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Vegetation, Pollen Rain, and Pollen Preservation, Sangre De Cristo Mountains, New Mexico

Hobart N. Dixon

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By

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INTRODUCTION

During the past 30 years pollen analysis has come to be an important tool in the investigation of prehistoric plant geography and climate. The method of pollen analysis has shortcomings, however, due to a lack of data pertaining to volume of pollen produced by different species, distance and direction of transport of the pollen, the relationships of the pollen preserved in the sediments with the vegetation which produced the pollen, the resistance of the pollen of different species to destruction, and the efficiency of pollen preservation in different sedimentary types. I have chosen the last three problems as a basis for the present investigation.

In this investigation I shall attempt to relate pollen percentages of recent sediments to relative phytosociological measures of the vegetation in each of six southwestern vegetational types. The establishment of such relationships will enable more accurate reconstructions of past plant associations and climate from studies of pollen profiles.

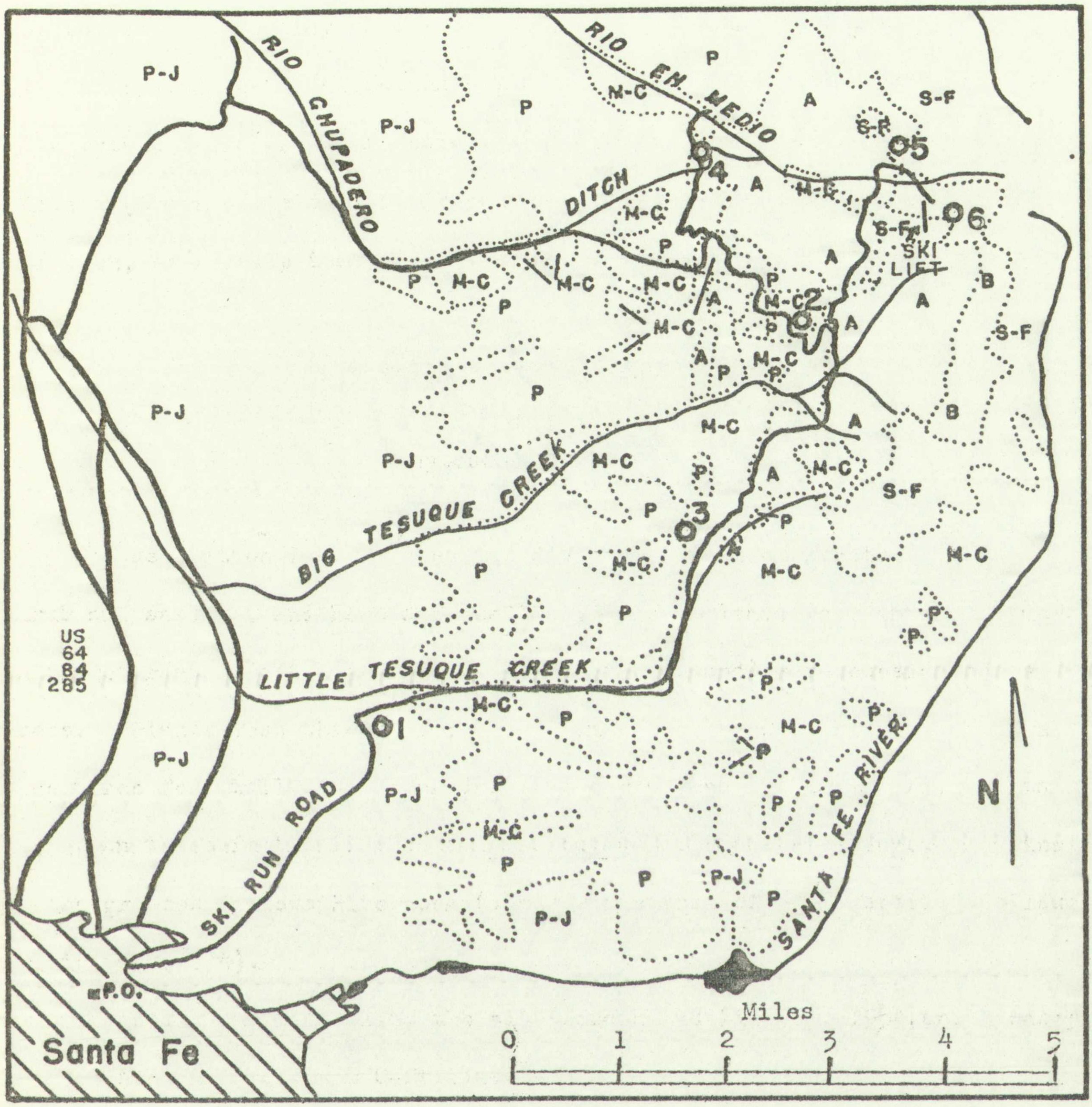
The resistance of the pollen of different species to destruction can be inferred by comparing the species composition of the current pollen rain with the species composition of the pollen extracted from recent sediments. By comparing the percentages of pollen extracted from different sediments in the same vegetational type, the efficiency of these sediments in preserving pollen can be judged.

The six vegetational types, located in the Sangre de Cristo Mountains northeast of Santa Fe, New Mexico, chosen for study are: Pinyon-Juniper, Western Yellow Pine, Mixed Conifer, Aspen, Subalpine Spruce-Fir, and Burned Subalpine Spruce-Fir. One study area was selected in each vegetational type.

The locations of the study areas and the extent of the vegetational types are shown in Fig. 1.

Several investigators have attempted to show the relationships of phytosociological measures of vegetation to percentages of pollen preserved in different media. Carroll (1943) compared the pollen from moss polsters with spruce-fir vegetation in the Great Smoky Mountains and found that relative pollen concentrations correlate best with relative basal area. Hansen (1949), working in the lowland forest of Oregon found that the abundance of trees over ten inches in diameter at breast height (dbh) correlated best with the percentages of pollen from polsters. In Quebec, Potzger et al. (1956), comparing pollen extracted from a bog with the composition of the surrounding forests, determined degrees of over- and under-representation of the tree species by the pollen, but did not attempt to correlate the relative species composition of the pollen with a relative phytosociological measure of the forest. In Vermont, Davis and Goodlett (1960) found that the concentrations of pollen from the bottom of ponds correlated best with the relative basal areas of trees in the vicinity. In vegetational types similar to those being investigated in the present study, Potter and Rowley (1960) found that the pollen extracted from polsters best correlated with relative density or relative cover, depending upon the situation. Martin, Schoenwetter, and Arms (1961), working in southeastern Arizona, compared species composition of the pollen found in stock tanks and soil samples with the composition of the surrounding vegetation, but drew no conclusions regarding correlations between the two.

Studies of the resistance of pollen to destruction and of the factors causing pollen degradation have been few. Sangster and Dale (1961) found that aspen pollen is not preserved in bogs, swamps, and ponds (but that



KEY

Study Area	Vegetational Type	Type Symbol
O 1	Pinyon-Juniper	P-J
O 2	Western Yellow Pine	P
O 3	Mixed Conifer	M-C
O 4	Aspen	A
O 5	Subalpine Spruce-Fir	S-F
O 6	Burned Subalpine Spruce-Fir	B

Fig. 1. Santa Fe, New Mexico, and vicinity showing major drainages, vegetational types, and locations of the six study areas.

pine pollen is) and they relate the ability of pollen to be preserved with its resistance to oxidation. These authors note that bacterial action is important in pollen destruction, while Goldstein (1960) found that chitrids (Order Chitridiales, Phycomycetes) are active in the degradation of pollen, especially that of the conifers.

MATERIALS AND METHODS

Phytosociology

The vegetation in each area was divided into three strata: tree, shrub and sapling, and herb and seedling. Those plants four inches or more in diameter at breast height ($4\frac{1}{2}$ ft above the ground) were considered as trees. Plants less than four inches diameter at breast height, but more than three feet tall, were considered as shrubs and saplings. All plants less than three feet tall were considered as herbs and seedlings. Terminology of the grasses follows Hitchcock (1950) while that of other species follows Harrington (1954).

The basic sampling unit, the elb (Woodin and Lindsey, 1954, and Lindsey, 1955), is based upon an 800-ft line with a right angle in the middle. In each area ten elbs were sampled, the locations of which were determined by choosing three numbers from a random number table with numbers ranging from 0 to 360. The first two numbers were compass bearing and distance, respectively, from the pollen sampler to the start of the elb; the third was the compass bearing of the first half of the elb. The direction of the second half of the elb was determined from the last digit of the third random number; the angle was to the right if the last digit was even, left if odd.

Total and relative cover of the plants in the upper strata were calculated from the lengths of the line which were superposed by the tree and shrub species. The values of density, basal area, and frequency were calculated from measurements of shrubs and trees in a strip 10 ft to either side of the line. Density was determined from the numbers of shrub and tree species in this strip and basal area was calculated from the diameters, taken at breast height, of all trees in the strip. To measure frequency (the relative number of sampling units in which a species appears) the strip was divided into sixteen 50-ft units for each elb.

The herb and seedling stratum was sampled by using a one-foot^2 wire frame placed to the right side of the line at the end of each 50-ft unit. Total and relative vegetational cover by species were estimated. This method gave a total of 160 herb and seedling sampling units for each area.

Sedimentary Pollen

Sediments for the extraction of recent pollen were taken from as many different sites within each area as possible. These sites included: stock tanks, springs, bogs, sod, moss polsters, and dry soils.

Water samples from tanks, springs, and bogs were stored in glass jars and preserved with a 10% phenol solution added in volumes equal to the samples. The sod, polsters, and soil samples were stored in envelopes after being air dried.

These sediments were treated as shown in Flow Sheet 1, Fig. 2. The addition of the bleach step in Flow Sheet 1 is an attempt to determine the amount of damage caused by this often necessary step.

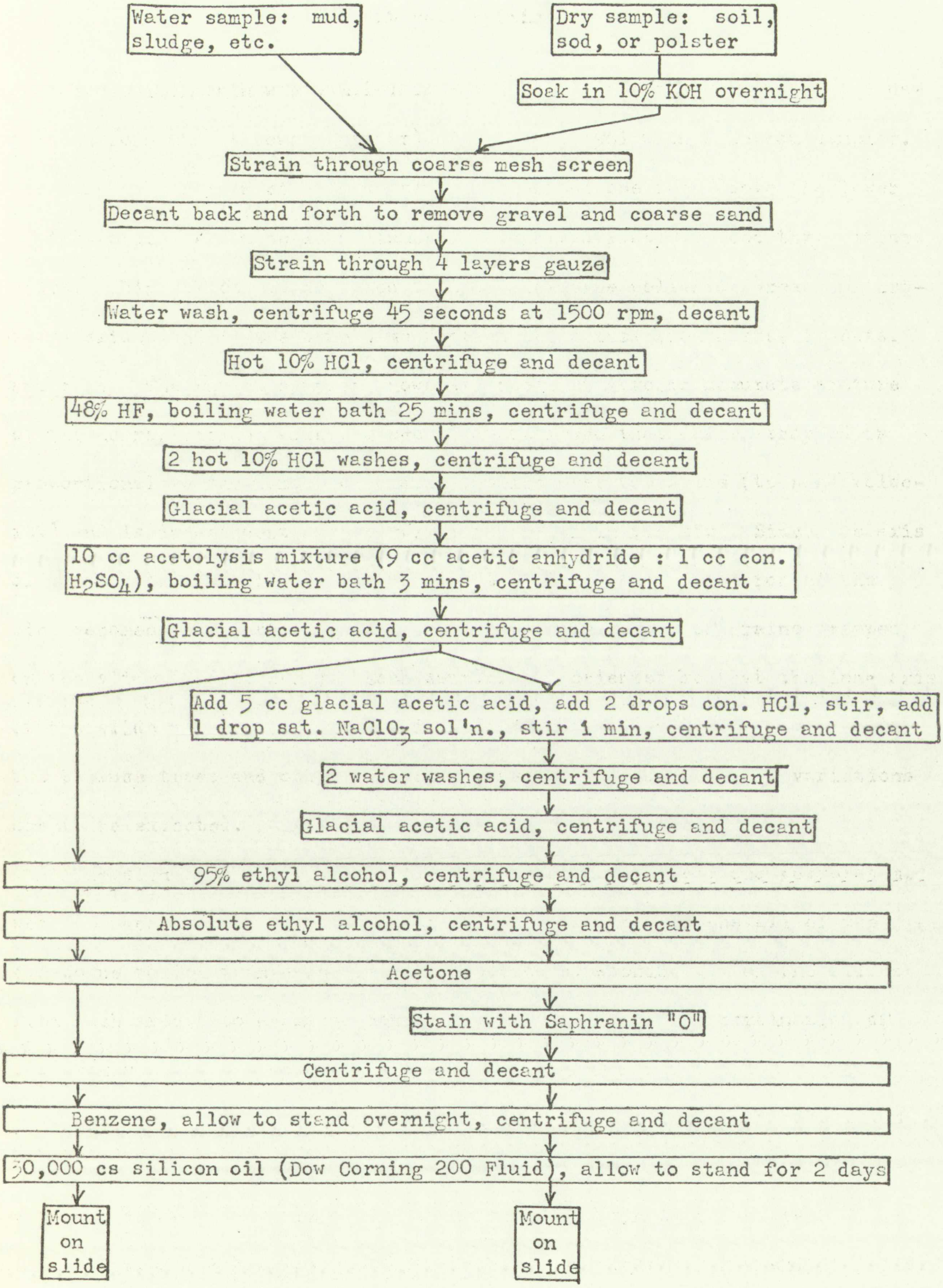


Fig. 2. Flow Sheet 1, showing treatments of the sediments for extraction of pollen.

Current Pollen Rain

The pollen rain was sampled in each area during the principal pollinating seasons (May through October) of 1960 and 1961 with a Durham sampler. The sampler consists of a slide platform mounted one inch above the lower of two horizontal, nine-inch diameter galvanized plates spaced three inches apart. This sampler is designed to trap air-borne pollen on greased microscope slides and at the same time protect the slides from birds, insects, and rain. The Durham sampler, however, does not give an accurate picture of the current pollen rain. Gregory (1950) found that pollen trapped is proportional to the number of grains passing over the slide (to wind velocity) and is independent of the volume of pollen in the air. Since one axis of the microscope slide is much longer than the other, direction of the wind becomes an important factor controlling the number of grains trapped on the slide (Ogden, 1960). Each sampler was oriented so that the long axis of the slide was parallel to the direction of the prevailing summer winds, but because trees and other obstacles cause air turbulence many variations are to be expected.

The slides, greased with a 1:3 mixture of mineral oil and petrolatum, were changed weekly. At the end of the two sampling seasons all of the air-borne pollen from each area was combined by washing all of the slides from each area into a common container with benzene. The combination of the weekly samples from each area was made because the study deals with total yearly production of pollen rather than with the weekly composition of the pollen rain, and because it was felt that an aliquot of all of the pollen rain samples would give a more accurate estimate of the yearly pollen production than would the sum of aliquots taken from weekly samples.

After the pollen from each area was combined it was treated as shown in Flow Sheet 2, Fig. 3. The different treatments were made in an effort to determine the amounts of reagent damage, if any, to the pollen.

Pollen Counts

Two hundred pollen grains were counted on each slide prepared as shown in Figs. 2 and 3 (Barkley, 1934) and several hundred more scanned for the presence of unusual species. Only the counts of those slides of pollen which had been treated with hydrofluoric acid and had been acetolyzed, bleached, and stained were used for comparisons between the current pollen rain and sedimentary pollen, as well as for the comparisons between the pollen from these two sources with the phytosociological measures of the vegetation. Only the counts of the arboreal pollen will be used for these comparisons because the non-arboreal pollen, coming from plants in locally controlled situations, is not indicative of overall climatic conditions.

The efficiency of pollen preservation by the different sedimentary types in each area is indicated by comparisons among the pollen extracted from these sediments and by comparisons between the pollen of each sediment and the current pollen rain. The relative resistance to decay by the pollen of different plant species is indicated by a comparison of the species composition of any sediment with that of the current pollen rain.

All counts were made using a Bausch and Lomb Dynazoom binocular microscope with 10X ocular lenses and 10X, 43X, and 97X objective lenses. Because the zoom system allows continual 1X to 2X magnification of the lens system, no fixed combination of lenses was used, the magnification being varied to fit the need. The more difficult identifications were made

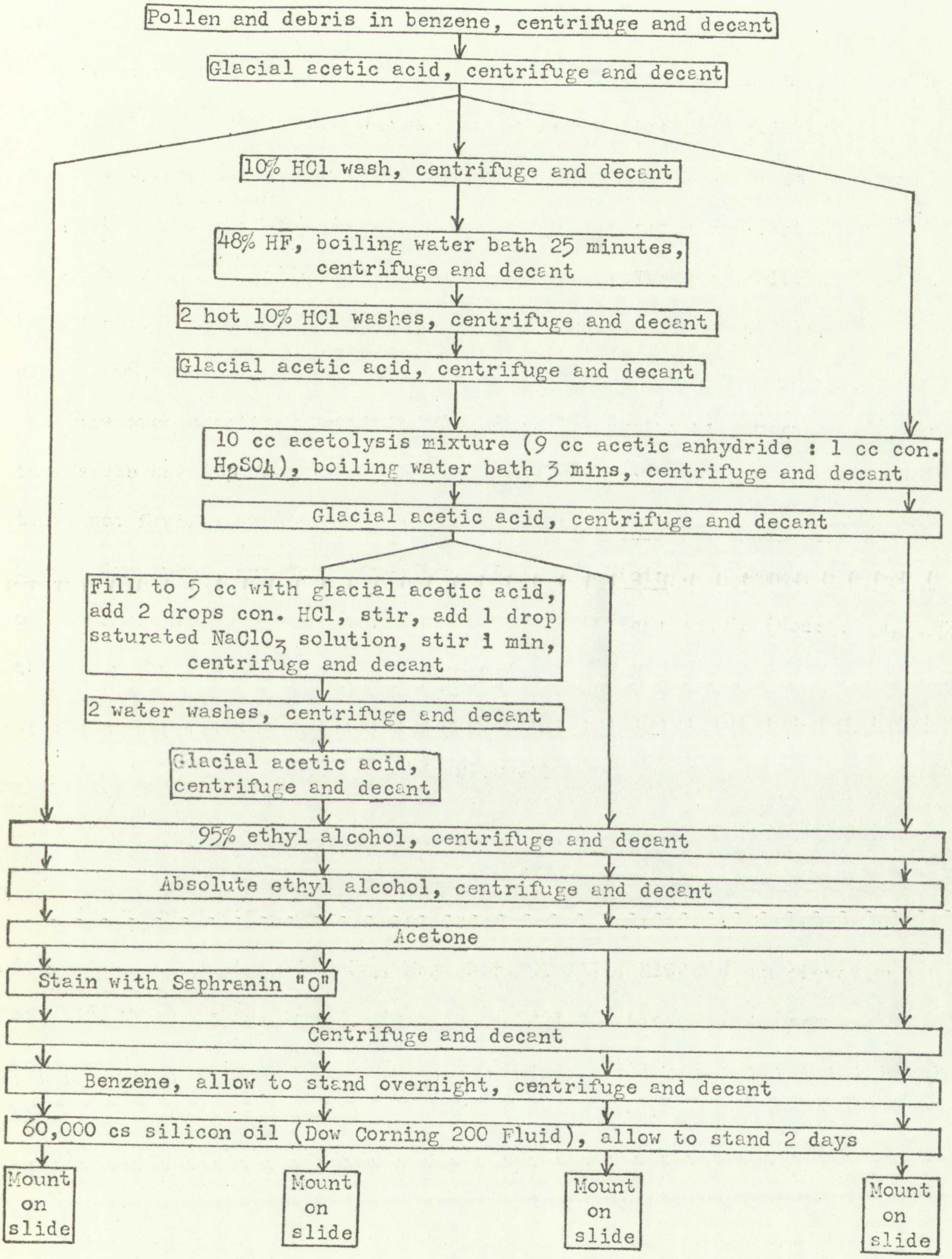


Fig. 3. Flow Sheet 2, showing treatments of the combined air-borne pollen rain samples.

using oil immersion.

Identification of the pollen was made by comparing unknown grains with reference slides of known species, the pollen of which was collected and prepared by the staff of the pollen laboratory at the Biology Department of The University of New Mexico. Additional, temporary reference slides were prepared from pollen from plant specimens in The University of New Mexico Herbarium. This dry pollen was washed with 95% ethyl alcohol, dilute KOH, and mounted in glycerine.

Whenever specific identification of pollen grains was impractical or impossible species were lumped into higher taxonomic units. These higher taxa, not further subdivided, include: Pinus, Juniperus, Abies, Picea, Salix, Gramineae, and Compositae (excluding Artemisia). Because pollen of the Chenopodiaceae and Amaranthaceae is indistinguishable (Wodehouse, 1935), these two families are lumped as chenopods.

RESULTS AND DISCUSSION

Pinyon-Juniper

The Durham pollen sampler located at the center of the Pinyon-Juniper Study Area was in the SE¼, NW¼, NW¼, Sec. 9, T17N, R10E, at an elevation of 7,765 ft above sea level. This point is 3.68 miles on an approximate bearing of 48° from the Santa Fe Post Office, and is midway between the Little Tesuque Creek to the north and the divide that separates the drainage of this creek from that of the Santa Fe River to the south, a distance of 0.4 mile.

The sampler was located on the south slope of an east-west ridge, the

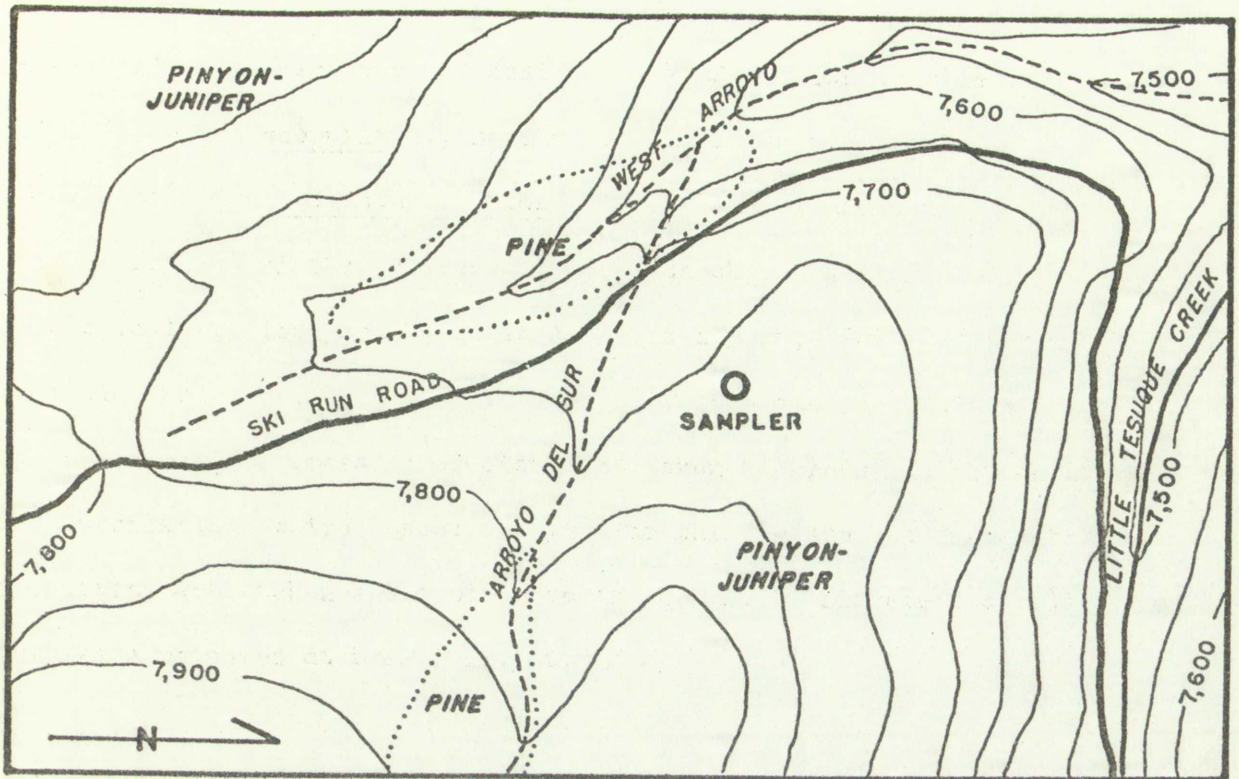
west end of which is just to the north of the sampler site. North of the ridge the slope drops steeply to the bottom of Little Tesuque Canyon, while to the west an equally steep-sided canyon, West Arroyo, runs north to the Little Tesuque. The road to the Santa Fe Ski Basin follows the east slope of West Arroyo and passes 250 ft to the west of the sampler site. The slope south of the sampler drops for about 300 ft at about 7° to a small arroyo, Arroyo del Sur, which runs west into West Arroyo. South of Arroyo del Sur the hill slopes gently upward to the divide 0.2 mile away.

The study area includes the south slope of the ridge and extends 500 ft down the north and west sides of this ridge. To the south the area extends 150 ft beyond Arroyo del Sur and to the west it parallels West Arroyo about 200 ft beyond the bottom of the canyon (Fig. 4).

The soil in the Pinyon-Juniper Study Area is derived from limestone and forms a thin, rocky mantle which barely covers the parent rock. Very little organic matter accumulates due to the intense summer thundershowers producing runoffs which float away most of the litter. There is, however, some accumulation of organic debris in isolated pockets along the arroyos and along the west side of West Arroyo where comparatively rich soil is formed.

This woodland is dominated by pinyon (*Pinus edulis* Engelm.) and junipers (*Juniperus scopulorum* Sarg. and *J. monosperma* Sarg.) which are healthy trees, well spaced and free from disease (Fig. 5). Western yellow pine (*Pinus ponderosa* Laws.) and Douglas fir (*Pseudotsuga taxifolia* Britt.) are found along the arroyos and on the west slope beyond West Arroyo.

Low ground cover is sparse, dominated by blue grama grass (*Bouteloua gracilis* Lag.) on the ridge tops and south slopes and by pinyon rice grass (*Piptochaetium fimbriatum* Hitchc.) on the north and west slopes of the



Contour interval 50 feet   1 inch equals 500 feet

Fig. 4. The Pinyon-Juniper Study Area showing principal drainages, topography, and vegetational types.

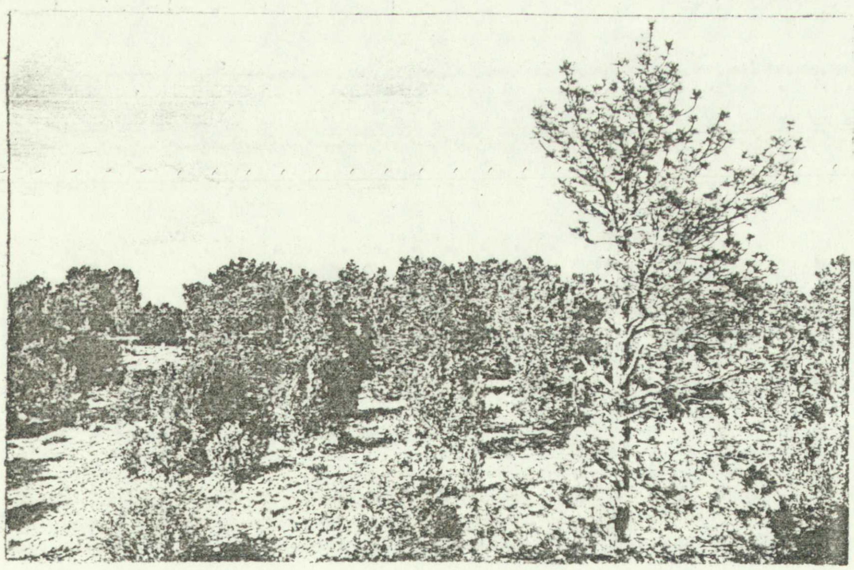


Fig. 5. The Pinyon-Juniper Study Area. View north toward sampler across Arroyo del Sur.

ridges. Along the arroyos and beside the road Russian thistle (Salsola kali L.), Kochia scoparia L., horehound (Marrubium vulgare L.), and annual sunflower (Helianthus annuus L.) are locally abundant.

The results of the analyses of the data obtained from the phytosociological studies, conducted in July and August, 1961, are shown by strata in Tables 1a, 1b, and 1c. The diffuse branching habit of the pinyon and juniper trees makes diameters taken at breast height meaningless in relation to true basal area. For this reason the diameters of these trees were taken one foot above the ground. Diameters of all other trees were measured at breast height.

TABLE 1a. Tree stratum in the Pinyon-Juniper Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		Importance %
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	
Pinus edulis	22.7	57.4	132.4	53.7	82.3	38.5	28.6	39.2	49.9
Juniperus scopulorum	7.8	19.8	52.5	21.6	63.8	29.5	22.0	31.5	23.6
Juniperus monosperma	7.4	18.4	56.4	23.2	60.7	28.0	16.0	21.8	23.2
Pinus ponderosa	1.0	2.7	3.3	1.3	7.5	3.5	4.3	5.9	3.5
Pseudotsuga taxifolia	0.6	1.5	0.8	0.3	1.9	0.9	1.1	1.6	0.9
Total	39.5		245.4				72.0		

TABLE 1b. Shrub and sapling stratum in the Pinyon-Juniper Study Area. Determinations as in Table 1a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Pinus edulis	4.3	73.2	225.0	69.3	91.3	46.8	63.1
Juniperus monosperma	0.7	12.4	38.4	11.9	57.5	29.5	17.9
Juniperus scopulorum	0.4	6.0	24.0	7.4	30.7	15.7	9.7
Pinus ponderosa	0.4	6.2	34.6	10.7	13.8	7.0	7.9
Pseudotsuga taxifolia	0.1	0.9	0.3	0.1	0.6	0.3	0.4
Chrysothamnus nauseosus	0.1	0.9	0.3	0.1	0.6	0.3	0.4
Ptelea angustifolia	0.1	0.4	1.1	0.3	0.6	0.3	0.3
Total	5.8		323.8				

TABLE 1c. Herb and seedling stratum in the Pinyon-Juniper Study Area. Cover and frequency based on 160 one-foot^2 quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Bouteloua gracilis	1.0	31.5	6.9	22.5
Piptochaetium fimbriatum	0.7	20.0	7.5	32.7
Pinus edulis	0.5	15.2	3.8	12.2
Mirabilis oxybaphoides	0.2	5.9	1.2	4.1
Sphaeralcea sp.	0.1	2.9	1.9	6.1
Hymenoxys argentea	0.1	2.9	0.6	2.0
Kochia scoparia	0.1	1.9	0.6	2.0
Lithospermum multiflorum	0.1	1.9	0.6	2.0
Total	2.8			

* Species with less than 1% relative foliage cover include: Bouteloua curtipendula, Agropyron sp., Yucca sp., Salsola kali, Trifolium sp., Misc. spp. unidentified.

The sedimentary material sampled in the Pinyon-Juniper Study Area is one type; coarse and rocky soil. Three sites near the Durham pollen sampler were sampled on October 28, 1960, for the extraction of recently deposited pollen. One sample was taken three feet east of a juniper tree and eight feet from the nearest pinyon, a second was taken under the edge of a pinyon and six feet from the nearest juniper, and the third was taken 20 ft from any tree.

Counts of the pollen extracted from these sediments by the hydrofluoric acid-acetolysis-bleach method (Fig. 2) are compared with the count of the current pollen rain in Table 2.

The low value of juniper pollen in the current pollen rain is due to the late beginning of the sampling seasons. Anthesis of both species of juniper was declining at the start of the 1960 sampling and had finished when the 1961 sampling began. Such a large count of juniper pollen in the pollen rain, even after the flowering season of this genus, would indicate an over-representation of juniper in the pollen rain as found by Potter and Rowley (1960) in the San Augustin Plains of west-central New Mexico.

Pollen rain concentrations of some species decrease exponentially with the distance from the source of the pollen (Ogden, 1960). This trend can be seen in the relative concentrations of juniper pollen in the sediments at different distances from juniper trees. The fact that the juniper pollen is deposited relatively close to the source trees is important because it suggests possible under-representation of pollen of this genus deposited in sediments distant from juniper trees.

TABLE 2. Analyses of pollen extracted from three similar sediments from the Pinyon-Juniper Study Area and of pollen found in the current pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources							
	Sediment 3 ft from juniper, 8 ft from pinyon		Sediment 8 ft from juniper, under pinyon		Sediment 20 ft from any tree		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%
Pinus	45	22.3	110	57.3	127	65.5	140	86.0
Juniperus	156	77.7	80	41.7	67	34.5	18	11.0
Pseudotsuga	0	0.0	2	1.0	0	0.0	1	0.6
Picea	0	0.0	0	0.0	0	0.0	3	1.9
Ulmus	0	0.0	0	0.0	0	0.0	1	0.6
Total arboreal	201		192		194		163	
Chenopods	3	27.3	10	47.7	9	50.0	21	46.6
Compositae	5	45.5	4	19.0	6	33.4	6	13.3
Artemisia	0	0.0	1	4.8	2	11.2	3	6.7
Gramineae	2	18.2	6	28.6	0	0.0	12	26.7
Caryophyllaceae	0	0.0	0	0.0	0	0.0	2	4.4
Unidentified	1	9.1	0	0.0	1	5.4	1	2.2
Total non-arboreal	11		21		18		45	
Total pollen	212		213		212		208	

The presence of Picea and Ulmus pollen in the current pollen rain can be accounted for by the abundance of these ornamental trees growing in Santa Fe, 3½ miles away, and around homes less than a mile from the sampler site. Artemisia is frequently found in local stands in the pinyon-juniper type, but none was found in the study area. It is assumed that

the *Artemisia* pollen was transported from stands of this genus located relatively far from the site of deposition.

The counts of the pollen extracted from the three sediment samples from the Pinyon-Juniper Study Area were averaged to give a more accurate indication of the species composition in this single sedimentary type. Only the percentages of the arboreal pollen found in the sediments correlate with the phytosociological measures of the vegetation. In Table 3 the sedimentary arboreal pollen percentages are compared with the various phytosociological measures of the tree stratum. An almost perfect correlation is seen between the relative concentrations of the pollen and the relative basal areas of the trees. The correlations become less perfect when the other relative measures are considered.

TABLE 3. Comparison of the average arboreal pollen extracted from the soil in the Pinyon-Juniper Study Area with phytosociological measures of the tree stratum.

Species	Arboreal pollen %	Phytosociological Measures			
		Relative cover %	Relative density %	Relative frequency %	Relative basal area %
Pinus spp.	47.9	60.1	55.0	42.5	45.1
Juniperus spp.	51.7	38.2	44.8	57.5	53.3
Pseudotsuga sp.	0.3	1.5	0.3	0.9	1.6

No correlations can be made between the relative amounts of the non-arboreal sedimentary pollen and the vegetation producing this pollen. Grasses compose over half of the relative non-arboreal cover, but they make up only 17% of the pollen. Chenopods and composites, on the other hand,

occupy a total of 11.4% of the relative cover and account for 77% of the preserved pollen. Artemisia, absent from the study area, makes up 6.2% of the sedimentary pollen.

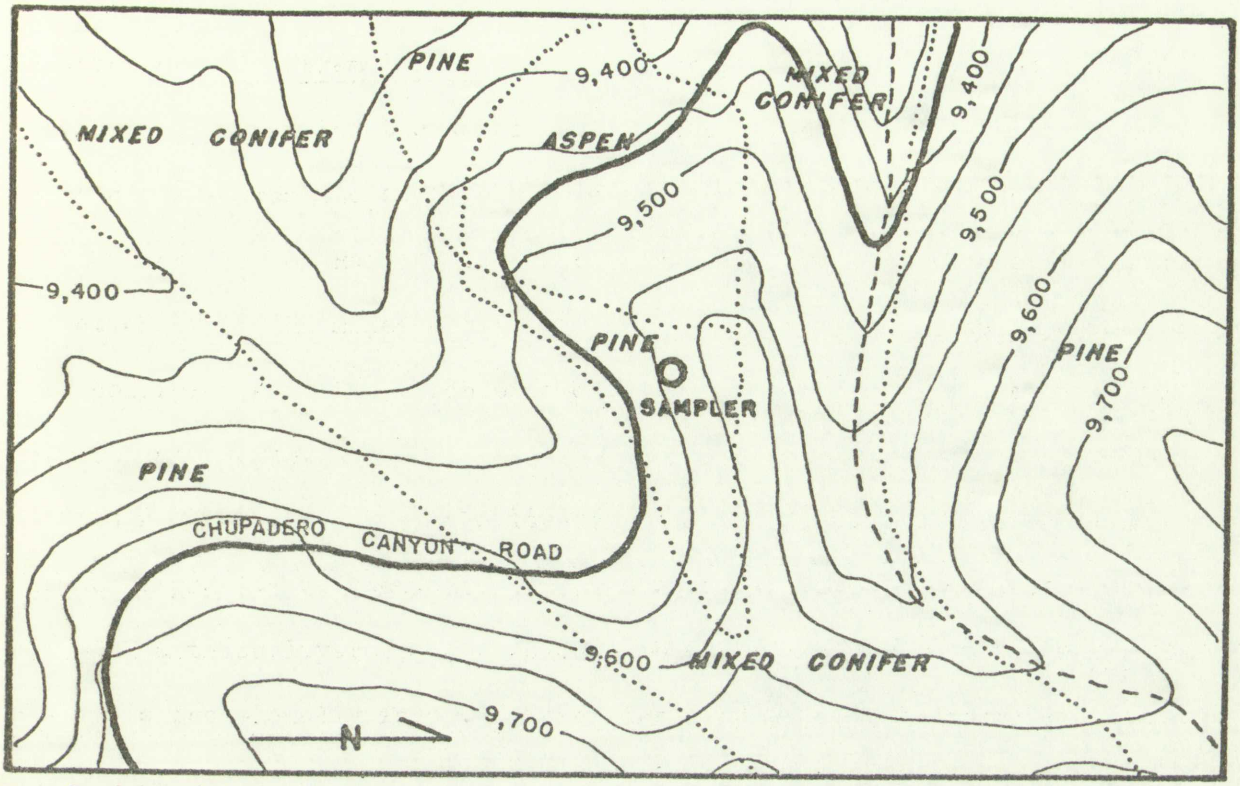
Only the arboreal pollen is considered to be a useful criterion by which the overall composition of prehistoric vegetation of the pinyon-juniper type can be assessed. Non-arboreal pollen is difficult to evaluate on a quantitative basis because herbaceous plants on different sites within this type contribute a perplexing variety of pollen to the sedimentary pollen spectrum. The non-arboreal pollen contributes qualitative information which, when used to augment the quantitative information derived from the arboreal pollen, will better indicate the climatic and site conditions under which a particular sediment in the pinyon-juniper type was deposited.

Western Yellow Pine

The center of the Western Yellow Pine Study Area, the pollen sample site, is located in the NW¼, Sec. 19, T18N, R11E. This point, at an elevation of 9,560 ft above sea level, is 9.08 miles on a bearing of 48° 30' from the Santa Fe Post Office. The area, in the Big Tesuque Creek watershed, occupies a part of the crest of a ridge which runs west from the bulk of the mountains (Fig. 6).

The sampler, mounted four feet above the ground, was located in the center of a large stand of western yellow pine. The open, mature stand (Fig. 7) is interspersed with an occasional Douglas fir.

Along the top of the east-west ridge, 300 ft north of the sampler, the pine is bounded by mixed coniferous forest dominated by Douglas fir, white fir (Abies concolor Hoopes.), limber pine (Pinus flexilis James),



Contour interval 50 feet   1 inch equals 500 feet

Fig. 6. The Western Yellow Pine Study Area showing principal drainages, topography, and vegetational types.

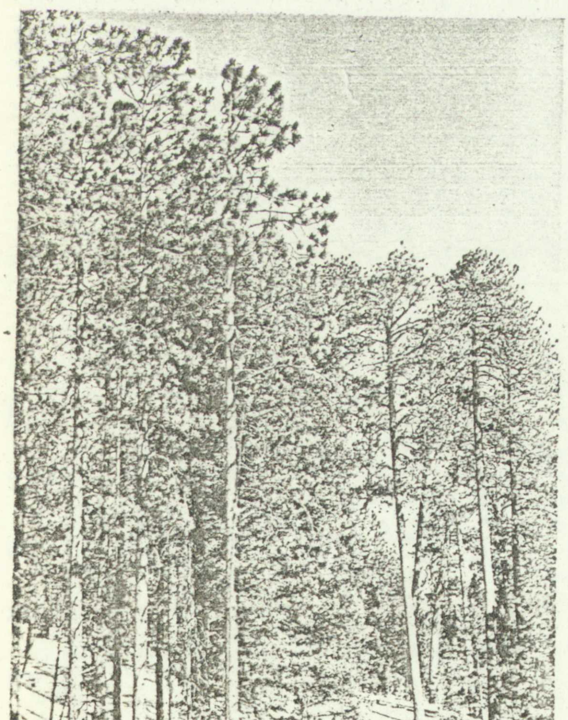


Fig. 7. The Western Yellow Pine Study Area. View northeast toward sampler from Chupadero Canyon Road.

and aspen (Populus tremuloides Michx.). The pine stand abuts on a stand of aspen 300 ft west of the sampler along the top of a ridge which joins the main ridge from the southwest. To the south the stand is bounded by the Chupadero Canyon Road, below which, in a southwest running canyon, the vegetation is of the mixed conifer type. To the east the pine blends with mixed conifer vegetation which extends onto the ridge from the canyons to the north and south.

The soil in the Western Yellow Pine Area is alluvial, derived from decomposed granite bedrock. In the pine stand the mineral soil is overlain with a thick layer of pine needles in which Arctostaphylos uva-ursi Spreng. is occasionally found. Where pine needles do not accumulate in the pine stand Ceanothus fendleri Gray is a common plant. In the mixed conifer and aspen stands which surround the pine there is formation of soil which supports such mesic plants as Vicia americana Muhl., Galium boreale L., Smilacina spp., and others. Along the road Gilia aggregata Spreng., Campanula rotundifolia L., Erigeron spp., Solidago spp., and Senecio spp. are often abundant.

The phytosociological studies were made in August, 1961. The analyses of the data obtained are shown by strata in Table 4a, 4b, and 4c.

Similar soil samples were taken from three sites in the Western Yellow Pine Study Area on October 28, 1960, for the extraction of recently deposited pollen. One was taken at the foot of the Durham pollen sampler, a second from an open area in the pine stand, and the third from soil at the foot of a large Douglas fir tree which had no branches within 30 ft of the ground. The counts of the pollen extracted from these sediments are shown in Table 5 with the counts of the pollen from the current pollen rain.

and sweet Cicely (Osmorhiza [illegible]). The pine stand similar to a tract of about 200 ft west of the samplers along the top of a ridge which joined the main ridge from the southwest. To the south the stand is bounded by the [illegible], to a westward trending [illegible] [illegible] [illegible] the north and south.

The soil in the Eastern Yellow Pine Area is alluvial, derived from decomposed granitic bedrock. In the pine stand the mineral soil is covered with a thick layer of pine needles in which [illegible] [illegible] is occasionally found. Where pine needles do not accumulate [illegible] the [illegible] is a common plant. On the [illegible] [illegible] the [illegible] is [illegible] with [illegible] [illegible] Viola [illegible], [illegible] [illegible] spp., and others. Along the road [illegible] spp., [illegible] spp., and [illegible] spp. are often abundant.

The pre-exploratory studies were made in August, 1960. The results of the data obtained are shown by graphs and tables 4a, 4b, and 4c.

Similar soil samples were taken from three sites in the Eastern Yellow Pine Stand area on October 21, 1960, for the determination of recently deposited pollen. One was taken at the foot of the Durham pollen samplers, a second from an open area in the pine stand, and the third from soil at the foot of a large Douglas fir tree which had no branches within 30 ft of the ground. The counts of the pollen extracted from these sediments are shown in [illegible]

TABLE 4a. Tree stratum in the Western Yellow Pine Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		Importance %
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	
Pinus ponderosa	23.7	38.1	97.2	30.0	55.7	27.7	77.5	45.8	32.5
Populus tremuloides	18.6	30.0	150.0	46.2	55.2	27.4	34.7	20.4	34.6
Pseudotsuga taxifolia	12.2	19.6	48.0	14.8	53.1	26.2	36.8	22.0	20.2
Abies concolor	7.3	11.3	28.7	8.8	35.6	17.6	19.8	11.6	12.6
Abies lasiocarpa arizonica	0.2	0.3	0.5	0.2	1.2	0.6	0.2	0.1	0.3
Pinus flexilis	0.2	0.3	0.5	0.2	1.2	0.6	0.2	0.1	0.3
Total	62.2		324.9				169.2		

TABLE 4b. Shrub and sapling stratum in the Western Yellow Pine Study Area. Determinations as in Table 4a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Populus tremuloides	5.8	41.6	324.9	41.5	73.8	28.5	37.2
Pseudotsuga taxifolia	2.4	17.2	87.8	11.2	46.8	18.1	15.5
Pinus ponderosa	1.9	13.9	104.0	13.3	46.2	17.8	15.5
Abies concolor	1.8	13.3	83.8	10.6	45.0	17.4	15.0
Salix bebbiana	0.9	6.2	49.3	6.3	14.4	5.5	6.0
Quercus gambellii	0.6	5.2	75.7	9.7	6.3	2.4	5.8
Shepherdia canadensis	0.2	1.1	9.2	1.2	5.6	2.2	1.5
Pinus flexilis	0.1	0.8	3.5	0.5	6.9	2.8	1.4
Acer negundo	0.1	0.6	2.2	0.3	1.9	0.7	0.5
Symphoricarpos oreophilus	0.1	0.1	0.5	0.1	1.2	0.5	0.2
Rosa spp.	0.0	0.0	28.8	3.7	5.0	1.9	1.8
Juniperus communis	0.0	0.0	13.4	1.7	5.6	2.2	1.3
Pinus edulis	0.0	0.0	0.3	0.1	0.6	0.2	0.1
Total	13.9		783.4				

TABLE 4c. Herb and seedling stratum in the Western Yellow Pine Study Area. Cover and frequency based on 160 one-foot^2 quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Vicia americana	3.0	17.3	23.8	16.3
Achillea lanulosa	2.1	12.6	25.6	17.7
Arctostaphylos uva-ursi	1.6	9.3	8.1	5.6
Artemisia franserioides	1.5	8.9	10.6	7.3
Fragaria ovalis	1.1	6.3	11.9	8.1
Bromus frondosus	1.0	5.9	11.9	8.1
Erigeron macranthus	0.8	4.9	7.5	5.1
Koeleria cristata	0.6	3.5	3.8	2.6
Draba aurea	0.6	3.5	5.0	3.4
Quercus gambellii	0.6	3.3	1.9	1.3
Pseudotsuga taxifolia	0.6	3.7	0.6	0.4
Rosa spp.	0.5	2.8	5.6	3.8
Thalictrum sp.	0.5	2.8	1.9	1.3
Viola canadensis	0.3	2.0	3.1	2.1
Solidago scopulorum	0.2	1.3	2.5	1.7
Ceanothus fendleri	0.3	1.8	1.9	1.3
Penstemon barbatus	0.2	1.3	1.9	1.3
Smilacina racemosa	0.2	1.1	1.2	0.9
Total	16.0			

* Species with less than 1% relative foliage cover include: Clematis pseudoalpina, Rubus strigosus, Pseudocymopterus montanus, Galium boreale, Thermopsis pinetorum, Geranium spp., Gilia aggregata, Salix bebbiana, Poa sp., Epilobium angustifolium, Campanula rotundifolia, Misc. spp. unidentified.

TABLE 5. Analyses of pollen extracted from three similar sediments from the Western Yellow Pine Study Area and of pollen found in the current pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources							
	Sediment at foot of pollen sampler		Sediment from open area in pine stand		Sediment from base of large Douglas fir		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%
Pinus	189	78.2	129	72.5	153	86.5	161	88.0
Juniperus	18	10.8	22	12.4	11	6.2	1	0.5
Pseudotsuga	7	4.2	16	9.0	8	4.5	13	7.1
Quercus	8	4.8	6	3.6	2	1.1	5	2.7
Abies	2	1.2	5	2.8	2	1.1	3	1.6
Picea	1	0.6	0	0.0	1	0.6	0	0.0
Total arboreal	165		178		177		183	
Compositae	24	51.1	12	30.8	19	59.5	1	3.8
Artemisia	3	6.4	1	2.6	2	6.2	3	11.5
Chenopods	15	31.9	19	48.7	4	12.5	13	50.0
Gramineae	5	10.6	2	5.1	5	15.6	8	30.8
Umbelliferae	0	0.0	4	10.2	0	0.0	0	0.0
Ephedra	0	0.0	0	0.0	1	3.1	0	0.0
Caryophyllaceae	0	0.0	0	0.0	0	0.0	1	3.8
Unidentified	0	0.0	1	2.6	1	3.1	0	0.0
Total non-arboreal	47		39		32		26	
Total pollen	212		217		210		209	

The high counts of juniper pollen in the sediments and the low counts in the pollen rain may be due to the late sampling season. If this is the case, the pollen of the junipers at lower elevations had been shed, carried to this area by the wind, and deposited on the soil surface before the pollen rain was sampled. This idea, however, only partially explains the value of juniper pollen (10%) in the sediments in the Western Yellow Pine Study Area if the juniper pollen concentrations fall offas rapidly with distance as indicated by the results from the Pinyon-Juniper type. More plausible is the idea that the low junipers in the Western Yellow Pine Study Area shed their pollen close to the ground and that this pollen is carried just above the ground by the low velocity winds in this forest type so that the concentration of juniper pollen in the pollen rain is well below the level of the sampler.

No aspen trees were observed in flower in either this study area or in any other area in the Sangre de Cristo Mountains during the two sampling seasons. This observation coupled with the evidence about the low resistance of aspen pollen to destruction leads us to expect low concentrations of this pollen, an assumption which is borne out by the absence of aspen pollen in the sediments and pollen rain in this area.

Arboreal species and those species in the shrub and sapling stratum which produce pollen indistinguishable from that of other, arboreal species in the same genera have been combined and new values for relative cover, relative density, and relative frequency have been calculated. These phytosociological measures are compared with the average arboreal pollen from the three similar sediments from the Western Yellow Pine Study Area in Table 6.

TABLE 6. Comparison of the average arboreal pollen extracted from three similar soil samples from the Western Yellow Pine Study Area with phytosociological measures of the arboreal-pollen-producing vegetation.

Species	Arboreal pollen %	Phytosociological Measures		
		Relative cover %	Relative density %	Relative frequency %
Pinus spp.	78.8	34.2	19.2	24.9
Pseudotsuga sp.	5.9	19.3	12.7	21.8
Abies spp.	1.8	12.3	10.6	17.6
Quercus sp.	2.9	0.8	7.1	2.1
Juniperus spp.	10.0	0.0	1.9	1.3
Populus sp.	0.0	32.2	44.3	26.3
Salix sp.	0.0	1.2	4.6	4.8
Acer sp.	0.0	0.1	0.2	0.6

The pine, very important in the composition of the sedimentary and air-borne pollen in the Western Yellow Pine Study Area, is less important in the phytosociological relationships of the vegetation. This is partly due to the abundance of aspen and Douglas fir, species which did not produce pollen during the two seasons that the studies were conducted in this area, but which account for as much of the vegetation as does the pine.

When the phytosociological data is recalculated using only those arboreal species which have contributed to the pollen rain or to the sedimentary pollen, relationships of the vegetation to the pollen become no clearer. Factors will have to be calculated which, when multiplied by the different pollen percentages will give a quantitative representation of the vegetation present. Such factors, offering only generalizations as to relative species compositions, will be discussed in a later section of this paper in which all of the data will be assembled and treated together.

Without the presence of aspen pollen there is no way to quantitatively determine the presence of this species from fossil pollen profiles. This inability to assess the status of the aspen is not a serious handicap, because climatic influences on the vegetation are indicated by the preserved pollen of other species.

A qualitative indicator of aspen, however, would allow more precise evaluations of prehistoric montane vegetation of the southwest. Such an indicator could be the preserved pollen of a species characteristic of the aspen type. Qualitative indicators of aspen will be discussed in a later section.

In the Western Yellow Pine Study Area pine pollen from the surface sediments greatly over-represents this genus, as does that of the juniper. White fir, aspen, and Douglas fir are under-represented in the sedimentary pollen. The chenopod group, not noted in this study area, makes up over 30% of the non-arboreal pollen found in the sediments, a value which could lead to misinterpretations of the sedimentary pollen since chenopod pollen is interpreted as representative of desert shrub and arid grassland vegetational types (Martin et al. 1961).

Mixed Conifer

The pollen sampler in the Mixed Conifer Study Area was located 1.2 miles north of the Hyde State Park Ranger Headquarters in the NE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 36, T18N, R10E at an elevation of 8,790 ft. The area lies in the Santa Fe National Forest just north of the Hyde State Park boundary. The sampler was located in the bottom of a north-running canyon 300 ft north of the divide that separates the drainage of this canyon from that of the

Little Tesuque Creek to the south (Fig. 8). The sampler was mounted level with the top of a small stone trough into which water is piped from an intermittent spring 500 ft to the southeast.

The west slope of the canyon rises steeply for several hundred feet and is dominated by almost equal numbers of western yellow pine, and limber pine. In the bottom of the canyon these two pine species merge with vegetation dominated by white fir, Douglas fir, and aspén. The white and Douglas firs make up the largest number of trees on the east slope of the canyon which is the west flank of the mountain (Fig. 9).

The coarse, gravelly soil is decomposed granite from the underlying bedrock. Little soil stability is found on either slope of the canyon. The soil on the slope to the west lacks stabilizing herbaceous vegetation due to the effects of pine needle accumulation and exposure, while that to the east is subjected to uncontrolled runoffs from the area disturbed by the Ski Run Road 300 ft above.

In the bottom of the canyon rich deep soil is formed. Here such species as Galium boreale L., Saxafraga bronchialis L., and Berberis repens Lindl. make up 100% ground cover in more sheltered sites.

The phytosociological studies of the Mixed Conifer Study Area were conducted in July and August of 1961. The results of the analyses of the data obtained are shown by strata in Tables 7a, 7b, and 7c.

The sediments sampled in the Mixed Conifer Study Area were of three types: mud from the stone trough, a moss polster from the north side of the trough, and a coarse soil sample taken a few feet south of the trough. Analyses of the pollen extracted from these sediment samples and of the current pollen rain are presented in Table 8.

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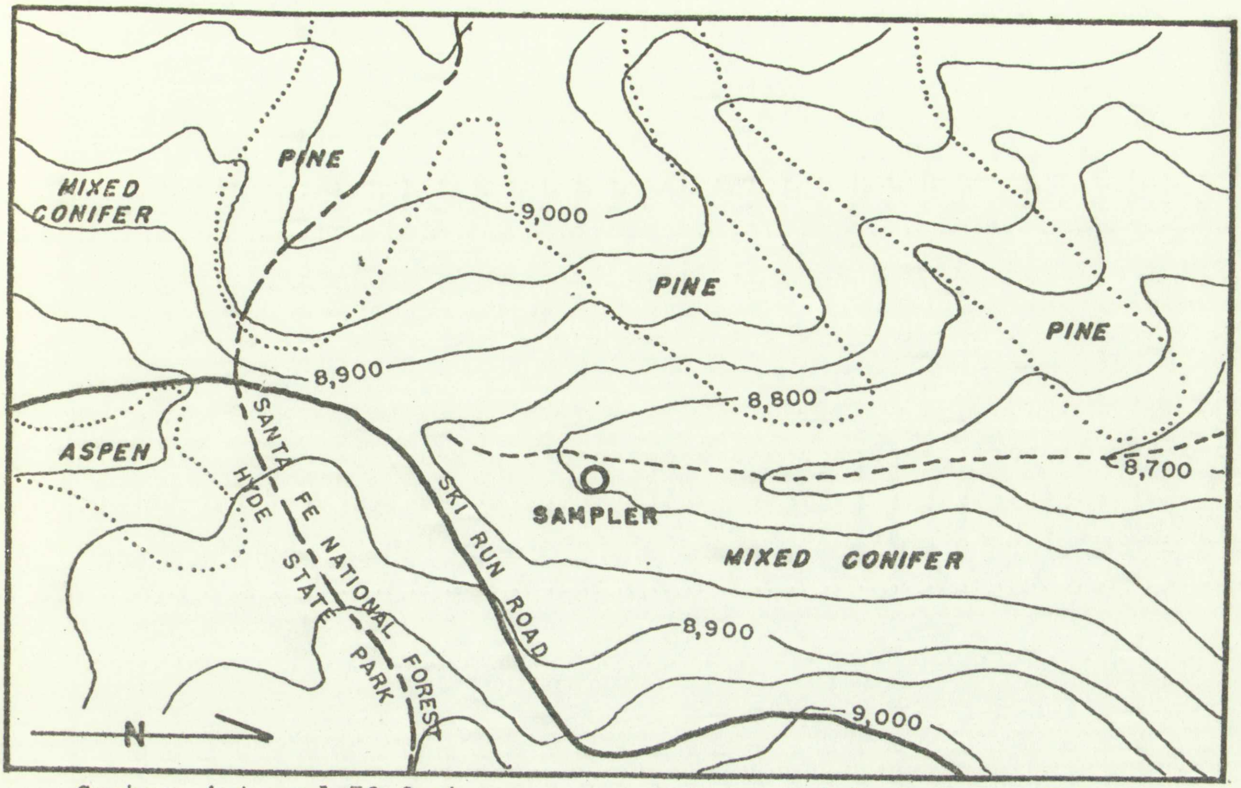


Contour interval 50 feet 1 inch equals 500 feet

Fig. 8. The Mixed Conifer Study Area showing principal drainages, topography, and vegetational types.

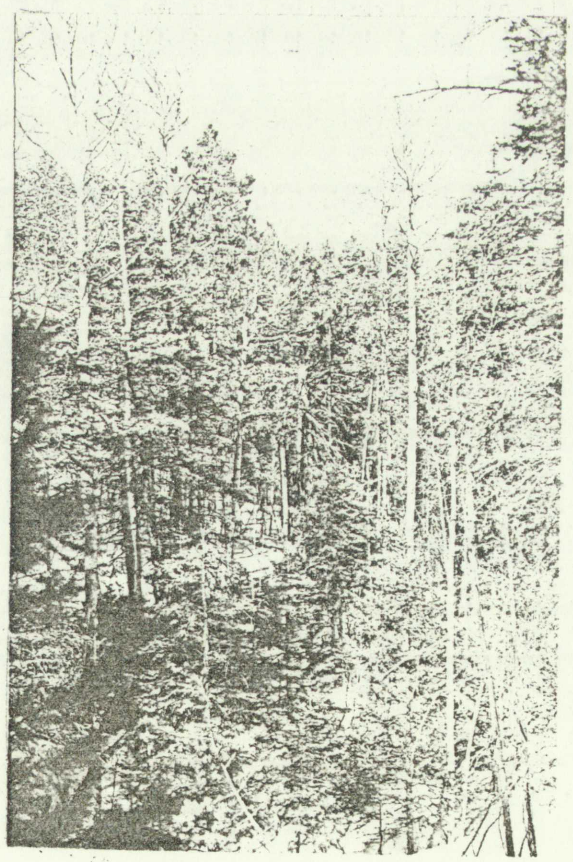


Fig. 9. The Mixed Conifer Study Area. View northwest toward sampler from Ski Run Road.

TABLE 7a. Tree stratum in the Mixed Conifer Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	Importance %
Pseudotsuga taxifolia	15.9	28.6	75.0	28.6	70.9	25.7	29.6	26.7	27.6
Populus tremuloides	10.9	19.8	60.5	23.1	41.2	15.0	16.2	14.7	19.3
Pinus ponderosa	10.4	18.8	47.2	18.0	55.7	20.2	20.3	18.3	19.0
Pinus flexilis	9.2	16.6	30.8	11.7	49.4	18.0	15.7	14.2	15.4
Abies concolor	8.8	15.9	48.3	18.4	56.8	20.7	28.7	25.9	18.3
Acer negundo	0.1	0.2	0.3	0.1	0.6	0.2	0.1	0.1	0.2
Juniperus scopulorum	0.1	0.2	0.3	0.1	0.6	0.2	0.1	0.1	0.2
Total	55.4		262.4				110.7		

TABLE 7b. Shrub and sapling stratum in the Mixed Conifer Study Area. Determinations as in Table 7a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Pseudotsuga taxifolia	4.4	24.2	151.8	13.1	77.5	17.4	18.2
Abies concolor	4.1	22.6	252.0	21.9	73.2	16.4	20.3
Populus tremuloides	3.6	19.8	123.4	10.6	55.5	12.5	14.3
Symphoricarpos oreophilus	1.6	8.9	163.0	14.0	53.1	11.9	11.6
Pinus flexilis	1.4	7.8	106.0	9.1	80.0	18.0	11.6
Quercus gambellii	1.1	6.3	197.7	17.0	22.5	5.0	9.4
Pinus ponderosa	0.9	4.7	70.6	6.1	44.4	9.9	6.9
Salix bebbiana	0.5	2.8	68.1	5.9	20.0	4.5	4.8
Juniperus communis	0.2	0.9	9.5	0.8	3.8	0.8	0.8
Acer negundo	0.1	0.4	1.0	0.1	2.5	0.6	0.4
Amelanchier alnifolius	0.1	0.3	0.1	0.1	1.2	0.3	0.3
Cercocarpus montanus	0.1	0.2	6.5	0.6	3.8	0.8	1.5
Pinus edulis	0.1	0.2	0.8	0.1	1.2	0.3	0.2
Shepherdia canadensis	0.1	0.1	6.3	0.5	5.0	1.1	0.6
Rosa spp.	0.1	0.1	2.4	0.2	3.1	0.7	0.3
Juniperus scopulorum	0.0	0.0	0.2	0.1	0.6	0.1	0.1
Rubus strigosus	0.0	0.0	0.2	0.1	0.6	0.1	0.1
Total	18.6		1159.6				

TABLE 7c. Herb and seedling stratum in the Mixed Conifer Study Area. Cover and frequency are based on 160 one-foot^2 quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Arctostaphylos uva-ursi	1.7	18.6	8.1	15.9
Antennaria sp.	1.3	14.2	8.7	17.1
Berberis repens	1.2	13.4	13.1	25.6
Quercus gambellii	1.2	12.5	5.5	11.0
Fragaria ovalis	0.8	8.8	10.0	19.6
Saxafraga bronchialis	0.6	6.6	10.6	20.8
Muhlenbergia montana	0.5	5.7	10.0	19.6
Artemisia franserioides	0.3	3.2	2.5	4.9
Clematis pseudoalpina	0.2	2.1	1.9	3.7
Symphoricarpos oreophilus	0.2	2.0	1.9	3.7
Agrostis scabra	0.2	1.8	1.2	2.4
Thalictrum sp.	0.1	1.5	1.9	3.7
Total	9.3			

* Species with less than 1% relative foliage cover include: Bromus frondosus, Epilobium angustifolium, Draba aurea, Pseudotsuga taxifolia, Rosa sp., Populus tremuloides, Salix spp., Galium boreale, Geranium sp., Pyrola sp., Viola sp., Misc. spp. unidentified.

TABLE 8. Analyses of pollen extracted from three different sediments from the Mixed Conifer Study Area and of pollen from the current pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources							
	Mud from inside stone trough		Polster from outside stone trough		Soil sample near stone trough		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%
Pinus	129	77.7	126	70.8	120	76.5	105	66.5
Juniperus	16	9.7	29	16.3	13	8.3	25	15.8
Quercus	12	7.2	10	5.6	10	6.4	10	6.3
Abies	7	4.2	6	3.4	5	3.2	11	7.0
Pseudotsuga	1	0.6	5	2.8	5	3.2	4	2.5
Salix	1	0.6	2	1.1	2	1.5	3	1.9
Total arboreal	166		178		157		158	
Chenopods	22	44.9	22	55.0	33	55.0	27	50.0
Compositae	13	26.6	7	17.4	16	26.7	5	9.3
Artemisia	5	10.2	5	12.5	5	8.3	4	7.4
Gramineae	6	12.2	5	12.5	6	10.0	15	27.8
Shepherdia	1	2.0	0	0.0	0	0.0	1	1.9
Caryophyllaceae	1	2.0	0	0.0	0	0.0	2	3.7
Umbelliferae	1	2.0	0	0.0	0	0.0	0	0.0
Symphoricarpos	0	0.0	1	2.5	0	0.0	0	0.0
Total non-arboreal	49		41		60		54	
Total pollen	215		218		217		212	

The counts of the pollen from the three different sediments and of the pollen rain in the Mixed Conifer Study Area are essentially the same. Differences can be seen in the relatively low counts of juniper pollen in the mud and soil samples in comparison with the polster and the pollen

rain, a fact suggesting better preservation of juniper pollen in polsters than in other media. The relatively low count of *Pseudotsuga* pollen in the mud sediment implies that moist environments are the most destructive to this species of pollen. Poor preservation of grass pollen in any sedimentary media is suggested by the low counts of sedimentary pollen compared with the high counts of this type of pollen in the pollen rain.

The measures of cover, density, and frequency of all species producing arboreal pollen have been recalculated and are compared in Table 9 with the percentages of arboreal pollen extracted from the sediments. Although these sediments differ widely in nature, the pollen counts are so similar that they have been averaged for this comparison.

The pollen of *Quercus* and *Salix* more closely approximates the phytosociological measures of these species than does the pollen of the other arboreal species. Juniper and pine are over-represented; the juniper by a factor of about ten, the pine by a factor of about seven. *Abies* and *Pseudotsuga* are both under-represented by a factor of about three. The aspen, as to be expected, is not represented at all by its pollen in the sediments.

The presence of the pollen of two non-arboreal species, *Symphoricarpos* and *Shepherdia*, gives an excellent qualitative indication as to the forest type. The presence of the pollen of *Symphoricarpos*, even in such a low amount, is significant because this shrub grows only in the shaded, more moist soil characteristically developed under mixed conifer vegetation. *Shepherdia*, although not restricted to the mixed conifer type, does seem to be found as an understory plant in those situations in which aspen makes up a portion of the tree stratum.

TABLE 9. Comparison of the average arboreal pollen extracted from three different sedimentary types in the Mixed Conifer Study Area with the phytosociological measures of the arboreal-pollen-producing vegetation.

Species	Arboreal pollen %	Phytosociological Measures		
		Relative cover %	Relative density %	Relative frequency %
Pinus spp.	75.0	30.6	18.9	24.4
Juniperus spp.	11.4	0.4	0.7	1.3
Quercus sp.	6.4	1.5	14.6	5.7
Abies sp.	3.6	17.9	22.3	22.1
Pseudotsuga sp.	3.3	28.2	16.8	23.3
Salix spp.	1.4	0.7	12.1	5.1
Populus sp.	0.0	20.2	13.7	15.9
Acer sp.	0.0	0.3	0.1	0.8
Amelanchier sp.	0.0	0.2	0.1	0.3
Cercocarpus sp.	0.0	0.2	0.5	0.9

The relative values of the arboreal pollen do not correspond with the phytosociological measures of the vegetation and factors for adjusting over- and under-representation will have to be computed. These factors will be discussed in a later section. Of greater importance in assessing forest composition is the presence of the pollen of species which are indicative of particular forest types. Two such qualitative indicators are Symphoricarpos and Shepherdia.

Aspen

The Aspen Study Area pollen sampler was fastened to a fence post next to a 9-ft diameter galvanized stock tank 9.55 miles on a bearing of 38° 30' from the Santa Fe Post Office. This location, at an elevation of 9,170 ft

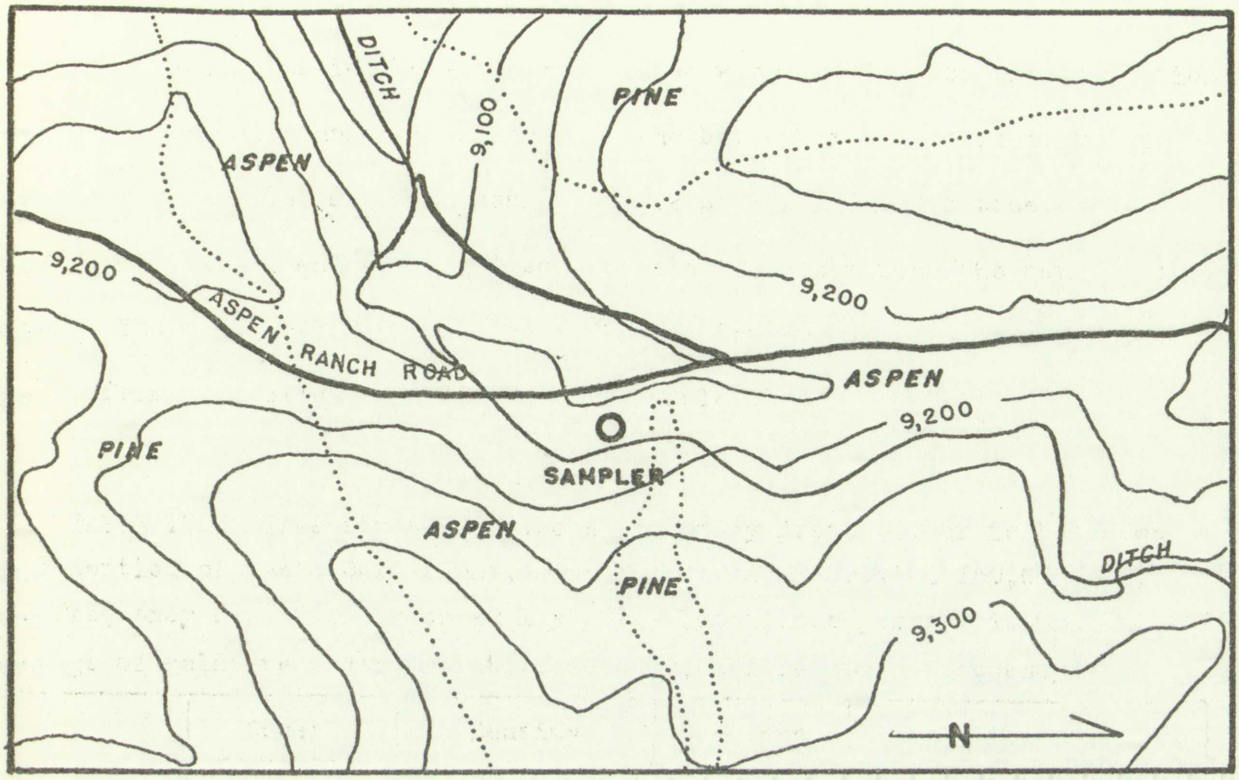
above sea level, is in the N½, NW¼, NW¼, Sec. 12, T18N, R10E. The study area, at the lower edge of the aspen vegetational type just above western yellow pine, is located on the broad, gently-sloping west flank of the mountain which is dissected by numerous, shallow, parallel valleys running to the west (Fig. 10).

In these valleys aspens make up the dominant vegetation. Scattered widely throughout the aspens are Douglas fir and white fir trees which increase in number on the north slopes of the ridges between the valleys (Fig. 11). Along the tops and south slopes of these ridges western yellow pine is the dominant tree beneath which dense stands of gambel oak (Quercus gambellii Nutt.) are common.

A ditch, carrying water from the Rio en Medio on the north to the Rio Chupadero on the south, passes 20 ft east of the sampler and supplies the water for the stock tank. Along this ditch alder (Alnus tenuifolia Nutt.) and willows (Salix spp.) are common.

The soil, shallow over granite bedrock, is poorly developed on the ridges under the western yellow pine, but is rich under the aspens in the valleys. On this rich soil ground cover is dense, commonly 100%, and is composed of Vicia americana Muhl., Thermopsis pinetorum Greene, and several species of grasses. Dense shrubby clumps of Juniperus communis L. are scattered in the valleys under the aspens.

The phytosociological studies of the Aspen Study Area were conducted in August of 1961. The analyses of the data obtained are presented by strata in Tables 10a, 10b, and 10c.



Contour interval 50 feet 1 inch equals 500 feet

Fig. 10. The Aspen Study Area showing principal drainages, topography, and vegetational types.

Fig. 11. The Aspen Study Area. View southeast toward sampler from Aspen Ranch Road.

Three sediments in the Aspen Study Area were sampled for the extraction of pollen. A mud sample was taken from the bottom of the stock tank, an organic soil sample was taken near the base of a Douglas fir tree close to the stock tank, and a mineral soil sample was taken from the bank of the ditch. The analyses of the pollen extracted from these sediments and of pollen from the pollen rain are shown in Table 11.

TABLE 10a. Tree stratum in the Aspen Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	Importance %
Populus tremuloides	48.9	86.3	406.0	94.6	91.8	69.0	89.3	89.0	90.9
Pinus ponderosa	3.9	6.8	11.7	2.7	17.4	13.1	6.8	6.8	7.5
Pseudotsuga taxifolia	3.0	5.3	9.3	2.1	18.8	14.1	3.0	3.0	3.4
Abies concolor	0.9	1.9	2.5	0.6	5.0	3.8	1.0	1.0	2.2
Total	56.7		429.5				100.1		

TABLE 10b. Shrub and sapling stratum in the Aspen Study Area. Determinations as in Table 10a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Populus tremuloides	4.4	35.6	412.0	37.0	79.4	32.7	35.1
Quercus gambellii	3.6	30.4	368.0	33.1	25.0	10.3	24.3
Juniperus communis	0.8	15.3	140.8	12.6	28.7	11.8	13.2
Pinus ponderosa	0.6	5.4	24.0	2.2	23.8	9.8	5.8
Salix bebbiana	0.5	5.0	62.2	5.6	19.4	8.0	6.2
Rosa spp.	0.2	2.0	45.8	4.1	23.2	9.5	5.2
Alnus tenuifolia	0.2	1.9	17.7	1.6	5.0	2.1	1.5
Juniperus monosperma	0.2	1.9	7.6	0.7	9.4	3.8	2.1
Pseudotsuga taxifolia	0.2	1.6	11.4	1.0	12.6	5.1	2.9
Symphoricarpos oreophilus	0.1	0.5	2.7	0.3	3.8	1.6	0.8
Shepherdia canadensis	0.1	0.3	17.4	1.6	8.8	3.6	1.8
Juniperus scopulorum	0.0	0.0	1.4	0.1	1.9	0.8	0.3
Pinus flexilis	0.0	0.0	1.4	0.1	0.6	0.3	0.2
Abies concolor	0.0	0.0	0.5	0.1	1.3	0.5	0.2
Pinus edulis	0.0	0.0	0.3	0.1	0.6	0.3	0.1
Total	10.4		1112.9				

TABLE 10c. Herb and seedling stratum in the Aspen Study Area. Cover and frequency based on 160 one-foot^2 quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Vicia americana	7.8	17.0	47.5	14.9
Poa pratensis	6.4	13.9	40.7	12.7
Rosa spp.	5.4	11.8	36.2	11.4
Arctostaphylos uva-ursi	3.1	7.0	15.0	4.7
Achillea lanulosa	3.0	6.6	40.7	12.7
Artemisia franserioides	2.7	6.1	17.5	5.5
Bromus frondosus	2.7	6.0	23.8	7.5
Juniperus communis	1.5	3.2	4.4	1.4
Quercus gambellii	1.5	3.2	4.4	1.4
Solidago scopulorum	1.1	2.5	10.6	3.3
Ceanothus fendleri	1.1	2.3	3.8	1.2
Geranium spp.	1.0	2.2	13.1	4.1
Trifolium sp.	1.0	2.1	3.1	1.0
Erigeron macranthus	0.9	2.0	14.4	4.5
Antennaria sp.	0.6	1.4	3.8	1.2
Fragaria ovalis	0.6	1.3	7.5	2.4
Taraxacum officionale	0.6	1.2	8.1	2.6
Total	44.8			

* Species with less than 1% relative foliage cover include: Gilia aggregata, Populus tremuloides, Berberis repens, Senecio sp., Solidago sp., Prunella vulgaris, Allium cernuum, Potentilla spp., Smilacina racemosa, Clematis pseudoalpina, Rubus strigosus, Ligusticum porteri, Campanula rotundifolia, Castilleja sp., Misc. spp. unidentified.

TABLE 11. Analyses of pollen extracted from three different sediments in the Aspen Study Area and of pollen from the pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources							
	Mud from stock tank		Organic soil from foot of Douglas fir		Mineral soil from bank of ditch		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%
Pinus	49	36.0	100	65.0	99	61.8	84	48.3
Quercus	25	18.4	29	18.8	23	14.4	58	33.3
Juniperus	24	17.6	15	9.8	23	14.4	15	8.6
Abies	3	2.3	3	1.9	4	2.5	8	4.6
Salix	6	4.4	2	1.3	5	3.1	5	2.9
Picea	1	0.7	1	0.6	1	0.6	2	1.1
Pseudotsuga	0	0.0	0	0.0	2	1.2	1	0.6
Populus	0	0.0	2	1.3	1	0.6	1	0.6
Alnus	28	20.6	2	1.3	2	1.2	0	0.0
Total arboreal	136		154		160		174	
Chenopods	31	37.8	23	40.3	24	46.2	15	34.1
Gramineae	27	33.0	13	22.8	10	19.2	23	52.2
Compositae	13	15.8	15	26.4	11	21.2	4	9.1
Artemisia	7	8.5	1	1.8	1	1.9	1	2.3
Shepherdia	1	1.2	3	5.3	1	1.9	1	2.3
Polygonum	0	0.0	0	0.0	1	1.9	0	0.0
Cyperaceae	1	1.2	0	0.0	0	0.0	0	0.0
Ephedra	2	2.4	0	0.0	0	0.0	0	0.0
Unidentified	0	0.0	2	3.6	4	7.7	0	0.0
Total non-arboreal	82		57		52		44	
Total pollen	218		211		212		218	

The differences in percentages between the pollen from the stock tank and the pollen from the other sources is apparent. Most significant is the high percentage of alder pollen in the tank, a value not equalled in the pollen from any other source. This alder pollen was undoubtedly carried into the tank with water from the ditch, along which alder trees are abundant. The high percent of alder pollen in the stock tank lowers the percent values for pine, oak, and juniper pollen in the tank. If the arboreal pollen from the tank is recalculated with the omission of the alder pollen, the pine and oak percentages assume values quite similar to those of the pollen rain, but the percentage of juniper pollen becomes almost double that value from any other source.

The high values of grass pollen in the stock tank and in the current pollen rain suggests that, in this vegetational type, the grass pollen is better preserved in water than in surface soils. The low percentage of composite pollen in the pollen rain may be due to the height of the pollen sampler above the ground.

The arboreal pollen from the two soil samples was averaged for comparison with the phytosociological measures of the vegetation. The comparisons of the average frequencies of pollen from the soil samples and the pollen from the stock tank with the phytosociological measures of the vegetation are presented in Table 12.

Pine is highly over-represented by its pollen in both sedimentary types. This over-representation is to be expected, however, due to the nearness of extensive stands of western yellow pine to the southwest. _Pseudotsuga_ is under-represented by its pollen, although not as much as in the other study areas. Willow and oak pollen correspond well with all phytosociological measures, while juniper pollen corresponds with relative

density and relative frequency, but over-represents the relative cover of this genus.

TABLE 12. Comparison of the average arboreal pollen extracted from two soil samples from the Aspen Study Area and of pollen extracted from mud from a stock tank in the same area with phytosociological measures of the arboreal-pollen-producing vegetation.

Species	Average arboreal pollen from soil %	Arboreal pollen from tank %	Phytosociological Measures		
			Relative cover %	Relative density %	Relative frequency %
Pinus spp.	63.4	36.0	6.7	2.5	13.0
Quercus sp.	16.6	18.4	5.4	24.8	10.0
Juniperus spp.	12.2	17.6	1.5	10.1	15.0
Abies spp.	2.1	2.3	1.3	0.2	3.5
Salix spp.	2.1	4.4	0.7	4.2	7.8
Pseudotsuga sp.	0.0	0.6	4.8	1.4	10.5
Populus sp.	0.0	1.0	79.3	55.5	38.2
Picea sp.	0.6	0.7	0.0	0.0	0.0
Alnus sp	1.3	20.6	0.3	1.2	2.0

Although the aspen is represented by a few pollen grains in the sediments, it is believed that these grains would not be preserved for any length of time. For this reason it is believed that non-arboreal _Shepherdia_ pollen, appearing in all of the sediments and in the pollen rain, is a better indicator of the aspen than the appearance of aspen pollen itself.

Subalpine Spruce-Fir

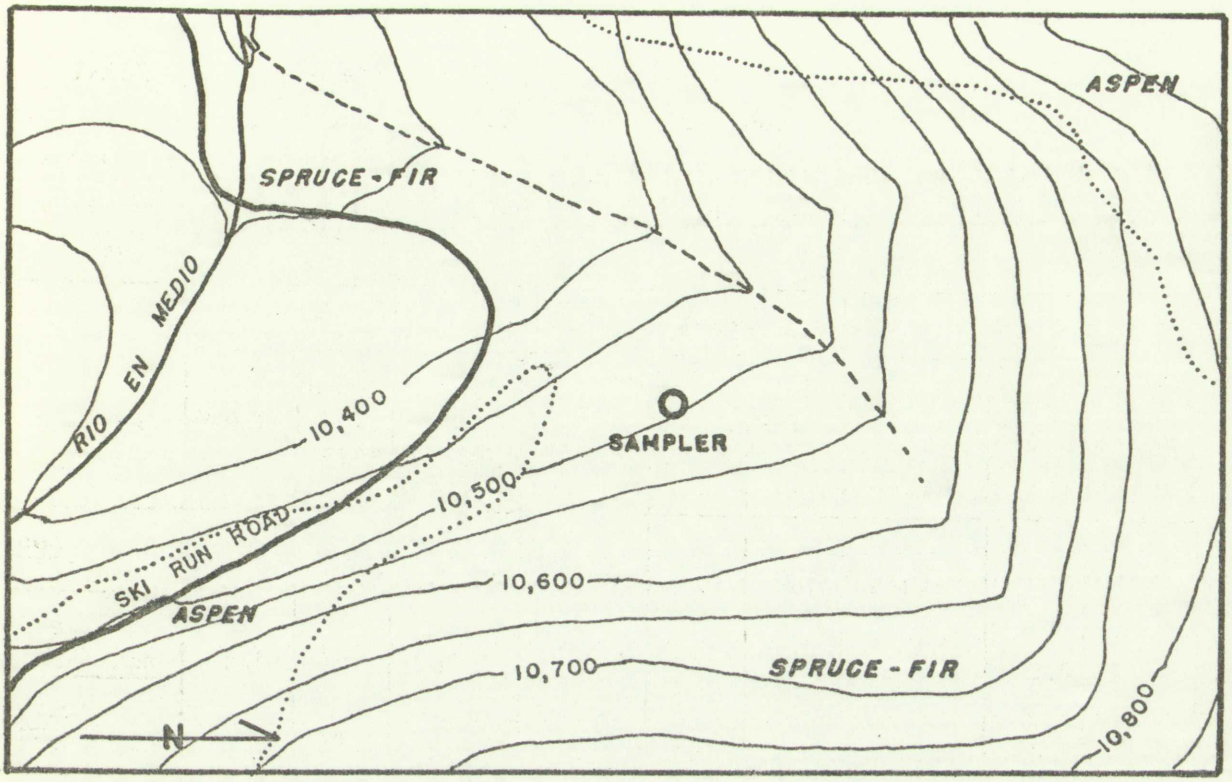
The pollen sampler which was the center of the Subalpine Spruce-Fir Study Area was located in the SE$\frac{1}{4}$, Sec. 8, T18N, R11E at an elevation of 10,490 ft above sea level. This point, 10.91 miles on a bearing of 45° 50' from the Santa Fe Post Office, is above the Rio en Medio on the southwest slope of the ridge which runs west from Lake Peak (Fig. 12).

The sampler was mounted six feet above the ground on a spruce snag at the south end of a bog in a dense stand of Engelmann spruce (*Picea engelmanni* Parry) and corkbark fir (*Abies lasiocarpa* var. *arizonica* Lemmon). Water coming from one of several springs inthe vicinity kept the bog continually wet during the two sampling seasons.

In the areas where adequate moisture is available, the spruce trees, interspersed with an occasional corkbark fir, form dense, closed-canopy stands (Fig. 13). Away from the moist areas, and on the south slopes above the Rio en Medio, the spruce trees are more scattered and reach great size. Aspen forms local stands in the spruce-fir type on the southwest slopes and higher on the south slopes they replace the spruce-fir.

The soil in this area is shallow, directly overlying the bedrock material. The soils on the upper slopes are poorly developed and support only a few species of grasses and sedges. In the spruce-fir stands richer soils are developed, but due to the poor light penetration few flowering plants are to be found. In the bogs and along the streams where there is more light such plants as *Prunella vulgaris* L., *Pedicularis groenlandica* Retz., *Gentiana thermalis* Kuntze, *Eleocharis* sp., and *Carex* spp. commonly make up much of the ground cover.

The results of the phytosociological studies, conducted in August of 1961, are analyzed by strata in Tables 13a, 13b, and 13c.



Contour interval 50 feet 1 inch equals 500 feet

Fig. 12. The Subalpine Spruce-Fir Study Area showing principal drainages, topography, and vegetational types.

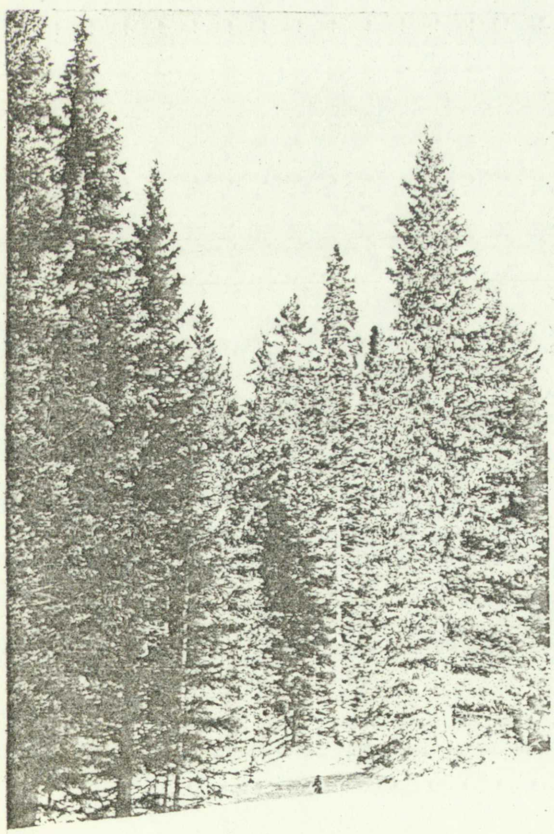


Fig. 13. The Subalpine Spruce-Fir Study Area. View north from a point 50 ft east of the sampler.

TABLE 13a. Tree stratum in the Subalpine Spruce-Fir Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	Importance %
Picea engelmanni	30.2	63.8	184.1	64.1	92.0	61.8	138.1	77.8	63.2
Abies lasiocarpa	8.8	18.3	47.9	16.6	37.5	25.2	19.5	10.9	20.0
Populus tremuloides	8.5	17.9	55.7	19.3	19.4	13.1	19.8	11.1	16.8
Total	47.5		287.7				177.4		

TABLE 13b. Shrub and sapling stratum in the Subalpine Spruce-Fir Study Area. Determinations as in Table 13a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Picea engelmanni	3.1	46.6	265.3	42.0	81.2	46.3	45.0
Populus tremuloides	1.5	22.2	78.0	12.4	36.2	20.6	18.4
Abies lasiocarpa	1.1	16.6	55.0	8.7	18.8	10.6	12.0
Ribes montigenum	0.7	9.7	173.0	27.4	21.3	12.1	16.4
Juniperus communis	0.2	2.2	13.6	2.2	6.9	3.9	2.8
Salix bebbiana	0.1	1.5	1.6	0.3	1.9	1.1	1.0
Sambucus racemosa	0.1	1.4	13.4	2.1	3.8	2.1	1.9
Ribes viscosissimum	0.0	0.0	24.8	3.9	4.4	2.5	2.1
Veratrum californicum	0.0	0.0	5.4	0.9	1.2	0.7	0.5
Lonicera involucrata	0.0	0.0	0.5	0.1	0.6	0.6	0.2
Total	6.8		629.6				

TABLE 13c. Herb and seedling stratum in the Subalpine Spruce-Fir Study Area. Cover and frequency based on 160 one-foot² quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Erigeron macranthus	2.8	10.6	18.8	8.0
Carex spp.	2.4	9.0	14.1	6.1
Fragaria ovalis	2.1	7.7	26.3	11.2
Helenium hoopesii	2.0	7.4	16.3	6.9
Achillea lanulosa	1.5	5.5	20.0	8.5
Solidago decumbens	1.5	5.5	10.6	4.6
Thermopsis pinetorum	1.4	5.2	6.9	3.0
Vicia americana	1.2	4.6	15.6	6.7
Caltha leptosepala	1.2	4.6	8.8	3.7
Vaccinium oreophilum	1.1	4.0	8.1	3.5
Epilobium angustifolium	1.0	3.7	11.2	4.8
Prunella vulgaris	0.9	3.4	3.1	1.3
Ribes spp.	0.9	2.3	3.8	1.6
Antennaria sp.	0.6	2.2	1.9	0.8
Picea engelmanni	0.6	2.1	4.4	1.8
Artemisia franserioides	0.5	1.9	3.1	1.3
Agrostis scabra	0.4	1.6	5.0	2.1
Potentilla spp.	0.4	1.5	3.8	1.6
Poa sp.	0.4	1.5	1.8	0.8
Abies lasiocarpa	0.3	1.3	2.5	1.1
Eleocharis sp.	0.3	1.2	3.1	1.3
Draba aurea	0.3	1.0	3.8	1.6
Viola spp.	0.3	1.0	3.1	1.3
Total	26.7			

* Species with less than 1% foliage cover include: *Taraxacum* sp., *Senecio* spp., *Aconitum columbianum*, *Pedicularis groenlandica*, *Rubus* spp., *Thalictrum* sp., *Eriogonum* sp., *Gentiana* spp., *Bromus* sp., *Juncus* sp., *Juniperus communis*, *Geranium* spp., Misc. spp. unidentified.

Three types of sediments were sampled in the Subalpine Spruce-Fir Study Area for the extraction of sedimentary pollen. One was a mud sample from the interface between the mud and water in the bog near the sampler, the second was a sod sample from the same area, and the third was a soil sample taken in a clearing between the spruce-fir forest and an aspen stand. The analyses of the pollen extracted from these sediments and of the pollen in the pollen rain are presented in Table 14.

The sod sample shows a larger spectrum of pollen than the dry soil sample because of the richer flora in the bog. The slightly greater species representation in the sod than in the mud may be due to the longer accumulation of pollen in the sod, an accumulation representing the average pollen production in the area and closely resembling the pollen rain. An exception to this similarity is the high value of Cyperaceae pollen in the sod because the pollen produced by the sod-forming sedges falls directly onto the soil surface and very little enters the pollen rain.

The pollen found in the soil sample taken from the open area between the spruce-fir and aspens shows a high percent of pine pollen. This is due, in part, to the site being to the windward of the spruce-fir forest and in this area lower concentrations of spruce and fir pollen would be expected. The low ratio of fir to spruce in this sample is due to the distance of fir trees which were near the other samples.

The counts of arboreal pollen from the bog mud and from the sod were averaged because it was felt that the mud would be eventually incorporated into the sod. The percentages of the pollen from this average count and those of the pollen from the open area between the spruce-fir and aspen stands are compared with the relative phytosociological measures of the vegetation in Table 15.

TABLE 14. Analyses of the pollen extracted from three different sediment types from the Subalpine Spruce-Fir Study Area and of pollen from the current pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources							
	Mud-water interface in bog		Sod from bog near the sampler		Soil from spruce-aspen ecotone		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%
Picea	103	62.6	67	50.8	60	42.0	85	52.5
Pinus	22	13.3	33	25.0	66	46.1	33	20.4
Abies	26	15.7	20	15.1	8	5.6	33	20.4
Juniperus	9	5.4	6	4.5	7	4.9	7	4.3
Quercus	4	2.4	1	0.8	1	0.7	2	1.2
Pseudotsuga	1	0.6	1	0.8	1	0.7	2	1.2
Salix	0	0.0	3	3.0	0	0.0	0	0.0
Total arboreal	165		132		143		162	
Chenopods	18	34.0	16	18.2	26	35.1	24	44.5
Gramineae	13	24.5	22	25.0	20	27.0	8	14.8
Compositae	10	18.9	12	13.6	9	12.2	15	27.8
Artemisia	4	7.5	4	4.1	7	9.5	2	3.7
Cyperaceae	5	9.5	25	28.4	5	6.8	0	0.0
Caryophyllaceae	0	0.0	2	2.3	1	1.3	1	1.9
Ribes	1	1.9	2	2.3	1	1.3	0	0.0
Liliaceae	0	0.0	1	1.2	1	1.3	0	0.0
Gentianaceae	0	0.0	0	0.0	0	0.0	2	3.7
Hydrocharitaceae	1	1.9	0	0.0	0	0.0	0	0.0
Scrophulariaceae	1	1.9	0	0.0	0	0.0	0	0.0
Umbelliferae	0	0.0	1	1.2	0	0.0	0	0.0
Viola	0	0.0	1	1.2	0	0.0	0	0.0
Unidentified	0	0.0	2	2.3	4	5.4	2	3.7
Total non-arboreal	53		88		74		54	
Total pollen	218		230		217		216	

TABLE 15. Comparisons of the average arboreal pollen extracted from two wet sediments from the Subalpine Spruce-Fir Study Area and of the arboreal pollen extracted from a soil sample just outside of a spruce-fir stand with phytosociological measures of the arboreal-pollen-producing vegetation.

Species	Average wet sediment pollen %	Pollen from dry soil %	Phytosociological Measures		
			Relative cover %	Relative density %	Relative frequency %
Picea sp.	57.2	42.0	62.4	64.3	52.3
Abies spp.	15.5	5.6	18.4	14.7	29.5
Juniperus spp.	5.1	4.9	0.4	1.9	3.6
Salix spp.	1.0	0.0	0.2	0.1	1.0
Pinus spp.	18.5	46.1	0.0	0.0	0.0
Quercus sp.	1.8	1.2	0.0	0.0	0.0
Pseudotsuga sp.	0.7	0.7	0.0	0.0	0.0
Populus sp.	0.0	0.0	18.6	19.1	13.5

The percentages of spruce pollen from the wet, bog sediments closely approximate all relative phytosociological measures of this species. *Abies* pollen percentages from the bog correlate well with measures of the fir trees in this area with the exception of relative frequency. Juniper pollen somewhat over-represents relative cover and relative density of this genus in this area, but approximates the value of relative frequency.

The pine, oak, and Douglas fir pollen found in the Subalpine Spruce-Fir Study Area sediments represent species which were not found in this vegetational type. This pollen has been transported to the area by up-canyon winds from stands of these trees over a mile down the Rio en Medio Canyon.

The aspens, making up a considerable portion of the vegetation in this area, are not represented in either the sedimentary pollen or pollen rain. This lack of representation is not considered to be significant for reasons already mentioned.

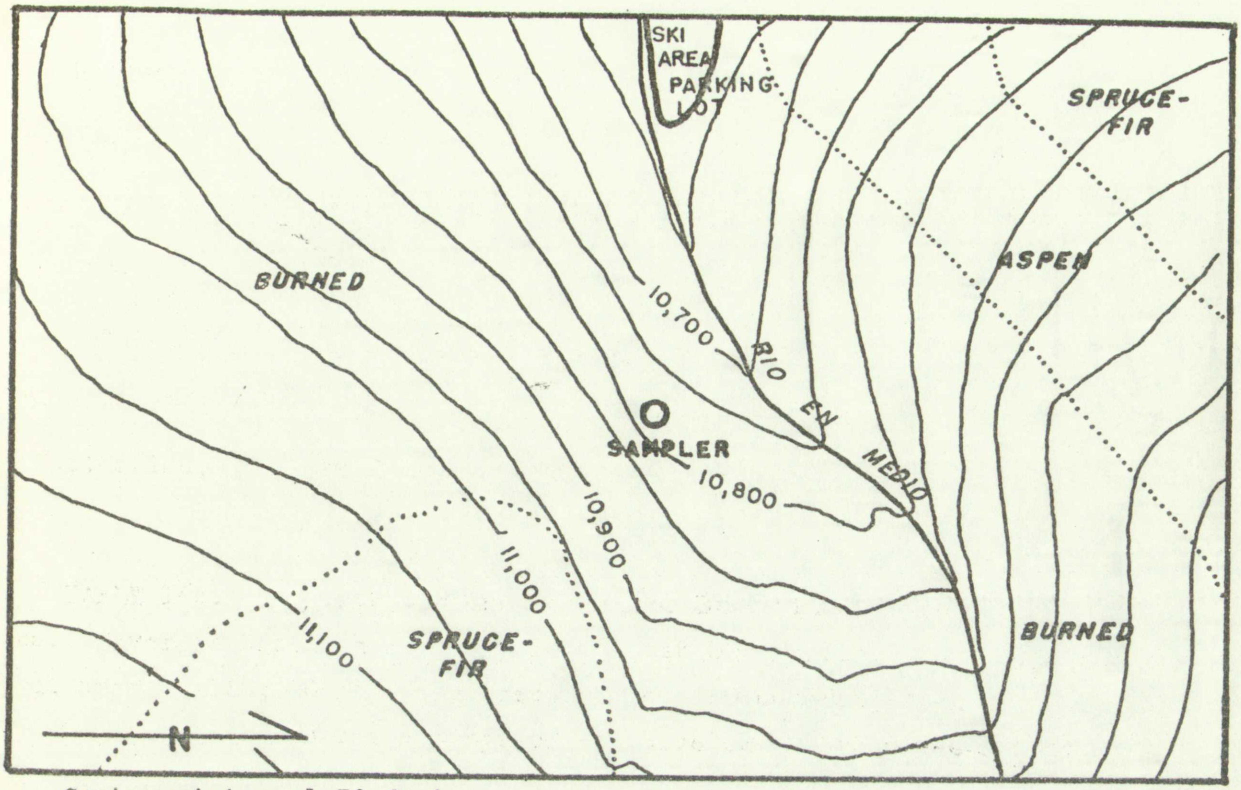
The sedimentary pollen percentages of spruce and fir closely approximate the values of relative cover for these species in the area. The results obtained from the studies conducted in this area will be combined and discussed with the results from the following study area in regard to establishing quantitative and qualitative relationships between pollen and vegetation in the spruce-fir type.

Burned Subalpine Spruce-Fir

The Burned Subalpine Spruce-Fir Study Area pollen sampler was located on the north slope above the Rio en Medio at the spring which supplies water to the Santa Fe Ski Basin 1800 ft to the west. This location, in the NE$\frac{1}{4}$, Sec. 17, T18N, R11E, is 10.91 miles on a bearing of 49° 10' from the Santa Fe Post Office at an elevation of 10,780 ft (Fig. 14).

This area, burned in the 1880's, is vegetated with scattered Engelmann spruce and corkbark fir with a dense shrub understory of _Salix planifolia_ var. _monica_ Schn., _Ribes montigenum_ McClatchie, _Ribes viscosissimum_ Pursh, and _Sambucus racemosa_ L. (Fig. 15).

The ground in the vicinity of the sampler site is boggy and the soil is richly organic and supports such plants as _Cardamine cordifolia_ Gray, _Sedum_ spp., _Carex_ spp., _Pyrola_ sp., _Caltha leptosepala_ DC, _Aquilegia caerulea_ James, _Mertensia fransiscana_ Heller, and _Mimulus gutattus_ DC. On the slope above the boggy area the soil is drier and more mineral and the ground cover is dominated by _Vaccinium oreophilum_ Rydb.



Contour interval 50 feet 1 inch equals 500 feet

Fig. 14. The Burned Subalpine Spruce-Fir Study Area showing principal drainages, topography, and vegetational types.

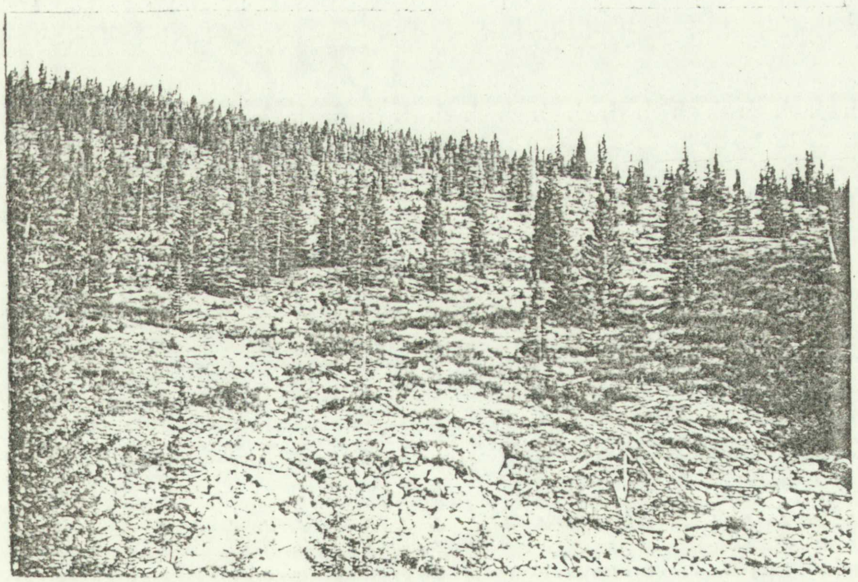


Fig. 15. The Burned Subalpine Spruce-Fir Study Area. View toward sampler across the Rio en Medio Canyon.

Restocking of the burned area has been slow, but seedling spruce trees are abundant throughout this area. The invasion of the north slope of the canyon by aspen is apparently prevented by a combination of altitude and exposure.

The phytosociological studies of this area were conducted in August of 1961. Analyses of the results of these studies are presented by strata in Tables 16a, 16b, and 16c.

TABLE 16a. Tree stratum in the Burned Subalpine Spruce-Fir Study Area. Cover is based on interception of ten 800-ft lines, density and basal area on 160,000 ft^2, and frequency on 160 quadrats 20 X 50 ft. Importance percent is the average of relative cover, relative density, and relative frequency.

Species	Cover		Density		Frequency		Basal Area		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Basal area ft^2/acre	Rel. basal area %	Importance %
Picea engelmanni	5.2	56.8	20.2	37.6	33.2	68.9	20.5	75.0	54.4
Populus tremuloides	3.3	36.5	31.6	58.9	22.1	10.6	5.0	18.3	39.2
Abies lasiocarpa	0.4	4.4	1.4	2.5	3.1	6.5	1.6	5.8	3.5
Pinus flexilis	0.2	2.3	0.5	1.0	1.2	2.6	0.2	0.9	2.0
Total	9.1		53.7				27.3		

TABLE 16b. Shrub and sapling stratum in the Burned Subalpine Spruce-Fir Study Area. Determinations as in Table 16a.

Species	Cover		Density		Frequency		
	Ground cover %	Rel. fol. cover %	Density /acre	Rel. density %	Freq. index %	Rel. freq. %	Importance %
Salix planifolia	9.8	54.1	1819.0	54.9	36.8	12,9	40.6
Populus tremuloides	3.3	18.1	147.8	4.5	13.1	4.6	9.1
Juniperus communis	1.5	8.2	201.0	6.1	31.3	10.9	8.4
Picea engelmanni	1.3	7.4	294.8	8.9	77.5	27.1	14.4
Ribes montigenum	0.7	4.3	335.0	10.0	38.1	13.3	9.3
Ribes viscosissimum	0.6	3.1	183.2	5.5	23.1	8.1	5.6
Veratrum californicum	0.2	1.0	131.8	4.0	16.9	5.9	3.6
Jamesia americana	0.2	1.2	17.7	0.5	1.9	0.7	0.8
Actaea arguta	0.1	0.8	22.7	0.7	6.3	2.2	0.9
Lonicera involucrata	0.1	0.7	60.3	1.8	21.3	7.4	3.3
Salix bebbiana	0.1	0.4	44.3	1.3	7.5	2.6	1.4
Sambucus racemosa	0.1	0.2	58.5	1.8	8.1	3.3	1.8
Abies lasiocarpa	0.0	0.0	0.8	0.1	1.9	0.7	0.3
Swertia radiata	0.0	0.0	1.1	0.1	1.2	0.4	0.2
Total	18.0		3318.0				

TABLE 16c. Herb and seedling stratum in the Burned Subalpine Spruce-Fir Study Area. Cover and frequency are based on 160 one-foot^2 quadrats.

Species	Cover		Frequency	
	Ground cover %	Rel. foliage cover * %	Freq. index %	Rel. freq. %
Vaccinium oreophilus	12.6	25.0	39.3	13.0
Salix planifolia	5.8	11.5	10.3	3.5
Epilobium angustifolium	5.3	10.3	31.8	10.5
Picea engelmanni	3.1	6.2	10.0	3.3
Achillea lanulosa	2.2	4.4	24.3	8.1
Fragaria ovalis	2.0	4.0	23.1	7.7
Solidago scopulorum	1.7	3.4	14.4	4.8
Caltha leptosepala	1.6	3.2	6.9	2.3
Antennaria ap.	1.1	2.2	5.6	1.9
Vicia americana	1.0	2.0	12.5	4.1
Thermopsis pinetorum	1.0	1.9	10.0	3.3
Erigeron macranthus	1.0	1.9	9.4	3.1
Artemisia franserioides	1.0	1.9	8.8	2.9
Poa pratensis	0.9	1.8	5.6	1.9
Juniperus communis	0.9	1.7	2.5	0.8
Carex spp.	0.7	1.4	6.9	2.3
Cardamine cordifolia	0.7	1.4	3.8	1.2
Veratrum californicum	0.7	1.3	3.8	1.2
Ribes montigenum	0.6	1.2	1.2	0.4
Helenium hoopesii	0.5	1.0	2.5	0.8
Total	51.2			

* Species with less than 1% relative foliage cover include: Actaea arguta, Lonicera involucrata, Potentilla spp., Bromus frondosus, Smilacina spp., Senecio wootoni, Geranium spp., Mimulus guttatus, Prunella vulgaris, Aconitum columbianum, Campanula rotundifolia, Rubus spp., Epilobium adenocaulon, Draba aurea, Phleum pratensis, Misc. spp. unidentified.

Four different sediment samples were taken from the Burned Subalpine Spruce-Fir Study Area for the extraction of pollen. One sample was taken from an open metal tank which had been used in the ski basin water system but which has now been discarded. This tank has been undisturbed for several years and was alternately wet and dry during the two seasons that the studies were conducted in this area. Samples were taken from a moss polster on a rock in the small stream that runs next to this tank and from soil at the foot of a spruce tree 40 ft east of the tank. A second soil sample was taken from the valley bottom at the head of the ski basin parking lot. Analyses of the pollen extracted from these sediments and of the pollen rain are presented in Table 17.

It is difficult to make meaningful comparisons of the pollen from the soil sample taken from the valley bottom with the pollen from those samples taken on the hillside because the two sites are so far apart and differ so widely in the composition of the nearby species. Therefore no comparisons will be made between the valley bottom sediments and those on the hillside except to point out the differences in the pollen spectra from the two sites.

The pine in the pollen rain is much less than that in the sediments near the sampler site. This fact suggests that pine pollen is better preserved in these three sedimentary types than the pollen of other species. The pollen of juniper and of the grasses seems better preserved in the tank mud, even with alternate wet and dry conditions, than it was in the polster and soil samples.

In Table 18 the arboreal pollen from each of these sediments is compared with phytosociological measures of the vegetation which produces this arboreal pollen.

TABLE 17. Analyses of pollen extracted from four different sediments in the Burned Subalpine Spruce-Fir Study Area and of pollen from the pollen rain. All pollen has been treated with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach.

Taxon	Pollen Sources									
	Mud from metal tank		Polster near sampler		Soil near sampler		Soil from bottom of valley		Current pollen rain	
	Count	%	Count	%	Count	%	Count	%	Count	%
Pinus	61	45.8	96	59.3	49	43.1	66	54.6	46	27.4
Picea	15	11.3	25	11.4	31	27.2	20	16.5	55	32.7
Salix	19	14.3	8	4.9	16	14.1	3	2.5	32	19.0
Juniperus	32	23.8	9	5.6	12	10.5	28	23.1	16	9.5
Abies	5	3.8	18	11.1	5	4.4	3	2.5	16	9.5
Pseudotsuga	1	0.8	5	3.1	0	0.0	0	0.0	3	1.8
Alnus	0	0.0	1	0.6	1	0.9	0	0.0	0	0.0
Populus	0	0.0	0	0.0	0	0.0	0	0.8	0	0.0
Total arboreal	133		162		114		121		168	
Chenopods	34	37.3	20	32.8	44	41.5	20	20.7	16	27.2
Gramineae	26	28.6	8	13.1	15	14.2	41	42.3	13	22.0
Compositae	11	12.1	20	32.8	22	20.7	31	32.0	6	10.2
Artemisia	3	3.3	1	1.6	12	10.3	2	2.1	3	5.1
Ranunculaceae	5	5.5	3	4.9	1	1.0	0	0.0	6	10.2
Liliaceae	6	6.6	4	6.6	1	1.0	0	0.0	1	1.7
Ribes	1	1.1	1	1.6	3	2.8	1	1.0	4	6.8
Sambucus	2	2.2	1	1.6	2	1.8	0	0.0	1	1.7
Cardamine	0	0.0	0	0.0	1	1.0	0	0.0	4	6.8
Sedum	1	1.1	0	0.0	0	0.0	0	0.0	2	3.4
Ericaceae	0	0.0	0	0.0	1	1.0	0	0.0	1	1.7
Caryophyllaceae	0	0.0	0	0.0	1	1.0	1	1.0	0	0.0
Ephedra	1	1.1	2	3.3	0	0.0	0	0.0	0	0.0
Umbelliferae	0	0.0	1	1.6	1	1.0	0	0.0	0	0.0
Unidentified	1	1.1	0	0.0	2	1.8	1	1.0	2	3.4
Total non-arboreal	91		61		106		97		59	
Total pollen	224		223		220		208		227	

TABLE 18. Comparisons of the arboreal pollen extracted from four sediments in the Burned Subalpine Spruce-Fir Study Area with Phytosociological measures of the arboreal-pollen-producing vegetation.

Species	Pollen Sources				Phytosociological Measures		
	Tank mud sample %	Polster sample %	Soil sample near tank %	Valley soil sample %	Relative cover %	Relative density %	Relative freq. %
Pinus spp.	45.8	59.3	43.1	54.6	0.8	0.1	0.7
Picea sp.	11.3	11.4	27.2	16.5	25.9	12.5	48.5
Salix spp.	14.3	4.9	14.1	2.5	39.4	72.3	21.8
Juniperus sp	23.8	5.6	10.5	23.1	6.1	8.0	18.5
Abies spp.	3.8	11.1	4.4	2.5	1.6	0.1	2.6
Pseudotsuga	0.8	3.1	0.0	0.0	0.0	0.0	0.0
Alnus sp	0.0	0.6	0.9	0.0	0.0	0.0	0.0
Populus sp	0.0	0.0	0.0	0.8	26.3	7.1	7.8

The presence of Pseudotsuga and Alnus pollen in the sediments is important in that neither tree grows within a mile of the sampler site. Pollen from the only pine trees in the area, across the canyon from the sampler site, would not tend to be carried across the canyon to the sampler site by predominantly up- and down-canyon winds and it is believed that most of the sedimentary pine pollen originated distant from this area.

Long distance transport of the pollen of these genera implies similar transport into this area of the pollen of other groups common to lower elevations. One such group, thought to be present due to long distance transport, is the chenopod group.

The complexity of the composition of both the vegetation and of the sedimentary pollen in the Burned Subalpine Spruce-Fir Study Area prevents any consistent correlations of the pollen with the phytosociological measures of the vegetation. There is an increasing approximation of the relative cover and relative density of *Picea* as the percentages of this species in the arboreal pollen increases above 10%. Below a value of 10% for the spruce pollen it is felt that this tree and its associated vegetation are not in the immediate vicinity of the sediment site. This level of 10% is partially based on the low concentrations of spruce pollen found less than two miles away in the Western Yellow Pine and Aspen Study Areas. The spruce pollen made up less than 1% of the arboreal pollen in each of the sediments in these two areas.

Correction Factors

Since pollen percentages and phytosociological relationships of the arboreal species vary among the different vegetational types, no single factor can be derived for any species which, when multiplied by the pollen percentage, will give an estimate of phytosociological measures for that species in more than one vegetational type. Also, a different correction factor must be used to convert pollen percentage to each of the several phytosociological measures. Since the correction factors are good only in that type for which they have been determined, it is essential that the type be determined before applying the factors.

Relationships exist between the pollen of species found in the sediments of different vegetational types which allow the determination of the general type. The following is an outline for determining veg-

etational types derived from the arboreal pollen percentages of representative sediments. The proportions of the pollen chosen approximate those to be found in the centers of the vegetational zones. Transitions between zones must be assessed by the use of the pollen proportions with the additional use of the qualitative indicators to be discussed in the next section.

The vegetational type is pinyon-juniper if the pollen of Juniperus exceeds 20% and if the total of Abies, Picea, Salix, and Quercus is less than 4%.

If the pollen of Picea exceeds 10% of the arboreal pollen and that of Abies is 1/10 or more the concentration of Picea, the type is spruce-fir.

In pollen samples which are of neither pinyon-juniper nor spruce-fir derivation, if the percent of Pinus pollen divided by the percent of Quercus pollen is less than three, or if the percent of Pinus divided by the product of the percents of Abies and Pseudotsuga is more than seven, the vegetational type is western yellow pine (WYP if $\frac{P}{Q} =< 3$, or if $\frac{P}{A \times Ps} = > 7$). If $\frac{P}{Q}$ is more than 3, or if $\frac{P}{A \times Ps}$ is less than 7 the type is mixed conifer. Values beyond the extremes of the percents of pollen from the different sediments were used for the above determinations to minimize errors which could arise due to a lack of adequate sampling. The pollen of the ubiquitous Salix and Juniperus cannot be evaluated for similar determinations.

In the pinyon-juniper type the pollen percentages of the pine, juniper, and Douglas fir closely resemble the values for relative basal area of the trees in this zone. Therefore, no factors correlating pollen to this measure of the vegetation are necessary, and the results would indicate the presence of the pinyon-juniper type.

In the spruce-fir type the pollen cannot be shown to accurately reflect the phytosociological measures of the vegetation by the application of a single factor. The fact that a sediment can, by methods shown above, be recognized as having been deposited under conditions allowing for growth of subalpine spruce-fir is significant without resorting to complicated mathematics to determine exact relationships.

In the zones between the pinyon-juniper and the subalpine spruce-fir the relationships of the pollen to the vegetation vary widely. Table 19 shows the relationships of the percentages of the pollen of the more important indicator species to the relative cover and density of these species in the western yellow pine, mixed conifer, and aspen vegetational types. Relative frequency has not been considered in these comparisons.

In all areas the over-representation by the Pinus pollen of the relative density of this genus is twice the over-representation of the relative cover. In all areas Quercus pollen over-represents the relative cover by an average of four times and under-represents the density of this species by an average of two times. The relative cover of Pseudotsuga in all of the areas is under-represented to a greater degree than is the relative density. Representation of Abies by its pollen is highly variable in the different areas.

TABLE 19. Conversion of percentages of arboreal sedimentary pollen to phytosociological measures, using four indicator species in the western yellow pine, mixed conifer, and aspen vegetational types.

Vegetational Type	Species	Factors for converting pollen % to phytosociological measures	
		Cover	Density
Western Yellow Pine	Pinus	0.50	0.25
	Quercus	0.25	2.00
	Pseudotsuga	3.00	2.00
	Abies	6.00	9.00
Mixed Conifer	Pinus	0.50	0.25
	Quercus	0.20	2.00
	Pseudotsuga	9.00	6.00
	Abies	5.00	8.00
Aspen	Pinus	0.12	0.05
	Quercus	0.35	1.50
	Pseudotsuga	16.00	4.00
	Abies	1.00	0.10

Qualitative Indicators

Assemblages of pollen are often more indicative of particular plant associations and forest type than are numerical relationships of a few of the species present. Qualitative indicators can be of great aid in assessing the true nature of prehistoric vegetation of the types now found in the Sangre de Cristo Mountains of New Mexico.

Aspen, although making up a large percent of the vegetation present in the study areas, does not appear as pollen in most of the sediments from these areas. The aspen type is found occupying areas in the western yellow pine type upward through the mixed conifer zone high into the area usually

occupied by subalpine spruce-fir. These aspen stands, invading after fires, are of short duration and are replaced by coniferous forests in a relatively short time. The lack of aspen pollen in the sediments does not constitute a serious drawback in paleoecological reconstruction because aspen is not indicative of a single climax zone and the pollen of other species preserved in the profile may be used to indicate the existence of aspen.

The presence of the pollen of non-arboreal indicators can be of great value to the palynologist. The pollen of Shepherdia, a plant usually associated with aspens at lower elevations, can tell much about the nature of the forest when used in conjunction with the pollen of other species present. The presence of Symphoricarpos pollen would indicate the presence of soil conditions such as those found under mixed conifer type trees. The pollen of bog-growing species found in the subalpine spruce-fir zone would bear out the evidence of the arboreal pollen and tell much about the site at which the sediments were formed.

Chenopods, common to desert shrub and desert grassland associations, contribute a remarkably high and consistent proportion of the non-arboreal pollen in the sediments in all of the study areas from 7,000 ft to 11,000 ft. Their presence is due to long distance transport from southwest of the Sangre de Cristo Mountains and indicates regional rather than local aridity. The presence of this group in such constant proportions in the montane deposits may be the common denominator by which absolute concentrations of the pollen of other species in the pollen rain and in the sediments may be gauged.

Pollen Preservation

The pollen of only one important species in the Sangre de Cristo Mountains, that of aspen, is not preserved in the sediments. The pollen of all other important species is preserved to some degree. Comparisons of the pollen extracted from the sediments indicate that there was less variation between the different sediments in their ability to preserve pollen than had been expecred. Pseudotsuga pollen is an exception in that it is apparently better preserved in dry sediments than in wet ones.

Reagent Damage

All of the samples of the air-borne pollen rain from each area were combined and then divided into four aliquots. These aliquots were treated as follows: one was only stained and served as a control; the second was treated with acetolysis mixture; the third was treated with hydrofluoric acid and acetolysis mixture; and the fourth was treated with hydrofluoric acid, acetolysis mixture, $NaClO_3$ bleach, and was stained. The counts of the pollen in the aliquots from all of the study areas were added by the type of treatment to give four large counts of pollen, each of which had undergone a different treatment. The total counts and percentages of some of the more important pollen types are shown in Table 20.

The pollen in the control material was difficult to count because it was extremely diluted with debris and the exine detatils of the pollen grains were obscured by their protoplasmic contents. These factors made the chance of overlooking pollen grains a serious problem. Counts of the pollen in the aliquots which were acetolyzed only or which had been treated

with hydrofluoric acid and acetolyzed were more easily made because the debris was less abundant and the protoplasmic contents had been removed from the grains by the acetolysis making important recognition features more visible. The material remaining after the complete treatment was almost pure pollen and the counts were made rapidly with no grains overlooked.

TABLE 20. Comparison of the analyses of pollen from aliquots that have been treated in four different ways.

Taxon	Treatment							
	Stained (untreated)		Acetolyzed		Hydrofluoric acid and acetolyzed		Hydrofluoric acid, acetolyzed, and bleached	
	Count	%	Count	%	Count	%	Count	%
Pinus	648	55.5	616	51.2	642	53.9	577	50.9
Picea	116	9.9	144	12.0	130	10.9	145	12.8
Chenopods	93	8.0	83	6.9	122	10.2	107	9.4
Juniperus	96	8.2	120	10.0	94	7.9	90	7.9
Abies	75	6.4	81	6.7	56	4.7	72	6.3
Gramineae	77	6.6	74	6.1	79	6.6	71	6.3
Compositae	23	2.0	39	3.2	34	2.9	37	3.3
Artemisia	21	1.8	34	2.8	24	2.0	15	1.3
Pseudotsuga	18	1.5	13	1.1	11	0.9	20	1.8
Total	1167		1204		1192		1134	

There is no reduction in the number of pollen grains of any species due to the destructive effects of the reagents used. There is no increase, on the other hand, in the counts of the smaller grains due to the removal of obscuring detritus if analyses of all the preparations are carefully made.

SUMMARY

The study was made to determine relationships of recent sedimentary pollen with the vegetation that has produced this pollen. Six vegetational types (pinyon-juniper, western yellow pine, mixed conifer, aspen, subalpine spruce-fir, and burned subalpine spruce-fir) were studied and it was found that in only the pinyon-juniper did the pollen closely represent phyto-sociological measures of the vegetation.

Relationships of the pollen to the vegetation are not as precise in the other types and factors have to be applied which will adjust relative pollen concentrations to relative phytosociological measures. These factors differ for each type and before they can be employed the type must be established. The determination of vegetational type is based upon the relationships of the pollen of different indicator species found in each type.

Once the type has been ascertained factors can be applied which will correct over- and under-representation of the phytosociological measures of the vegetation by the pollen percents. For climatic interpretations these factors are unnecessary, however, since the type which has been determined indicates the prevailing climatic conditions.

The pinyon-juniper type can be recognized by high concentrations of _Juniperus_ pollen (over 20%) and low total concentrations of _Salix_, _Quercus_, _Abies_, and _Picea_ pollen in the sediments.

The subalpine spruce-fir type (including both burned and unburned) can be recognized by the presence of over 10% _Picea_ pollen in the sediments and a value of _Abies_ pollen equal to 1/10 or more the concentration of the _Picea_.

Western yellow pine is recognized if the percent of _Pinus_ pollen

divided by that of Quercus is less than three, or if the Pinus pollen percent divided by the product of the Abies and Pseudotsuga pollen percents is more than seven.

If the Pinus/Quercus value is more than three, or the Pinus/Abies x Pseudotsuga value is less than seven the vegetational type is mixed conifer.

The fact that the presence of aspen cannot be quantitatively assessed, due to the lack of the pollen of this species in the sediments, is of minor importance. Aspen, a post-fire-invader of all of the vegetational types above pinyon-juniper, is of temporary nature and the pollen of the other, more permanent species indicates the true climax vegetational type for that area.

Qualitative indicators are as important in determining vegetational types under which sediments were deposited as are quantitative indicators. Two qualitative indicators are Symphoricarpos, usually associated with the mixed conifer type, and Shepherdia, normally found growing close to aspens. The presence of such indicators allows accurate assessments of prehistoric vegetational types similar to those presently found in the Sangre de Cristo Mountains.

Pine pollen, being produced in abundance and transported for long distances, over-represents this genus in the sediments in all of the study areas above the pinyon-juniper type.

The pollen of Pseudotsuga under-represents this genus in areas where this tree is abundant, but due to occasional long distance transport over-represents this species in areas distant from stands of Pseudotsuga.

The spruce trees of higher altitudes do not produce large volumes of pollen. Consequently sediments short distances away from stands of spruce contain relatively low concentrations of Picea pollen.

The consistently high percentages of chenopod pollen in all of the areas indicates overall regional aridity and not conditions of local aridity.

Pollen analyses are made more quickly and easily when the organic and inorganic detritus has been removed by treatments with hydrofluoric acid, acetolysis mixture, and $NaClO_3$ bleach. Results from a controlled experiment made in conjunction with this study show that the pollen of the many different species is not adversely effected by various treatments using these harsh reagents.

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