"Bluing" and the "Red Rot" of the Western Yellow Pine with Special Reference to the Black Hills Forest Reserve

Plant Industry, Bull. 36

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 36.

B. T. GALLOWAY, *Chief of Bureau.*

THE "BLUING" AND THE "RED ROT" OF THE WESTERN YELLOW PINE, WITH SPECIAL REFERENCE TO THE BLACK HILLS FOREST RESERVE.

BY

HERMANN VON SCHRENK,
SPECIAL AGENT IN CHARGE OF THE MISSISSIPPI VALLEY LABORATORY,

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

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BUREAU OF PLANT INDUSTRY.

B. T. Galloway, *Chief.*

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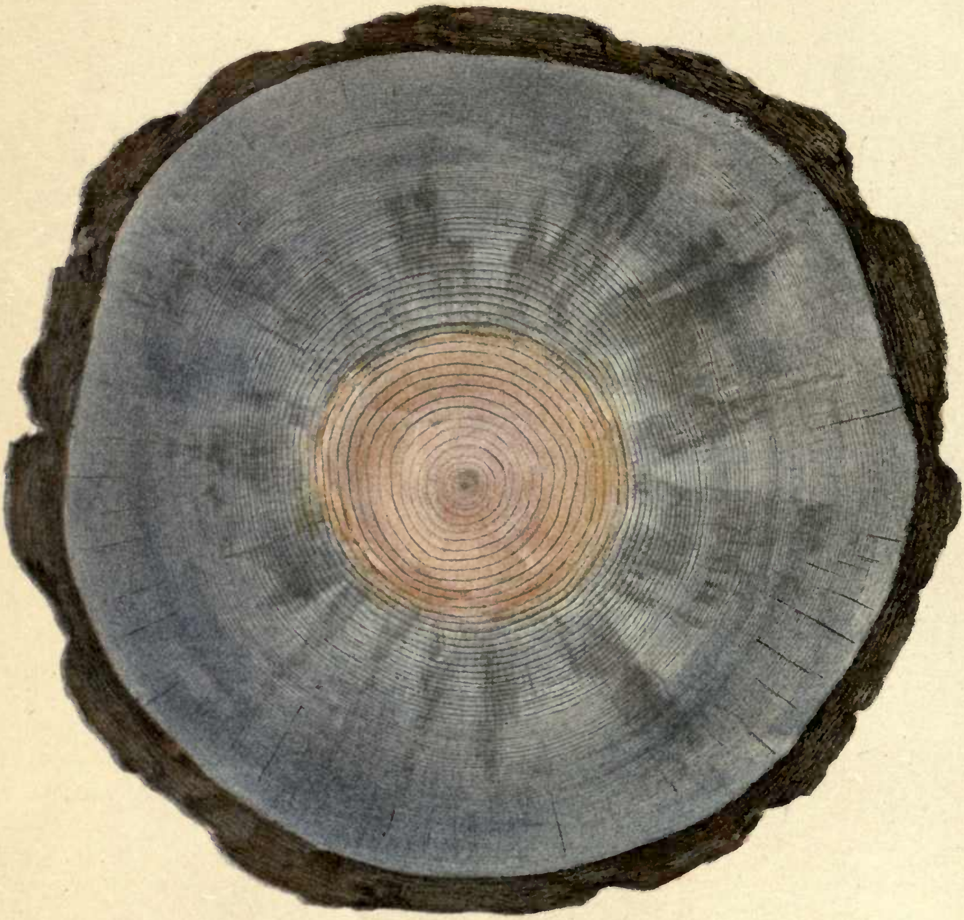

CROSS SECTION OF A DYING TREE OF THE BULL PINE, SHOWING BLUE COLOR.

U. S. DEPARTMENT OF AGRICULTURE.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., December 24, 1902.

Sir: I have the honor to transmit herewith a technical paper on The "Bluing" and the "Red Rot" of the Western Yellow Pine, with Special Reference to the Black Hills Forest Reserve, and respectfully recommend that it be published as Bulletin No. 36 of the series of this Bureau.

This paper was prepared by Dr. Hermann von Schrenk, Special Agent of this Bureau in Charge of Timber Rot Investigations, a line of work being conducted jointly by this Bureau and the Bureau of Forestry, and it was submitted by the Pathologist and Physiologist with a view to publication.

The illustrations, which comprise 14 full-page plates, several of which are colored, are considered necessary to a full understanding of the text.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The report submitted herewith, entitled The "Bluing" and the "Red Rot" of the Western Yellow Pine, with Special Reference to the Black Hills Forest Reserve, covers in part an investigation undertaken by the Bureau of Plant Industry in cooperation with the Bureau of Forestry in the broad field of the diseases of forest trees and the means of controlling them, as well as the causes of and methods of preventing the decay of all kinds of timber, especially that valuable for construction purposes. At the present time an immense quantity of dead and dying timber of the bull pine is standing in the Black Hills Forest Reserve, South Dakota. The amount has been variously estimated, but will probably approach 600,000,000 feet. The death of the trees was caused by the pine-destroying beetle of the Black Hills, as shown by investigations conducted by the Division of Entomology of the United States Department of Agriculture.[a] Following attack by the beetles the wood of the tree is invaded by various fungi, one of which causes the blue coloration of the wood. Dr. von Schrenk has demonstrated, however, that the fungus which causes the bluing does not injure the strength of the wood.

The rapid decay or "red rot" of the timber is caused by another fungus, and its ravages can be forestalled by a proper use of the wood. A series of recommendations is made, which, if followed, will result in the saving of a very large part of the dead wood.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF THE PATHOLOGIST AND PHYSIOLOGIST,
Washington, D. C., December 23, 1902.

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[a] Bull. 32, n. s., Division of Entomology, U. S. Dept. of Agriculture, 1902.

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INTRODUCTION.

The present investigation was undertaken to determine—

(1) The cause of the blue color of the dead wood of the western yellow pine, commonly known as the bull pine (*Pinus ponderosa*), and the effect of the coloring on the value of the wood.

(2) The reason for the subsequent decay of the wood, the rate of decay, and whether the decay could be prevented.

(3) Whether it would be possible to use the dead wood before it decayed; first, to reduce the fire danger; second, to prevent the decay and thereby save an immense quantity of timber.

DEATH OF THE TREES.

The physiological changes which take place in the bull pine (*Pinus ponderosa*) as a result of the attack of the pine-bark beetle (*Dendroctonus ponderosæ* Hopk.[a]) are intimately connected with the fungus diseases under consideration, and may therefore be referred to briefly.

According to Hopkins, the beetles enter the bark of the living trees in July, August, and September. The primary longitudinal burrows or galleries are excavated by the adult beetles, and the transverse, broad, or larval mines (Bull. 32, n. s., Division of Entomology, U. S. Department of Agriculture, Pls. I and III and fig. 1) through the inner bark and cambium of the main trunk have the effect of completely girdling the tree, and by September the cambium and the bark on the lower portion of the trunk are dead. The foliage of the trees thus attacked, however, shows no change from the normal healthy green until the following spring, when the leaves begin to fade.

The first signs of disease noticeable in an affected tree are visible in the spring of the year following that of the attack by the beetle. Here

[a] Hopkins, A. D. Insect Enemies of the Pine in the Black Hills Forest Reserve. Bull. 32, n. s., Division of Entomology, U. S. Dept. of Agriculture, pp. 9, 10.

and there one will find the needles of affected trees turning yellowish. The bright green fades almost imperceptibly, starting near the tip of the needle. The needles first affected are those on the lowest branches (Pl. II), and on these branches the discolored leaves will be more or less scattered. By the end of May most of the leaves on an affected tree will be pale green or yellowish. (Pl. II; Pl. III, 2.) This yellow color increases in intensity during the summer and makes the affected trees a conspicuous mark among the healthy green trees. Trees in this stage are locally known as "sorrel tops" or "yellow tops." When standing on a hillside, groups of "sorrel tops" can be easily detected at a distance of several miles. It is rather a difficult matter to show the contrast in a photograph. The middle tree on Pl. II, fig. 1, shows the contrast with the green trees on the left to some extent.

The yellow needles are drier than the green ones and show a marked disintegration of the chlorophyll. As they continue to dry the color changes gradually through various intermediate stages (Pl. III, 3) to a reddish brown. This color (Pl. III, 4) becomes very marked after the trees have passed through the second winter. The needles are then dry and they begin to fall off. Such trees are known as "red tops." (See Pl. II, fig. 1; Pl. IV, fig. 1.) The leaves finally fall off completely, leaving the branches bare. Such trees without any leaves are known as "black tops." (Pl. IV, fig. 2.) The group of trees on Pl. II, fig. 1, shows the green trees and the "sorrel tops" and "red tops" (rapidly becoming "black") side by side.

To summarize the foregoing: One finds the living trees attacked in July and August; the following spring the leaves turn yellow ("sorrel tops") and gradually red ("red tops"), and the third year they drop off altogether ("black tops"). It is a difficult matter to say at what point the trees are dead. Girdled trees die with different degrees of rapidity, depending upon the species. The black gum (*Nyssa sylvatica*) will live—i. e., will have green leaves—for two years after being girdled; so also several species of oak. Pines and spruces rarely live more than a year, and generally not so long.

The reason for the different behavior of these trees is probably to be found in the different power to conduct water through the inner sapwood. The subject is one about which little is known as yet. In the case of the bull pine, after the girdling by the beetles certain changes take place in the cambium and the newer sapwood which leave no doubt as to the death of those parts. By September, as described below, the cambium and bark are actually dead and partially decayed for 30 feet or more from the ground. The leaves are still green and full of water the following spring. The only way in which this can be accounted for is by assuming that sufficient water passes through the inner sapwood to keep the crown of the tree supplied

WHEN ARE THE TREES DEAD?

The question as to when a tree is dead is one of considerable practical importance in determining which trees in the forest should be cut. For this purpose it is safe to assume that a tree may be pronounced dead when the bark is loose at the base of the tree for considerable distances up the trunk. A tree with its bark in this condition can not possibly recover. The wood under this loose bark will always be found to be dark in color and will appear covered with shreds of bark when the bark is pulled off. It must be remembered that such trees will have green leaves. The criterion of green or yellow leaves is not a safe one to follow, and ought not to be considered in making specifications for cutting dead timber. Attention is here called to the recommendation (4) made on page 35.

THE "BLUE" WOOD.

Very soon after the attack of the bark beetles (*Dendroctonus ponderosæ*) the wood of the pine turns blue. The color at first is very faint, but it soon becomes deeper. A cross section of a trunk several months after the beetle attack will appear much as shown on Pl. V, fig. 1. Lines of color extend in from the bark toward the center of the tree, and increase rapidly in intensity until the colored areas stand in sharp contrast to the unaffected parts. The color appears in small patches at one or more points on the circumference of the wood ring. At first it is a mere speck, but this gradually spreads laterally and inward, eventually forming triangular patches on cross section. The color likewise spreads up and down the trunk from the central spot. As the time passes after the first attack of the beetles, several color patches may fuse. Their progress laterally and upward toward the center of the trunk may be equally rapid on all sides of the tree, or more rapid on one side than on another (Pl. V, fig. 2). The intensity of the color may vary considerably on the two sides of one and the same trunk. After a certain period of time the whole sapwood will have a beautiful light blue-gray color, as shown on Pl. I. The wood which adjoins the inner line of the "blue" wood is of a brilliant yellow color, which contrasts sharply with the blue outside and the straw yellow of the heartwood. This yellow area is in the form of a ring of more or less irregular shape. Sometimes it is formed of one annual ring very sharply defined; then, again, it may include all or only parts of several annual rings. As the wood grows older, the blue color becomes deeper and the yellow ring more sharply defined.

RATE OF GROWTH OF THE BLUE COLOR.

The first signs of the blue color are usually found several weeks after the attack by the beetles at points on the trunk in the immediate vicinity of the attack. The first signs of the blue color are found in the base of the trunk. On Pl. VI, fig. 1, three sections of a tree which was attacked the latter part of July, 1901, are shown. The sections were cut in November, 1901, at points 5 feet, 16 feet, and 36 feet from the ground. The sapwood of the first section, 5 feet up, is entirely blued; the second section, 16 feet up, is blue here and there; while the section made in the top, 36 feet up, is without a particle of blue color. Note in this connection that the sections with blue color show the cross sections of the galleries of the bark beetles (*Dendroctonus ponderosæ*) in the layer formed by the cambium layer, the outer wood, and the inner bark. The sections on Pl. VI, fig. 1, show some of these galleries filled with sawdust. A more advanced stage is shown on Pl. VI, fig. 2. In this tree the sapwood is blue from the ground up into the extreme top. The smallest section, cut from the tree in the upper part of the crown, is blue with the exception of the innermost rings, i. e., the beginning of the heartwood.

The blue color develops very rapidly when once the tree is attacked. Standing trees attacked by the beetles in July, 1902, showed signs of blue color in three weeks. Three months after the attack the sapwood of the lower part of the trunk is usually entirely blue, as shown on Pl. I. The year following the attack, i. e., when the trees have reached the "sorrel-top" stage, the bluing has reached the top, and late that year, when the "red-top" stage is reached, the entire sapwood is blue (Pl. VI, fig. 2).

An experiment was made during the past summer to see whether the blue color would appear in trees felled before being attacked by the pine-bark beetle. It may be said at this point that they did "blue" just as the standing ones did.

NATURE OF THE "BLUE" WOOD.

Some weeks after the attack by the bark beetles, changes take place in the bark and the newer wood which ultimately result in the bark becoming loose and separating from the tree. When the first flow of resin into the galleries has stopped, the air enters into the galleries, and channels of communication with the outside are established through which the water in the cambium and newer wood can escape. The result of this is that a moist atmosphere prevails in the air chambers, very favorable to the growth of fungi. As the cambium and bark cells lose water they shrivel and break from one another, so that after a few months the bark breaks away from the wood proper. On the south and southwest sides of the trees the bark dies most rapidly, and here, contrary to the general occurrence, it frequently adheres firmly to the tree. On the shaded sides of the trunk the bark becomes loosened, as described, before six months have elapsed. The surface of the wood is moist, very dark in color, and feels somewhat clammy.

Numerous white strands of fungus mycelium make their appearance after six months or more. As the wood of the trunk dries, the bark, loose at first, tightens, so that in the "black-top" stage it adheres quite firmly to the trunk. When cut into, it peels off in large sheets very readily, however.

The "blue" wood differs very little from the sound wood in general appearance, except its color. It is full of moisture at first, but loses this rapidly, so that in two years after the beetle attacks the wood it may be almost perfectly seasoned, even when completely covered with its bark. The "blue" wood is said to be very much tougher than the green wood, so much so that the tie makers in the Black Hills can be induced to cut wholly blued wood only with difficulty. This toughness and a possible reason therefor are discussed hereafter.

STRENGTH OF THE "BLUE" TIMBER.

Ever since its first appearance there has been considerable discussion as to the strength and durability of the "blue" timber when compared with sound timber. It was universally believed that it would prove very much inferior in both respects. A test was made in the testing laboratory of the department of civil engineering of Washington University, St. Louis,[a] to determine the comparative strength of the "blue" and the healthy timber. Sections of tree trunks 5 feet long were cut from trees at points 10 to 15 feet from the ground, and were shipped to St. Louis, where they were sawed into blocks of several sizes. For the compression tests, blocks 2 by 2 by 4 inches and 3 by 3 by 6 inches were cut and planed to the exact dimensions, or as nearly so as possible.

For the cross-breaking strength, sticks 2 by 2 inches by 4 feet, and 3 by 3 inches by 4 feet were prepared. The blocks for these tests were kiln-dried at a temperature of 172° F. until an approximately constant weight was reached. It was found that completely dried blocks would not shear at all. The moisture content of the green blocks was slightly higher than that of the "blue" blocks.

Three kinds of timber were used: A—Green timber; B—"Blue" timber taken from "sorrel-top" trees, i. e., trees dead about one year; C—"Blue" timber taken from "red tops" and "black tops" (mostly the latter), i. e., trees dead about two years.

The tests were made with the machinery described by Johnson in early reports[b] of the Division of Forestry. Every block was carefully measured. The results, reduced to the average crushing strength and the average cross-breaking strength per square inch, are

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[a] The machinery was put at the writer's disposal through the courtesy of Prof. J. L. Van Ornum.

[b] Timber Physics, Bulls. Nos. 6 and 8, Division of Forestry, U. S. Department of Agriculture.

given in the following table. The number of pieces used for each test is given in a separate column. It will be noted that the heartwood pieces were kept distinct from the pieces cut from the sapwood.

Compression strength in pounds per square inch.

Kind of timber.	Heartwood.		Sapwood.	
	Number of pieces tested.	Average strength.	Number of pieces tested.	Average strength.
		Pounds.		*Pounds.*
A. Green timber	210	3,919.74	1,575	5,089.98
B. "Blue" timber, 1 year old	190	3,876.44	649	5,130.95
C. "Blue" timber, 2 years old	131	4,017.48	770	5,308.32

Cross-breaking strength in pounds per square inch.

Kind of timber	Heartwood.		Sapwood.	
	Number of pieces tested.	Average strength.	Number of pieces tested.	Average strength.
		Pounds.		*Pounds.*
A. Green timber	338	5,375.26	553	5,832.66
B. "Blue" timber, 1 year old	317	5,361.17	242	5,818.84
C. "Blue" timber, 2 years old	322	5,665	272	6,843.31

The figures given in this table show that the "blue" timber is slightly stronger, both when compressed endwise and when broken crosswise. This result is probably due to the fact that the "blue" wood was slightly drier than the green wood when the tests were made. It is scarcely probable that the presence of fungus threads in the cells of the wood in any way strengthens the fiber. However that may be, these tests show beyond doubt that for all practical purposes the "blue" wood is as strong as the green wood. Under the conditions now existing in the Black Hills Forest, the "blue" wood is certainly very much stronger than the green wood. It is in effect seasoned timber. The trees have stood in the most favorable position possible for drying, with thousands of holes in the bark made by the beetles through which the water could escape, assisted by the winds which constantly sweep by the trunks. Where wood is used, as it unfortunately is in these days, almost immediately after it is cut from the forest, the "blue" wood is certainly as good so far as its strength is concerned as the green wood, and ought not to be discriminated against because of supposed weakness.

LASTING POWER OF THE "BLUE" WOOD.

The wood of the bull pine is one which is not very resistant to decay-producing fungi. Under ordinary conditions, such as are found in the State of Nebraska outside of the arid belts and in the Black Hills, the wood will last from four to six years when placed in the ground in the form of a cross-tie, for instance. Dead trees may stand in the forest for many years without decaying, especially when killed by fire, but ordinarily when the bark remains on the trees they begin to decay after the third year.

From observations made on the "black-top" trees now standing in the forest it would seem that the lasting power of the "blue" wood would be very small. It is perhaps not fair to compare these trees with sound ones, for their bark is full of holes, giving fungus spores every opportunity to enter, as described below. When placed in the ground this wood rots very fast, if one can draw conclusions from the dead tops lying around in the forest. There is every reason why it should rot rapidly. The hyphæ of the "blue" fungus have opened passageways for the rapid entrance of water and for other fungi in almost every medullary ray. Dried wood will probably last a long while, especially if properly piled, so as to allow the air to circulate between the separate pieces. When sawed and split for cord-wood, the "blue" wood should keep just as long as the green wood. The tendency to rapid decay can be largely done away with by treating the wood with some preservative. Ties were cut during the past spring from green timber and from dead trees. These were shipped to Somerville, Tex., where they were impregnated with zinc chloride. These ties were laid in the tracks of the Santa Fe Railroad and are now under observation. A second lot of ties has been cut during the past summer from green trees and from "sorrel tops," "red tops," and "black tops." These will be treated within a short time and laid in the track of a Mexican railway so as to determine the relative resistance of the various grades of "blue" timber in a tropical climate as compared with the green timber. On the particular road chosen for this experiment the life of very resistant timbers is short.

THE "BLUE" FUNGUS.

The blue color of the wood is due to the growth of a fungus in the wood cells. The staining of wood due to fungi has been known for many years, especially the form known as "green wood" (*bois verdi*). In Europe this green coloration attracted the attention of foresters and investigators as early as the middle of the last century, and a number of descriptions and discussions appeared from time to time (particularly in France), in which an attempt was made to account for this phenomenon. A green dye was extracted from this wood, which at one time was thought to be valuable because of its absolute permanency. Various dicotyledonous woods showed the green color; among others, beech, oak, and horse-chestnut.

In spite of numerous investigations, the causes of the green color and its relation to the wood remained comparatively obscure until recently, when Vuillemin published an extended account[a] showing that one form of the green color was due to the growth in the wood of one of the Discomycetes, *Helotium æruginosum*. Vuillemin mentions a number of other fungi which have been described as causing the green color, among others, *Propolidium atrocyaneum* Rehm, on wood of the poplar; *Nævia æruginosa* Rehm, on the tansy; and *Fusarium æruginosum* Delacroix, on potato tubers.

Without going into details, Vuillemin established the fact that the green coloring matter, called xylindeine, is formed by the hyphæ of *Helotium æruginosum*, and that the presence of these green-colored hyphæ gives the green color to the wood. The wood fiber itself remains colorless. The xylindeine is soluble in alkalis and can readily be extracted. The wood fiber is not destroyed, but remains intact. The name "green decay" is therefore incorrectly applied, for the green wood is in no sense decayed. This is an interesting fact, for it will be remembered that the same has been said of the "blue" wood. A more detailed comparison of the relation of this green coloring matter and the fungus forming it to the coloring matter in the "blue" wood will be published in another paper.

The blue stain of coniferous woods is a familiar defect in the United States, particularly in the South, where freshly sawed lumber, especially shingles and lath, is affected during the moist warm weather of April, May, and June. The blued lumber is considered as a low-grade material, and many precautions are taken by Southern manufacturers to prevent loss. A full account of this trouble and a discussion as to its cause and methods for its prevention are now in preparation.

In Europe the blue color of pine wood was first noted by Hartig,[b] who refers briefly to the fact that a fungus (*Ceratostoma piliferum* (Fr.) Fuckel), is the cause of bluing in coniferous wood, especially of pine trees which have been weakened by caterpillars, and of firewood. He states that the hyphæ of this fungus, which are brown, grow rapidly inward into the trunk through the medullary rays and that they avoid the heartwood, probably because of its small water content.

The blue color of coniferous wood in this country is probably caused by the same fungus referred to by Hartig, although it seems necessary to refer to it under a different name (*Ceratostomella pilifera* (Fr.) Winter).

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[a] Vuillemin, Paul. Le Bois Verdi. (Bull. de la Soc. d. Sciences de Nancy, Ser. II, **15**: 90–145; 1898. 1 pl.) References to earlier works on the green color are given in this paper.

[b] Hartig, Robert. Lehrbuch der Pflanzenkrankheiten, 1900, pp. 75 and 106. (See also earlier editions of the Lehrbuch für Baumkrankheiten; see also Frank, A. B., Krankheiten der Pflanzen, **1**: 107, 1895.)

CERATOSTOMELLA PILIFERA (Fr.) Winter.

Sphæria pilifera Fr. Systema Myc., 2: 472, 1830; Berkeley, Grevillea, 4: 146, 1876.

Sphæria rostrata Schum. Enum. Fl. Sae., 2: 128.

Ceratostoma piliferum (Fr.) Fuckel. Symb. Myc., p. 128; Ellis & Everhart, N. A. Pyrenomycetes, p. 193.

Ceratostomella pilifera (Fr.) Winter. Rabenhorst's Kryptogamenflora, etc., 1, Pt. II: 252, 1887; Engler & Prantl, Nat. Pflanzenfam., Pt. I, Abt. 1: 406; fig. 259.

The "blue" fungus was first described by Fries, who placed it in the genus *Sphæria*. Later it was placed in a new genus (*Ceratostoma*) by Fuckel, and remained in this genus until recently, when Winter in his revision of the family *Ceratostomeæ* put the fungus in the genus *Ceratostomella*.[a] This genus is characterized as "perithecia more or less superficial, or immersed (sometimes only for a short time), generally tough, leathery, or carbonaceous, with marked, generally well-developed beak. Spores variable, typically unicellular, hyaline. Species mostly on wood." The genus *Ceratostoma* differs from *Ceratostomella* only in having the spores brown instead of hyaline. This seems a very weak character upon which to separate two genera, and Winter realizes this, as indicated in a note (p. 253), where he says: "I hesitate to accept the genus *Ceratostomella*, for the different color of the spores does not seem to be sufficient basis for a genus. I do it only to satisfy generally accepted demands."

As the present investigation is not materially concerned in the validity of any particular name, the writer accepts Winter's name, leaving the question of whether it ought to be *Ceratostoma* or *Ceratostomella* to others.

Ceratostomella pilifera occurs, according to Winter, on coniferous woods, mostly on pine timber. Winter remarks that in spite of the very common occurrence of this species, he was able to find the mature asci but once, and gives a figure of the two asci he saw. This is borne out by the findings mentioned hereafter. Four forms of *C. pilifera* are described, which are probably forms modified by the substratum on which they grew, and of less interest in this connection.

The fruiting bodies of the "blue" fungus occur in thousands on blued logs and boards in favorable seasons; the long necks of the perithecia when looked at sideways form veritable forests on a board. In the pine forests of the Black Hills the perithecia are to be found on decaying sticks, in the cracks formed when trees or branches break off, and sometimes under the loosened bark of dead trees. It is a strange fact, however, for which no very plausible reason can as yet be assigned, that with the thousands of dead and "blue" trees now in that forest the asci of the fungus should be comparatively so rare.

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[a] Saccardo, P. A. Michelia, 1: 370.

The growth and development of the fungus may be briefly noted as follows:[a] The spores of the "blue" fungus (Pl. VII, 8) are probably blown about by the wind in countless thousands, and at the time of the beetle attack in July and August some of these spores lodge in the holes made in the bark of the living pine tree by the bark and wood-boring beetles. The atmosphere of these holes is constantly kept moist by the water evaporating from the trunk. In these holes the spores can germinate within a day after falling there.

In drop cultures of pure water the spores germinate readily overnight. The hyphæ grow into the bark tissues and into the cambium, and from there they enter the cells of the medullary rays. The readiness and rapidity with which the hyphæ grow into the medullary rays lead one to suspect that the food substances, stored in the medullary rays at this period of the year in considerable quantities, exert a chemotropic stimulus. In the early stages of development one finds the hyphæ of the "blue" fungus only in the medullary ray cells. After a hypha has entered one medullary ray cell it branches and spreads to the neighboring cells (Pl. VII, 1 and 2; Pl. VIII, figs. 1 and 2), so that in a very short time the entire ray is filled with the hyphæ, most of which grow in the ray toward the center of the trunk. Numerous starch grains are usually found in the ray cells during the early part of August; these are rapidly dissolved by the fungus and serve as a source of food supply for a considerable period of time. The hyphæ are at first colorless, very thin-walled, and full of vacuoles and oil globules. They branch rapidly, forming numerous septa. If the starch supply is abundant, hyphæ several microns in diameter may be formed (Pl. VII, 2). These are constricted at the septa and show signs of rapid development. The older hyphæ turn brown, and with the first signs of the brown color in the hyphæ the bluish coloration of the wood begins. One of the first effects seen after the hyphæ have entered the medullary ray cells is the gradual solution of the walls separating the medullary ray cells from one another (Pl. VII, 1, 2, and 3). The walls which separate the ray cells from the neighboring wood cells may become very thin, as shown in the middle ray (Pl. VII, 1), but they are rarely dissolved entirely. The intermediate walls, on the other hand, entirely disappear. This leaves a tube with a cross section having the shape of the cross section of the ray, extending into the trunk from the bark. This tube is sometimes filled entirely with a mass of brown hyphæ, the larger number of which extend in the direction of the ray (Pl. VIII, figs. 1 and 2). From the ray cells some hyphæ make their way into adjacent wood cells (Pl. VII, 2; Pl. VIII, figs. 1 and 2). They grow along these, both up and down

[a] A fuller discussion of its cultural characteristics, spore germination, and the blue color will be printed at a later date.

(Pl. VII, 1), giving off branches to other wood cells.[a] In this manner the whole wood body becomes penetrated by the brown hyphæ in a very short time after the first infection. The number of hyphæ in the wood cells proper, i. e., excluding the medullary ray cells and the cells of the wood parenchyma, is very small indeed. This is probably due to the fact that the fungus finds scant material upon which to live in the wood cells. The hyphæ are apparently able to puncture the unlignified walls here and there, but they stop at that point. The writer was not able to demonstrate that the hyphæ could attack the lignified walls. In other words, the "blue" fungus is one which confines its attack to the food substances contained in the storing cells of the trunk and to the slightly lignified walls of these storing cells. The best instance of the resistance which the lignified walls offer to the dissolving action of the hyphæ is found in the outer walls of the medullary rays, which are composed in part of the more heavily incrusted walls of the adjacent wood fiber.

The resin ducts are attacked in much the same manner as the medullary rays. (Pl. VII, 3; Pl. VIII, fig. 2.) The walls of the component cells are dissolved, leaving a tube filled with brown hyphæ. When looked at with a low-power magnifying glass, a cross section of the wood shows the resin ducts as black spots in the wood ring.

The rate at which the hyphæ advance in the medullary rays keeps them considerably in advance of the hyphæ in the wood cells and also of the blue color which follows the appearance of the hyphæ in the rays. When the hyphæ have reached the heartwood they cease growing inward. One reason for this may be the absence of food materials in the rays of the heartwood, and another may be the greater lignification of the heartwood cells. It is very certain that the hyphæ do not flourish in the heartwood, neither in the medullary rays and resin ducts nor in the wood cells proper. Hartig ascribes the restriction of the fungus to the sapwood to the smaller amount of water in the heartwood, but it would seem to the writer that there would hardly be so very sharp a line between the points where growth does take place and where it does not, if it were a matter of water supply alone. The readiness with which the fungus can enter heartwood and sapwood cells and the presence or absence of food substances would seem to be factors of more importance in determining the regions where the fungus could or would not grow.

The growth in the medullary rays comes to a stop within six months after the first infection, and perhaps earlier. This applies to such wood as is infected in July or August. By December or January the whole sapwood will be filled with hyphæ. In the top of the tree the

[a] The hyphæ growing out from the medullary rays, as shown in Pl. VIII, fig. 2, make the wood cells appear septate. This, of course, is not the case.

development is probably very similar, although it was not possible to make an accurate determination of this fact because of the great irregularity in the rate with which infection takes place after the beetle attack. The rate of growth in the trunk varies considerably. Some trunks are invaded on all sides with equal rapidity; some, on the other hand, seem to be more resistant on one side or another. A good idea as to the presence or absence of the fungus can usually be obtained by observing the extent of the blue coloration, to which reference is made below.

EFFECT OF "BLUE" FUNGUS ON THE TOUGHNESS OF THE "BLUE" WOOD.

On page 13 it was stated that the "blue" wood was considered very much tougher than the healthy wood. The tie cutters in the Black Hills find that it is very much harder work to cut cross-ties from the "black-top" wood than from green trees—so much so that they demand additional pay for cutting these ties.

When split with an ax, the two halves of a block seem to hang together more firmly, and it requires more strength to wedge them apart. Chips do not fly off as easily. The only explanation which can be suggested for this peculiar behavior of the diseased wood is that in the "blue" wood we have an enormous number of filaments, all extending radially through the wood. These filaments occur in bunches, much interwoven, scattered at regular intervals through the wood. It is estimated that at a point about 1 foot in from the bark there are about 39,000,000 medullary rays per square meter of tangential surface, or about 3,700,000 per square foot. Even if the tensile strength of one hypha is not very great, when it comes to 4,000,000 bundles these may have some effect in holding masses of wood fiber together (see Plate VIII). This view is strengthened by the fact that it seems easier to split the "blue" wood along radial lines than on tangential lines. In making ties the tangential cut is used almost entirely, and it is possible that these hyphal bundles are responsible for the toughness. When split tangentially and viewed edgewise, one can see some of these hyphal bundles projecting from the medullary rays, as if they had been pulled out and stretched before being torn.

RELATION OF THE "BLUE" FUNGUS INFECTION TO THE BEETLE HOLES.

As has been previously stated, the first evidences of the presence of the "blue" fungus are seen some weeks after the beetles have bored into the cambium layer. The first signs of blue color in the wood might be expected just under a hole in the bark or near such a hole, or under the tube excavated in the bark extending from such a hole. This, however, is not always the case; in fact, is rarely the case. The small triangular patches of color may appear anywhere within the area attacked by the beetles. Why this should be so it is difficult to explain satisfactorily. The spores must enter the region between the wood and the bark through the beetle holes and burrows, for there is no other way for them to get through the bark. Cracks in the bark are practically entirely wanting in the living trees. The only explanation possible is that the hyphæ start their growth in the bark and cambium layer, the parts richest in food materials, and then grow inward at one or more points independent of the beetle holes.

As soon as the living bark and wood die, a wood-boring beetle enters the wood and makes numerous small holes all through the sapwood (see Pl. IX). It enters felled trees within a few days after the tree is cut. The holes which it makes extend radially into the trunk, sometimes with great directness, then again obliquely. The beetles bore with great rapidity, so that they may have reached the heartwood in the course of a few months. These holes form very convenient channels for the entrance of the hyphæ of the "blue" fungus, and they take advantage of their opportunities. Before they appear in the wood cells surrounding the holes made by the wood-boring beetle, one finds great masses of another fungus in the open ends of the wood cells bordering the hole. This is the so-called "ambrosia" fungus,[a] which the beetles carry into the holes with them, and upon the spores of which they feed. The hyphæ of this fungus are colorless and thick walled. They extend into the wood cells away from the holes only a short distance, but near the holes they grow into dense mats, which practically plug the lumen of the wood fibers toward the beetle hole. The bunches of sporophores with the round pores project into the beetle hole from these mats.

The hyphæ of *Ceratostomella* can be distinguished readily from those of the "ambrosia" fungus. They are thin walled, full of vacuoles, and turn brown very soon. There seems to be no relation between the two, although such a relation is not impossible. The development of the "ambrosia" fungus is now being investigated, and it is hoped that this study will throw more light on any possible relation.

This class of beetle probably carries the spores of *Ceratostomella* with it into the holes it makes, much as it carries the "ambrosia" spores. This seems probable from the fact that the "blue" fungus seems to start at various points along a beetle hole; in other words, it does not grow down into the hole from the outside. Sections made at right angles to the hole show that the fungus starts to grow on all sides of the hole, and that it makes most rapid headway in a direction parallel to the long axes of the wood fibers (Pl. IX). When once the hyphæ have reached the medullary rays from the wood fibers, progress in all directions

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[a] Hubbard, H. G. The Ambrosia Beetles of the United States. Bull. 7, n. s., Division of Entomology, U. S. Dept. of Agriculture, 1897, pp. 9–30.

becomes equally rapid. The blue color appears around the beetle holes soon after the entrance of the "blue" fungus. Usually it forms two rings extending from the hole along the wood fibers. Various stages of this first appearance of the color are shown on Pl. IX. The spread of the "blue" fungus within the wood, through the agency of wood-boring beetles, is an occurrence frequently found in many coniferous woods. The central figure at the bottom of Pl. IX is from a photograph of a log of western hemlock found in the Olympic Forest Reserve, in Washington, which shows an even more striking case of the spread of *Ceratostomella* from holes made by *Gnathotricus occidentalis* Hopkins MS. This particular piece of wood was cut from a fallen trunk, about 6 inches in from the bark.

FRUITING ORGANS OF THE "BLUE" FUNGUS.

The "blue" fungus forms its fruiting bodies on the surface of the wood in which it is growing. Air seems to be necessary for the formation of the fruiting bodies. A good deal of moisture in the surrounding air is necessary likewise. No fruiting organs are formed in dry air. In the forest they occur in the cracks formed when a blued trunk is broken off, on broken branches, and at such other points as are exposed to the air. So far the writer has been unable to find the perithecia of *Ceratostomella* on the surface of standing trunks under the bark, although a diligent search has been made for them at all seasons for two years. When, several months after the beetle attack, the bark becomes loose, so that it separates from the wood, a space is left between the bark and wood. In this space numerous fungi develop in quantities, among others a species of *Alternaria* which lines the pupal chambers of the *Dendroctonus*, and a species of *Verticillium*. The whole atmosphere of this region is surcharged with moisture, and yet the "blue" fungus does not fructify here, for there is probably not enough air.

The black perithecia of the "blue" fungus, *Ceratostomella pilifera* (Fr.) Winter, are familiar objects on blued boards or shingles, where they occur in thousands side by side. The perithecia are formed within a few hours when the conditions are favorable. At various points on the surface of the wood, in some instances out of every medullary ray, masses of hyphæ grow out forming a dense mass which gradually develops into an egg-shaped body (Pl. VII, 4). The surface of the young perithecium shows irregular polygonal markings, which gradually become indistinct as the perithecium turns jet black almost to its tip. At the tip of the young perithecium a number of hyphæ grow out parallel with one another (Pl. VII, 4) in a direction perpendicular to the substratum. They remain colorless at the tip. These hyphæ grow in length with remarkable rapidity and form a long bristle-like neck several times as long as the diameter of the perithecium (Pl. VII, 6). This neck becomes very brittle as soon as the perithecium is mature, and breaks off at the slightest jar or touch. The tips of the hyphæ composing the neck remain joined at the top until the spores are discharged; they then separate and form a sort of cup-shaped support for the spore mass (Pl. VII, 9). The body of the perithecium when mature is about 180μ in diameter and 160μ high, and is covered with scattering brown hyphæ. The neck averages about 1,050μ in length and 20μ in thickness.

The spores of *Ceratostomella* are elongated and somewhat curved (Pl. VII, 8). They are very small, and the asci in which they are borne are almost round or egg-shaped (Pl. VII, 7) and exceedingly evanescent, so much so that it is very difficult to find them. Hundreds of perithecia in all stages may be examined without showing a sign of asci. When the spores are mature, they are discharged through the neck, either in the form of a large drop (Pl. VII, 5, *s*), or in a long, worm-like mass. The spores are held together by a mucilaginous material, which will not mix with water. It is suggested that this serves admirably to spread the spores through the agency of crawling insects and worms, both common on wood where the perithecia are likely to be found. The spores germinate in water after a few hours, sending out a short hyaline germ tube, which branches very soon after its appearance. The discharge of the spores takes place when a certain amount of moisture has accumulated within the perithecium. A rain storm often brings about a worm-like discharge from ripening perithecia. In cultures a globular discharge takes place, probably because of the more equitable distribution of water. The spores measure 5.5μ by 2.5μ, average.

GROWTH IN ARTIFICIAL MEDIA.[a]

The "blue" fungus grows quite readily in artificial media. In pine agar the mycelium develops rapidly; less so in ordinary agar or gelatin. Cultures are most readily obtainable in pure condition by inoculating pine agar tubes with pieces of blued wood removed (with care so as keep them sterile) from the inner portion of a blued log. The hyphæ grow out from the blued pieces and soon grow through the agar to the surface. On nearly all cultures of this character perithecia developed on the surface of the agar within a week. The ascospores germinate in a few hours, and at the end of thirty-six to forty-eight hours a colorless mycelium bearing large numbers of conidia has developed. At first these conidia were regarded as contaminations, but their repeated appearance in cultures made from pure cultures of the

[a] The cultural work was carried on in conjunction with Mr. George G. Hedgcock, assistant in pathology.

ascospores leaves no doubt as to their being a stage of the "blue" fungus. Cultures made from these conidia developed a mycelium on which both conidia and perithecia appeared. Work with these conidia is still in progress and a report upon the results accomplished is to be published in full at a later date.

In four to five days in good growing cultures on rich pine agar or on sterile pine blocks the older threads of the colorless mycelium begin to turn brown, and at the end of seven to nine days young perithecia begin to form. These are at first hyaline and change rapidly from brown to black. They mature quickly, and at the end of from twelve to eighteen days some will be found ejecting the ascospores. In twenty-one days nearly all perithecia in a culture will be mature.

DISSEMINATION OF THE SPORES.

The sudden appearance of the "blue" fungus on lumber piles and over large areas at once, and its simultaneous appearance within the trunks of the pine trees seem to point to the distribution of the spores of the fungus by the wind. It was thought that the bark beetles might be instrumental in carrying the spores into their holes. This they might do by having the spores adhering to their bodies or by feeding on the spores and depositing these in their holes. To test these hypotheses, beetles were placed in tubes of melted pine agar, thoroughly shaken, and then plated. Quite a number of beetles were dissected and cultures were made, using their alimentary canals, as well as some of their feces, as infecting material. In none of these cultures did any "blue" fungus appear. A very characteristic bacterium was obtained from the alimentary tracts, but no *Ceratostomella*. A number of live beetles (*Dendroctonus*) were allowed to walk about on pine agar plates, but no "blue" fungus developed. These trials are by no means to be regarded as conclusive, for they were not exhaustive. They are to be repeated on a larger scale this winter and in the summer when the beetles emerge. The number of perithecia developing on dead sticks and in cracks is sufficient to account for any infection which takes place in the Black Hills forest. This applies with equal force to all regions where the "blue" fungus occurs.

The months of May, June, July, and August are the ones during which the most rapid development of this fungus takes place.

THE BLUE COLOR.

Wood in which the mycelium of *Helotium æruginosum* (and probably of other "green" fungi) grows turns green very soon after the fungus gets into the wood. As shown by Vuillemin and others, the green color is due to a substance formed as a product of metabolism of the fungus, which is deposited in the form of regular granules in the hyphæ and fruiting bodies of the fungus. The green matter, xylindeine, is confined to the fungus threads and in no way stains the wood fibers. Vuillemin states expressly (p. 144) that "there is no green decay or green staining of the wood. The wood appears green when the colored thallus of *Helotium æruginosum* or of analogous fungi is found in its elements." With the highest powers of the microscope he was unable to find any coloration of the walls of the wood. The green color is therefore due to the presence en masse of green-colored threads.

Similar instances of color due to the presence of colored mycelium are found on pine and spruce wood, where brown and black lines are formed by masses of dark hyphæ bunched at particular points in the wood cells. The familiar zigzag and fantastic lines often found in wood of the tulip tree and in birch and maple are due to similar fungus threads. In none of these cases are the wood fibers themselves colored.

So far as known to the writer, no attempt has ever been made to explain the nature of the blue color of coniferous woods. The color is a difficult one to define. A number of the writer's artist friends who were called into consultation pronounced it a blue gray, approaching Payne's gray. Freshly cut wood looks decidedly blue, but as the wood dries the color fades somewhat and dry wood is mouse gray. The color is by no means regular; here and there some of the yellow of the healthy wood shines through. The drawing shown on Pl. I is perhaps a little too blue. Pl. V is closer to the real color. Certain portions of the blued wood look greenish when viewed obliquely.

There are two possible explanations as to the cause of the so-called blue color: (1) The wood may appear colored because of the presence of the colored fungus threads in the wood. The mass effect of such colored threads might make the wood appear colored. (2) The wood might be colored by a pigment or stain formed either by the fungus or as a result of the fungus growth in the wood, and this pigment might stain the walls of the wood fibers.

The first explanation holds good for the "green" wood. Here a pigment is formed in the hyphæ and fruiting bodies of the fungus, and it is because of the presence of the green-colored bodies in the fungus threads, according to Vuillemin, that the entire wood looks green. Careful examinations made of the "blue" wood by persons trained to observe colors, called into consultation by the writer, have led to somewhat conflicting results, and it is therefore thought inadvisable in the present stage of the investigation to enter on a lengthy discussion of the color subject. A number of facts may be stated, however. Examinations of the wood fibers of sound and "blue" wood showed that it was possible in most instances to distinguish between the sound and the "blue" wood. The walls of the sound wood look somewhat darker (with a suggestion of purple) than the blued fiber. This method of examination, with high magnification, is a rather uncertain one, however, for the refraction caused by the containing liquids, which are purplish, and of light falling from a blue sky, is apt to show very faint traces of color which do not belong to the wood. It may be stated definitely that the fibers of the "blue" wood show no indication whatever of any color element seen in the wood en masse.

The hyphæ constitute the only color element present in the "blue" wood which could not be detected in the sound wood. These are present in the medullary rays and adjacent cells, as described above. These hyphæ are pale reddish-brown, a color which may be obtained by taking a pale tinge of warm sepia. This color is very distinct and stands out in sharp contrast to the surrounding yellow wood fibers. (See Pl. VIII, showing the contrast.) How these brown hyphæ could make a blue gray or mouse gray it is difficult to understand, for no density of such a brown, even in combination with straw yellow (of the wood fiber), could possibly produce blue gray. It would therefore seem probable, or at least possible, that there is some pigment with a blue element in the "blue" wood which is so faint that its detection in thin microscopic sections becomes almost impossible.

All efforts to extract any color of a blue nature from the wood have so far failed. Extracts of blued wood with ether, alcohol, benzol, chloroform, alkalis, and acids gave evidence that changes of some sort had taken place in the wood fiber, for the extracts of sound and "blue" wood differed materially in nearly every instance. No signs of any blue or blue-gray color were obtained.

It seems necessary, therefore, to leave this matter for further investigations, which are now in progress.

SUMMARY.

In the foregoing chapters a peculiar disease of the dying wood of the bull pine has been described. The wood turns blue in August and September, after the trees are attacked by the beetles. The blue color starts near the base of the tree and gradually spreads upward until the entire sapwood is blue. The "blue" wood is somewhat tougher than the healthy wood and has been shown to be practically as strong as the healthy wood.

DECAY OF THE "BLUE" WOOD.

The changes which the "blue" fungus brings about in the wood of the western yellow pine can hardly be called decay. It is true that the medullary rays are destroyed in part and that the walls of many wood fibers are punctured, but as a whole the wood is sound in the ordinary acceptance of that term. It is not rotten, or doty, or decayed. The "blue" fungus attacks cell contents and not the cell walls.

After the wood has been dead for some time certain changes begin, which in the end result in the entire decay of the wood. The dead wood may or may not be blue, for the processes by which the wood changes to decayed wood are the same for wood which is entirely healthy and for the "blue" wood.

THE "RED ROT" OF THE WESTERN YELLOW PINE.

The "red rot" of the western yellow pine usually starts in the tops of the "black-top" trees, i. e., trees which have been dead for two or more years. At one or more points, usually on the north or east side of a tree, one will find that the wood immediately under the bark starts to rot. This rot starts at the bark and gradually extends inward (Pl. X, fig. 1). The wood when it shows the first signs of this decay is wet and soggy and rapidly becomes brittle, so that it crumbles into small pieces when rubbed. A plane will no longer make a smooth surface (Pl. X, figs. 1 and 2), for the knife tears out small pieces of the wood fiber. The color of the wood changes from blue to red yellow. When the decay has gone on for some time, bands and sheets of a white felty substance are found filling certain cracks which result because of shrinkage in the wood mass (Pl. X, fig. 2). These white sheets consist of masses of fungus threads densely interwoven. The destruction of the wood continues until the heartwood is reached, and as this is exceedingly small in the tops of these trees one will find that after some time almost the entire wood mass has changed to a brown, brittle, resistless mass (Pl. XI). The completely rotted wood crumbles into a fine powder when crushed between the fingers. When wet it is of a cheesy consistency. When the water has evaporated from such wood it is like so much brown charcoal.

CAUSE OF THE "RED ROT."

The "red rot" of the dead timber is caused by one of the higher fungi which grows in the wood, and by so doing brings about the decay of the wood. The spores of this fungus fly about in the forest and some of them lodge in bark crevices of the dying trees. The numerous beetle holes afford every opportunity for entrance to the wood, and it is therefore not surprising to find that the majority of the "black-top" trees become infected sooner or later with the spores of this fungus. The spores germinate and hyphæ grow into the dead cambium and the wood, where they attack such organic matter as has been left by the "blue" fungus. They go farther, however, and attack the cell walls of the wood fibers, from which they extract the cellulose. As a result of this, the wood fibers shrink in volume and crack in regular lines extending obliquely across the cell walls. As the solution of the cellulose goes on, large numbers of fibers separate in a body from the adjoining ones, often along the lines of medullary rays, and the spaces so formed are rapidly filled with fungus threads, giving rise to the white sheets already spoken of. (See Pl. X, fig. 2.)

CONDITIONS FAVORING THE DEVELOPMENT OF THE "RED-ROT" FUNGUS.

One of the most important factors which influences the development of the "red-rot" fungus, and one which holds for all fungi, is water. If the trees in the Black Hills were dry, the red rot would make but slight progress. At the time when the attack takes place the trees are full of water, especially the tops, for these have lived longer than the butts of the trees, and water was pumped into them long after the lower parts of the trees were dead. The top, therefore, is the most favorable point for the "red-rot" fungus, and it is there that it is found developing most rapidly. From the top the fungus may grow down, so as to affect the lower part of the trunk, but as this has been drying continuously since the beetle attack one will find that it is very rare for those parts of the trunk situated at points 5 to 30 feet from the ground to be seriously injured by this fungus in the first years after the death of the trees. This is an exceedingly important consideration when the practical phase of this subject is taken into account.

The relation of the water supply to the "red rot" is illustrated very well in the large number of trees where the bark has died and peeled off from one side of the tree. On Pl. X, fig. 2, a photograph of such a case is reproduced. The bark has fallen off on the south and southwest sides of the tree, but it still is attached to the opposite side. The result of this peeling becomes evident very soon, for on that side the wood dried very rapidly, while on the other side the bark prevented such evaporation. The wood remained moist, and here the "red-rot" fungus found a footing and conditions favorable for its growth. The result was that in the course of some months the north and northeast sides of that trunk were completely decayed, while the opposite side remained sound. A similar instance is shown in the largest section on Pl. VI, fig. 2; in this case at the base of the tree.

Where the bull pine grows on hillsides not exposed to the sun or wind, or where there is much undergrowth, one will frequently find the "red-rot" fungus entering the trees at the base before it attacks the top. This is likewise due to the fact that the water has not left the trunk with sufficient rapidity to prevent the attack.

FINAL STAGES AND FRUITING ORGANS.

When the tops become rotted almost to the heart they become so weak that they are broken off by the first wind. In those sections of the Black Hills Forest Reserve where the beetle attack took place some four or more years ago there are thousands of dead trees standing with their tops broken off much like those shown in Pl. XII. In this view the tops can be seen lying on the ground. Pl. XIII, fig. 1, shows the lower end of one of these tops. One will note how sharp it has broken off—almost straight across. One of the sheets of mycelium has curled over at the extreme right of the figure. The cross sections of such a top (reproduced on Pl. XI, figs. 1 and 2) show how completely the wood has been destroyed and that there is small chance for such a top remaining on the tree very long.

Where the "red-rot" fungus attacks the tree at its base it brings about the decay of the larger roots underground, and also of the sapwood of the trunk close to the ground (Pl. VI, fig. 2, large section, and Pl. XI, fig. 3). After a time the roots become weakened to such an extent that they are no longer able to keep the trunk in an upright position, and the result is that the tree is blown over. Such a fallen tree is then attacked rapidly at all points by the "red-rot" fungus, and in a few years nothing is left of it but a pile of rotted wood.

When the wood has been completely destroyed the fruiting organs of the "red-rot" fungus begin to form. Some of the hyphæ grow out through the bark and form a flesh-colored knob (Pl. XI, fig. 1), which rapidly increases in size and turns reddish in color. This knob gradually widens horizontally, forming a shelf, and on the lower side of this shelf numerous pores appear. One of these bodies is seen growing out from the fallen top shown on Pl. XIII, fig. 1, a little below and to the right of the small branch extending out toward the front of the picture. (See also Pl. XI, fig. 2, and Pl. XIII, fig. 2.) After a year a mature fruiting body or sporophore (commonly called a punk, mushroom, or toadstool) has developed, from which spores are discharged at intervals. These spores are formed in the small tubes found on the lower side of the sporophore, and on a quiet night one can see them coming from the sporophore in white clouds as they are being discharged in countless thousands. The spores are so light that they are carried many miles by the winds and lodge on every stick and tree in the vicinity.

The sporophores of this fungus may grow for many years. At different periods, the length of which is not yet definitely known, they add a ring on the outside and thereby increase in size. The one shown attached to the section on Pl. XI, fig. 2, is probably 2 years old, while the one at the base of the tree on Pl. XIII is probably several years old. The sporophores may occur singly or in groups of two or three together. When a top falls so as to lie close to the ground where it is likely to be kept wet, the sporophores will develop every few inches, so that there may be as many as 20 or 30 on a log 10 feet in length. On standing trees they occur only at the base of the trees (Pl. XIII). Here they grow close to the ground and oftentimes their lower surfaces are actually in the ground. Grass, pine needles, and stones almost hide the entire sporophore.

Older punks are rough on top and appear to be covered with some waxy substance which has hardened and cracked. This substance, when scraped, resembles a hard resin. It is brittle, and is readily soluble in alcohol and xylol. It has a sticky appearance, and when freshly formed on the younger parts its bright red color forms a distinguishing character not readily overlooked. The younger parts are sometimes flesh color, then again reddish yellow in color, and as they grow older they turn more decidedly red. The surface is at first smooth and waxy, and as the sporophore grows older it becomes very much wrinkled. The outer waxy covering cracks (Pl. XIII, fig. 2), and the whole surface then seems to be coated with a dull gray, lime-like substance, which is exceedingly characteristic.

The red-rot fungus belongs to the Hymenomycetes, genus *Polyporus* (*Fomes*), and differs decidedly from other species of this genus. The species most closely related to it are *Polyporus pinicola* and *Polyporus marginatus*. Its whole appearance, its color, hard resinous covering, and very rough surface distinguish it from these species. It has been decided to consider it as a new species—*Polyporus ponderosus*, n. sp.—which may be described as follows:

A large *Polyporus* of the *Fomes* type usually growing singly (Pl. XI, fig. 2), sometimes two or three together (Pl. XIII, fig. 2), broadly applanate; about as thick in the back as it is wide (Pl. VII, figs. 10 and 11); top, when young, flesh-colored to yellow red, becoming darker red with age; smooth when young, rapidly becoming rough and covered with irregular nodules. Older specimens show numerous ridges, formed by regular additions (annual) on the edge and below. Top covered after the first year with a hard, brittle, dull, resinous substance, which cracks as it grows old, and looks sandy or crystalline. Lower surface smooth, pores very regular, almost round, extending out to a line which is about one-fourth inch in width. (See Pl. VII, figs. 10 and 11.) Common on dead trees and fallen logs of the western yellow or bull pine (*Pinus ponderosa*) in South Dakota.

RATE OF GROWTH OF "RED ROT."

The question as to the rate of growth of the "red rot" is one of great practical significance. The "red rot" fungus is the principal cause which prevents the dead wood from lasting indefinitely. It usually attacks the trees when they have reached the "black-top" stage; i. e., toward the end of the second year after the beetle attack, and thereafter. The larger number of trees are probably free from this rot until the third year. To make this clearer, one may make a schedule of the stages through which the trees go, about as follows:

1899, July.—Live trees attacked by the bark-boring beetles.

1899, September.—Wood of the lower part of the trunk starting to blue.

1899, December.—Wood blue to the heart below, and wood of the top partially blue.

1900, May.—"Sorrel-top" stage; leaves turning yellow; wood wholly blued.

1900, October.—"Red-top" stage; leaves red and lower ones starting to fall off; wood blue, but sound.

1901, May.—"Black-top" stage; leaves falling off and fallen wood starting to decay; "red rot" in the tops.

1901, October.—"Black-top" stage; leaves all fallen; top badly decayed and in many instances broken off.

This calendar must be considered a tentative one, based upon observations of two years, although in the main it is probably correct. The "red-rot" part is extremely variable, and can not be assigned to any definite period. The time when the tops will begin to decay is dependent upon the weather at any particular season, the amount of rain, the vigor of the tree and the length of time it takes the tree to die completely after the beetles have attacked it, the position of the tree in the forest, the prevailing winds, and probably other factors more or less related to those mentioned.

It is exceedingly important that this variability be recognized, for its bearing on the cutting and utilization of the dead timber is of the greatest importance. There may be "black-top" trees which will be sound from the ground to the very top, and these trees may have stood in the forest for years in this condition. Not far away one will find others which have barely reached the "black-top" stage which may show signs of decay to within a few feet of the ground. It is therefore entirely impossible to lay down a hard and fast rule, and to state that the "black tops" after a year are all of no value as timber.

The average conditions in the Black Hills are certainly very favorable for the development of "red rot," and one will probably not be very far from the truth when he assumes that after the trees have reached the "black-top" stage they are liable to decay and deteriorate within a comparatively short time; that time probably will not exceed two years.

AMOUNT OF DISEASED TIMBER.

In the foregoing, but brief reference has been made to the actual condition of the forests in South Dakota at this time and to the extent of the injury following the attack of the bark beetles. The amount of dead wood, both standing and fallen, is very large, and as the beetles are still at work, it is steadily increasing. It is, of course, rather difficult to make estimates of the exact amount without an actual survey of the whole region. A trip through the worst region—i. e., north of Spearfish River and west of the Burlington Railroad tracks—was made during the past summer, in company with several expert timbermen, for the purpose of determining about how much dead and dying timber one could safely count on removing this winter. Estimates were individual, and these estimates[a] agreed fairly well as to the relative amounts of the various grades of timber present. Taking these estimates as a basis, it appears that about half of the timber in this particular region is now dead. This refers to the standing timber, and leaves the fallen timber entirely out of consideration. This immense amount of timber is drying out rapidly and forms a tremendous fire danger. Should fire start in these woods, it would sweep the dead as well as the living trees from the hillsides. The great danger of leaving the trees with the beetles in them, which will be "sorrel tops" next summer, has been pointed out by Hopkins. Besides these two dangers, there is still another point worthy of attention, and that is the loss, under present conditions, of the value of this wood. The following considerations are made, keeping in mind both the protection of the living timber against further insect and fire loss and the possible utilization of the vast amount of dead timber.

POSSIBLE DISPOSAL OF THE DEAD WOOD.

IN THE BLACK HILLS.

Timber from the Black Hills Forest Reserve is now being used by the mining interests in the Hills, and to a very small extent by the railroads on their lines in South Dakota. The mining interests use the wood for mine props, lagging, and fuel. They are absolutely dependent on the timber in the Reserve for the lumber necessary for use in mining, for their fuel, and for their water, which is conserved because of the forests on the hillsides. The railroads use the wood for crossties on the lines which extend from Lead City and Deadwood south to the State line. The timber used for mine props, lagging, etc., by all the mines in the Black Hills is stated to be about 75,000,000 feet at the maximum. The amount of timber used for ties is practically inappreciable, and at this writing most of the tie cutting has practically stopped.

It appears from this that the amount of dead timber which could possibly be used in the Black Hills is not more than 75,000,000 feet.

[a]The exact estimates were as follows:

Kind of timber.	I.	II.	III.
	Per cent.	*Per cent.*	*Per cent.*
Green timber	40	40	50
"Sorrel tops"	25	25	25
"Red tops"	20	15	15
"Black tops"	15	20	10

The third estimate was made by Dr. Hopkins and the writer.

IN THE REMAINING PARTS OF SOUTH DAKOTA.

The Black Hills are situated in the extreme southwest corner of South Dakota, and the only railroad connection which they have with the surrounding territory is southward into Nebraska. It is therefore entirely impracticable to consider a possible use of any of the dead timber in parts of South Dakota outside of the Black Hills.

It appears from the foregoing that only a very small amount of the dead timber can be used in the Black Hills, and that practically none can be taken to other parts of South Dakota. The only practicable method of disposing of this surplus amount would be to ship it out of the State, but this is not permissible under the present forest-reserve law, as will be pointed out hereafter.

VALUE OF THE DEAD WOOD.

The dead wood which ought to be removed from the Black Hills Forest Reserve is of all grades and values, and for practical purposes it is impossible to draw any lines grading the same which will hold good. It must be taken for granted that the only wood which can be considered as worth anything at all is wood which shows no sign of decay or rot. Most of the timber, in fact nearly all, will be blue. The blue color, as has been previously shown, ought not to make much difference as regards its strength, and if properly treated with preservatives it is probable that the "blue" wood will be serviceable for ties and lagging.

The wood which is dead in the forest now rots rapidly, as has been pointed out, and every day that it is left makes large amounts of it less valuable than it was before. At best one may expect that timber which is killed by the beetles one year will begin to decay after two years.

In fixing the price of this dead timber it should be remembered that in order to get it out, lines of railroad would have to be constructed at a very considerable cost. Even with such lines the cost of bringing the dead timber from the forest to points where it could be utilized would be great. The expense of bringing timber from Montana and Wyoming to Nebraska (such cost including the first cost of the timber plus the transportation) will about equal the cost of bringing the timber from the Black Hills to Nebraska. That the wood must have some value to be worth going for at all is obvious, but, as has been pointed out, its value will depend upon the rapidity with which it is removed.

INSPECTION.

One of the greatest difficulties which will be encountered in the utilization of the dead timber will be in connection with the inspection of the material used. There will be vast quantities of the timber which will be hard and sound, but badly blued. Then again, if the recommendations as to the cutting of live trees which are infested with beetles are followed there will be timber which will in all respects be like the green timber. A tie cut from the top of a tree in September, after the beetle attack in August, will usually be perfectly healthy, i. e., it will show no traces of blue color or only very slight ones.

All timber which is entirely sound, i, e., not decayed, is fit for the uses to which it can be put in the Northwest, either for mine timbers, lagging, ties, etc. The blue color is not to be considered as a sign of decay. Timber which shows rotten spots of any size in the sapwood should not be used. An idea of what such decayed spots look like can be gained by studying the photographs reproduced on Pl. X, figs. 1 to 3, and Pl. XIV, fig. 1. Besides the defect caused by the "red rot," one will sometimes find logs which show decay in the center. This is a disease of the *living* tree, and when more than one or two rings are affected by the disease, such logs should likewise be rejected. The tie section shown on Pl. XIV, fig. 2, is an example of this form of rot.

A careful and intelligent inspector who familiarizes himself with the causes of the decay in the Black Hills Forest Reserve ought to have no difficulty in determining after some practice which timber is fit for use and which ought to be rejected. No amount of chemical treatment will, so far as we now know, make a practically decayed log serviceable.

RECOMMENDATIONS.

Bearing in mind the considerations just referred to, the following recommendations are made:

(1) *Removal of wood from the forest.*—The dead timber should be removed from the Black Hills Forest Reserve at once. It forms a standing fire menace. The standing beetle-infested trees serve to spread the insect trouble. This dead timber should be removed at once, or at the earliest possible moment, and the living infested trees should be felled and peeled as recommended by Dr. Hopkins, for with every day the situation becomes more and more difficult to handle.

(2) *Sale of wood.*—In order to rid the forest of danger from fire, from further insect and fungus spread—in other words, in order to protect the remaining living trees from further destruction—the dead wood should be removed. The cost of operation in removing the dead timber is very considerable: (1) Because of the distance from lines of transportation; (2) because of the greater difficulty in cutting this wood; (3) because of the scattered localities in which it is found; (4) because of the constant care and selection necessary to get good sound wood. Therefore, because of this increased cost, it is recommended that the dead and beetle-infested timber be sold at a nominal

price to such as may apply therefor, this to be done in order to induce persons to assist in clearing the forest with all possible speed.

(3) *Removal from South Dakota.*—It has been pointed out that the great mass of dead timber now in the Black Hills Forest Reserve can not be used in South Dakota. It is therefore recommended (again as a measure of protection for the living forest) that the forest-reserve law be so amended as to permit the shipment of the dead and beetle-infested timber from the State of South Dakota.

In making such a change, it ought to be understood that shipping timber from the State should in no way interfere with the industries dependent upon such timber in the State where the timber is situated. The case under consideration is an example in point. The mining interests of the Black Hills are absolutely dependent for their timber supply on the wood in the Black Hills, and if any timber is removed from the region of the Black Hills, i. e., from the State of South Dakota, it should be taken from regions in the Black Hills which are not tributary to the important mining interests in the Hills. In other words, if any timber is removed from the Black Hills, it should come from the region south and west of the Little Spearfish River.

(4) *Timber which should be removed.*—The timber which should be removed is the dead and beetle-infested timber. For the purposes of inspection dead timber should be considered as timber which comes from trees whose leaves are no longer green—that is, the "sorrel tops," the "red tops," and the "black tops." "Beetle-infested timber" has been specified by Dr. Hopkins.

This dead timber will be "blue timber," and much of it is now decayed. Contractors should be required to cut and remove only such timber as is perfectly sound, without any signs of decay.

PLATES.

DESCRIPTION OF PLATES.

PLATE I.—Frontispiece. Cross section of the trunk of a dying tree of the western yellow or bull pine (*Pinus ponderosa*) from the Black Hills, South Dakota. This tree was attacked by the beetles in August, 1901. The section was cut at a point 6 feet from the ground during the early part of November, 1901. Note the beetle holes in the bark; also the yellow ring between heartwood and sapwood.

PLATE II.—Dying trees of the bull pine. Fig. 1 shows several trees; at the left two live, green trees, a "sorrel-top" tree in the center, and a "red-top" tree at the right. Photographed August 5, 1902. Fig. 2 shows several live, green trees at the left and a "sorrel-top" tree toward the right. Note that this tree is still green at the top. Photographed August 5, 1902.

PLATE III.—Various stages showing the gradual color change of leaves of the bull pine (*Pinus ponderosa*) after they have been attacked by the bark beetles (*Dendroctonus ponderosæ*). 1. Leaves from a healthy tree. 2. Leaves from a "sorrel-top" tree. 3 and 4. Leaves from trees changing to the "red-top" stage. When the leaves have reached the stage of 4 they fall off and are completely dead.

PLATE IV.—Fig. 1. Group of bull pines (*Pinus ponderosa*) near Elmore, S. Dak., showing a "red-top" tree in the center and healthy trees on both sides. Fig. 2 shows a group of "black-top" trees from which all leaves have fallen. This photograph was made in November, 1901, and it is probable that these trees were attacked by the beetles in August, 1899.

PLATE V.—Sections of trunks of the bull pine (*Pinus ponderosa*), showing the "blue" disease. Fig. 1 shows an early stage. This section was cut in November, 45 feet up in the trunk, from a tree attacked by the beetles in August of the same year. The tree is still alive at this point. The blue color has started at two separate points. Fig. 2. A later stage, showing the blue color spread out over one-half of the section. Note the yellow ring at the border of heartwood and sapwood.

PLATE VI.—Fig. 1. Three sections from a bull pine made in November, 1901. This tree was probably attacked by the beetles the latter part of July, 1901. The sections were made at points 5 feet, 16 feet, and 36 feet, respectively, from the ground, i. e., the largest section was cut from the butt, the second one about half way up, and the third in the top. The healthy wood photographs white, and all darker shades represent blued wood. Note the beetle holes in the bark. Fig. 2. Three sections from a bull pine made in November, 1901. This tree was probably attacked by the beetles in July, 1900. It is a "black-top" tree. The sections were made at points 4 feet, 26 feet, and 40 feet from the ground. All are blue. The section near the ground shows "red rot." This happens frequently where the bases of the trees are shaded by long grasses and bushes. In most trees the base will be found sound. The whole tree was dead.

PLATE VII.—Mycelium and fruiting bodies of the "blue" and "red-rot" fungi. 1. Tangential section of "blue" wood; *m*, cross sections of hyphæ of the blue fungus (*Ceratostomella pilifera* (Fr.) Winter), growing in the medullary rays; *h*, hyphæ growing longitudinally in the wood fibers. These hyphæ are brown. 2. Cross section of "blue" wood, showing longitudinal section of medullary ray with hyphæ of the "blue" fungus (*h*) growing in the ray and into adjoining cells; the ray cells have been destroyed; *m*, cross sections of hyphæ of *Ceratostomella pilifera*. 3. Cross section of a medullary ray, with resin duct showing the internal cell walls wholly dissolved out. Masses of brown hyphæ, *m*, of the "blue" fungus extend longitudinally through the ray. 4. Young perithecium of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter), grown on pine agar culture. 5. Mature perithecia of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter), grown on pine agar culture, showing the spores, *s*, discharging from the top of the beak. The line at the side equals 0.1 mm. 6. Two perithecia of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter) just before the discharge of the spores. Perithecia from culture on pine wood. 7. Two asci with spores of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter). 8. Spores of the "blue" fungus (*Ceratostomella pilifera* (Fr.) Winter). 9. Top of beak of perithecium of *Ceratostomella pilifera* (Fr.) Winter, just after the discharge of the spore mass. The hyphae composing the tip of the beak have spread out, forming a sort of support for the spore mass. 10 and 11. Median sections of sporophores of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.), natural size.

PLATE VIII.—Photomicrographs showing the structure of "blue" wood. Fig. 1. A radial section, showing how the hyphæ of the "blue" fungus grow in the medullary rays, being confined almost entirely to the rays. Magnification, 80 diameters. Fig. 2. A tangential section, showing how the hyphæ completely fill the medullary rays. Numerous small hyphæ grow out into adjoining cells in a tangential direction. This makes the wood cells in the photograph look as if they were septate. The apparent septa are hyphæ. Magnification, 80 diameters.

PLATE IX.—A number of pieces of wood from the bull pine (*Pinus ponderosa*), showing holes made by wood-boring beetles. The trees from which these pieces were taken were in most cases dead, either standing or felled. The "blue" fungus has started to grow in the wood cells bordering on these holes, and is gradually spreading to other cells from these holes as a center. Note that these wood pieces show both radial and tangential surfaces. The piece of wood in the center at the bottom of the plate is western hemlock.

PLATE X.—Sections of "black-top" trees of the bull pine (*Pinus ponderosa*), showing early stages of the "red rot" caused by *Polyporus ponderosus*, n. sp. Fig. 1. Section of a dead tree 35 feet up from the ground. This tree had probably been dead for eighteen months to two years. The decay has just started in at several points on the north and northwest sides of the tree. Note that the larger part of the wood is blue. The healthy, unaffected wood is white. Note also the beetle holes in the bark. Fig. 2. A section from a similar "black-top" tree, showing a more advanced stage of decay. The whole section was blue. The decay started on the side where the bark prevented the rapid evaporation of moisture from the wood and had reached the heartwood. Note the radial and tangential sheets of white mycelium. Fig. 3. A section from the same tree from which fig. 2 was taken, made some 15 feet higher up. The section is blue, but shows few signs of decay. This shows how the "red rot" usually attacks the tree somewhere below the crown.

PLATE XI.—Sections of "black-top" trees of the bull pine, showing advanced stages of decay caused by *Polyporus ponderosus* n. sp. Figs. 1 and 2. These two sections were cut from a fallen top of a "black top" such as is shown in Pl. XIV, fig. 1, one near the point where the top broke off, the smaller one near the top of the crown. Both show how completely the wood has been destroyed. This stage was probably reached about three years after the beetle attack. Fig. 3. The lower figure shows a section cut 4 feet from the ground from a standing "black-top" pine. On one side a fruiting body of *Polyporus ponderosus* is to be seen, which is probably two years old. The sapwood is wholly converted into a brown, brittle mass. Such a tree is liable to be blown over at any time.

PLATE XII.—A group of "black-top" trees of the bull pine near Elmore, S. Dak., showing how the tops break off after the trees have been dead for some time. Many of the tops are visible, lying near the base of the trees. A single "black top" from which the top has not fallen is seen at the left. The standing trunks are decayed for several feet downward from the point where the top broke off. The base ot these trunks is generally sound, and contains enough timber to make a good cross-tie.

PLATE XIII.—Fig. 1. View of a broken top, showing how it has broken off almost straight across. Near the middle of the figure a fruiting body of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.) is growing out. Fig. 2. Base of a dead bull pine (*Pinus ponderosa*) near Elmore, S. Dak., showing a number of fruiting organs of the "red-rot" fungus (*Polyporus ponderosus*, n. sp.) growing out from the wood. These are the bodies variously known as "punks," "toadstools," "mushrooms," or "frogstools." The double one to the left is very old. Note the cracked upper surface. A section of the trunk made at the point where these bodies are growing out would appear much like Pl. XI, fig. 3.

PLATE XIV.—Sections of the ends of two cross-ties cut from dead timber, showing defects which are so serious that ties of this kind should be rejected. Fig. 1. Defective because of the "red rot." Fig. 2. Defective because of a disease of the living timber.

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FIG. 1.—"GREEN," "SORREL-TOP" AND "RED-TOP" TREES.

FIG. 2.—"GREEN" AND "SORREL-TOP" TREES.

DYING TREES OF THE BULL PINE.

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COLOR CHANGES IN LEAVES OF THE BULL PINE

1. Leaves from healthy tree. 2. Leaves from "Sorrel-top" tree.
3 and 4. Leaves from trees turning of the "Red-top" stage.

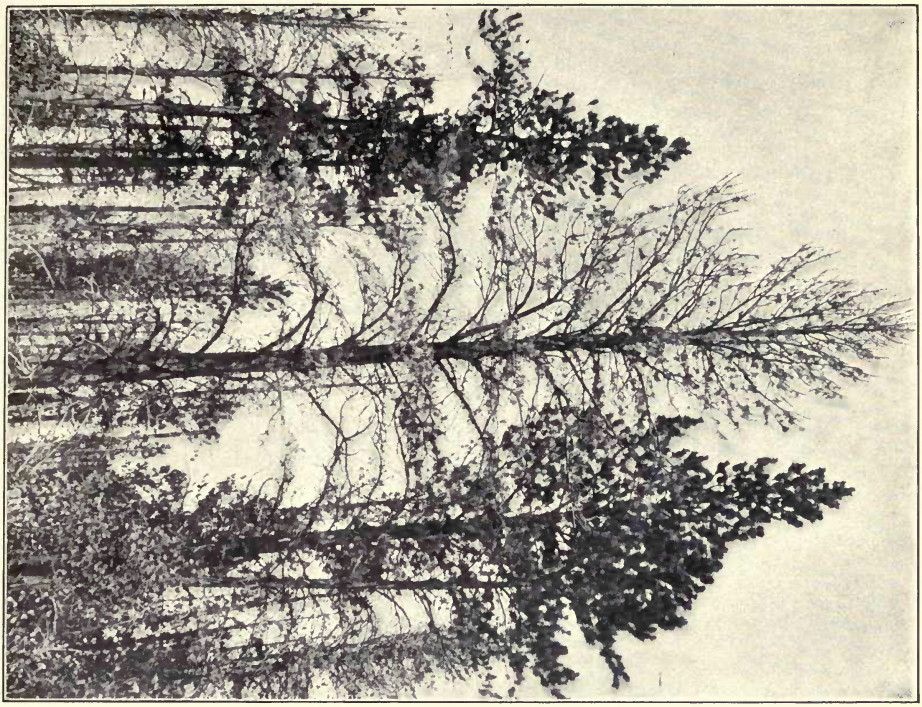


FIG. 1.—"RED-TOP" TREE IN A GROUP OF HEALTHY TREES NEAR ELMORE, S. DAK.

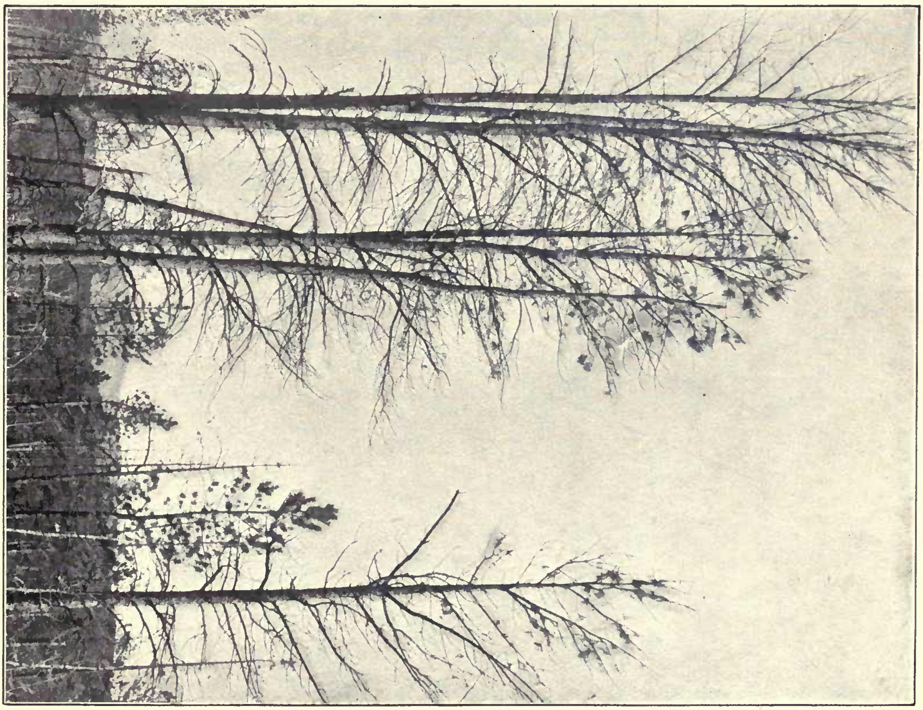


FIG. 2.—"BLACK-TOP" TREES.

Fig. I.

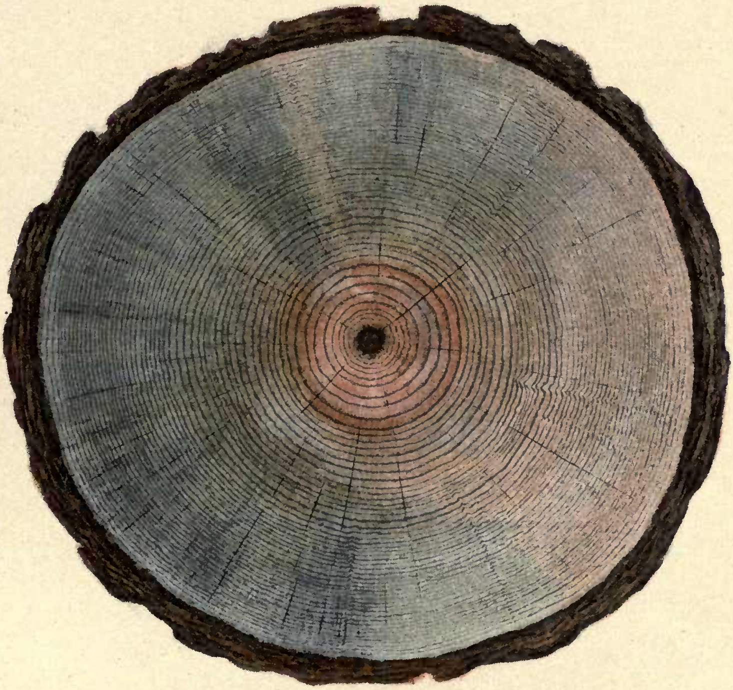


Fig. II.

SECTIONS OF TRUNKS OF THE BULL PINE, SHOWING EARLY STAGES OF "BLUE DISEASE".

Fig. I.

Fig. II.

SECTIONS OF TRUNKS OF THE BULL PINE, SHOWING EARLY STAGES OF "BLUE DISEASE".

FIG. 1.—SECTIONS FROM TREE DEAD FIVE MONTHS.

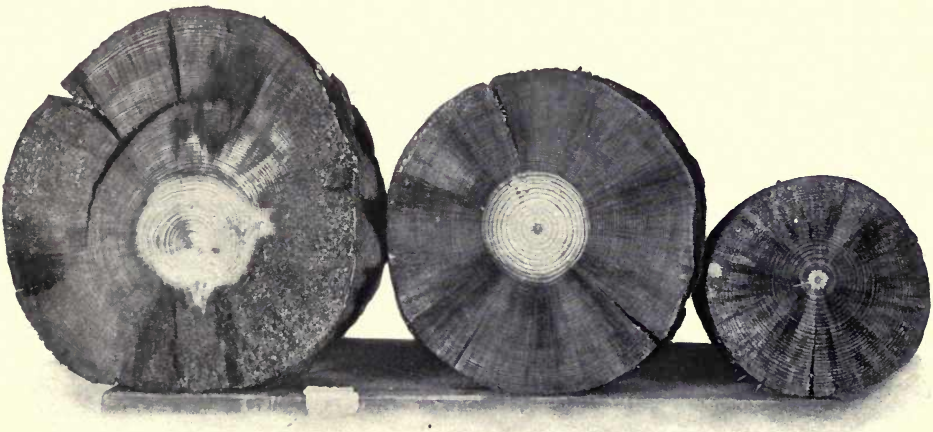
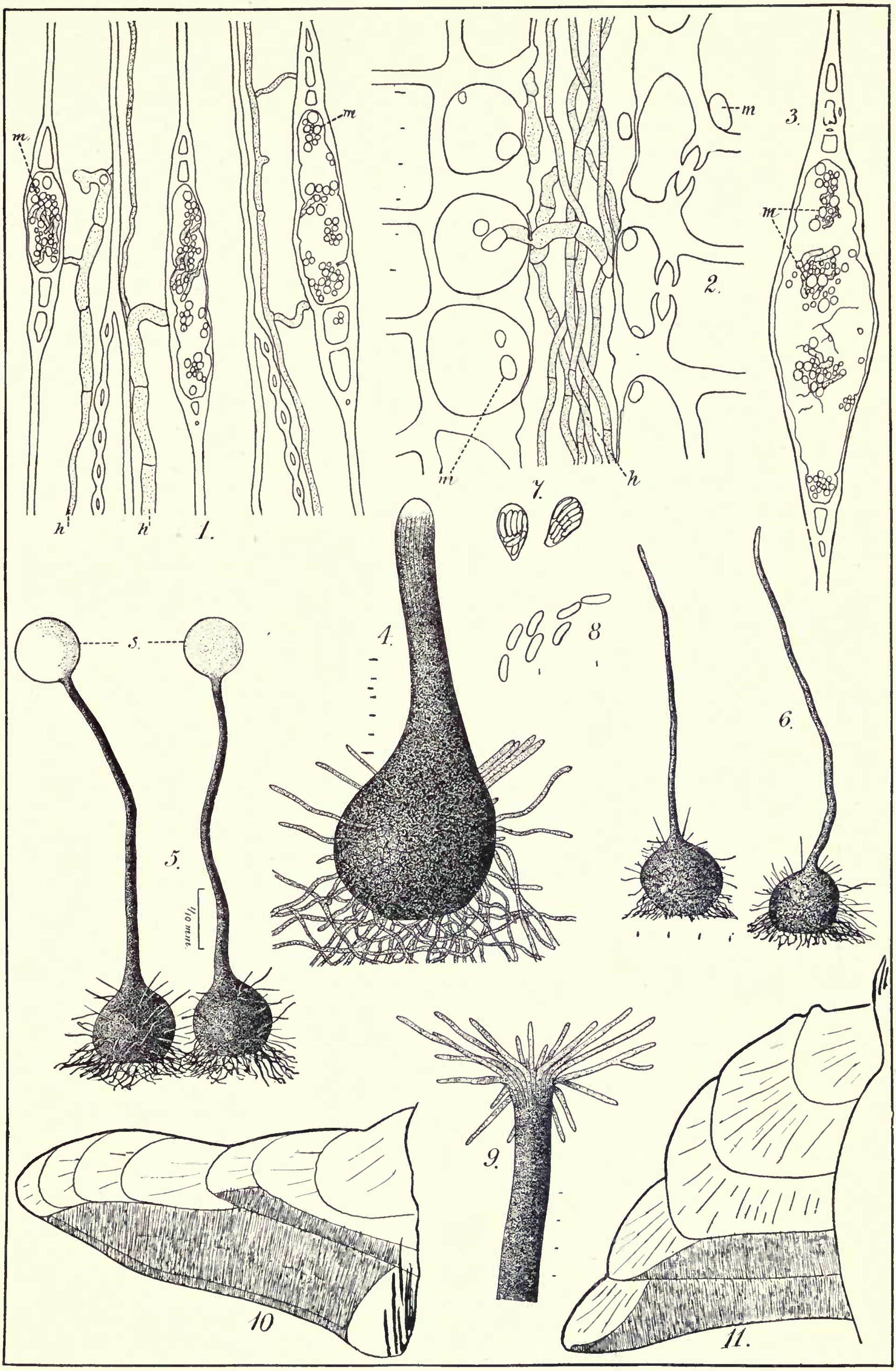


FIG. 2.—SECTIONS FROM TREE DEAD EIGHTEEN MONTHS.

"BLUE" SECTIONS FROM DEAD TREES.



MYCELIUM AND FRUITING BODIES OF "BLUE" AND "RED-ROT" FUNGI.

1, Tangential section of "blue" wood; 2, cross section of "blue" wood; 3, cross section of a medullary ray; 4, young perithecium of the "blue" fungus (*Ceratostomella pilifera*); 5, mature perithecia of the "blue" fungus; 6, two perithecia of the "blue" fungus; 7, two asci with spores of the "blue" fungus; 8, spores of the "blue" fungus; 9, top of beak of perithecium of *Ceratostomella pilifera* just after the discharge of the spore mass; 10 and 11, median sections of sporophores of the "red-rot" fungus *Polyporus ponderosus*, n. sp.).

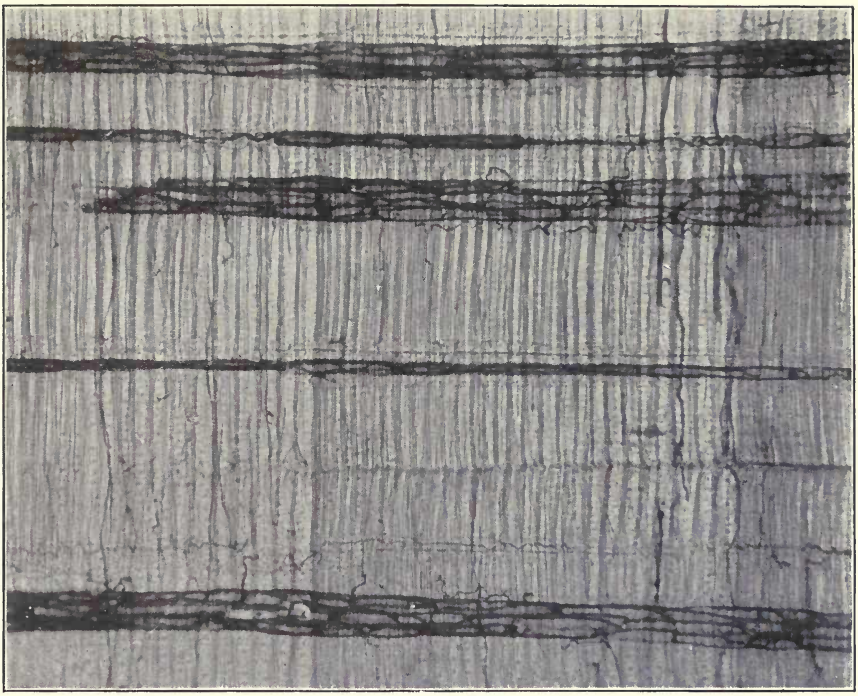


FIG. 1.—RADIAL SECTION.

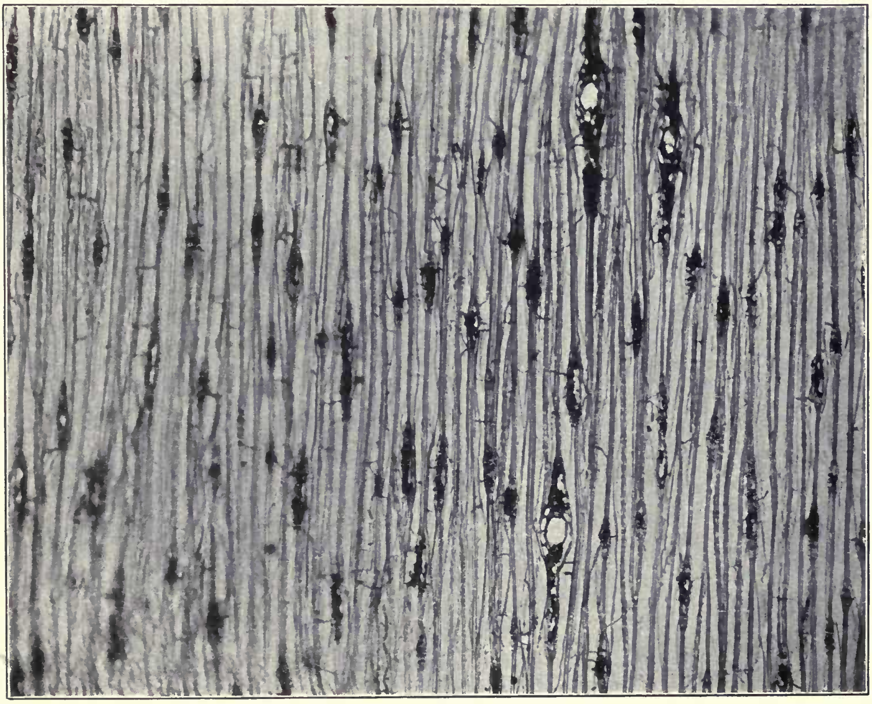
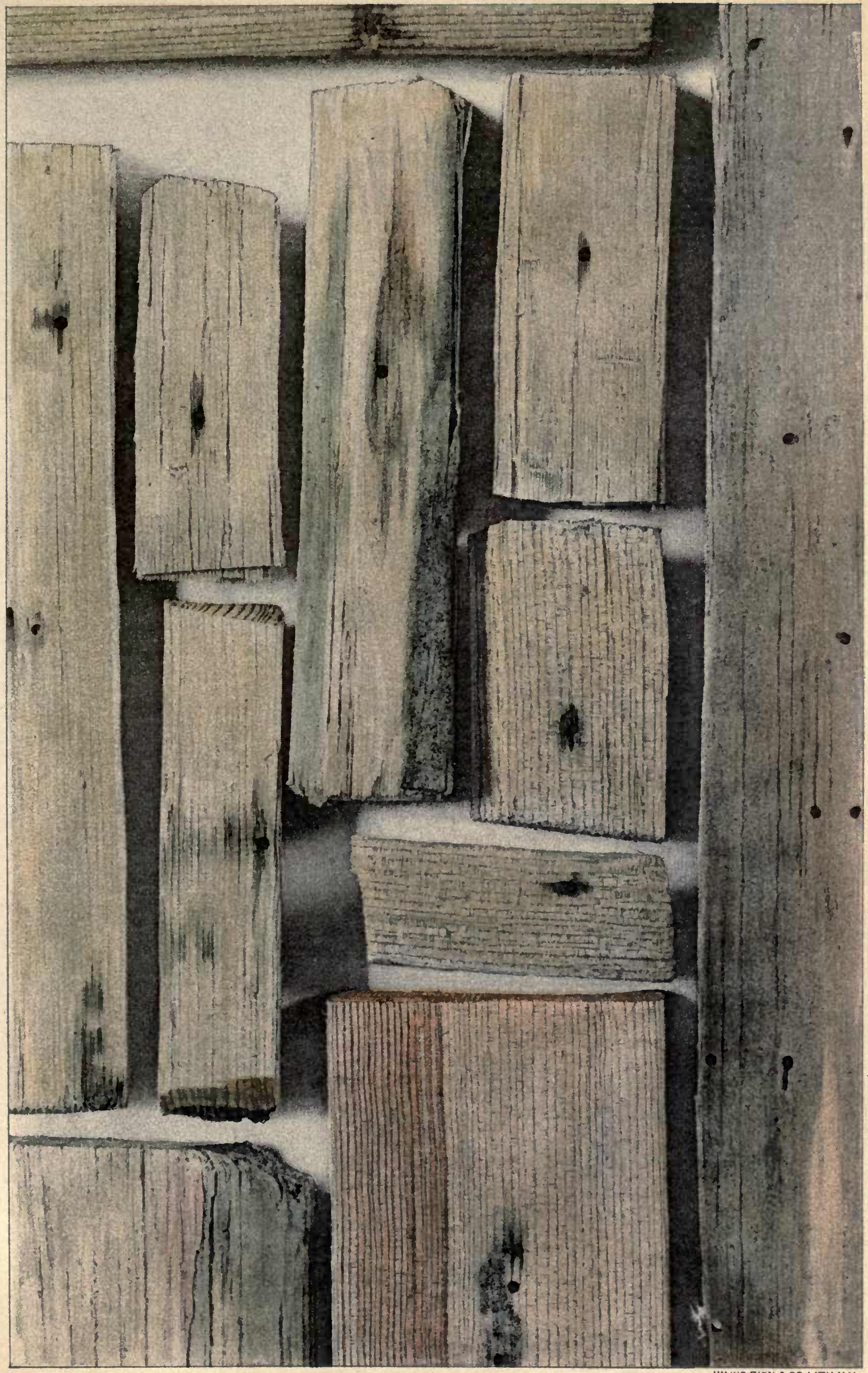


FIG. 2.—TANGENTIAL SECTION.

SECTIONS OF "BLUE" WOOD.



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PIECES OF WOOD FROM THE BULL PINE, SHOWING BLUE FUNGUS STARTING FROM HOLES MADE BY A WOOD-BORING BEETLE.

FIG. 1.—SECTION TAKEN 35 FEET FROM THE GROUND FROM A DEAD TREE.

FIG. 2.—SECTION SHOWING MORE ADVANCED STAGE OF DECAY.

FIG. 3.—SECTION FROM TREE SHOWN IN FIG. 2, MADE 15 FEET HIGHER UP.

EARLY STAGES OF "RED ROT."

FIGS. 1, 2.—SECTIONS FROM THE TOP OF A FALLEN TREE.

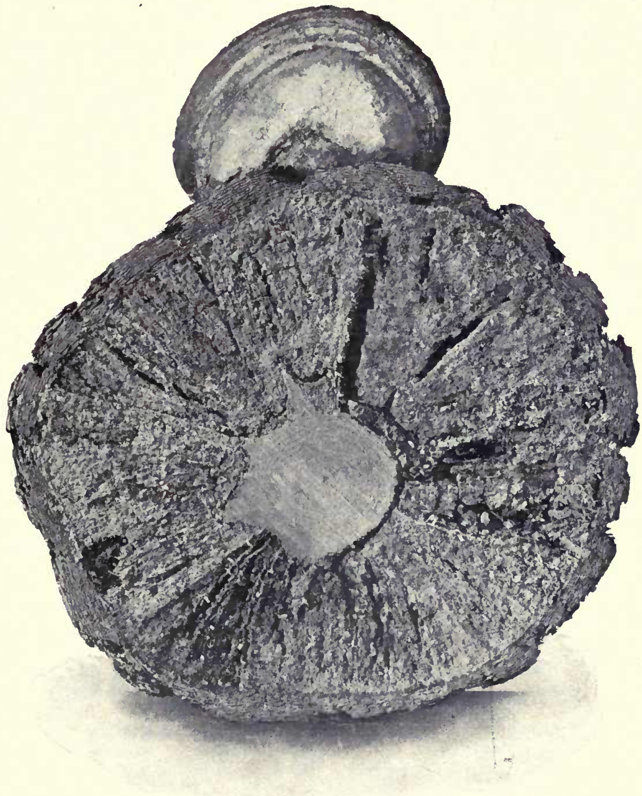

FIG. 3.—SECTION FROM A STANDING PINE, 4 FEET FROM THE GROUND.

SECTIONS FROM "BLACK-TOP" WESTERN YELLOW PINE TREES, SHOWING ADVANCED STAGES OF DECAY.

GROUP OF BROKEN "BLACK-TOP" TREES.

FIG. 1.—TOP OF "BLACK TOP" BROKEN OFF.

FIG. 2.—POLYPORUS PONDEROSUS GROWING ON DEAD PINE STUMP.

FIG. 1.—WOOD AFFECTED WITH "RED ROT."

FIG. 2.—DISEASED WOOD FROM LIVING TREE.

SECTIONS OF REJECTED CROSS-TIES.

BULLETINS OF THE BUREAU OF PLANT INDUSTRY.

The Bureau of Plant Industry, which was organized July 1, 1901, includes Vegetable Pathological and Physiological Investigations, Botanical Investigations and Experiments, Grass and Forage Plant Investigations, Pomological Investigations, and Gardens and Grounds, all of which were formerly separate Divisions, and also Seed and Plant Introduction and Distribution, The Arlington Experimental Farm, and Tea Investigations and Experiments.

Beginning with the date of organization of the Bureau, the independent series of bulletins of the several Divisions were discontinued, and all are now published as one series of the Bureau.

The bulletins issued in the present series are:

No. 1. The Relation of Lime and Magnesia to Plant Growth. 1901.
2. Spermatogenesis and Fecundation of Zamia. 1901.
3. Macaroni Wheats. 1901.
4. Range Improvement in Arizona. 1901.
5. Seeds and Plants Imported through the Section of Seed and Plant Introduction. Inventory No. 9, Nos. 4351–5500. 1902.
6. A List of American Varieties of Peppers. 1902.
7. The Algerian Durum Wheats: A Classified List, with Descriptions. 1902.
8. A Collection of Economic and Other Fungi Prepared for Distribution. 1902.
9. The North American Species of Spartina. 1902.
10. Records of Seed Distribution and Cooperative Experiments with Grasses and Forage Plants. 1902.
11. Johnson Grass: Report of Investigations Made During the Season of 1901. 1902.
12. Stock Ranges of Northwestern California. 1902.
13. Experiments in Range Improvement in Central Texas. 1902.
14. The Decay of Timber and Methods of Preventing It. 1902.
15. Forage Conditions on the Northern Border of the Great Basin. 1902.
16. A Preliminary Study of the Germination of the Spores of Agaricus Campestris and Other Basidiomycetous Fungi. 1902.
17. Some Diseases of the Cowpea. 1902.
18. Observations on the Mosaic Disease of Tobacco. 1902.
19. Kentucky Bluegrass Seed: Harvesting, Curing, and Cleaning. 1902.
20. Manufacture of Semolina and Macaroni. 1902.
21. List of American Varieties of Vegetables. 1903.
22. Injurious Effects of Premature Pollination. 1902.
23. Berseem: The Great Forage and Soiling Crop of the Nile Valley. 1902.
24. The Manufacture and Preservation of Unfermented Grape Must. 1902.
25. Miscellaneous Papers. 1902.
26. Spanish Almonds and Their Introduction into America. 1902.
27. Letters on Agriculture in the West Indies, Spain, and the Orient. 1902.
28. The Mango in Porto Rico. 1902.
29. The Effect of Black Rot on Turnips. 1903.
30. Budding the Pecan. 1902.
31. Cultivated Forage Crops of the Northwestern States. 1902.
32. A Disease of the White Ash Caused by Polyporus Fraxinophilus. 1903.
33. North American Species of Leptochloa. 1903.
34. Silkworm Food Plants. 1903.
35. Recent Foreign Explorations, as Bearing on the Agricultural Development of the Southern States. 1903.