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VEGETATION IN RELATION TO SLOPE EXPOSURE AND GEOLOGY IN THE ARBUCKLE MOUNTAINS

A DISSERTATION

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BY

H. L. HUTCHESON, Jr.

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VEGETATION IN RELATION TO SLOPE EXPOSURE AND

GEOLOGY IN THE ARBUCKLE MOUNTAINS

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H. L. H.

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CHAPTER I

INTRODUCTION

Vegetation types are commonly related to variations in soil type, and soil types are closely related to the material from which they are derived. Vegetation types are being used in mapping geologic structure since the improvement of aerial photography and the adoption of this photographic method by geologists (Cuyler, 1931). In the Wichita Mountains of Oklahoma, Buck (1964) and Crockett (1964) found correlations between vegetation, soil type, and geologic formations. Other authors have found a relationship between vegetation and geology (Hollick, 1899; Cuyler, 1931; Penfound, 1944; Forsberg, 1959), and between vegetation and soil type (Beals and Cope, 1964; Dwyer and Santelman, 1964).

On viewing aerial photographs of the Arbuckle Mountains, striking patterns of vegetation, apparently corresponding to the underlying geologic formations, are obvious. Many authors have remarked on these apparent correlations (Gage, 1908; Bruner, 1931; Hopkins, 1938, and 1942; Waterfall, 1948; Hall, 1952a and 1952b; Dale, 1956).

The Arbuckle Mountains are also characterized by variations in topography which appear to be correlated with the geologic formations. These topographic variations become another factor affecting the distribution of the plants. Next to climate, topography, with its influence on edaphic and atmospheric factors, probably plays the most important role in control of forest types in a given region (Potzger, 1935). Vegetation differences on adjoining north and south facing slopes may appear as striking alternations (Cottle, 1932; Potzger, 1935; Cooperrider, 1962) or as more subtle differences resulting from shifts in dominance of the species on different exposures (Braun, 1935; Cantlon, 1953).

The variations in vegetation on diverse slopes have been attributed to modifications of environmental factors associated with the different exposures (Turesson, 1914; Shreve, 1922 and 1927; Bates, 1923; Platt, 1951; Parker, 1952; Cantlon, 1953, among others). In general, it has been found that north-facing slopes differ from south-facing slopes in soil and air temperature, soil and atmospheric moisture, light intensity, and wind velocity.

The present investigation was conducted to study some of the apparent correlations between geologic formations and vegetation in the Arbuckle Mountains, and to what extent they are affected by topographic factors.

The Arbuckle Mountain area forms an exceptional outdoor laboratory for studying the effect of lithological and topographical features on the structure of vegetation. Although the region is referred to as "mountains" it is mountainous only in a structural sense. Topographically it is a low plateau of 860 square miles rising a few hundred feet above the surrounding prairie and sloping from an elevation of 1,350 feet on the west to 750 feet on the east. These mountains are located in the south-central part of Oklahoma in Murray, Carter, Pontotoc, and Johnston Counties, The region is drained by the Washita River which flows across it in a generally north to south direction. The name Arbuckle Mountains was derived from Fort Arbuckle, which was named for Brevit Brigadier General Matthew Arbuckle (Reeds, 1927).

The so called "western limb of the Arbuckles" (the portion from the Washita River westward) consists of a large truncated anticline of 150 square miles. This anticline is bounded on the north and south sides by the Sycamore limestone and the Woodford formation. The large central area of the anticline consists of the Arbuckle limestone group. The most distinct topographic features of this section are the East and West Timbered Hills composed of pre-Cambrian porphyritic rock and rising 400 feet above the rest of the anticline. Portions of this western limb are extensively used as recreational areas. Several church and civic camps as well as commercial attractions are located near the numerous streams, springs, and waterfalls.

The geology of the Arbuckles is well known (Taff,1903, 1904; Reeds, 1910, 1927; Morgan, 1924; Cooper, 1926; Decker and Merritt, 1928; Decker, 1939; Ham, 1955). Sedimentation began in the Cambrian and continued through the Mississippian. The sediments remained relatively undisturbed until the uplifting of the Hunton Arch and the Arbuckle Anticline during the Pennsylvanian. Subsequent erosion continued until the area was inundated in the early Cretaceous. A late Cretaceous uplift occurred which initiated erosion again. The present topographic features of the area are a result of erosion since the removal of the Cretaceous deposits.

United States Weather Bureau records for Sulphur and Ardmore (Sulphur being the closest station to the northern flank and Ardmore the closest station with a long term record to the southern flank) show annual mean temperatures of 63.0 and 64.2 degrees Fahrenheit respectively. August is the warmest month with a mean temperature of 83.3 (Sulphur) and 84.29 (Ardmore).

The winters are usually mild and short in duration, while the summers are long and generally hot with the maximum temperatures often above 100 degrees between June and September. Extreme temperatures recorded have been 115 degrees and -15 degrees. The annual frost-free season is 218 days and lasts from about March 29 to November 2 (U.S.D.A. yearbook 1941).

The average annual precipitation is 38.40 inches for Sulphur and 37.14 for Ardmore. Most of the precipitation occurs in April, May, and June. The summers of 1963 and 1964, when this study was conducted, were exceptionally dry. The 1963 total for Sulphur was 19.54 inches (18.86 inches below the average) and for Ardmore, 14.81 inches (22.33 inches below average). In 1964 the months of June and July were 5.75 inches and 5.12 inches below average for the two stations. This was the hottest and driest July in Oklahoma since 1954. A statewide series of showers during the last two weeks of August ended the drought, causing the wettest August in Oklahoma since 1917. The August total was 4.75 inches (2.23 inches above the average) for Sulphur and 4.98 inches (2.21 inches above the average) for Ardmore. This still left both stations 2.91 inches below the average for the three summer months, which means that with the exception of one and one-half months this study was conducted during an extremely dry period.

Because of the extensive limestones similar in properties to those of the Edwards Plateau of south-central Texas and the bald knob areas of southwestern Missouri, the vegetation of the Arbuckles is remarkably similar to these two areas even though they are widely separated. Palmer (1934), Hopkins (1938), (1942), Hall (1952b), and Dale (1956) have discussed these floristic affinities.

Bruner (1931) considers the Arbuckle Mountains to be located within the Oak-Hickory savannah, between the deciduous forest formation and the true prairie association. According to Bruner, "Climatically the area should be dominated by grasses, but the open porous soil permits the growth of trees, and in places, turns the balance decidedly in their favor." Hall and Carr (1964) state that

> in the ecotone between oak-woodland and prairie in southern Oklahoma, limestones weather into dark soils with a high colloidal content, good soil moisture retention, but high hygroscopic coefficients. These soils support prairie vegetation. On the other hand the sandstones weather into light soils with poorly developed colloidal fractions, low water retention, but low hygroscopic coefficients. These sandy soils do not hold water against the vegetation and consequently black-jack, post-oak forest develops readily.

CHAPTER II

THE STUDY AREAS

Two geologic formations were selected for this study, the Sycamore limestone and the Woodford formation. These two formations form opposing slopes of the row of hills on the outermost flanks of the Arbuckle anticline (Fig. 1). On the southern flank of the mountains the Sycamore presents a southern exposure, while on the northern flank it presents a northern or northeastern exposure (Fig. 2). The reverse is true for the Woodford formation, thus presenting a natural, controlled situation for the comparison of exposure and geology.

The Sycamore formation is a lenticular mass of siliceous limestone of lower Mississippian age, varying from a distinct slate-blue color to a dirty bluish-brown on fresh fracture. On weathering this color changes to a characteristic light brownish-yellow hue, due to the presence of small amounts of iron. This limestone has a high concentration of SiO_2 (39.03 to 40.85%), compared to a CaO concentration of 20.09 to 28.92% (Cooper, 1926). This is considered highly siliceous for limestone. Cooper gives the general composition of the Sycamore as:

Sand	12.6%
Shale	30.7%
Limestone	54.4%
Iron oxides	1.2%

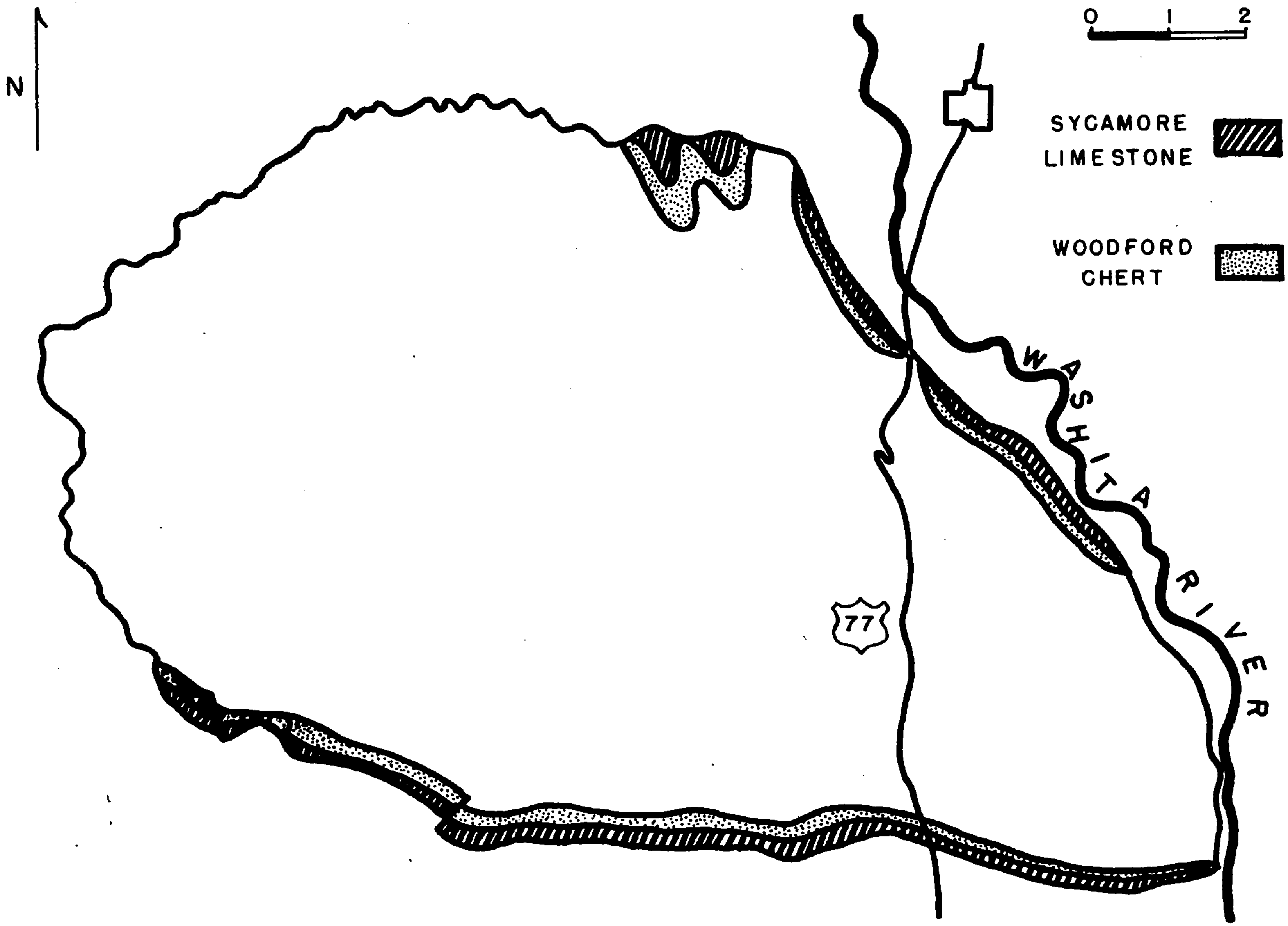

Figure 1. Diagram of Western Limb of the Arbuckle Mountains showing Location of the Sycamore Limestone and Woodford Chert.

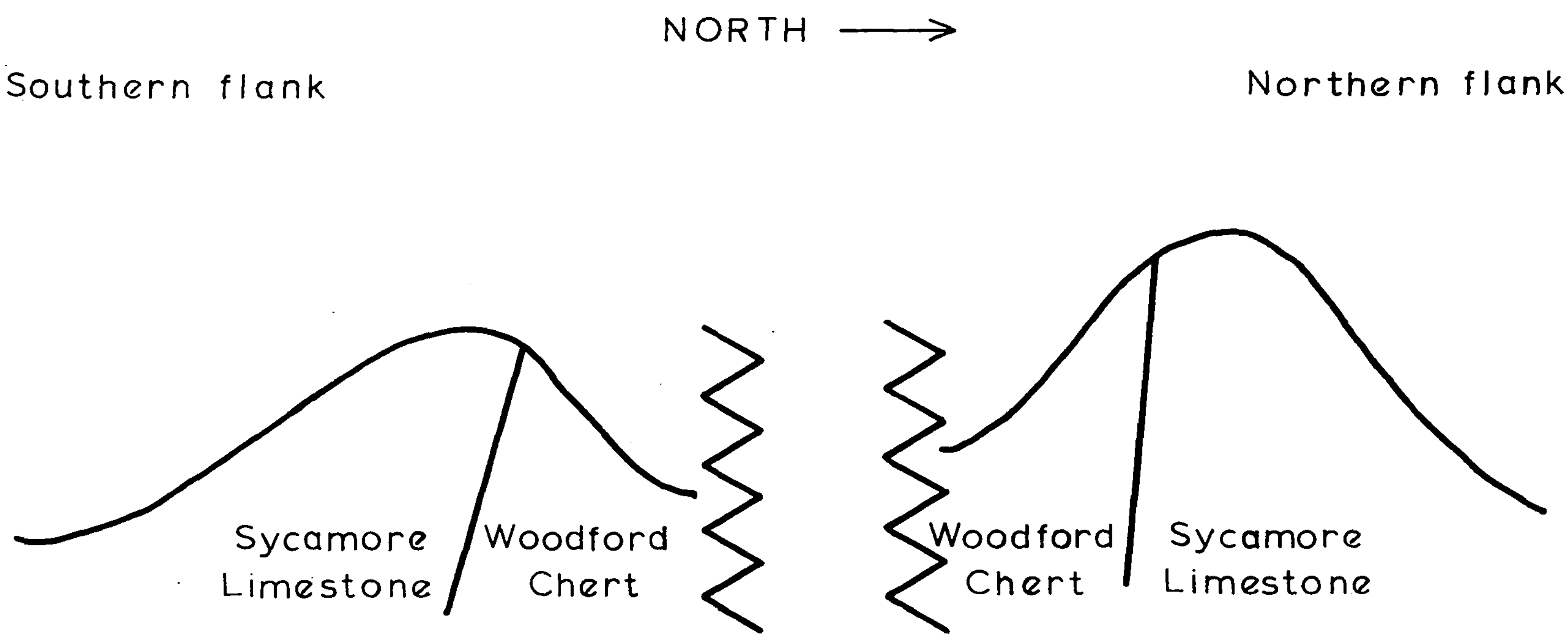

Figure 2. Cross-sectional view showing relationships of the Sycamore limestone and the Woodford chert on the two flanks of the Arbuckle Mountains. Vertical scale slightly exaggerated.

The Woodford formation is described by Morgan (1924) as consisting of brown and black slate and shale, and by Ham (1955) as consisting of dark colored fissile shale, siliceous shale and bedded chert. This formation is commonly called "Woodford Chert", and will be referred to as such in this study. It is distinctly marine in lithologic character and is considered to be upper Devonian to lower Mississippian in age. It is important to note that there is no break of any magnitude between the Woodford and the Sycamore. Deposition was apparently continuous between the two.

Aerial photographs, geological maps, and actual reconnaissance were used to select hills consisting of the two formations for sampling. Sites were selected on the basis of the distinctness of the geologic formations and relative freedom from disturbance. These criteria eliminated many parts of the formations, particularly along the southern flank, where considerable clearing and herbicidal spraying has occurred. The northern flank has excaped much of this treatment, being unsuitable for grazing. In many parts of the northern flank, erosion and faulting have disrupted the slope exposure relationships. Some trees had been cut on the southern flank, but the areas studied had apparently never been cleared. The present vegetation in the areas sampled resembles the description and photographs of Reeds (1927) and the limited description of Gage (1908). Aerial photographs taken in 1939 and 1949 show little change except a possible increase in woody plants and in the grassland areas.

CHAPTER III

METHODS

Sampling of the vegetation indicated that the differences in these sites were probably due to the availability of moisture, since the vegetation appeared to differ in relative xericity. To determine if these differences were caused by the geologic formations it was decided to determine the soil texture which would be the edaphic factor most affecting the soil moisture. To determine if these differences were due to slope exposure, it was decided to measure the rates of evaporation, since this would be the aerial factor most affecting soil moisture. It was also decided to determine the soil moisture itself and the soil reaction.

Vegetational Analysis

A modification of the point-centered quarter method of vegetation analysis (Cottam and Curtis, 1956) was used in this study to determine the relative density of the vegetation. The apparatus used consisted of an upright steel rod with cross bars protruding at right angles dividing an imaginary circle into quarters. The rod was pushed into the ground at predetermined intervals, and the species nearest the point in each quarter was recorded. Points were established at intervals of twenty yards along pace transects. Twenty-five points were sampled along each transect. A minimum of five transects was taken in each habitat. Ten transects were taken on the north-facing limestone and fifteen were taken on the south-facing limestone. The larger number of transects was taken on the limestone to cover vertical variations in the vegetation due to a horizontal banding in the rock strata.

At each point trees and saplings, shrubs and vines, and herbs were recorded separately giving a total of twelve plants at each point. A total of 875 points (10,500 plants) was recorded for the four habitats, from June 10 to August 20, 1963. In determining actual density the number of plants of each species, and the total number of individuals, were tallied for each sample. Relative density was determined by dividing the number of individuals of each species by the total number of individuals. This proved to be a rapid and effective method of sampling a large area. In addition to density, the per cent aerial cover was estimated for herbaceous plants at each point using a one square foot plot delimited by the four arms of the point-center frame.

Soil Analysis

Soil samples were taken along alternating transects at intervals of forty yards, six samples being collected along each transect. Six transects were studied in each habitat with the exception of the south-facing limestone, where nine transects were taken due to the greater number of vertical variations in rock strata. A total of 162 samples was collected from the four habitats.

Samples were collected at the three to six inch depth. Deeper samples proved impractical due to the relatively low percentage of soil and high percentage of rock below six inches. This rocky nature of the soil prevented the use of an auger to obtain the samples. The collection technique consisted of digging a two foot long trench exposing a profile of the upper nine inches of soil. The three to six inch horizon was delimited and the soil was removed from between the rocks with a hand trowel.

The soil texture (per cent sand, silt, and clay) was determined for each sample using the method outlined by Bouyoucos (1936). The soil reaction (pH) of each sample was determined electrometrically. Ten grams of soil, based on ovendry condition, were mixed with 50 grams of aerated distilled water. This suspension was tested on a standardized pH meter, and the soil reaction (hydrogen ion concentration) was averaged for each habitat.

Soil moisture was determined using electrical resistance gypsum blocks described by Bouyoucos and Mick (1940) and by Shearer (1963). Two transects (three on the south-facing limestone) were selected for each habitat. Six blocks were located along each transect at forty yard intervals. The cylindrical gypsum blocks, one inch in length, and with 24-inch electrical leads, were buried at a depth of six inches. Readings were taken at weekly intervals from June 30 to September 30 using a Delmhorst model KS meter. The sequence of readings was varied to avoid bias from time of sampling. This method of measuring moisture tension provides a measure of the availability of water to plants rather than the moisture content of the soil. It is therefore applicable across a wide range of soil textures without correction. This method has the advantage of allowing a large number of soil moisture determinations to be made. A total of 756 determinations was made during this study.

Evaporation Measurements

Evaporation was measured with four Livingston porous clay cup atmometers at a height of three feet on each slope except the south-facing limestone. On this slope eight atmometers were used, four in open grasslands and four in wooded areas. Readings were taken weekly from June 30 to September 30, with the sequence varied each week. Two rain gages were maintained during the summer of 1964, one on the north flank of the mountains and one on the south flank.

CHAPTER IV

RESULTS AND DISCUSSION

Evaporation

The highest average rate of evaporation (more than 399 ml. per week) was recorded from the open grassland near the top of the south-facing limestone (Table I). Since the reservoir of water in some of the atmometers was exhausted on three occasions, the actual rate of evaporation at this level was higher than the figures given in the table. The second highest average rate (385.7 ml. per week) was in the grassland lower on the same slope. The wooded areas at the bottom and middle of the same slope had averages of 298.8 and 287.2 ml, respectively. The average rate of evaporation for all areas of this slope was more than 342.7 ml. per week. The prevailing southerly winds strike this slope with all of their force. At almost all times during the summer a strong hot wind was noticeable moving up this slope. These winds, together with the greater insolation on this slope would increase evaporation from the soil as well as transpiration from the plants. Cottle (1932) found evaporation on the north slope to be only 56-76 % as great as on the south slope in Texas. Gail (1921) found evaporation to be 50% greater on south slopes in Idaho.

The south-facing chert had a much lower rate of evaporation than did the south-facing limestone. This was probably due to its position on the north flank of the mountains, where high terrain to the south would have deflected much of the wind.

TABLE 1

EVAPORATION IN MILLILITERS PER WEEK. EACH FIGURE REPRESENTS THE AVERAGE FROM TWO ATMOMETERS.

south flank			limestone		chert		North →	chert	limestone	north flank
	Bot.[a]	Mid.[b]	Mid.	Top[b]	Top	Bot.	Bot.	Top	Top	Bot.
June 30	254.6	346.4	272.6	368.6	250.2	290.3	195.3	282.7	348.3	219.5
July 7	382.1	423.5	364.6	498.7	334.4	298.2	336.8	366.8	314.1	290.8
15	500.1	584.2	450.4	598.2	368.6	365.8	409.1	693.4	410.3	351.7
21	438.1	561.3	413.7	604.7+	300.1	366.4	381.9	411.8	423.1	338.2
28	433.8	682.8	296.4	604.0+	346.7	373.2	410.6	444.6	448.6	379.8
Aug. 4	416.2	498.6	378.7	525.6	288.7	379.1	347.7	383.7	368.4	325.5
11	517.1	641.1	453.8	656.1+	389.1	462.0	376.5	422.7	400.2	319.8
17	183.7	266.7	235.9	267.2	227.5	236.0	212.5	229.3	257.7	174.9
24	182.3	275.4	232.4	279.7	144.3	168.1	189.4	185.2	244.4	149.1
30	130.2	216.8	185.9	270.1	116.4	126.2	150.1	154.4	153.9	134.1
Sept. 7	305.0	303.7	278.9	371.1	197.1	227.8	282.2	269.1	288.9	232.4
15	306.6	324.4	254.3	383.9	283.8	261.5	249.4	256.2	270.9	221.5
20	56.2	82.6	73.1	51.3	48.7	50.7	51.9	54.1	49.1	46.8
29	75.8	191.8	130.1	107.9	125.1	150.5	87.7	87.3	131.1	98.1
Avg.	298.8	385.7	287.2	399.0+	244.3	268.3	262.9	303.0	293.5	234.4

a. Bot. - bottom Mid. - mid-slope b. In open grasslands

The north-facing chert and limestone had average rates of 256.3 and 264.0 ml. respectively. These rates were only 75 to 93% of those on the south-facing slopes. The greater rate on the limestone could be due to its exposed position along the northern flank of the mountains where it might receive more air current. Cantlon (1953) reported a tendency for daytime wind direction to be up-slope on both north and south facing slopes in New Jersey, due to eddy currents on the lee side.

On all slopes except the north-facing chert, evaporation was greater near the top than near the bottom.

Soil Texture

The soil on both geologic formations was very stony. The soil formed a relatively shallow layer over the Sycamore limestone. The rock under the surface was massive, with the soil restricted to cracks or pockets. The Woodford chert was characterized by a mixture of soil and small rocks extending to a greater depth than the soil on the limestone.

The soil texture was similar on both geologic formations with the limestone being slightly more sandy (Table 2). The average per cent of sand was 48.5 for the limestone and 45.5 for the chert. The soil would be classified as a sandy clay loam on the limestone and a clay loam on the chert. Of the four habitats, the south-facing limestone had the highest average per cent sand (48.9) while the north-facing chert had the lowest (42.5).

There were greater textural variations vertically on each slope than between the slopes and between formations. The limestone on both exposures had a higher percentage of sand at the top than at the bottom. The highest percentage on the chert was at the bottom. The reverse was true for the percentage of clay, the highest percentage being at the bottom on the

TABLE 2

TEXTURAL ANALYSIS OF THE SOILS

south flank	North →								north flank
	limestone			chert		chert		limestone	
	Bot.	Mid.	Top	Top	Bot.	Bot.	Top	Top	Bot.
% Sand	48.3[a]	42.0	56.3	40.2	44.9	53.6	43.4	54.7	41.7
% Silt	19.6	28.9	22.5	25.6	25.0	14.5	24.3	17.6	20.0
% Clay	32.2	32.4	22.7	34.6	30.1	32.0	32.3	27.9	37.8
Soil Class[b]	SCL	CL	SCL	CL	CL	SCL	CL	SCL	CL

aAll figures represent an average of eighteen samples

bCL - clay loam, SCL - sandy clay loam

limestone and at the top on the chert.

There were variations in soil texture on different hills and between samples on each hill. These variations were more common on the chert than on the limestone. This was probably due to contamination by limestone rocks from the top of the slope.

Soil Reaction

The soil reaction differed considerably between the habitats (Table 3). The average soil reaction of the south-facing limestone was 5.83. If samples from the bottom of the slope were excluded the average would be 6.15, which is much nearer the average of the north-facing limestone. The north-facing chert had an average reaction of 5.28 which was higher than the 4.62 average for the south-facing chert. The north-facing limestone was generally less acid at the bottom than at the top. The other habitats were more acidic at the bottom. The low pH values could possibly be attributed to a greater amount of acid forming organic matter in the upper soil layers where the samples were taken. The siliceous nature of the parent materials would also be a factor. Cain (1931), working in the Great Smoky Mountains, found that soils on mountain slopes generally increase in acidity upward because of the vertical increase in organic content and in leaching intensity. In general the hills sampled in the present study showed more acidity near the bottom. This could be correlated with an increase in organic matter toward the bottom of the slopes.

The soil pH appeared to be determined largely by the parent material although there were variations with different exposures. These variations could be due to differences in the organic content of the soil caused by the vegetation.

TABLE 3

AVERAGE VALUES OF SOIL REACTION
ON THE SIX HILLS SAMPLED

	south flank			North →					north flank
	limestone			chert		chert		limestone	
	Bot.	Mid.	Top	Top	Bot.	Bot.	Top	Top	Bot.
Average for habitat	5.54[a]	6.09	6.22	5.64	5.08	4.37	5.21	6.24	6.35
Average for Hill I	5.43[b]	6.35	5.93	5.85	4.92	4.16	4.90	5.71	6.55
Average for Hill 3	5.63	5.89	6.38	5.36	5.19	4.40	5.25	6.84	6.22
Average for Hill 5	5.53	6.18	6.65	5.99	5.18	4.75	6.37	5.85	6.33

Soil Moisture

The soil moisture results are presented in Table 4. The data are presented as Delmhorst meter readings rather than as bars tension, so that the more subtle differences between habitats will be evident. These readings can be converted to moisture tension using Table 5. An indication of the approximate percentage of water at a given meter reading will vary with different soils. Readings below five (15 bars tension) indicate unavailable water.

With the exception of the north-facing sycamore limestone, the average readings remained below five until the week of August 17. During this week 2.50 inches of rain were recorded, and the readings increased several hundred-fold. Despite an additional 2.50 inches of rain in the following four week period, the readings had dropped below five by September 15. The following week (September 20) 3.0 inches of rain fell, causing an increase in the readings which continued until the end of the study, one week later on September 29.

The south-facing limestone (which had the most xeric vegetation) had an average reading for the three months of 59.9 which was the highest average of the four slopes. The south-facing chert had an average reading of 43.8, which was the lowest reading of the four slopes. The two north-facing slopes had readings of 55.1 and 57.2 for the chert and limestone respectively. Cottle (1932) reported 5 to 16% less soil moisture on south-facing slopes than on north-facing slopes in Texas. Gail (1921) and Parker (1952) both reported that the soil on south-facing slopes in Idaho was below the wilting coefficient for longer periods.

The period of this study was characterized by extremes, there was a severe deficiency for the first month and a half, and an abundance the second half. When the moisture readings are averaged separately for the

TABLE 4

SOIL MOISTURE AVERAGES EXPRESSED IN DELMHORST METER READINGS

	south flank limestone			chert		North →	chert	north flank limestone		
	Bot.	Mid.	Top	Top	Bot.	Bot.	Top	Top	Bot.	Rainfall in inches
June 30	3.4[a]	4.5	3.3	9.3	4.3	4.0	4.2	10.7	11.5	
July 7	1.0	.8	.7	4.3	2.0	2.7	3.3	4.5	6.8	
14	.2	.7	0	.8	1.3	2.3	2.3	3.8	5.5	
21	.5	.7	0	.7	.5	2.2	3.0	4.3	3.5	
28	.8	.3	0	.5	.5	1.2	2.3	3.5	4.8	
Aug. 4	1.0	1.5	.7	1.8	1.3	2.0	2.0	4.8	5.7	.42
11	.2	.7	0	.5	.3	1.8	1.8	3.0	3.5	
17	170.8	170.7	144.5	174.2	168.3	163.8	152.6	183.2	159.0	2.50
24	175.2	178.8	149.7	170.7	149.0	112.3	80.5	175.2	127.8	1.87
30	136.0	162.8	127.0	95.2	46.2	19.7	15.3	103.7	45.3	.63
Sept. 7	12.5	13.0	15.3	7.5	1.7	2.3	2.3	8.0	18.0	
15	.6	2.2	1.0	2.2	1.5	3.8	3.7	3.8	4.7	.03
20	168.8	172.4	149.0	169.2	163.0	152.8	126.8	179.2	148.2	3.00
29	176.8	182.0	183.3	180.0	181.8	181.2	173.6	183.8	179.2	2.95
Average	60.6	63.7	55.3	58.4	51.6	46.6	41.0	62.3	51.7	11.40

a. Each figure represents an average of six readings

TABLE 5

CONVERSIONS FOR DELMHORST MOISTURE METER, MODEL KS

Moisture Tension (bars)	Ohms	Meter Reading	Approx. H_2O in Soil (%)
.2	330	175	Field Capacity
.3	490	160	
.4	630	148	
.6	1000	125	
.8	1550	103	75
1.0	2000	87	
2.0	5700	44	50
4.0	16000	17	
6.0	25000	10	25
10.0	39000	6	
15.0	50000	5	Wilting Point

two moisture regimes, it can be seen that the different slopes exhibit different responses for low and high moisture conditions (Table 6). The south-facing limestone had the lowest readings during the dry period, but had the highest readings during the rainy period. The two limestone slopes

TABLE 6

SOIL MOISTURE AVERAGES FOR FIRST AND SECOND HALVES OF THE STUDY[a]

	south-facing limestone	north-facing chert	south-facing chert	north-facing limestone
Before Aug. 17	0.9	2.0	2.5	5.4
After Aug. 17	118.6	107.9	84.8	109.1

a. Expressed in Delmhorst meter readings

had higher average readings for the entire period than did the two chert slopes. The slightly sandier texture of the soils on the limestone could permit a somewhat faster rate of infiltration. More important would be the difference in depth of the two soils. The massive limestone should restrict the water to the upper areas, resulting in higher readings at the 6-9 inch level which was sampled. The large number of surface stones on the chert would tend to increase the soil moisture on these slopes. Lamb and Chapman (1943), found in New York, that a layer of surface stones decreased runoff and evaporation, resulting in a higher content of soil moisture. The soil surface on the limestone was not characterized by as many stones.

The soil moisture readings were higher near the top than near the bottom of the north-facing slopes but higher near the bottom of the south-facing slopes (Table 4). This corresponds inversely to the rates of evaporation (Table 1). The <u>rate</u> of transpiration would be related to the rate of evaporation, and would be greater on the south-facing slopes, but the amount of water transpired would be related to the leaf area which would be greater on the north-facing slopes. This could be an important factor in reducing the soil moisture when the tension was below fifteen bars. Shear and Stewart (1934) found that in Illinois, white oak removed more water from the first four feet of soil than did green ash or silver maple. This could be an explanation for the much lower readings on the south-facing chert, since oaks formed 85% of the trees on this slope.

The differences in soil moisture at the nine inch level appear to be the result of a complex interaction of several factors, the most important being depth of soil, rate of evaporation, and vegetative cover. There appeared to be a tendency for the south-facing slopes to drop below the wilting coefficient before the north-facing slopes, but no positive evidence of this was found. Since severe wilting was not observed in the trees and shrubs, it must be concluded that there was a greater amount of water in the root zone than at the nine inch level, and that the relative amounts could also be different at greater depths. The greatest amount of wilting occurred on the two limestone slopes.

Vegetation

South-facing Sycamore Limestone

The upper portion of the south-facing slope was essentially a grassland with scattered or clonal shrubs and a few scattered trees (Fig. 3). *Prunus angustifolia*[1] was the most abundant shrub at the top of the slope, with a relative density of 29%, but was rare or absent at the lower levels. *Symphoricarpos orbiculatus* and *Smilax bona-nox* were also important here as well as at lower levels. *Rhus glabra* was abundant at the top but was rare or absent at the lower levels.

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1 Botanical nomenclature follows Waterfall (1962), except that varieties have not been designated.

Stipa leucotricha was the dominant grass at all levels except the bottom of this slope. There was an exceptionally high quantity of dead *Bromus japonicus*. Subsequent observations the following spring indicated that *B. japonicus* was the dominant species of the spring aspect.

The extremely dry conditions of the spring and summer of 1963 undoubtedly affected the herbaceous composition of these habitats. Few plants were observed flowering, and much die-back was observed in many of the plants. This probably accounts for the high relative density of *Stipa leucotricha* which appeared to be less susceptible to drought than other grasses. Because of the harmful effect of the drought, more significance should be placed on the woody species.

Celtis spp.[2] (41.0%) and *Ulmus alata* (38.6%) had the greatest relative density of the trees at the top of the slope although they were widely scattered. *Diospyros virginiana* (5.1%) was found near the top but not at lower levels. There was a greater number of saplings in proportion to trees at this level.

The middle of the slope was characterized by a horizontal outcrop of rocks supporting more woody vegetation than the areas immediately above and below it. Again *Celtis* spp. was the most abundant tree. *Fraxinus americana* and *Quercus stellata* were next in abundance, but showed considerable horizontal localization. *Symphoricarpos orbiculatus* constituted 75% of the shrubs at this level. *Sporobolus asper* was much more abundant here than at other levels. Below the wooded outcrop there was typically an area of

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2 The various species of *Celtis* were considered together as ecological equivalents. Apparent hybridization made it almost impossible to separate them in the field. Species which occur in the area are: *C. laevigata*, *C. occidentalis*, *C. tenuifolia*, and *C. reticulata*.

Figure 3. View showing part of southern flank of mountains. L-Sycamore limestone. C-Woodford chert. Light colored diagonal line is the location of a pipeline.

grassland although the degree of openness varied from hill to hill.

The bottom of the slope was characterized by a forested area on a somewhat deeper soil. The most abundant trees at this level were *Celtis* spp., *Quercus stellata*, and *Ulmus alata*. *Cornus drummondii* was an important part of the understory on the western-most hill sampled but was rare or absent on the other hills.

Herbs were sparse at this level, forming only 5% cover (as opposed to 12.4% for the rest of the slope). The average cover for the entire slope was 9.9%, which was the greatest cover in the four habitats. The greater amount of light penetration on this slope is probably responsible for this greater cover. The most abundant herbs here were *Elymus virginicus* and *Carex* sp.

This south-facing slope supported the most xeric vegetation of the four habitats. It was the only one studied with significant grassland areas. Because of the vertical variations, it would be difficult to consider the plants on this slope as a community. The dominant trees for the slope as a whole were hackberry (*Celtis* spp.), winged elm (*Ulmus alata*), and post oak (*Quercus stellata*), but these occurred only in bands or scattered in the grassland.

North-facing Woodford Chert

This habitat constitutes the opposite side of the hills from the south-facing limestone (Fig. 3). The vegetation was a closed forest with a dense understory of saplings. This vegetation was much more uniform than that of the south-facing limestone, and could be considered as a post oak-white ash community since *Quercus stellata* and *Fraxinus americanus* were the trees with the greatest relative density. This particular association of post oak and white ash has not been reported in Oklahoma before. White ash was not a dominant in any of the stands reported by Rice and Penfound (1959). Ulmus alata, Quercus velutina, and Q. muehlenbergii were of secondary importance, each comprising 10.3% of the total. There were many saplings of Ulmus alata, Fraxinus americana, and Celtis spp. The most abundant shrub in this habitat was Symphoricarpos orbiculatus. Herbs were sparse, forming a cover of only 5.2%. The most abundant herbs were Carex spp., with Aster sagittifolius and Galactea volubilis also important. Muhlenbergia sobolifera was the most abundant grass.

South-facing Woodford Chert

This habitat consists of the south side of the row of hills along the north flank of the mountains (Fig. 4). The slopes have many gullies indicating erosion of the relatively coarse, loose rock. The vegetation was a more open forest or woodland with few saplings and almost no shrubs or vines. Oaks formed 86% of the trees (Quercus stellata - 62.4%, Q. marilandica - 17.3%, and Q. velutina - 6.8%). Blackjack oak (Q. marilandica) tended to be more abundant on the lower parts of the slope. Juniperus virginiana was common in the area, but only as saplings. It was more abundant at the upper levels of the slope. This community would be considered a post oak-blackjack oak community. This community was discussed by Rice and Penfound (1959), and Dwyer and Santelmann (1964). It resembles the Post oak-Blackjack Forest Type of Duck and Fletcher (1943) which covers a large part of the state.

The most common shrubs in this habitat were Rhus aromatica and Rhus glabra. Shrubs were extremely rare here. In many instances no shrubs could be found within fifty feet of the point. Potzger (1935) states that the oak-hickory type of forest is usually quite devoid of shrubs.

The herbaceous layer of this community was dominated by Lespedeza

Figure 4. View showing part of northern flank of mountains. L-Sycamore limestone. C-Woodford chert.

virginica and Carex spp. The lespedeza was more abundant on the upper portions of the slope while the sedge was more abundant on the lower portions. Andropogon scoparius and Bouteloua hirsuta were the dominant grasses, with relative densities of 11.0 and 7.3 % respectively. Andropogon scoparius was only rarely observed on the lower parts of the slope. The per cent herbaceus cover was only 6.1. The understory vegetation was more abundant where the cover story canopy allowed some direct light penetration, and it is felt that the relatively high per cent cover was due to increased light penetration in this more open forest.

North-facing Sycamore Limestone

This was the steepest slope of the four studied, and was covered by a closed forest (Fig. 4). The most abundant tree was Quercus velutina (27.8%), with Fraxinus americana (16.1%) and Ulmus alata (14.6%) next in abundance. This would be classified as a black oak-white ash-winged elm community and would be another new association for the state. Quercus velutina and Fraxinus americana were more abundant on the upper slope whereas Ulmus alata was more abundant on the lower slope. Cornus drummondii was an important constituent of the understory, both at the top of the slope and at the bottom. Quercus shummardii was encountered on some hills but was absent on others. Symphoricarpos orbiculatus and Rhus glabra were the most common shrubs near the top of the slope. Rhus glabra was not abundant on the lower portions. Abundant vines in the habitat included Parthenocissus quinquefolia near the top, and Smilax bona-nox near the base. Galactea volubilis and Amphicarpa bracteata were abundant herbs at all levels. Carex spp. and Andropogon scoparius were more common at the upper levels than at the lower levels. The herbs on this slope formed a cover of 5.2% near the bottom and 4.3% near the top.

The brow of these hills, which was not sampled, consisted of a sparse grassland with cactus (*Opuntia* spp.) and many forbs. There were scattered junipers and mottes of *Prunus angustifolia*, with a few scattered deciduous trees also occurring here. In general this brow presented a much more xeric physiognomy than did the slopes on either side of the hills.

Comparison of the Four Communities

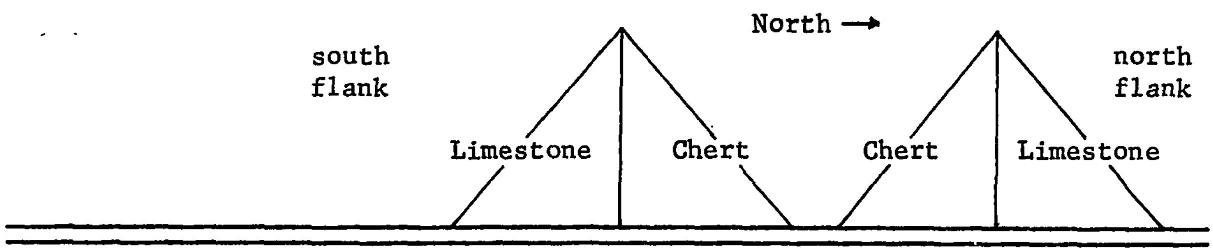
The two north-facing slopes were the most similar, both in physiognomy and floristic composition (Tables 7, 8, and 9). Six species were dominants in their respective communities. These six were: *Quercus stellata*, *Q. marilandica*, *Q. velutina*, *Fraxinus americana*, *Ulmus alata*, and *Celtis* spp. Four of these species (*Q. stellata*, *Q. marilandica*, *Q. velutina*, and *U. alata*) were listed as dominants in the oak-hickory savannah by Rice and Penfound (1959).

The dominance of hackberry (*Celtis* spp.) on the south-facing limestone makes this a unique vegetation type, although the vegetation was not uniform enough to be considered a community. The almost complete restriction of hackberry to the Sycamore limestone formation is in agreement with the findings of Beal and Cope (1964). They found *Celtis occidentalis* to be associated with poorly drained soil and with high calcium soil in Indiana. Buck (1964) found *C. reticulata* to be more important on poorly drained soils, and Cantlon (1953) found hackberry to be more important on south-facing slopes.

The dominance of white ash (*Fraxinus americana*) in two of the communities was also unique, since it did not rate mention in any of the communities of Rice and Penfound. Both of the communities in which it is a dominant are on north-facing slopes. Cantlon (1953) also found white ash to be more abundant on north-facing slopes in New Jersey. Beals and Cope (1964) and Elliott (1953) reported white ash to be associated with poorly drained soils,

TABLE 7

RELATIVE DENSITY OF TREE SPECIES
EXPRESSED AS PER CENT OF TOTAL



	Limestone	Chert	Chert	Limestone
Juniperus virginiana..........	.6			
Sapindus drummondii...........	1.1			
Diospyos virginiana	1.7			
Forestiera pubescens..........	2.1			
Carya illinoensis.............	3.2			
Crataegus spp.................	5.0			
Cercis canadensis.............	1.5	1.7		
Prunus mexicana...............	1.9	1.7		1.6
Celtis spp.	39.1	1.7		4.3
Quercus stellata	10.7	29.3	62.4	9.1
Ulmus alata	20.0	10.3	3.0	16.4
Fraxinus americana	7.3	27.6	6.0	17.1
Ulmus americana..............	1.0	1.7	.8	1.6
Quercus velutina		10.3	6.8	29.9
Carya cordiformis		1.7	3.8	5.9
Quercus muehlenbergii........		10.3		11.8
Bumelia lanuginosa	3.3			2.2
Quercus marilandica		1.7	17.8	

TABLE 8

RELATIVE DENSITY OF SHRUBS AND VINES
EXPRESSED AS PER CENT OF TOTAL

North →

south flank	Limestone	Chert	Chert	Limestone north flank
Prunus angustifolia	10.0			
Rosa foliosa	.1	6.0		.5
Vitis spp.	.3	1.0		9.3
Rhus radicans	4.3	.4	2.1	2.9
Parthenocissus quinquefolia	1.0	12.4	1.4	23.1
Rhus aromatica	1.0	1.4	36.3	5.8
Symphoricarpos orbiculatus	53.3	75.4	18.5	26.1
Smilax spp.	23.4	5.2	12.3	16.8
Rhus glabra	6.8		29.5	13.8
Celastrus scandens				1.0
Ceanothus americanus				.6

TABLE 9

RELATIVE DENSITY OF THE MORE IMPORTANT HERBACEOUS SPECIES EXPRESSED AS PER CENT OF TOTAL

North →

	south flank			north flank
	Limestone	chert	chert	Limestone
Aristida purpurascens	3.3			
Artemesia ludoviciana	4.9			
Stipa leucotricha	18.2			
Bromus japonicus	2.3	3.7		.3
Panicum scribnerianum	10.0	2.5		.1
Elymus virginicus	11.2	4.0		.3
Solidago delicatula		3.0		2.4
Croton spp.	.4	.7	.8	4.4
Solidago mollis	.1	1.8	2.7	7.1
Muhlenbergia soblifera	.3	15.5	1.0	1.6
Carex spp.	8.6	31.1	22.3	9.5
Aster sagittifolius	2.8	21.5	.8	11.1
Andropogon scoparius	5.6	.7	11.0	4.3
Galactia volubilis		8.8	6.6	15.7
Antennaria plantaginifolia		1.6	.2	2.4
Sporobulus asper	6.7	.5	4.2	
Lespedeza virginica	.2		22.8	1.2
Bouteloua hirsuta	5.3		7.3	.3
Bouteloua curtipendula	2.5			
Amphicarpa bracteata			1.5	18.0
Per cent cover	9.9	5.2	6.1	4.8

whereas Shanks (1953) found it to be limited to well drained soils. The results of this study indicate that differences in soil drainage had little effect on the importance of white ash, but that other factors associated with slope exposure were more important.

Three species of trees (Quercus stellata, Ulmus alata, and Fraxinus americana) were present in all four habitats and abundant in three of them. Quercus velutina and Q. meuhlenbergii were more abundant on the two north-facing slopes. Bumelia lanuginosa was recorded as a tree only on the Sycamore although saplings were present in all habitats. Buck (1964) also reported it to be more important on poorly drained soils.

Blackjack oak (Quercus marilandica) was found only on the well drained Woodford chert, and post oak (Q. stellata) was more abundant there (Table 7). This was the most pronounced correlation between plants and parent material of the study. Buck (1964) and Dwyer and Santelman (1964) reported that blackjack oak was more abundant on deeper or better drained soils.

Five trees did not appear to be reproducing well. Fraxinus americana, Quercus stellata, Q. marilandica, Q. muehlenbergii, and Q. velutina all had sapling:tree ratios below five. Of the five, post oak had the lowest ratio (1.4). On the north-facing chert, hackberry had a very high rate of reproduction, 59 saplings for each tree.

Symphoricarpos orbiculatus was the most ubiquitous of the shrubs and vines (Table 8). It occurred on all slopes, and in the grasslands as well as in the wooded areas. Smilax spp. were also significantly abundant in all four habitats. Prunus angustifolia was recorded only from the south-facing limestone. Parthenocissus quinquefolia was considerably more important on the north-facing slopes than on the south-facing slopes.

Carex sp. was the only herb significantly abundant in all four habitats (Table 9). Two plants, Solidago delicatula and Aster sagittifolius were either restricted to, or more important on the north-facing slopes. Two species, Sporobolus asper and Bouteloua hirsuta, were more important on the south-facing slopes. Cottle (1932) found B. hirsuta to be more abundant on south-facing slopes in Texas. Bouteloua curtipendula was found only on the limestone. It is interesting that each habitat had a dominant herb which was more or less restricted to that habitat - Stipa leucotricha on the south-facing limestone, Muhlenbergia sobolifera on the north-facing chert, Lespedeza virginica on the south-facing chert, and Amphicarpa bracteata on the north-facing limestone.

Many plants reported by Cantlon (1953) to be more important on the south-facing slopes, such as Quercus velutina, Vitis spp., Amphicarpa bracteata, Muhlenbergia sobolifera, and Solidago sp., were more important on the north-facing slopes here. On the other hand, Cottle (1932) reported Bouteloua curtipendula and Andropogon scoparius to be more abundant on the north-facing slopes in Texas, whereas they were more abundant here on the south-facing slopes. This illustrates rather markedly the climatic differences between New Jersey, south-central Oklahoma, and southwestern Texas.

The four habitats were compared by calculating coefficients of similarity (Oosting, 1956) based on relative frequency of trees (Table 10), shrubs and vines (Table 11), and herbs (Table 12). The coefficient was calculated by the formula 2w/a + b times 100, where a is the sum of frequencies on one habitat, b is the sum of frequencies on another habitat, and w is the sum of the lowest of each pair of frequencies for the species occurring in both stands.

On the basis of the tree composition, the most similar communities were on the two north-facing slopes. The least similar were on the two south-facing slopes, which tended to contravene a correlation between vegetation types and exposure. The average coefficient for all communities with the same exposure was 42%. The average coefficient for the communities with

TABLE 10

COEFFICIENTS OF SIMILARITY BASED ON RELATIVE DENSITY OF TREES

	S.L.		
N.C.[a]	35%	N.C.	
S.C.	21%	50%	S.C.
N.L.	42%	64%	29%

TABLE 11

COEFFICIENTS OF SIMILARITY BASED ON RELATIVE DENSITY OF SHRUBS

	S.L.		
N.C.	61%	N.C.	
S.C.	42%	27%	S.C.
N.L.	55%	47%	54%

TABLE 12

COEFFICIENTS OF SIMILARITY BASED ON RELATIVE DENSITY OF HERBS

	S.L.		
N.C.	23%	N.C.	
S.C.	30%	38%	S.C.
N.L.	22%	42%	35%

[a]N - north facing, S - south facing, C - chert, L - limestone

different exposures, but on the same formation, was slightly higher (46%). Both of these averages were higher than the average (32%) of the communities with neither exposure nor parent material the same. This would indicate that the tree layers of these communities are affected by both slope exposure and the nature of the underlying rock formations.

The most similar communities on the basis of shrubs, had neither exposure nor parent material in common (Table 11). This means that shrubs and vines as a unit were poor indicators. Table 8, however, indicates that individual species such as Parthenocissus quinquefolia are correlated with these factors.

On the basis of herbs, the average coefficients of those communities having the same slope exposure is higher than for those communities having the same parent material. In this investigation, this correlation of herbs with exposure probably reflects the nature of the overstory vegetation.

All of the communities differed significantly in composition, which contradicts the statement of Gage (1908) that the forest floras on all formations in the Arbuckles are similar.

The Arbuckle Mountains, although surrounded by previously described vegetation types, form a relatively small isolated area with many communities almost completely unlike the surrounding areas.

CHAPTER V

SUMMARY

The vegetation was investigated on two slope exposures on each of two geologic formations (the Sycamore limestone and the Woodford chert) in the Arbuckle Mountains of south-central Oklahoma.

Three plant communities were described; post oak-blackjack oak, post oak-white ash, and black oak-white ash-winged elm. Of the three, only the post oak-blackjack oak community had been described previously. The occurrence of white ash in such a dominant position had not been reported from the state prior to this study. A fourth vegetation type occurred in which hackberry and winged elm were the most common species.

The rates of evaporation were determined on each of the four slopes. Evaporation was greater on the south-facing slopes than on the north-facing slopes, and greater near the top of the slopes than near the bottom.

The soil moisture, texture, and pH were determined for the four habitats. The soil texture was very similar on all geologic formations. The soil pH appeared to be influenced mainly by the parent material, being less acidic on the limestone. The pH also seemed to be partially influenced by the vegetation on the slopes. The soil moisture at the nine inch level did not appear to be indicative of the soil moisture in the root zone of the trees and shrubs. The abnormal rainfall distributions also made it difficult to relate soil moisture to specific factors. In general, soil moisture appeared to be governed by an interaction of evaporation, soil drainage, and vegetative cover.

The distribution of most shrubs appeared to be independent of both exposure and parent material. The distribution of herbs appeared to be determined largely by the overstory vegetation. Trees proved to be the best indicators of both parent material and slope exposure.

Several species, such as *Fraxinus americana*, *Quercus velutina*, and *Q. muehlenbergii*, showed a strong correlation with slope exposure. Other species (*Parthenocissus quinquefolia*, *Solidago delicatula*, *Aster sagittifolius*, *Sporobolus asper*, and *Bouteloua hirsuta*), appeared to be correlated with exposure, but were more probably indirectly influenced through the type of overstory on the different exposures.

A few species (*Quercus marilandica*, *Q. stellata*, and possibly *Bouteloua curtipendula*) were correlated with the geologic formations.

The differences in the communities were due primarily to shifts in dominance. There were few "indicator species". The differences in the communities appeared to be caused by an interaction of parent material and slope exposure, with neither exerting full control. Of the two, slope exposure appeared to be slightly more important.

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