE SHAGBARK

RADIAL

As most of the water is lost from the cross section, and since the outside of the blocks dries much faster than the inside, it shrinks while the interior is still moist, forming checks usually along the rays. Checks formed during the first day. Most of the checks closed after a few days to two or four weeks. Some checks were due to greater tangential shrinkage and were permanent. See Figs. 7c, d for checking in blocks. Occasionally, due to defects in a ring, ring checks appear.

CASEHARDENING AND HONEY COMBING. When wood is dried rapidly, the outer portion becomes dry and set, while the inner portion is still at full water content. This is casehardening. When the wet interior dries it contracts and internal checks appear, causing a honey-combed condition. This was not met with in these tests.

RELATIVE HUMIDITY. When wood has lost all the moisture in air-drying, it begins to fluctuate in weight and in size to some extent due to changes in the relative humidity of the air. In drying, wood loses its free water and its hygroscopic water. Wood has absorptive power and easily takes on water vapor from the air into its cell walls. Relative humidity has a more noticeable effect on wood when it is air-dry or oven-dry as then small changes can be easily noticed.

Table 5 shows the effect of relative humidity upon blocks. Very little emphasis was placed upon absorption of water by oven-dry wood except to measure and weigh the blocks after 2 or 3 days exposure to air.

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Table 5. Relation of Relative Humidity to Shrinkage and Weight Loss.

Days	Rollingstone Shagbark A-Tangent			Rollingstone Walnut-Radial			Caledonia Butternut-Tangent			Caledonia Bitternut-Radial		
	Meas.	Wt.	Hum.	Meas.	Wt.	Hum.	Meas.	Wt.	Hum.	Meas.	Wt.	Hum.
1	3.499	104.86	33	4.202	52.62	30	.672	53.87	27	.450	52.78	33
2	.493	104.24	21	4.200	52.50	24				.443	52.40	21
3.	.484	103.86	21	4.200	52.49	31	.668	53.64	33	.440	52.24	21
4.	.480	103.70	29	4.200	52.56	27	.663	53.36	21	.438	52.23	29
5.	.477	103.40	27	4.202	52.64	36	.661	53.35	21	.437	52.14	27
6.	.475	103.28	35				.661	53.37	29	.437	52.16	35
7.				4.202	52.67	30	.661	53.35	27			
8.	.474	103.48	46	4.201	52.60	34				.442	52.49	46
9.	.476	103.80	39	4.204	52.78	33				.448	52.87	39

SUMMARY AND CONCLUSIONS

The tests carried on with the butternut, walnut, bitternut, and shagbark indicate:

1. The structure of the wood of the walnuts and hickories is a basis for distinguishing them and for placing them in their different types of uses.

2. The density or specific gravity of a wood is indicative of its strength qualities. The greater the specific gravity the greater is its strength as a rule. This is borne out by comparing shagbark hickory with butternut or with black walnut.

3. The greater the amount of summerwood in proportion to the amount of springwood the greater is the strength. Butternut is weaker than walnut and shagbark stronger than bitternut.

4. Water in wood is found as free water in the cell cavities and as hygroscopic water associated with the cell wall molecules. The free water evaporated first and the hygroscopic water last. Wood does not shrink until the hygroscopic moisture begins to leave (the "fibre-saturation point"). Dry wood absorbs hygroscopic water.

5. Shrinkage in the radial direction averages nearly three-fourths that in the tangential direction. In volume it is greater than in radial or tangential directions. The denser woods, as hickory, shrink more than the more porous wood, as butternut. Conversely the hickory loses the least moisture in per cent of green weight and the butternut the most. This is due to the greater free water holding capacity of the more porous

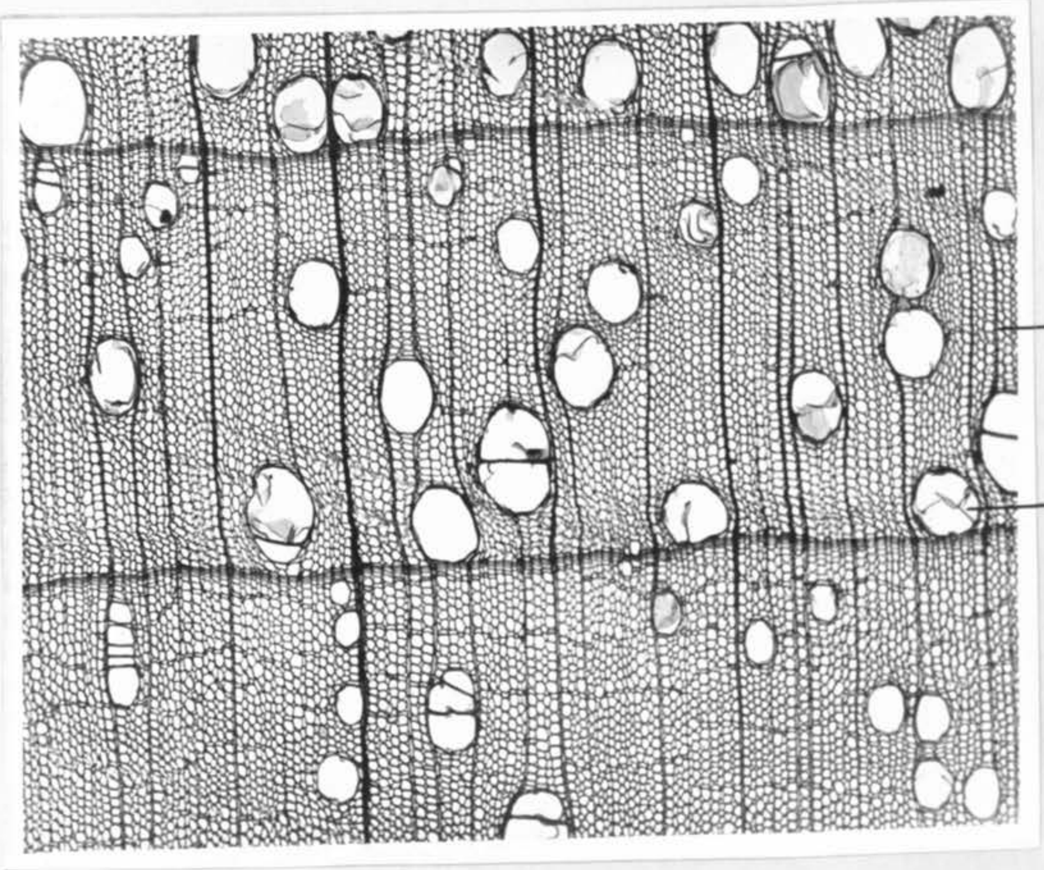
butternut. The denser hickory has an almost vertical shrinkage rate compared with that of the porous butternut. Shrinkage varies inversely as the moisture per cent.

6. Checks in seasoning wood are (1) temporary, due to faster drying on the outside and eventually closing when the interior dries out, and (2) permanent, due to greater tangential shrinkage. Both weaken the wood structure.

More tests on the walnuts and hickories of Minnesota should be conducted, covering more trees to insure more definite statements as to the properties of these woods. In the near future these species will be a valuable asset to the state's timber resources, for the southeastern part of Minnesota has commercial possibilities with its well forested counties. Studies should be made in different localities where distinct soil types are found, to note any possible differences in wood quality. The tests conducted for this paper indicate that, with the exception of the shagbark, the Caledonia trees have a slightly less specific gravity than the Rollingstone trees. This might be due to soil or climatic factors, or to both. These were not applied in this study. Because there are commercially valuable trees in southeastern Minnesota, these things are well worth considering.

DESCRIPTION OF PLATES

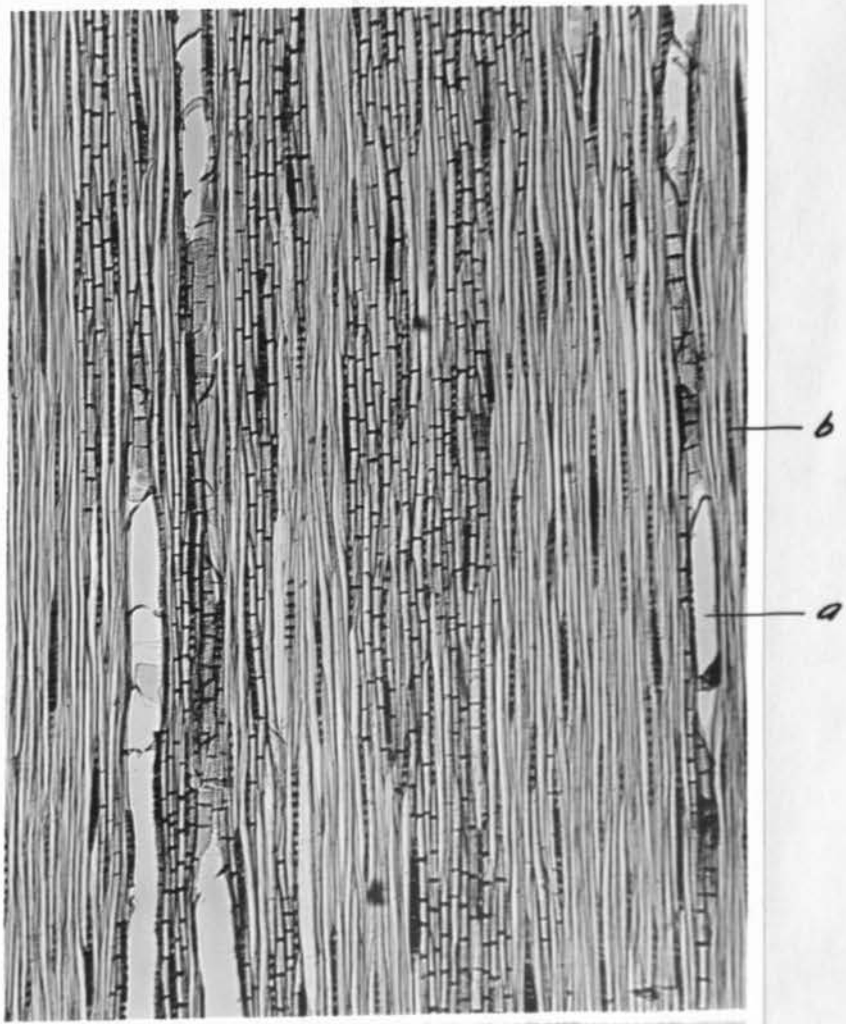
All photomicrographs show a magnification of 50 diameters.



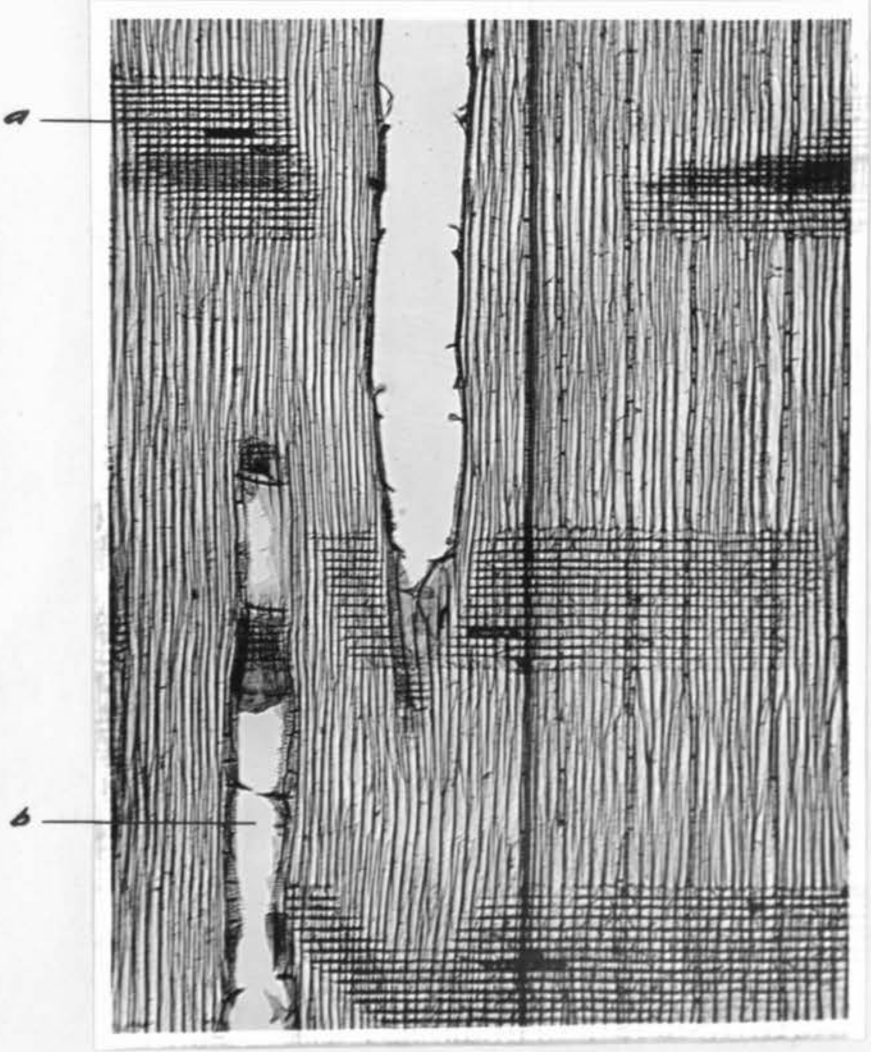
BUTTERNUT CROSS SECTION

a. Vessel with tyloses

b. Wood fibres

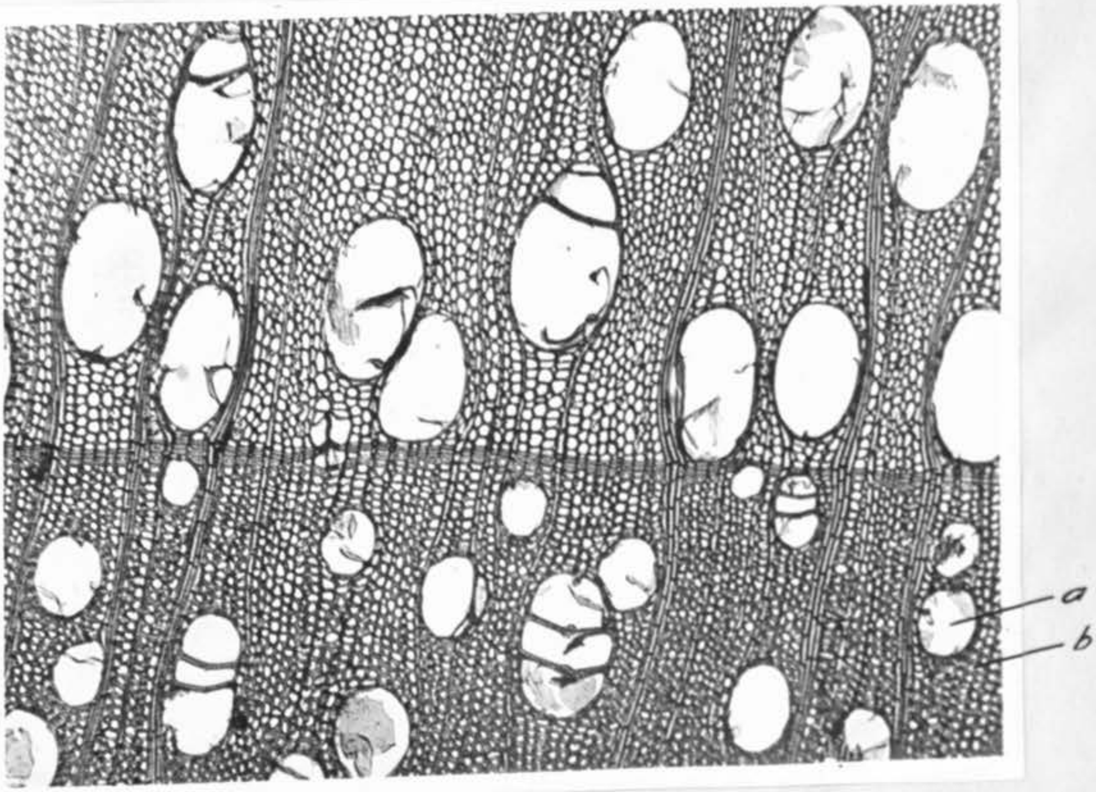


BUTTERNUT TANGENTIAL SECTION
a. Vessel
b. Ray - Cross section.



BUTTERNUT RADIAL SECTION

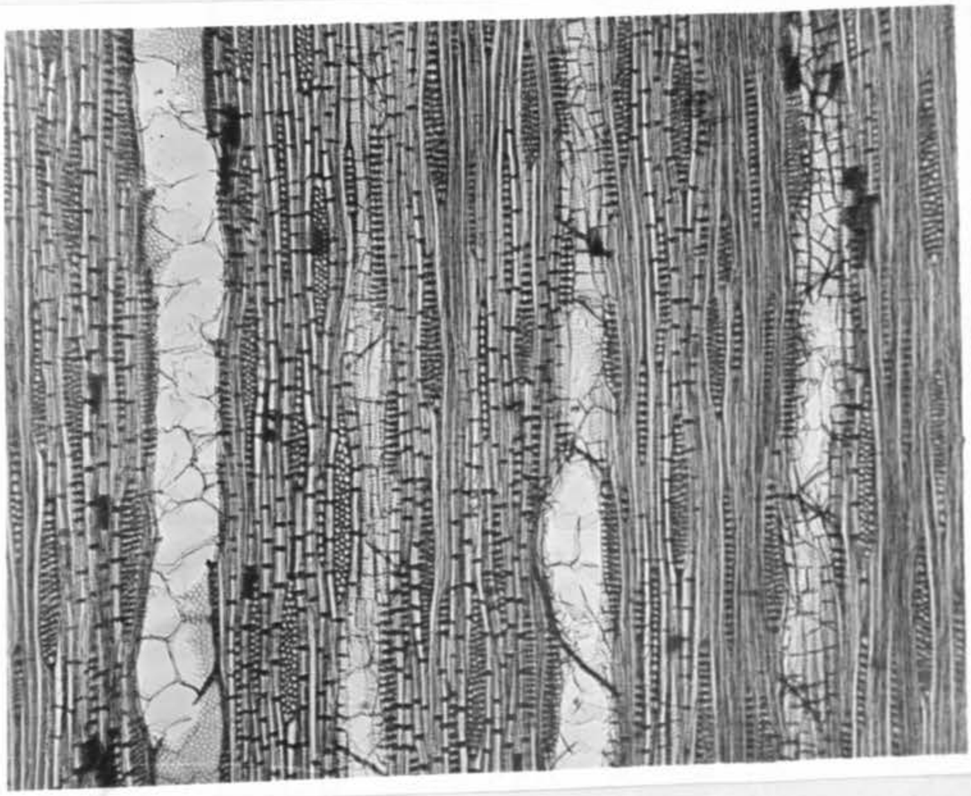
a. Ray
b. Vessel



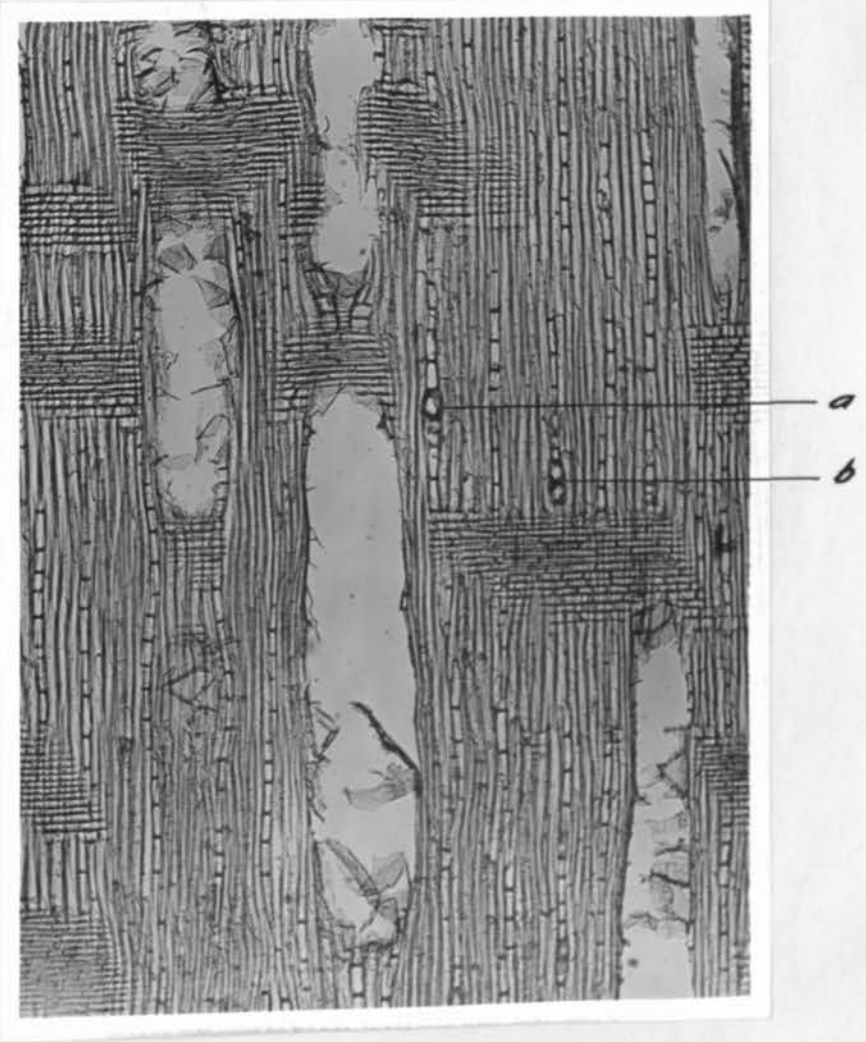
BLACK WALNUT CROSS SECTION

a. Vessel with tyloses

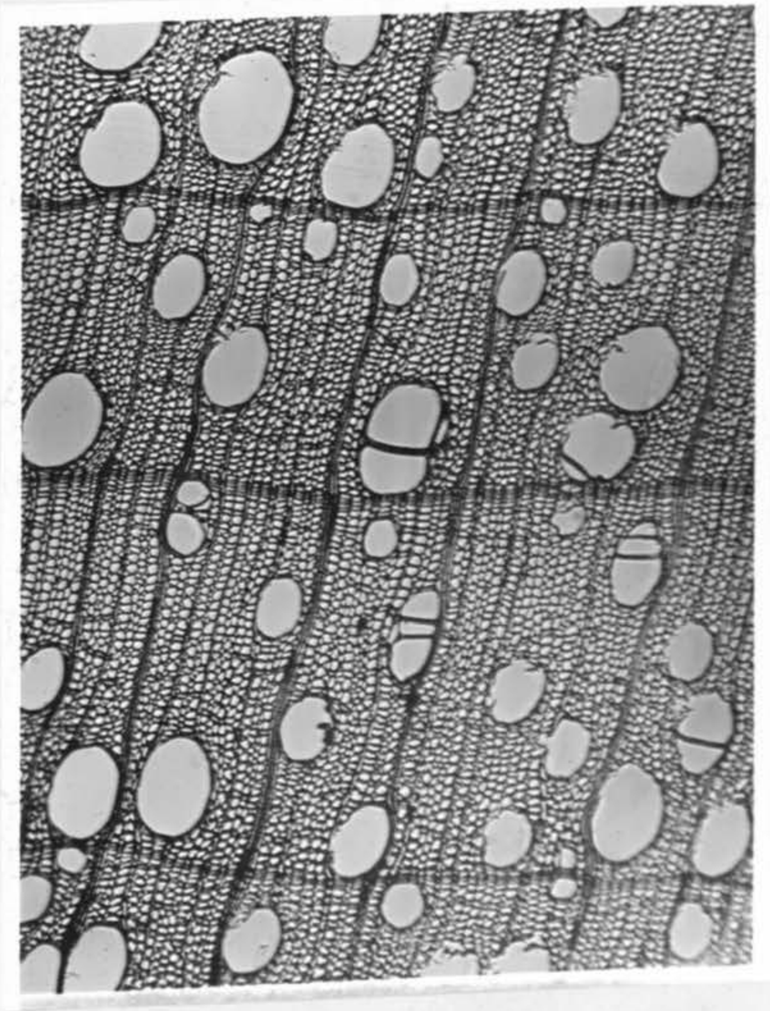
b. Wood fibres



BLACK WALNUT TANGENTIAL SECTION

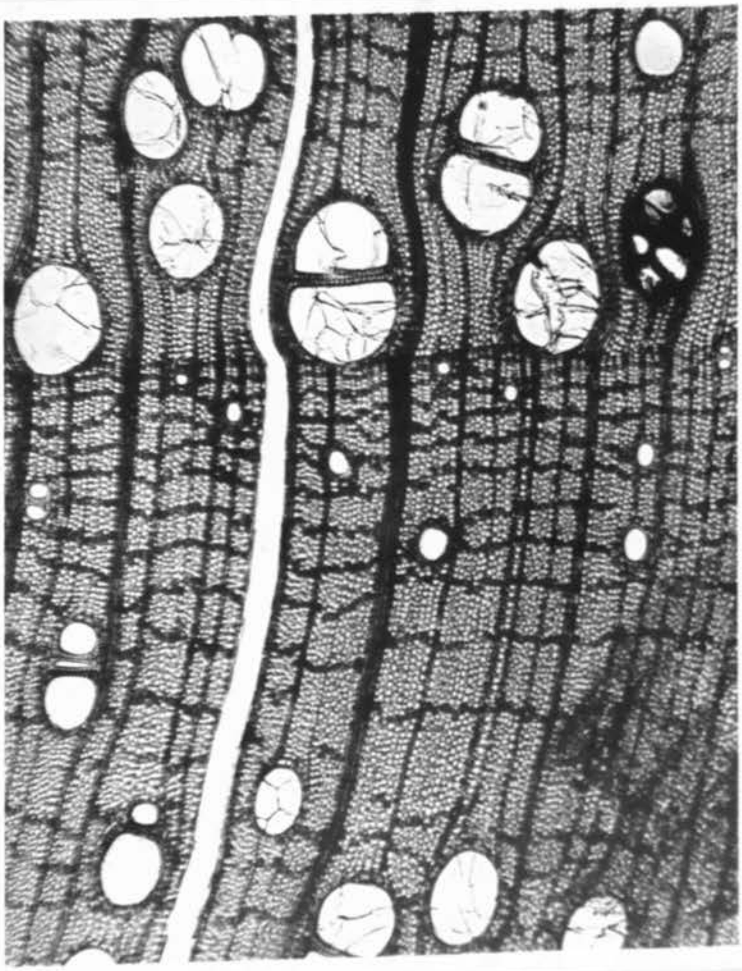


BLACK WALNUT RADIAL SECTION
SHOWING CALCIUM OXALATE CRYSTALS IN
WOOD PARENCHYMA AT a AND b.



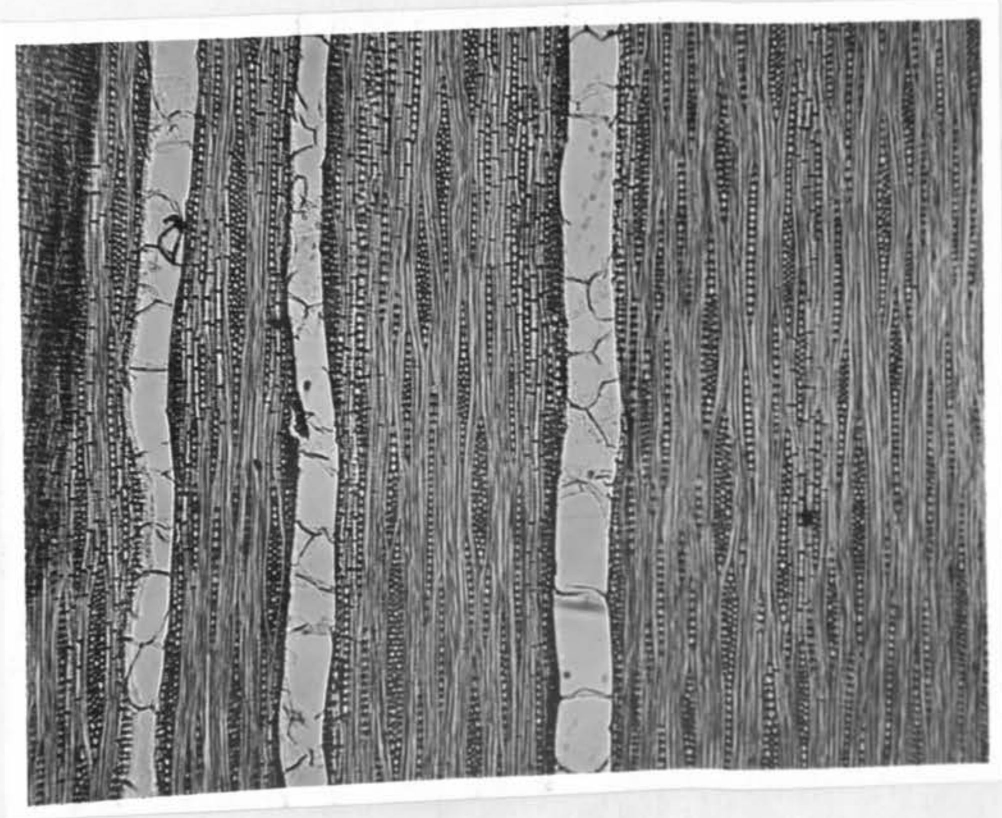
BITTERNUT CROSS SECTION

PLATE Xa

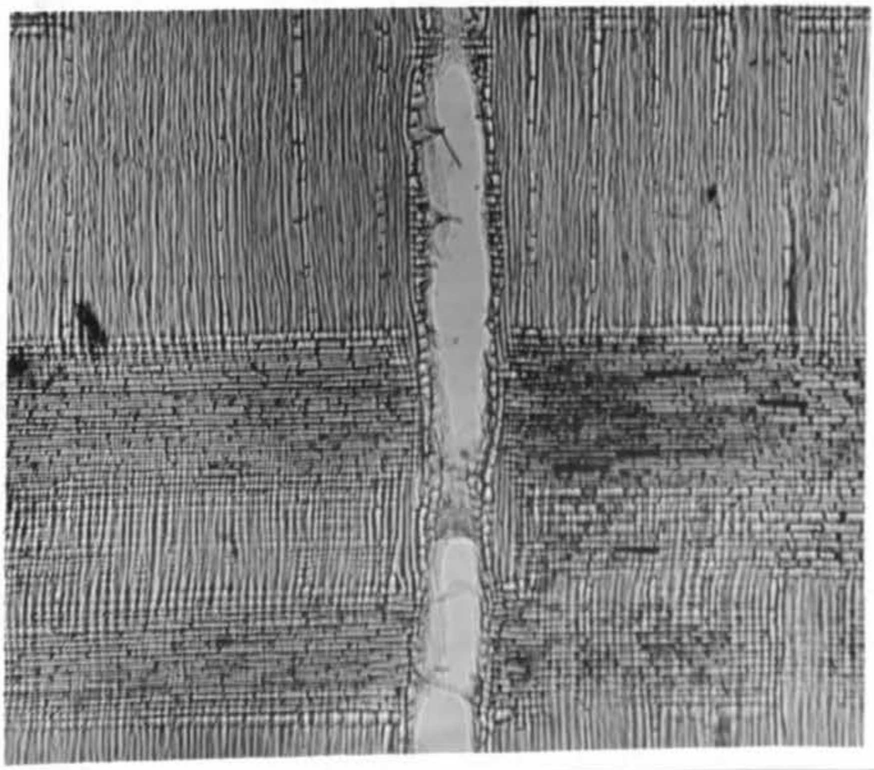


BITTERNUT CROSS SECTION

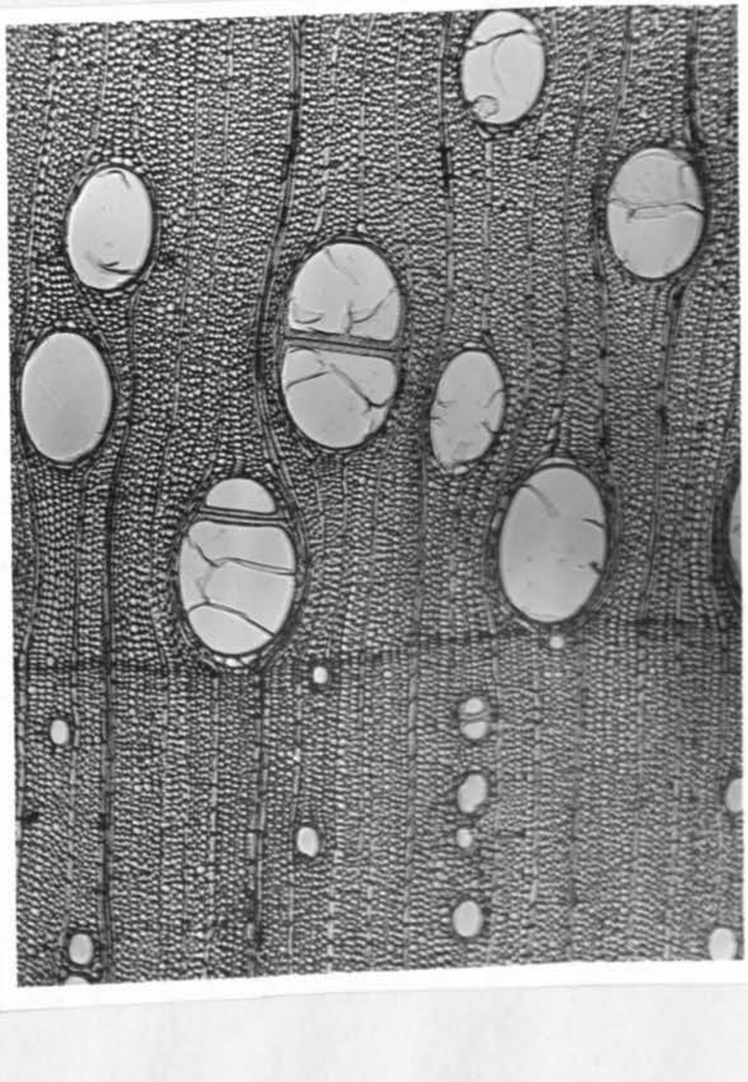
SHOWING WOOD PARENCHYMA IN
TANGENTIAL LINES



BITTERNUT TANGENTIAL SECTION



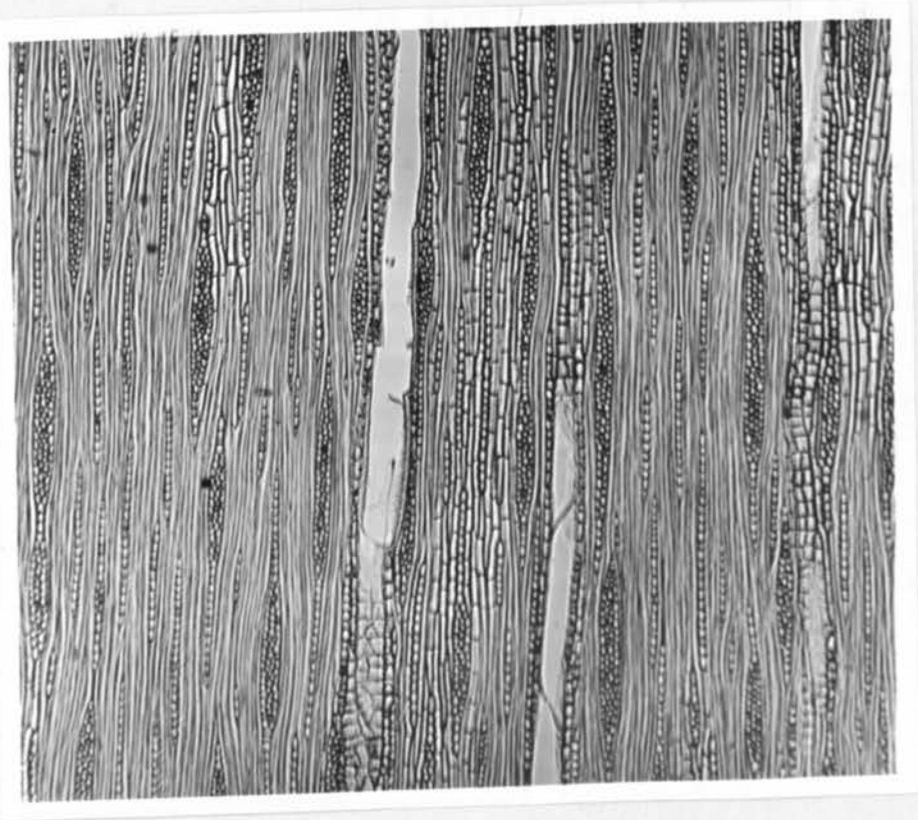
BITTERNUT RADIAL SECTION



SHAGBARK CROSS SECTION

NOTE THICK WALLED FIBRES

PLATE XIV



SHAGBARK TANGENTIAL SECTION

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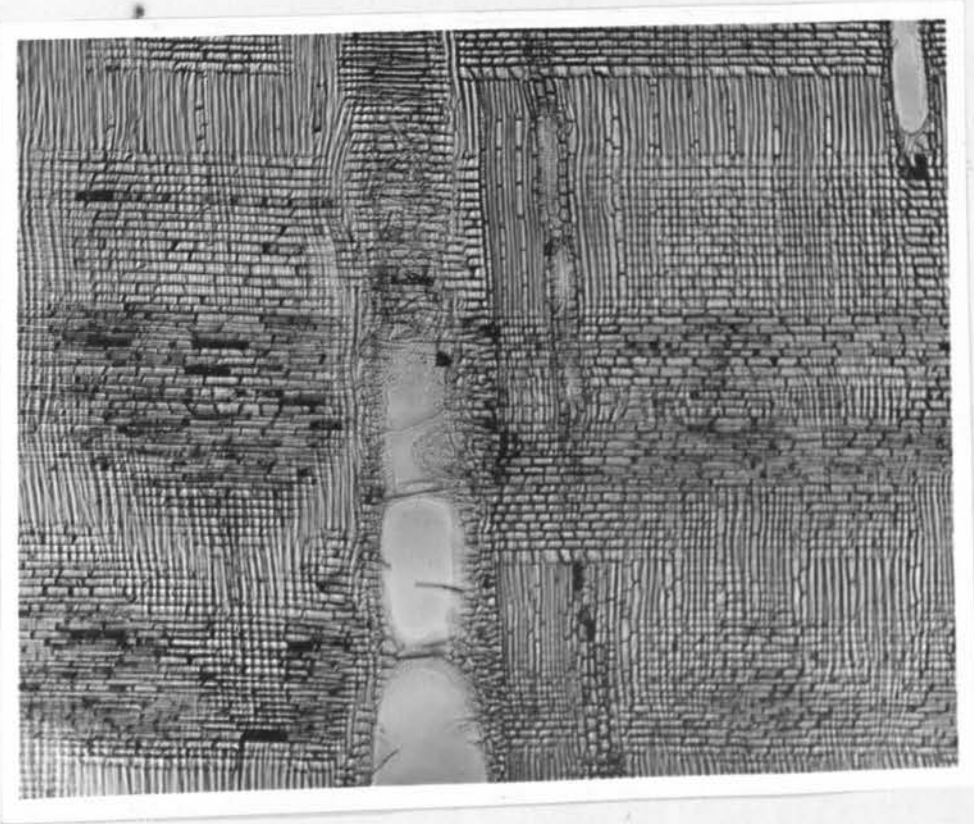

SHAGBARK RADIAL SECTION

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