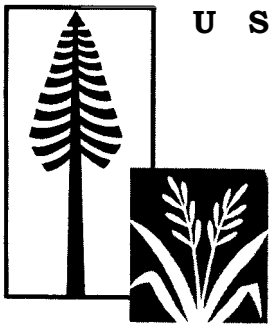
Variations in the Monoterpene Composition of Ponderosa Pine Wood Oleoresin

Richard H. Smith



U S. FOREST SERVICE RESEARCH PAPER
PSW- 15 1964

Pacific Southwest Forest and Range
Experiment Station - Berkeley, California
Forest Service - U. S. Department of Agriculture

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CONTENTS

The Author

Richard H. Smith is studying the problems of resistance of pines to destructive forest insects. He joined the U. S. Department of Agriculture in 1947. Before coming to the Berkeley station in 1955, he served at the Forest Service's Southeastern Station, where he conducted studies of bark beetles and borers infesting southern forests, and at the Beltsville Forest Insect Laboratory, where he studied the biology and control of powder post beetles. A native of Ellenville, N. Y., he earned bachelor's (1942) and master's (1947) degrees in forest entomology at the New York State College of Forestry, and a doctorate (1961) in entomology at the University of California, Berkeley.

Pine wood oleoresin has long been suspected of playing an important, if not decisive, role in the resistance of pines to bark beetles. Resin (oleoresin) is considered a secondary plant substance and, therefore, does not re-enter the basic metabolic pathways, although some workers have expressed doubt about the secondary status. Resin is a complex mixture of molecules and, in essence, can be considered a supersaturation of rosin in turpentine. Rosin is a mixture of resin acids; turpentine a mixture of terpenes.

Mirov (1960) summarized the work on pine terpenes before 1959. Most of these studies have been of two types: (a) bulk sample analyses in which the resin from several trees was mixed before analysis; and (b) single tree analysis. These procedures either masked individual tree variation or failed to account for it. Practically all studies were based on resin collected from an open wound cut into the pine stem, steam distillation, and conventional chemical methods which at best could not detect constituents of small percentage. These methods were slow and required as much as a quart of resin.

The use of gas chromatography for terpene analysis was mentioned briefly by Mirov (1960). Bannister et al. (1960) applied this analytical procedure to the study of hybridism in *Pinus radiata* D. Don and *P. attenuata* Lemm. Their results showed some but not striking variation in terpene composition between individual trees of these two species. Williams and Bannister (1962) analyzed the wood terpenes of 22 species of pines grown in New Zealand. Analyses of 21 of the species were based on single tree samples. No reference was made to the original source of the tree. Sandermann (1962) found differences between 10 trees of *P. maritima* and 3 trees of *P. pinaster* in the percent of α-pinene and β-pinene. Smith (1964) found considerable differences in the quantitative terpene composition of 10 trees of *P. contorta* Dougl.

A brief résumé of the research efforts attempting to relate resin with the resistance of pines to bark beetles has been published recently (Smith 1961; Smith and Eaton 1963). Resin properties which have been investigated include quantity, [1] pressure (Vité and Wood 1961), and quality (Smith 1961). Research on quality showed that *Dendroctonus* bark beetles were differentially affected by resin vapors of different pine species. Recent investigation by the author has suggested that individual terpenes of pine resin differed in their effect on adult bark beetles.

The possible implication of terpenes in the resistance of pines to bark beetles and the lack of adequate data on the variation in terpene composition between ponderosa pines pointed to a need for study of this variation. This paper reports on a study seeking to determine variability in pine resin terpene composition of ponderosa pine which might be associated with (a) time and place of obtaining resin from a tree, (b) method of preparation and analysis of the sample, and (c) age, elevational, and local differences between trees.

Procedures

All samples of resin were collected with a closed-face microtap (Smith 1961) ; practically all taps were one-half inch in diameter, though a few were 2 inches. Samples usually were prepared for analysis within 2 to 3 days after collection, although a 1- to 2-month delay caused no change in the terpene constituents.

Two subsamples were prepared from each collection of resin, if enough resin was available. From 1 to 8 cc. of fresh resin were poured from the collection vial into a Hickman molecular still; 0.5 to 1.0 cc. was allowed to remain in the vial, and an ether or ethanol extract was obtained by adding these two solvents at the rate of from one to one-third the volume of resin. The molecular still was operated at 40° C. for 20 to 24 hours,

[1] Callaham, R. Z. Oleoresin production in the resistance of ponderosa pine to bark beetles. 1955. (Unpublished doctor's thesis on file at Univ. Calif., Berkeley.)

using ice to cool the condensing surface. The recovered distillate and the prepared extract were transferred to ½-dram screwcap vials and held at 5° C. Molecular distillation was not possible when a collection held less than 2 cc. of resin.

Samples were analyzed by gas-liquid chromatography. [2] Helium was the gas phase; the column was 8 feet by ¼ inch stainless steel. The liquid phase for practically all work was 10 percent or 20 percent β, β' oxydipropionitrile (ODPN) (Klouwen 1962) on a solid support of 60/80 acid washed Chromosorb W. For qualitative comparisons, two other liquid phases were used: 20 percent didecylphthlate (DDP) (Bannister 1959) and 20 percent LAC—446 (Bernhard 1961). The data recorder, a Brown "Electronik" with disc integrator, had a sensitivity of 1 millivolt full span and a balancing speed of 1 second full span.

Operational conditions for the oxydipropionitrile columns were: temperatures of 120° to 130° C. on the injector, 55° to 60° C. on the column, 145 ° to 151 ° C. on the detector; filament current of 200 ma.; helium flow of 60 or 90 ml. per minute at the outlet port; sample volume of 0.2 μl to 4.0 μl.

Qualitative determinations were made by comparing relative retention times with existing values and with those obtained by the use of known compounds and known mixtures. These determinations were cross-checked on all three columns. Quantitative determinations were made by internal normalization of disc integrator values (fig. 1); that is, the number of integrator units for each peak was divided by the total units for the sample to give the percent of each terpene in the whole sample.

[2] Aerograph A-90-P with thermal conductivity detector. Mention of commercial products in this report does not constitute an endorsement of products by the U.S. Forest Service.

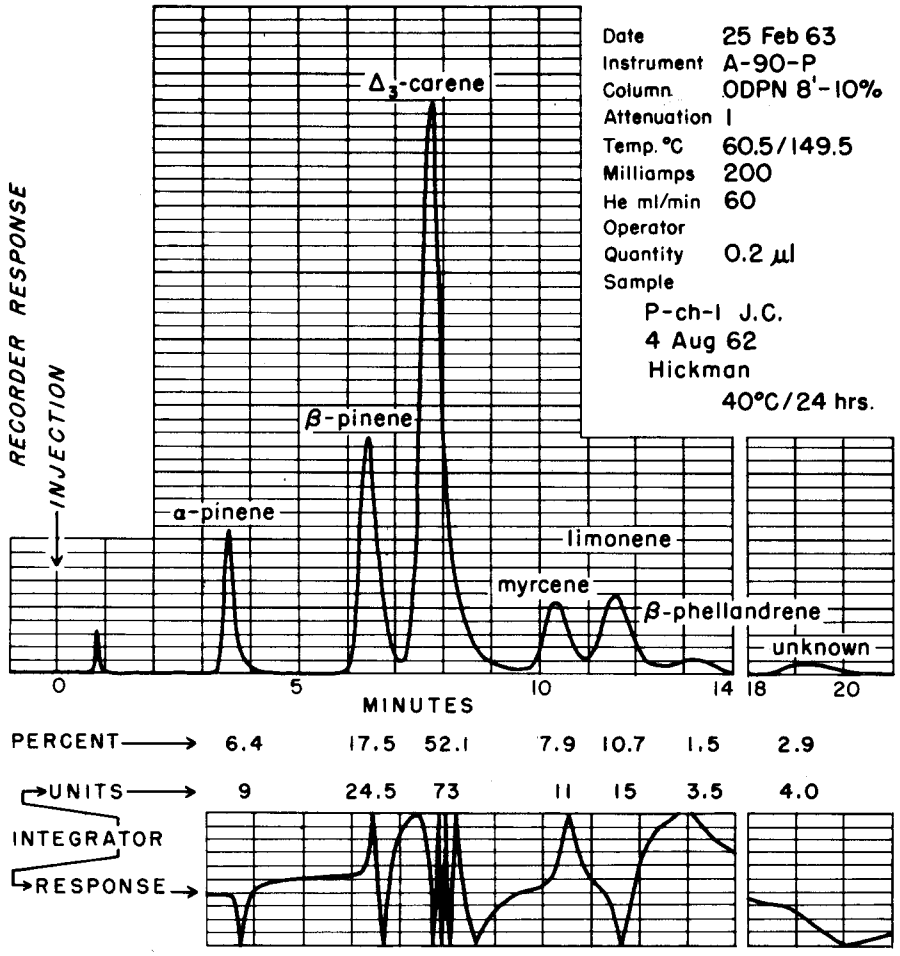

Figure 1.—Chromatogram of the monoterpenes in the resin of a ponderosa pine.

Results and Discussion

Column Comparisons

Columns were compared for qualitative determinations. Relative retention values for the LAC–446 and ODPN columns were obtained for ponderosa pine resin and for a synthetic mixture of terpenes whose individual retention times had been obtained beforehand (table 1). The coincidence of the unknown peaks with the known terpenes on two different columns is a sound basis for the qualitative determinations.

Quantitative comparisons of the three columns (table 2) showed very close agreement. This result essentially eliminated the possibility of reactions while the sample was passing through the column and provided a basis for assuming that the values obtained on any one column were nearly the real values.

Sample Preparation

Quantitative comparisons were made between the two types of sample preparations, ether extract and unaltered molecular distillate. Selected samples represented a wide range of terpene composition. Approximately the same values were obtained for both types of preparations (table 3). Both preparations should be made, though, because the ODPN column does not clearly separate ether and heptane, and a small impurity of ether coincides with part of the camphene peak. The ether preparation is fast and is recommended for studies in which many samples are to be processed quickly or where heptane and camphene are absent or are minor constituents. It is also the only method which can be used if the resin sample is less than 1 cc.

Distillation and Holding Time

The period of distillation and the length of time of holding the sample after distillation could cause variation in the analysis of terpene composition. A check of the period of distillation was made by processing about 7.5 cc. of freshly collected ponderosa pine resin in the molecular still. At successive intervals the distillate which had collected since the previous interval was analyzed; the percent terpene composition was determined for each period. The cumulative values (table 4) show that

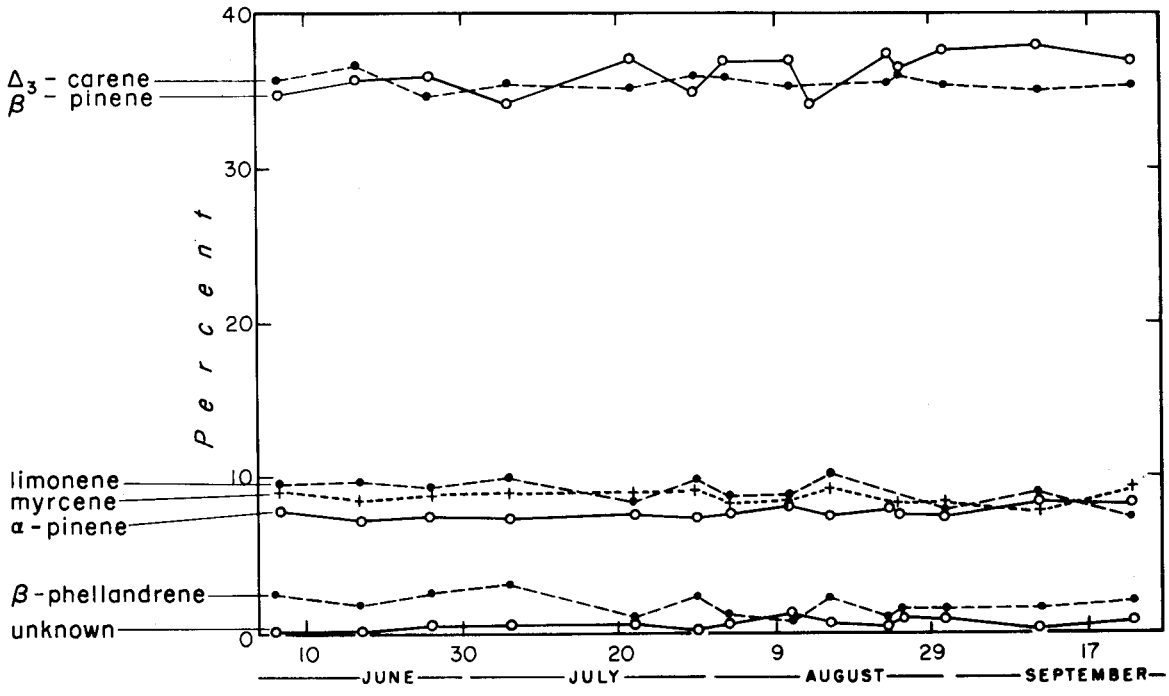

Figure 2.—Seasonal trend in the monoterpene composition of the resin of one ponderosa pine.

even the first few drops of distillate gave a reasonable representation of the actual composition. Practically no change occurred after 12 hours. Therefore, the 20- to 24-hour period removes all terpenes from small samples of ponderosa pine resins. These results also indicated that this resin was essentially azeotropic; that is, the constituents of the mixture of volatiles vaporized in proportion to their concentration in the mixture. Holding the samples had no effect on the results as shown by the analyses of these same samples 3 months later.

The effect of holding time of both distillate and extract was determined by analyzing samples representing a wide range in composition. The results (table 5) show no change in either preparation for 6 months, the maximum time tested.

Period of Resin Flow

The molecular distillates of the first and second 24-hour flow of resin from the wounds of five different trees were analyzed for terpene composition to substantiate the assumption that there was no change related to time of flow from a wound. The results (table 6) showed approximately the same composition for both periods.

Variation within a Tree

Tests were made to determine the magnitude of variation of terpene composition which could be related to the time and place of tapping a tree.

One tree was tapped at the four cardinal directions at 3 feet and at 60 feet above the ground. The samples were prepared with ethanol and were analyzed with the didecylphthlate column. The results (table 7) showed little difference between the four compass positions or between the two heights. Further work will be needed to determine the authenticity of a slight increase in β-pinene and slight decrease in limonene plus β-phellandrene when going from the top of the tree to the bottom. The slight changes could be due to sampling or analytical methods.

Five trees were tapped at 3 feet and at 15 feet

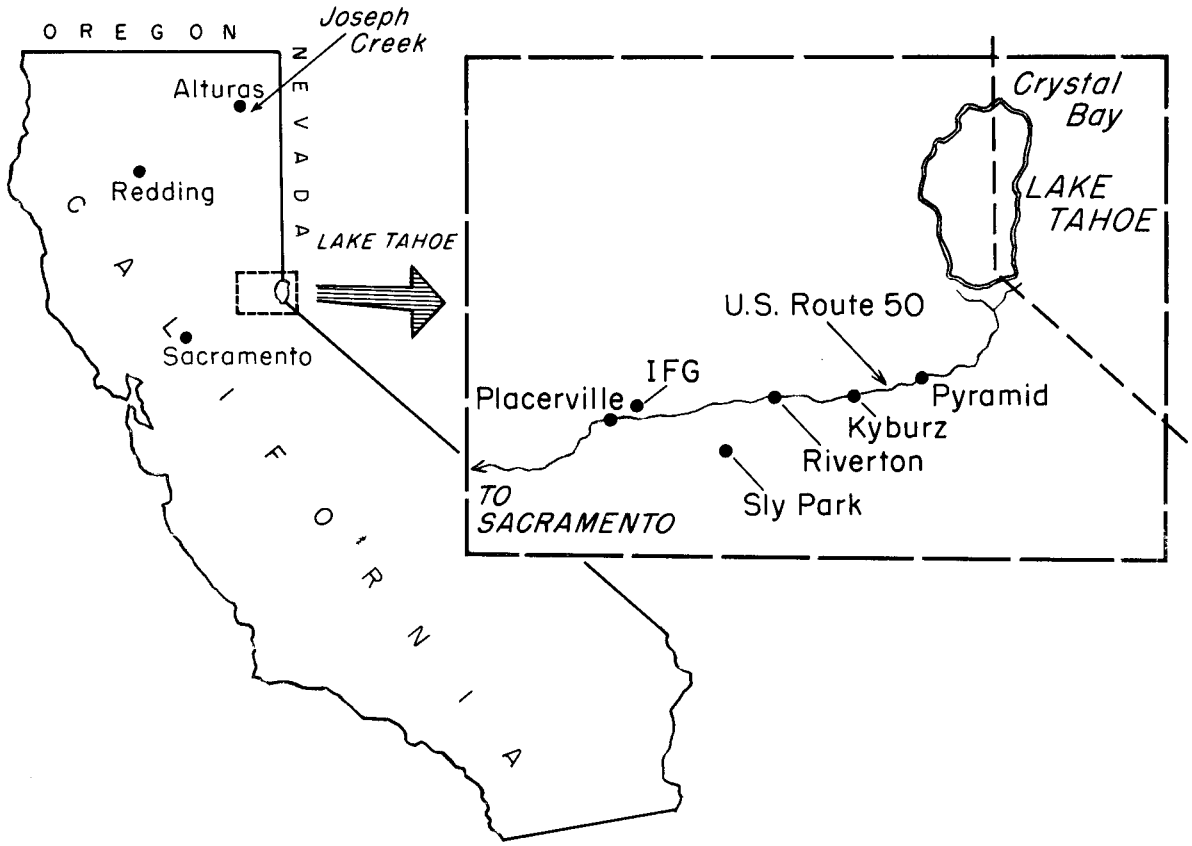

Figure 3.—Location of ponderosa pines used for gas chromatographic analyses of terpenes.

above the ground (table 8), and no changes could be associated with height; though myrcene percentage is consistently higher at 15 feet, the difference is still quite small.

Seven trees were tapped on the north and south sides (table 9). Again no changes in terpene composition could be associated with place of sampling the tree.

The effect of time of sampling a tree was determined by tapping: (a) one tree periodically during the growing season (fig. 2), (b) 11 trees both in the growing season and in the dormant season (table 10), and (c) one tree in four consecutive years (table 11). Each of these variables had little or no effect on terpene composition. The slight reduction in β-phellandrene during the dormant season was consistent for all trees, but it may be too small to be real and may be simply an attribute, of procedure. Additional sampling will be needed to see if there is a trend from year to year. Other ponderosa pines and other species of pines may not give the same results obtained by these limited samples.

Age, Elevation, and Local Variation

Seven locations were selected in the central Sierra Nevada and one location in the north Warner Mountains near Alturas, California (fig. 3) to give a range in age, elevation, and locality of ponderosa pine. The average terpene composition for each plot (table 12) showed no pattern which might be associated with age or elevation, although the plots differed widely. A larger sampling should be made to permit a sounder basis for any conclusion about age or elevation.

Variation between Trees

Resin was collected from 64 trees located in the eight plots (table 12). Table 13 summarizes the average analysis for each tree; figure 4 illustrates the frequency distribution and the average value for each terpene. The wide range in composition from tree to tree is readily apparent. Variations

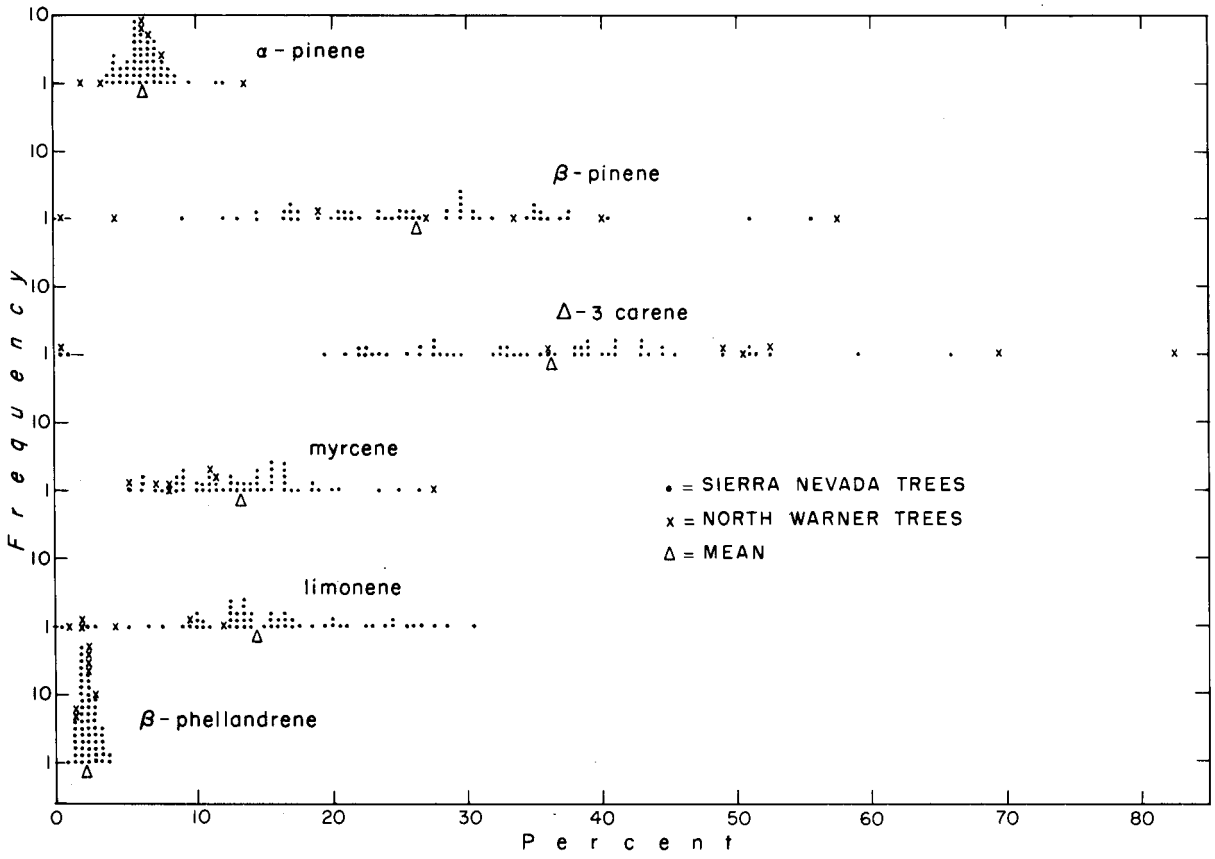

Figure 4.—Variation of individual terpenes in the total terpene of the resin of 64 ponderosa pines.

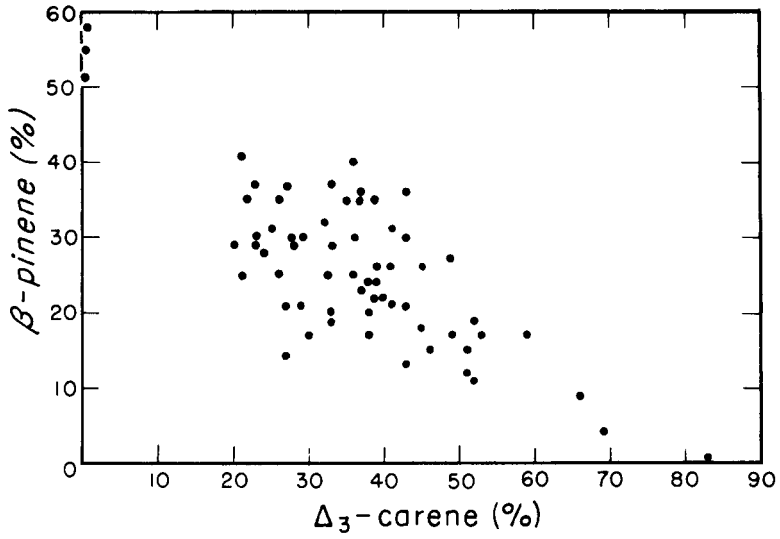

Figure 5.—Relationship of Δ_3-carene and β-pinene in resin from 64 ponderosa pines.

between trees were much greater than those of plot averages. A far greater range in percent composition was obtained than reported by Mirov (1960) for bulk sample analysis for ponderosa pine resins representing the extensive range of this tree in western United States. Furthermore, Mirov (1960) called Δ^3-carene "the specific terpene of *Pinus ponderosa,*" yet 3 trees out of 64 had amounts which could be classified only as trace. A fairly strong inverse relationship existed between the amount of β-pinene and Δ_3-carene (fig. 5).

Obviously, the terpene composition of ponderosa pine resin is not uniform. An analysis of one tree or a small number of trees may mean very little in defining this characteristic. Further sampling and analysis should be made to more adequately determine the limits of terpene composition and to see if there are distinct types.

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APPENDIX

Table 1. Relative retention time [1] on two different columns for known compounds and for ponderosa pine resin vapor

Peak	Terpene	ODPN[2]		LAC-446[3]	
		Known	Ponderosa pine	Known	Ponderosa pine
1	Heptane	--	.29	--	.15
2	α-pinene	1.00	1.00	1.00	1.00
3	Camphene	1.54	1.51	1.43	--
4	β-pinene	1.89	1.88	1.83	1.81
5	Δ_3 carene	2.30	2.32	2.40	2.38
6	Myrcene	3.16	3.19	2.73	2.70
7	Limonene	3.51	3.54	3.45	3.40
8	β-phellandrene	4.00	4.01	3.67	3.62
9	Unknown	--	5.91	--	5.89

[1] *Based o 1.00 for α-pinene.*

[2] *3.415 minutes to α-pinene at 55°C. and 60 ml./min.*

[3] *10.620 minutes to α-pinene at 60°C. and 60 ml./min.*

Table 2. Ponderosa pine resin monoterpene composition determined with different columns

Tree	Column	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrenen	Unknown [1]
				Percent				
1	LAC	6.5	31.4	46.8	8.1	7.1		--
	ODPN	5.4	25.9	51.2	7.0	6.3	2.0	2.2
2	LAC	5.6	13.8	43.5	14.0	23.1		--
	ODPN	4.4	12.9	43.7	13.1	22.3	3.6	(2/)
3	LAC	7.5	13.9	49.8	12.1	14.1		2.6
	ODPN	5.0	14.6	51.8	11.2	13.1	1.9	2.3
4	LAC	8.6	37.4	34.2	10.6	9.2		--
	ODPN	7.4	33.8	34.4	9.7	10.0	2.1	2.7
5	DDP	1.5	3.9	72.1	9.5	12.2		--
	ODPN	2.2	3.3	73.3	7.8	11.1	1.1	1.1
6	DDP	5.9	38.3	43.8	11.7	.4		--
	ODPN	7.6	40.0	37.4	11.3	1.4	2.3	2.3
7	DDP	5.4	18.2	55.4	9.5	11.0		--
	ODPN	6.4	17.5	52.1	7.9	10.7	2.5	2.7

[1] *Determinations of the unknown were not made for the DDP column.*

[2] *Trace.*

Table 3. Terpene composition of the resin of selected ponderosa pine prepared by ether extract (Ext.) and by molecular distillation (Dis.)

Tree number	Prepara-tion	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β- Phellan-drene	Unknown
					Percent			
1	Dis.	5.9	21.0	37.6	19.6	13.2	1.2	1.4
	Ext.	5.4	19.8	38.6	17.3	14.6	1.9	2.4
2	Dis.	9.1	22.1	28.6	15.0	21.9	2.5	.7
	Ext.	8.0	20.6	29.1	13.4	25.1	1.7	2.0
3	Dis.	11.8	49.2	--	16.5	18.7	3.8	--
	Ext.	10.8	52.8	--	14.9	19.2	2.3	--
4	Dis.	6.9	28.9	19.2	16.9	25.2	1.6	1.2
	Ext.	6.3	29.5	20.1	14.4	26.2	2.2	1.2
5	Dis.	5.6	21.4	26.5	24.1	19.1	1.8	1.6
	Ext.	5.2	21.4	28.2	21.8	20.2	2.0	1.1
6	Dis.	3.8	13.8	26.5	25.5	25.5	3.0	1.9
	Ext.	4.2	14.5	27.7	23.3	27.3	1.4	1.6
7	Dis.	4.4	16.9	52.7	9.5	11.7	2.0	2.8
	Ext.	3.4	15.7	55.5	9.0	12.6	1.1	2.8
8	Dis.	8.0	9.0	66.5	8.2	4.5	.4	3.3
	Ext.	7.8	9.1	64.4	9.1	5.3	.7	3.7

Table 4. Terpene composition of molecular distillates of a sample of ponderosa pine resin at cumulative periods of time

Hour	Cumulative amount recovered	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown
	Ml.				*-Percent-*			
FIRST ANALYSIS								
1st	0.2	11.0	39.5	32.3	7.9	6.2	3.1	(1/)
2nd	.5	10.4	38.1	33.0	8.5	6.9	3.1	(1/)
3rd	.7	9.9	38.5	33.0	8.4	7.1	3.0	0.3
4th	.85	9.5	38.0	33.1	8.4	7.4	3.2	.4
5th	1.00	9.2	37.5	33.3	8.6	7.5	3.4	.6
9th	1.20	8.8	36.7	33.5	8.7	7.8	3.8	.8
13th	1.35	8.6	36.1	33.5	8.8	8.0	4.0	1.3
24th	1.45	8.4	35.8	33.6	8.8	8.1	4.2	1.2
ANALYSIS THREE MONTHS LATER								
1st	--	10.2	38.4	31.6	8.2	6.8	4.4	.4
2nd	--	9.2	36.6	31.6	8.8	8.2	5.1	.5
3rd	--	9.0	36.8	32.3	8.9	8.0	4.5	.5
4th	--	8.6	36.0	32.9	9.0	8.4	4.6	.4
5th	--	8.3	35.6	33.2	9.1	8.8	4.6	.5
9th	--	8.0	35.0	33.6	9.1	9.0	4.8	.5
13th	--	7.9	34.7	33.8	9.1	9.2	4.8	.5
24th	--	7.7	34.5	33.9	9.1	9.2	5.0	.5
Ether extract		7.0	31.4	35.0	10.2	11.1	3.1	2.1

[1] *Trace.*

Table 5. Analysis of two types of sample preparation of ponderosa pine terpenes at two times after preparation

Tree	Type of preparation	Time of analysis [1]	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown
			- - - - - - - - - - Percent - - - - - - - - - -						
1	Distillate	(a)	5.3	14.4	50.5	11.2	12.3	2.1	4.2
		(b)	6.2	15.6	52.7	10.0	11.7	1.0	2.7
2	Distillate	(a)	7.8	35.5	35.2	8.6	9.4	1.6	2.0
		(b)	7.7	36.0	36.0	8.6	9.3	1.4	1.0
3	Distillate	(a)	8.0	41.4	20.7	11.9	15.3	1.9	.8
		(b)	8.2	42.4	21.1	10.6	15.3	1.6	.8
4	Distillate	(a)	12.2	52.0	([2])	17.2	16.8	1.8	.0
		(b)	12.3	52.0	([2])	16.5	17.1	2.1	.0
5	Distillate	(a)	5.6	21.4	26.5	24.1	19.1	1.8	1.6
		(b)	5.5	21.9	26.5	23.3	19.2	1.4	1.9
6	Distillate	(a)	3.8	13.8	26.5	25.5	25.5	3.0	1.9
		(b)	4.1	15.0	27.1	24.2	26.5	1.8	1.2
7	Extract	(a)	4.1	17.4	30.2	15.1	31.4	1.7	([2])
		(b)	3.4	16.7	30.7	14.8	31.8	1.5	1.1
8	Extract	(a)	6.1	27.6	27.3	12.2	21.2	4.1	1.5
		(b)	5.3	29.6	29.6	12.1	20.4	2.9	([2])
9	Extract	(a)	6.2	36.2	44.1	6.4	5.3	1.8	([2]
		(b)	6.8	36.8	43.4	5.5	4.8	.9	1.
10	Extract	(a)	14.1	55.2	([2])	28.0	([2])	2.8	.0
		(b)	12.4	59.3	([2])	26.0	1.2	1.2	.0
11	Extract	(a)	8.4	38.1	34.3	12.5	2.9	2.9	.9
		(b)	7.1	39.2	36.5	11.6	2.0	2.0	1.6
12	Extract	(a)	3.3	5.4	64.2	9.2	12.9	2.5	1.7
		(b)	2.7	3.6	70.5	7.6	11.6	1.8	2.2

[1] *(a) Immediately after preparation of sample*
(b) Four to six months after preparation.

[2] *Trace.*

Table 6. Monoterpene composition of the first and second 24-hour flow of ponderosa pine resin

Tree number	24-hour period	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown
				Percent				
1	1st	8.9	34.4	30.9	9.5	10.0	4.0	2.3
	2nd	8.2	34.9	35.8	8.9	8.3	1.9	2.1
2	1st	5.0	14.6	51.9	11.2	13.1	1.9	2.3
	2nd	5.4	13.8	52.2	10.8	12.9	2.7	2.3
3	1st	6.7	34.3	38.2	9.5	7.1	2.1	2.1
	2nd	7.2	31.8	37.0	10.5	8.0	3.1	2.5
4	1st	6.1	31.6	44.3	9.4	7.1	.5	1.0
	2nd	5.8	31.1	40.9	9.3	8.9	1.6	2.4
5	1st	8.0	41.0	20.4	11.5	16.4	1.5	1.2
	2nd	8.2	42.4	21.1	10.6	15.3	1.6	.8

Table 7. Monoterpene composition of a ponderosa pine resin at two heights on the trunk and at the cardinal directions around the tree

Compass position	α-pinene	β-pinene plus myrcene	Δ_3 carene	Limonene plus β-phellandrene
		Percent		
60 FEET HEIGHT				
N	7.1	45.9	38.4	8.6
E	7.4	45.3	39.9	7.5
S	7.4	46.7	39.9	6.0
W	8.2	45.8	38.4	7.6
X	7.5	45.9	39.2	7.4
3 FEET HEIGHT				
N	5.7	49.3	40.2	4.8
E	7.0	49.1	39.6	4.3
S	7.3	47.6	40.1	4.9
W	6.9	47.3	39.7	6.9
X	6.7	48.3	39.7	5.2

Table 8. Monoterpene composition of the resin of ponderosa pines at two trunk heights

Tree number	Height	α-pinene	β-pinene	Δ_3-carene	Myrcene	Limonene	β-phellandrene	Unknown
	Feet				*Percent*			
3	15	5.7	35.2	52.9	3.1	0.4	0.9	1.8
	3	5.5	34.7	52.0	3.6	.7	.9	--
10	15	6.6	23.3	48.5	8.3	7.5	4.4	1.5
	3	5.0	29.1	48.3	6.8	6.3	1.3	3.1
14	15	1.2	--	86.3	11.8	--	([1])	([1])
	3	1.0	--	86.7	9.4	1.5	.5	1.0
56	15	7.8	40.8	34.0	12.1	1.9	1.9	1.5
	3	7.6	40.0	37.4	11.3	1.4	2.3	([1])
Ch. 1	15	8.1	17.1	46.1	9.7	11.0	4.5	3.5
	3	6.4	17.5	52.1	7.9	10.7	2.5	2.9

[1] *Trace.*

Table 9. Monoterpene composition of ponderosa pine resin from the north (N) and south (S) side of the tree

Tree number	Side of tree	α-pinene	β-pinene	Δ_3-carene	Myrcene	Limonene	β-phellandrene	Unknown
					Percent			
1	N	5.5	25.9	38.9	13.0	14.3	1.4	1.0
	S	5.3	26.2	38.3	13.1	14.0	1.6	1.6
2	N	3.1	15.4	38.5	13.6	25.9	2.1	1.4
	S	4.0	17.8	37.4	14.5	22.3	1.2	2.8
3	N	5.8	35.2	25.4	14.4	16.2	1.8	1.2
	S	7.1	33.3	26.0	14.6	15.4	3.7	([1])
4	N	6.1	27.6	27.3	12.2	21.2	4.1	1.5
	S	5.3	29.9	29.3	11.7	19.6	3.2	.9
5	N	8.0	25.9	23.5	12.0	27.9	2.8	([1])
	S	7.4	29.8	24.7	10.7	26.4	1.0	([1])
6	N	6.4	31.3	31.7	12.8	13.6	3.0	1.1
	S	5.0	29.8	33.1	13.6	14.0	3.7	.8
7	N	6.5	35.9	24.9	14.7	15.5	1.1	1.4
	S	7.8	36.9	22.9	14.9	12.0	4.7	.8

[1] *Trace.*

Table 10. Monoterpene composition of ponderosa pine resin obtained during the active (August) and inactive (March) growing seasons

Tree	Month	α-pinene	β-pinene	Δ_3-carene	Myrcene	Limonene	β-phellandrene	Unknown
					Percent			
1	August	7.8	35.3	34.7	9.1	9.5	1.7	1.9
	March	6.9	34.5	37.5	8.9	9.6	.9	1.7
2	August	5.8	14.9	50.8	11.0	12.7	2.0	2.8
	March	5.0	14.6	53.6	10.5	12.3	1.0	3.0
3	August	7.9	35.9	37.3	8.6	6.7	1.4	2.2
	March	8.2	35.1	38.2	8.1	7.3	1.3	1.8
4	August	6.6	30.7	35.9	16.0	6.0	2.5	1.6
	March	6.5	33.4	36.6	15.3	5.7	.6	1.9
5	August	7.9	41.0	21.2	11.1	16.2	1.7	.9
	March	7.3	40.9	20.1	11.5	18.1	.9	1.1
6	August	6.4	30.1	43.1	5.9	10.4	1.7	2.4
	March	7.3	32.6	40.0	5.1	12.6	1.3	1.1
7	August	7.9	34.9	38.9	5.2	10.1	1.4	1.6
	March	7.1	32.9	41.2	5.8	10.4	1.0	1.6
8	August	5.7	25.8	44.5	6.8	13.6	1.6	2.0
	March	5.8	27.9	42.6	6.6	14.0	1.3	1.8
9	August	7.7	8.9	65.9	8.5	5.0	.9	3.1
	March	7.1	9.4	62.7	9.7	6.5	1.2	3.4
10	August	7.2	35.3	37.4	9.2	7.5	1.6	1.8
	March	6.7	35.0	36.2	10.9	8.4	1.6	1.2
11	August	7.1	29.4	40.9	9.2	9.8	1.6	2.0
	March	6.3	33.3	38.9	10.3	8.6	1.1	1.5

Table 11. Monoterpene composition of one ponderosa pine in 4 years

Component	July 1960	July 1961	July 1962	March 1963
			Percent	
α-pinene	8.4	7.3	7.4	7.0
β-pinene	39.1	35.8	33.8	33.6
Δ_3 carene	36.8	36.7	34.4	37.5
Myrcene	7.1	8.6	9.7	9.4
Limonene	7.3	9.9	10.0	9.9
β-phellandrene	.7	1.7	2.1	1.0
Unknown	.6	([1]/)	2.7	1.6

[1] *Trace.*

Table 12. Terpene composition for average ponderosa pine resin in eight plots in the central Sierra Nevada and Warner Mountains, California

Plot, trees sampled (No.)	Elevation	Stand age	α-pinene	β- pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown
	Feet	*Years*				*Percent*			
Institute of Forest Genetics - 11	2,700	25-50	7.1	29.4	40.9	9.2	9.8	1.6	2.0
Sly Park No. 1 -12	3,600	50-75	6.0	26.5	31.4	13.7	18.9	2.4	1.1
Sly Park No. 2[1] - 6	3,600	15-30	7.1	31.5	24.6	12.9	20.5	2.1	1.3
Riverton - 6	3,000	150-300	7.9	30.4	25.4	17.5	16.0	1.9	.9
Kyburz - 7	4,000	150-300	6.0	24.9	28.8	17.4	19.8	1.8	1.3
Pyramid - 3	5,000	150-300	4.4	18.2	46.8	14.1	13.0	1.7	1.8
Crystal Bay - 12	6,300	50-80	5.2	22.3	42.4	13.3	13.4	1.8	1.6
Joseph Creek - 7	4,700	50-80	6.2	25.9	48.6	11.1	4.7	1.8	1.7
Mean (weighted)	--	--	6.3	26.4	36.2	13.3	14.5	1.8	1.5

[1] *50 yards from Sly Park No. 1.*

Table 13. Average monoterpene composition for ponderosa pines and for plots

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Tree number	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown	Number of analyses
	- - - - - - - - - Percent - - - - - - - - - -							
1	7.8	35.3	34.7	9.1	9.5	1.7	1.9	9
2	5.8	14.9	50.8	11.0	12.7	2.0	2.8	8
3	7.1	29.4	40.9	9.2	9.8	1.6	2.0	3
4	6.6	30.7	35.9	16.0	6.7	2.5	1.6	5
5	7.9	41.0	21.2	11.1	16.2	1.7	.9	4
6	6.4	30.1	43.1	5.9	10.4	1.7	2.4	4
7	7.9	34.9	38.9	5.2	10.1	1.4	1.6	3
8	5.7	25.8	44.5	6.8	13.6	1.6	2.0	7
9	7.7	8.9	65.9	8.5	5.0	.9	3.1	3
11	7.2	35.3	37.4	9.2	7.5	1.6	1.8,	6
12	6.5	30.9	40.4	9.9	8.9	1.5	1.9	5
X	7.1	29.4	40.9	9.2	9.8	1.6	2.0	--
				SLY PARK NO. 1				
1	5.3	26.3	38.5	12.8	14.0	1.6	1.5	5
2	3.8	17.2	37.9	13.6	24.1	1.5	1.9	4
3	6.2	34.9	26.5	14.0	15.0	2.6	.8	3
4	4.5	17.2	29.6	15.4	30.7	1.8	.8	3
5	5.7	29.4	28.7	11.9	20.3	3.1	.9	4
6	7.1	27.5	24.2	11.5	27.4	2.1	.2	4
7	6.9	24.3	38.8	16.4	11.0	1.3	1.3	2
8	6.2	31.9	31.9	12.9	13.1	3.0	1.0	3
9	7.5	37.3	23.4	14.7	13.4	3.0	.7	3
10	6.5	23.4	36.7	11.7	17.5	2.2	2.0	4
25-1	6.8	30.3	22.3	20.2	16.5	2.9	1.0	4
25-2	5.5	16.9	49.2	8.5	15.5	2.3	2.1	2
25-3	6.3	24.9	25.7	12.6	25.3	3.7	1.5	2
X	6.0	26.5	31.4	13.7	18.9	2.4	1.1	--
				SLY PARK NO. 2				
1	8.4	31.8	24.8	18.2	13.3	2.4	1.1	3
2	5.0	24.0	38.5	9.0	20.1	1.5	2.0	2
3	4.8	18.9	32.6	14.7	24.5	2.3	2.2	3
4	5.8	29.3	28.1	5.9	28.3	1.3	1.3	2
5	7.2	29.6	23.2	13.8	21.0	3.5	1.7	2
6	11.5	55.3	.4	15.5	15.5	1.8	--	2
X	7.1	31.5	24.6	12.9	20.5	2.1	1.3	--
				RIVERTON				
1	5.7	20.7	38.2	18.4	13.8	1.4	1.8	3
2	9.3	34.9	22.2	20.4	10.5	2.4	.3	2
3	8.7	21.4	28.8	14.4	23.2	2.4	1.1	3
4	11.9	51.2	(1/)	16.6	18.2	2.1	--	6
5	5.5	25.3	35.5	16.8	13.4	2.0	1.5	4
6	6.1	28.6	27.7	18.3	16.9	1.4	1.0	3
X	7.9	30.4	25.4	17.5	t6.0	1.9	.9	--
				KYBURZ				
1	6.7	29.3	19.6	15.7	25.8	1.8	1.1	3
2	7.6	36.9	33.3	7.4	12.6	1.5	.7	3
3	5.6	21.4	27.3	23.3	19.5	1.5	1.4	4
4	4.0	14.4	27.3	24.9	26.5	1.8	1.1	5
5	6.3	25.7	21.9	19.1	24.3	1.7	1.0	3
6	6.2	21.8	38.9	14.8	13.2	2.5	2.6	3
7	5.4	24.8	33.1	16.5	17.1	1.6	1.5	3
X	6.0	24.9	28.8	17.4	19.8	1.8	1.3	--

See footnote at end of table.

Table 13. Average monoterpene composition for ponderosa pines and for plots, continued

Tree number	α-pinene	β-pinene	Δ_3 carene	Myrcene	Limonene	β-phellandrene	Unknown	Number of analyses
	- - - - - - - - - - Percent - - - - - - - - - -							
PYRAMID								
1	4.0	16.5	52.6	10.3	12.3	1.9	2.4	5
4	5.2	20.5	43.2	14.3	14.2	1.3	1.3	6
5	4.2	17.6	44.7	17.6	12.4	1.8	1.7	3
X	4.4	18.2	46.8	14.1	13.0	1.7	1.8	--
CRYSTAL BAY								
1	4.4	12.8	43.6	12.5	22.6	2.8	1.3	5
1a	5.3	25.8	40.8	10.3	13.6	2.1	2.1	2
1b	4.0	20.8	41.2	10.8	19.9	1.3	2.0	2
1c	6.2	16.7	59.2	15.5	([1]/)	.3	2.1	2
2	4.6	22.4	39.8	13.5	16.4	1.8	1.5	5
2a	6.1	28.5	33.1	12.5	16.1	2.4	1.3	2
2b	3.5	11.8	51.0	16.6	12.8	1.9	2.4	2
2c	3.4	14.5	45.5	16.7	15.5	1.7	2.7	2
3	7.4	35.9	43.0	6.0	5.3	1.5	.9	5
3a	6.9	37.7	26.6	10.1	16.6	1.5	.6	3
3b	5.0	20.0	32.7	26.4	12.4	2.9	.6	3
3c	5.4	21.2	51.7	8.6	9.9	1.2	2.0	4
X	5.2	22.3	42.4	13.3	13.4	1.8	1.6	--
JOSEPH CREEK								
3	5.8	33.3	50.6	4.6	1.3	1.8	2.6	3
10	5.8	27.1	49.0	7.2	6.5	2.3	2.1	4
14	1.5	.1	82.5	11.1	1.5	1.4	1.9	6
56	7.7	40.0	35.8	11.6	1.8	2.0	1.1	5
Ch-1	6.4	18.8	52.5	7.8	9.6	2.2	2.7	4
Ch-4	13.3	57.5	([1]/)	27.5	.4	1.3	--	3
Ch-5	2.8	4.1	69.4	8.2	12.0	1.8	1.7	3
X	6.2	25.9	48.6	11.1	4.7	1.8	1.7	--
Grand X	6.3	26.4	36.2	13.3	14.5	1.8	1.5	--

[1] *Trace.*

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