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Influence of Geologic Parent Material and Climate on Distribution of Shortleaf Pine in Missouri

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SUMMARY AND CONCLUSIONS

The major factors of environment which might account for the relative presence or absence of shortleaf pine, were evaluated in Missouri by field observations during a two-year period. A comparison of early and recent records revealed that pine still occurs in substantially the same general areas where it occurred over a century ago. Likewise, pine is not present where it was not recorded originally.

The first field observations were directed toward evaluating environmental factors that determine the natural range boundaries of pine. The second series of field observations were directed toward an interpretation of outlying pine disjuncts. Finally, the center of the range of shortleaf pine in Missouri was examined. All field studies were extensive surveys in which the relative presence and thrift of pine were related to pertinent environmental factors. Strong relationships were established around the natural range boundary, with good supportive evidence from pine disjuncts. Less precise relationships were found toward the center of shortleaf pine's natural range in the Missouri Ozarks.

The 17-inch isohyet of winter precipitation (Nov.-Apr.) defines the northwestern extremity of pine, suggesting the essentiality of adequate winter moisture. Gentle relief, loessial soils, glades, and the Jefferson City geologic formation act as biophysical barriers, as indicated in Figure 25.

The Roubidoux geologic formation—a dolomitic sandstone—is the major pine-bearing stratum of the Missouri Ozarks. Stands of shortleaf pine and pine-oak are especially prominent where the topography is rolling to steep and the content of sandstone in the residuum is high. The prevailing soil type which develops from Roubidoux residuum is Clarksville stony loam.

At the geologic center of the Ozarks, oak-pine stands are associated with the soils developed from Lamotte sandstone and pre-Cambrian granite, especially in well-dissected terrain. The Bodine stony loam soil associated with the Burlington cherty limestone of the southwestern Ozarks also supports disjunct stands of oak-pine.

Of 17 geologic-soil combinations recognized in this study, four support the vast majority of pine, pine-oak, and oak-pine stands. At one extreme, ten soil series are considered to be "off-site" for pine because they are seasonally either too dry or too wet or both. At the other extreme, three soil series are considered to be "off site" for pine because they are better adapted to the more exacting hardwoods. On these sites, pine does not appear to be a good competitor with its hardwood associates. Thus, shortleaf pine is pictured as a prominent component of the Ozark forest on sites which lie between these two extremes.

Influence of Geologic Parent Material and Climate on Distribution of Shortleaf Pine in Missouri

P. W. FLETCHER AND R. E. MCDERMOTT

INTRODUCTION

Shortleaf pine (*Pinus echinata,* Mill.) is the only pine native to Missouri. Ranging farther north and west than the other southern pines (loblolly, slash, and longleaf), the botanical range of shortleaf pine extends up the Atlantic seaboard from Florida to New York, and from east Texas to southern Missouri, as shown in Figure 1 (Munns, 1938). Figure 2 shows the occurrence of shortleaf pine in the Ozark Province of southern Missouri as depicted by Liming (1946). He estimated that shortleaf pine was abundant[1] on 4.2 million acres (black on map) and infrequent[2] on an additional 2.4 million acres (hatched on map) of the Missouri Ozarks. This combined acreage constitutes 44 percent of the forest land[3] in Missouri.

King *et al.* (1949) reported shortleaf pine as a prominent component[4] of the Missouri Ozark forest on 226,000 acres, with an additional 794,000 acres of oak-pine[5]. Field observations reveal that pure stands[6] of shortleaf pine are very rare. They seldom cover more than a few acres. Instead, this species is present characteristically as a frequent but not abundant member of the oak-pine association throughout the Missouri Ozarks.

[1]Area in which pine-bearing lands are continuous except for scattered pine-free areas usually less than one section (640 acres) in size.

[2]Area in which pine-bearing lands are scattered areas usually less than one section in size and several miles apart.

[3]Best sustained land-use is forestry, largely in forest growth at present.

[4]Stands in which shortleaf pine trees comprise at least 60 percent of the dominant and codominant trees, termed *pine-oak* in this report.

[5]Stands of pine, oaks, and other hardwoods in which pines comprise 20-60 percent of the dominant and codominant trees, termed *oak-pine* in this report.

[6]Shortleaf pine comprises 80 percent or more of the dominant and codominant trees.

Fragmentary evidence from old land and timber company records[7] indicates that the original timber stands in the Ozark Province contained a large volume of pine on small, scattered areas, but a relatively small volume of pine on extensive areas. Thus, there were few sections of land where the volume of pine averaged more than 5,000 board feet to the acre, although individual acres may well have cut 30,000 board feet or more, even with the low utilization standards which prevailed at that time. Record (1910) observed in 1906 that the better stands of shortleaf pine contained volumes "ranging from 1200 to 12,000 board feet per acre with a probable average of about 2500 feet. . . . One acre in Carter County was known to contain 115 merchantable (13") pine trees with a total volume of 25,000 feet." Nevertheless, shortleaf pine was a highly desirable timber species when the logging industry was at its peak in Missouri, between 1900 and 1910 and has continued in high esteem.

Foresters prize shortleaf highly in their efforts to rehabilitate the Ozark forest. The high economic value of the wood, coupled with its capacity to produce more merchantable volume per acre in a shorter time than its associated hardwoods, makes it most attractive to forest land managers. Also, there is a wealth of sound ecological and silvicultural knowledge about shortleaf pine (Haney, 1955). The opportunity to market small-sized trees as fence posts treated with preservatives now makes early and frequent thinnings profitable. A pulpwood market for small bolts, both pine and hardwood, may develop in Missouri in the near future. A market for pine poles could conceivably appear, bringing premium prices for top quality trees. If forest land managers are to take full advantage of economic considerations such as these, their concern is (1) where should pine be favored over its associated hardwoods, (2) how should pine be favored, (3) what will it cost to favor it, and (4) what are the expected financial returns. This report describes pine sites in the Missouri Ozarks.

FACTORS OF ENVIRONMENT

Past History

Early historical evidence regarding location of shortleaf pine in the original forest was given by Schoolcraft (1821, 1853). He recorded his observations in a diary while on a foot journey through the Ozarks in 1818 and 1819. Figure 3 shows the approximate route of his trip from Potosi to Springfield and back by way of Batesville, Ark. He found plains

[7]Recollections of the senior author's examination of records in the files of the late Paul D. Kelleter, former Forest Supervisor, U. S. Forest Service. These records were recently donated to the State Historical Society, and at present are not available for detailed study.

grasses and park-like post oak on the gently undulating central Ozark Plateau and on the Springfield plains. Pine is still prominent where Schoolcraft found it—on steep rocky slopes of the central and eastern Ozarks.

A forest type map of the Missouri Ozarks, prepared by C. F. Marbut (Record, 1910) delineated the area of mixed pine and hardwoods. The pine area occupied "one large block in the southeastern Ozarks, with seven small lots scattered about. Fully 8 percent of the mixed pine hardwoods type had been cut over by 1906. . . . All of the uncut pine timber at this time, except for five million board feet, occurred on 218,000 acres owned by six companies."

The stippled shading in Figure 4 encloses the area within which pine trees are recorded as section and quarter-corner witness or line trees in the General Land Office Survey of 1848 for 12 townships in the south central Ozarks. Virtually the same area still supported continuous pine stands 100 years later, according to Liming (1946). Pine now occurs only as widely scattered individual trees in the non-shaded areas of Figure 4, where no pine witness trees were recorded in 1848. These areas are known locally as "post oak flats."

The average diameter of 658 pine witness trees recorded in these 12 townships in the G.L.O. survey of 1848 was 15.5 inches. The 1848 witness tree records for all tree species on a portion of the Missouri National Forests are summarized in Table 1.

TABLE 1 -- WITNESS TREES RECORDED IN THE 1848 GENERAL LAND OFFICE SURVEY OF 12 TOWNSHIPS IN THE WILLOW SPRINGS DISTRICT, MISSOURI NATIONAL FORESTS.

Species	Number of Townships species recorded in	Total Number of trees	Average Diameter, Inches
Pine	10	658	15.48
Post oak	11	977	12.20
Black oak	12	466	12.37
Blackjack oak	11	374	8.13
White oak	12	428	14.31
Hickory	9	28	10.43
Gum	8	20	12.75
Red oak	2	89	13.91
Walnut	4	10	11.20
Elm	5	7	8.29
Dogwood	3	4	7.25
Bur oak	2	2	16.00
Ash	3	4	13.00
Sycamore	1	1	12.00
Hawthorne	1	1	6.00
Sassafras	1	2	7.50
Mulberry	1	1	18.0
		3072	12.74

Of 17 tree species recorded, 5 included 94 percent of the total number of witness trees; shortleaf pine accounted for 21 percent of the total. The same 5 species (pine, post oak, black oak, blackjack oak, and white oak) were also the most frequently recorded ones for the 12 townships, with hickory recorded only 28 times in 9 townships. Blackjack oak, a consistent member, averaged only 8 inches in diameter, considerably below the average of all species together.

Further indication that the original pure pine forest contained trees of many sizes, but with an average diameter of only about 15 inches, is shown in Figure 5. This photograph of a logging operation in a stand of pine on the Willow Springs District was taken about 1880, when the first major cuttings were made in the best pine stands. It suggests that the original stands were essentially even-aged, but contained post, pole, and saw-timber sizes, much as they do today. However, there are few second growth pine stands now with so little hardwood undergrowth and so much grassy and herbaceous cover as shown in this early photograph.

From measurements of 247 pine stumps, Record (1910) found that breast height diameters of 6.7; 12.7; and 16.6 inches were attained at 50; 100; and 150 years, respectively—a growth rate which compared favorably with that of shortleaf pine in Arkansas on comparable sites.

Climate

Missouri is uniquely situated where north meets south and east meets west in climate, soil, and vegetation. Northwest Missouri has the characteristic mid-continent climate and plains vegetation, whereas southeast Missouri reflects the influence of the Gulf of Mexico and supports the oak-hickory and oak-pine associations of the deciduous forest formation. Figures 6, 7, and 8, (Decker, 1955), reveal that southeast Missouri receives about 14 inches more precipitation annually than northwest Missouri, and most of this difference is due to higher winter precipitation. The range of shortleaf pine in Missouri lies entirely within the 17-inch isohyet of winter precipitation shown in Figure 8. Climographs for northwest and southeast Missouri, as shown in Figure 9, further reveal that low winter precipitation distinguishes the grassy northwest from the forested southeast.

Loess

Between the northwest Missouri prairie and the southeast Missouri oak-pine forest lies an irregular and poorly defined forest-prairie transition zone in which shortleaf pine is absent. This zone is characterized by stands of post oak on broad, gently rolling ridge-tops which are undissected peneplain remnants (shaded area of Figure 3). Where the land surface is almost level, it is free of rocks, and formerly supported plains grasses and plains animals according to Schoolcraft (1821, 1853). Bordering these grassy plains he observed open, park-like stands of post oak and its associate, blackjack oak. Down-slope from these post oak flats, where rocky surface soils commence, were denser stands dominated by black oak.

Thorp and Smith (1952) considered that the rock-free silt loam soil on these upland plateau areas was transported there by wind in Pleistocene time. These loess deposits lie as a mantle on undissected upland plateaus throughout the state. The greater thicknesses close to the Missouri and Mississippi Rivers suggest that the river flood plains are the source areas, as shown in Figure 10. Shortleaf pine in the Missouri Ozarks is largely confined to the loess-free, well-dissected terrain.

Slope

The general location of steep slopes supporting immature soils and lithosols is shown within the darkly shaded areas of Figure 11, from Collier (1955). Level uplands supporting mature soils and park-like post oak stands are stippled. Within its natural range in the Ozarks, shortleaf pine is most prominent where slopes are over 10 percent. However, there are extensive areas in southwest Missouri and the northeast Ozarks with slopes of over 10 percent which are not pine-bearing lands. An explanation for these exceptions lies in the nature of the parent rocks and the residual soil formed from them.

Geology

The geology of Missouri has been mapped with a great deal of care by many men over a long period of years (Branson, 1944). The generalized geological map of Missouri (Figure 12) delineates the major bedrock formations that occur beneath the land surface. These rock formations roughly form concentric ovals around the pre-Cambrian granite and porphyry of the eastern Ozarks, the oldest rocks in the state. This granite and porphyry core is considered to be the root of an ancient mountain system that was exposed during a long period of erosion and finally buried by the deposits of the Cambrian and Ordovician seas. Each successive concentric oval, outward from the granite, is progressively younger in geologic age, as shown in Table 2. These rock formations are of sedimentary origin. Rocks of several geologic ages are missing in places because of ancient erosional cycles or lack of deposition before re-submergence beneath the seas, and deposition of the next younger formation.

In general, all formations dip regionally away from the pre-Cambrian granite core, but very slightly. Thus, in moving outward (and up-section) from the granite, one successively encounters (with some omissions) the

TABLE 2 -- GENERAL DESCRIPTION OF GEOLOGIC FORMATIONS OF THE OZARKS
(Branson, 1944)

System	Formation	General Description	Thickness in Feet Average	Thickness in Feet Maximum
Pennsylvanian Mississippian Devonian Silurian	Burlington	Not represented in the Ozarks proper		
Ordovician	St. Peter	Pure quartz sandstone, chart-free, thick-bedded, non-fossiliferous.	30-60	105
	Everton	Mod. cherty dolomite with thin-bedded sandstone.	45-80	475
	Powell	Pitted siliceous dolomite with thin-bedded sandstones.		(170)
	Cotter	Very argillaceous, cherty, thin-bedded dolomite, very thin sandstone, oolite beds, molluscans.		(60)
	Jefferson City	Pitted dolomite, sparsely fossiliferous, with thin beds of cherty nodules and evenly-bedded "cotton rock."		(150-175)
	Roubidoux	Interbedded cherty dolomite and sandstone, more sandstone in south Ozarks than in north.		(70-160)
	Gasconade	Profusely cherty (creamy) dolomite, mod. thick-bedded.		(190-250)
	Van Buren	Thin-bedded cherty dolomite, weathers in steps.		200
	Gunter	Sandstone and conglomerate.		15-20
Cambrian	Eminence	Very cherty, rusty dolomite, some shale and irregular sandstone lenses, weathers to deep red sticky clay.	185	
	Potosi	Cherty dolomite (drusy quartz) weathers to deep red or brownish clay (pinnacled appearance).		400
	Derby-(Doerun)	Chert-free dolomite.		110
	Davis	Chert-free shaly limestone-dolomite.	70	170
	Bonneterre	Chert-free massive-bedded, barren, crystalline dolomite.	375	50-450
	Lamotte	Chert-free arkosic sandstone, well-bedded.		100-300
Pre-Cambrian		Porphyry Granite, reddish, mostly coarse-grained.		

Lamotte, Bonneterre, Derby-(Doerun) Potosi, Eminence, Gasconade, Roubidoux, and Jefferson City formations, with Mississippian and Pennsylvanian strata in north and west Missouri. This relationship is illustrated by the generalized cross-section shown in Figure 13.

The Roubidoux and Gasconade formations characterize the preponderant part of the Ozark surface rock outcrops, with Potosi-Eminence common near valley bottoms in the eastern Ozarks, and the Jefferson City formation prevailing on uplands throughout the periphery of the Ozark Province to the north, west, and south into Arkansas.

Figure 14 shows where the *Jefferson City formation* (including the Cotter, Everton, and Powell) occurs at or just beneath the land surface. This formation is dolomitic, siliceous in part. The outer extremity of this formation constitutes most of the geologic boundary of the Ozark Province.

The most extensive surface rock in the central Ozarks is the *Roubi-*

doux formation, composed of sandstone interbedded with cherty dolomite. This formation occurs down-section and beneath the Jefferson City formation, as shown in Figure 15. It averages about 150 feet in thickness, with 30 to 60 percent sandstone. It is found at lower elevations near most of its peripheral boundary, at middle elevations on the North Fork, White River and Piney River, and on ridges and upper slopes in the central Ozarks. It is the geologic formation directly beneath the Butler County "flatwoods" and crops out on the upper slopes of the "breaks" along the Black, Current, and Eleven Points Rivers.

Lying directly beneath and down-section from the Roubidoux is the thick-bedded *Gasconade formation* of cherty dolomite (Figure 16). It becomes successively more prominent in lower, middle, and upper slopes of river valleys from the North Fork White River east toward the pre-Cambrian center of the Missouri Ozarks in Iron and St. Francois Counties.

Beneath the Gasconade and down-section from it are the older dolomitic formations of Cambrian age. Successively, these are the *Eminence, Potosi, Derby-(Doerun), Davis, Bonneterre,* and the *Lamotte* sandstone. Collectively, these formations form a less extensive area of surface rocks than the Gasconade, and a far less extensive area than the Roubidoux. The Eminence and Potosi formations, like the Ordovician above, are cherty dolomites, whereas the middle and early Cambrian formations—Derby-(Doerun), Davis, Bonneterre, and Lamotte— are chert-free.

Pre-Cambrian granite and porphyry, which crops out at the geologic center of the Missouri Ozarks, is the characteristic bed rock of the St. Francis Knob and Basin region of the eastern Ozarks. This region is also the physiographic center of the Ozark Province, for these granite and porphyry knobs rise sharply as much as 1,000 feet above the valley floors.

Residuum

Throughout most of the Ozarks there is a variable depth of residuum which mantles the bedrock. Figure 17 shows, in a general way, the maximum thickness of residuum[8] as determined from drilled well cores. Ranging up to 200 feet thick, residuum is the unconsolidated material derived from impurities—clay and chert—by a "slump" or decompositional "let down" of the previously overlying dolomitic bedrock. Thus, in the central Ozarks, the land surface with Roubidoux bedrock commonly has a residuum mantle from the Jefferson City formation. Similarly, Gascon-

[8]Unpublished map, prepared from drilled well records by the Missouri Geological Survey and Water Resources (1955) for the U. S. Forest Service. Basis-544 records in 47 Counties, averaging 11.6 records per County, ranging from 3 in Ripley County to 26 in Texas County.

ade bedrock in the central Ozarks is generally mantled with residuum from the Roubidoux, the thickest accumulations being on ridges, thinning out on slopes, and disappearing on the bluffs of larger valleys. It is for this reason that the nature of the soil material in a given locality is often more closely related to the residuum from a formerly over-lying geologic formation than to the bedrock itself.

Soils

The soils of the Ozark Province have not yet been completely classified and given series and type names. Table 3 lists 16 soil series with their associated parent materials. Two of these have not been named and three others have provisional names only. Ozark soils are considered to be transitional between the gray-brown podzolic soil group to the north, and the red-and-yellow podzolic soil group to the south.

Figure 18 shows the general location of eight major Ozark soil areas from soil series combinations recognized by Miller and Krusekopf (1929). The Ozark Plateau is shown as the black and double-cross-hatched portion of the map, broadly associated with the Jefferson City geologic formation. The un-marked openings indicated within the Ozark Province represent the "rough stony land" along major rivers such as the Osage, Gasconade, Piney, Meramec, St. Francis, Black, Current, and White Rivers. The characteristic and most extensive soil type in these "window" areas is the Clarksville stony loam. More recently, the soils of the glade country in the southwestern Ozarks have been termed Gasconade or "Taney" by Scrivner and Frieze (1953). There is also evidence to justify the separation of "Eminence" stony loam and others from Clarksville stony loam in the eastern Ozarks.[9] In general, the "Eminence" subsoil is a reddish clay, whereas the Clarksville subsoil is a pale yellow.

The Clarksville and "Eminence" stony loam soils are the most difficult series to distinguish. Criteria for field recognition, supplementing Table 3, are differences in location within the Ozarks; topographic position; differences in size, color, nature, and volume of the chert; presence, absence, or relative amount of sand rock in the solum; color of the subsoil; and nature and color of the unconsolidated parent material (residuum).

[9]Personal communication from H. H. Krusekopf, professor emeritus of soils, University of Missouri.

TABLE 3 -- GENERAL DESCRIPTION OF THE MAJOR UPLAND SOIL SERIES IN THE MISSOURI OZARKS
Department of Soils (1955) 10/

Series	Associated soil forming Material	Color		Texture		Degree of Profile Devel.
		Surface	Subsoil	Surface	Subsoil	
1. Menfro	Loess	Brown	Brown	Silt loam	Silty clay loam	Moderate
2. Grenada-like	Loess	Green-brown	Yellow-brown	Silt loam	Silty clay	Moderate strong
3. Gerald	Loess 11/	Green-brown	Green-brown	Silt loam	Clay	Very strong
4. Lebanon	Loess 11/	Light green	Yellow-brown	Silt loam	Silty clay	Very strong
5. Bodine	Burlington limestone	Light brown-green	Yellow-brown	Very stony loam	Cherty silt loam	Slight to moderate
6. Tilsit	St. Peter sandstone	Brown-green	Yellow-green	Sandy loam	Silty clay loam	Moderate
7. Gasconade 12/ "Taney"	Cotter dolomite	Black	Black	Clay loam	Clay	Slight
8. Union	Jefferson City dolomite	Light brown	Brown	Clay loam	Silty clay	Moderate
9. Clarksville A	Jefferson City dolomite	Light green	Brown-yellow	Silt loam	Gravel clay loam	Moderate strong
10. Hanceville	Roubidoux sandstone	Yellow-green	Yellow-brown	Loam	Sandy clay	Moderate
11. Clarksville B	Roubidoux sandstone	Light green	Pale brown-yellow	Stony loam	Stony loam	Moderate
12. "Eminence" 12/	Gasconade Eminence Potosi	Green-brown	Red-brown	Stony loam	Stony, silty clay loam	Moderate
13. No Name†	Derby-(Doerun) Davis	(shaly dolomite, chert-free, soil, gray, sticky when wet)				
14. Hagerstown	Bonneterre dolomite-limestone	Brown	Red-brown	Silt loam	Silty clay	Moderate
15. No name 12/	Lamotte sandstone	(similar to Clarksville gravelly loam, perhaps more nutrients from the				
16. Ashe	Granite and Porphry	Yellow-green	Yellow-brown	Stony loam	Stony clay loam	Moderate

10/ Modified by suggestions of H. H. Krusekopf, Professor Emeritus of Soils, University of Missouri. The soils of the Missouri Ozarks are currently under consideration in the expectation that reclassification will provide additional soil series to fit distinctive field differences.

TABLE 3 -- (Continued)

Permeability	Topography	Present Dominant land use	Inherant Fertility	Location	Original Native Vegetative Cover
Free	Hilly	Pasture and crops	High	River Hills, N. E. Ozarks	Oak-basswood-maple
Moderate slow	General rolling	Forest & pasture	Medium low	"Flatwoods", S. E. Ozarks	Oak-hickory
Very slow	Nearly level	Crops	Medium	W. Cent. Ozark Plateau	Plains or mid-grass
Very slow	Nearly level	Pastures and crops	Very low	W. Cent. Ozark Plateau	Post oak flats
Moderate	Rolling to hilly	Forest and pasture	Very low	S. W. Ozark Border	Oak-pine
Moderate	Rolling	Crops and pasture	Low	N. E. Ozark Border	Cedar-hardwoods
Moderate	Hilly	Range	Medium	S. W. Mo., White River	Glade
Moderate	Hilly	Crops and pasture	Low	N. & E. Ozark Border	Black oak
Moderate	Rolling	Pasture and forest	Very low	W. Cent. Ozark Plateau	Black oak-post oak
Moderate	General rolling	Forest and pasture	Very low	Cent. Ozark Plateau	Post oak-mid-grass
Free	Hilly	Forest	Very low	Central Ozarks	Pine-oak
Moderate free	Hill	Forest	Medium low	Central Ozarks	Oak-(pine)
				E. Ozarks	Oak-hickory
Free	General rolling	Crops	Medium	E. Ozarks	Oak-hickory
Arkosic rock)				E. Ozarks	Oak-pine
Moderate	Hilly	Forest	Very low	E. Ozarks	Oak-pine

11/ Some authorities consider that shale is the soil-forming material rather than loess.
12/ No accepted name at present.

DISCUSSION OF PINE-ENVIRONMENT RELATIONSHIPS

Natural Range Boundaries

Billings (1952) presented an excellent summary of the current trends and concepts in evaluating the environmental complex for plants. He stressed the principle of holocoenotic environment—developed by Allee and Park (1939) and amplified by Cain (1944)—which states that plant reactions reflect the net effect of the whole environmental complex. The factors of a terrestrial plant environment were segregated into major categorical groups—climatic, edaphic, geographic, pyric, and biotic—with appropriate subdivisions of each group into phases or mechanisms. An analysis of some of the environmental factors correlated with the distribution of shortleaf pine in Missouri attests the aptness of the holocoenotic concept.

1. *Climate:* Hocker (1956) demonstrated that climatic variables of temperature and precipitation exerted a marked influence on the distributional limits of loblolly pine. He found that the loblolly pine region was characterized during the winter by a greater number of days with precipitation and a greater frequency of effective precipitation than the region north of the range of the species. Also, the average winter temperature within the loblolly pine region was somewhat higher than that north of the range of the species.

The distribution of shortleaf pine in Missouri appears to be associated with the winter cyclone path of the lower Ohio Valley. As shown in Figure 8, the 17-inch isohyet of winter precipitation rather closely defines the northwestern extremity of shortleaf pine, suggesting the essentiality of adequate winter moisture.

Winter temperature in Missouri decreases from south to north and winter precipitation decreases from southeast to northwest. Together these patterns suggest a northwesterly physiological limitation of winter water for growth and a northerly limitation imposed by decreasing availability of water due to decreasing water absorption by roots with decreasing temperature, as shown by Kramer (1942) and Kozlowski (1943).

2. *Gentle Relief and Loess:* Within the 17-inch isohyet of winter precipitation, there are extensive areas of land with few pine trees and no pine stands. Perhaps the largest of these pineless areas are those of gentle relief and/or rock-free soil, as shown by Figures 3, 11, and 18. The combination of gentle relief and well-developed silt loam soil profiles, characteristic of broad upland plateaus, occurs widely throughout the western, central and southeastern Ozarks. Thorp and Smith (1952) considered these soils to be

Pleistocene eolian deposits. Among these soil types are the Gerald, Lebanon,[13] and Clarksville silt loams of the western and central Ozarks, and the Grenada-like silt loam of the southeastern Ozarks.

Schoolcraft (1821) observed that grassy plains prevailed on the gently-rolling central Ozark Plateau near the present towns of Salem, Licking, Raymondville, and Summersville, and again near Springfield. The dark-colored Gerald soils are now in crops or pasture, and the light-colored Lebanon soils are in unimproved range pasture or covered with stands of post oak. As outlined in Table 3, these soils have a very strong degree of profile development, characterized by a dense subsoil pan formation.

The Grenada-like silt loam soil which mantles the "flatwoods" of the southeastern Ozarks has a moderately well-developed subsoil pan, or fragipan,[14] which restricts the downward movement of water and limits the depth of root development. Fletcher and McDermott (1957) observed that this soil when on level to gently rolling land, ranged from constant supersaturation (waterlogged) throughout the winter and spring to sustained wilting percentage during the summer and fall.

Working in the Piedmont region of southeastern United States, Copeland (1949) found that a high incidence of littleleaf disease of shortleaf pine was associated with the Iredell and related soils having poor internal drainage. He considered that this disease stemmed from the malfunctioning of the roots associated with a root-rotting organism *(Phytophthora cinnamoni,* Rands) which thrives when the soil is warm and wet, as in May, in soils with subsoil pans.

Further evidence that these well-developed silt loam soils may be "off-site" for shortleaf pine is afforded by the generally poor showing of shortleaf pine plantations on them during the past 20 years. Growth rate has been slow and pronounced damage has resulted from attacks of the pine tip moth (*Ryacionia frustrana,* Comstock). It remains to be seen whether these pine plantings will survive what seems to be a "hostile site" and live to produce merchantable products larger than fence posts in reasonable time. It appears that these sites are seasonally either too wet or too dry (or both) for good growth and development of shortleaf pine. Indeed, the presence of post oak on the Lebanon silt loam soils suggests that it is better able to tolerate these moisture extremes than its associated species, including shortleaf pine. Eastern redcedar, evidently more drouth resistant than shortleaf pine, may also tolerate the excessive soil moisture of winter and spring on these post oak flats. Beilmann and Brenner (1951)

[13]Closely related to the Lebanon silt loam are the Ozark, Baxter, and Nixa silt loams of the Springfield Plains region bordering the western Ozarks.

[14]Krusekopf, H. H. and C. L. Scrivner (1954). Soil survey of the University Forest, Butler County, Missouri. Unpublished file report, Mo. Agr. Exp. Sta.

called attention to the rapid invasion since the early thirties of eastern red cedar on many post oak flats in the western Ozarks.

All in all, the Gerald, Lebanon, Clarksville, and Grenada-like soils on upland flats never have supported stands of natural pine, as indicated in Figures 3 and 4. It seems evident that these loessial flats have been a biophysical barrier to shortleaf pine. Although occasional pines may be found on adjacent Clarksville gravelly loam soil (essentially loess-free and slightly more dissected), pine does not appear to have migrated appreciably into the flat loessial soils from these seed sources.

3. *Glades:* Another extensive pineless area within the 17-inch isohyet of winter precipitation is the White River glade country of the southwestern Ozarks. The thin, black, calcareous, rendzina-like Gasconade or "Taney" soil of this area develops as a lithosol from the argillaceous Cotter dolomitic bedrock. The most prominent woody vegetation is Ashe juniper and eastern redcedar, frequently distributed in concentric rings on the contours between glade rock outcrops. Associated with the cedars is the unique chittim or smoketree (*Cotinus obovatus,* Raf.) with grassy herbaceous vegetation as the dominant ground cover, including bluestems, drop-seed, and Indian grass, according to Scrivner and Frieze (1953), Martin and Crosby (1955), and Kucera (1957). The herbaceous vegetation on the thin soil of these steep slopes was called "semi-alpine" by Schoolcraft (1853). Cedar seems to be invading the glade country at an accelerated rate during the past 20 years. This may be associated with increased fire protection, coupled with continued grazing by livestock.

Experimental pine plantings on the glades have been complete failures. The site is too drouthy for survival of planted pine seedlings. Here again, cedar shows much greater drouth-resistance than shortleaf pine. Cedar occurs here and on other dry, rock outcrops, not because it prefers such arid sites, but because it tolerates them better than many of its associates.

4. *Jefferson City Geologic Formation:* Within the pine region of Missouri, gentle relief with or without a loess mantle appears to limit the occurrence of shortleaf pine, although the loess mantle provides a more severe limitation. The Jefferson City geologic formation, a thin and evenly-bedded cherty dolomite, is the bedrock directly beneath the land surface throughout extensive peripheral areas of the Ozark Province, as shown in Figure 14. Where no loess mantle is present, Clarksville gravelly loam is the dominant soil and black oak is the predominant tree species. Shortleaf pine occurs only as widely scattered small stands or individual trees, with occasional small patches on abandoned pastures close to a pine seed

source. Neither pines nor hardwoods exhibit good form and quality. Where small pine stands do occur, they are usually on the deeper, cherty soils on moderately steep slopes. In general, the Jefferson City dolomite formation constitutes a barrier to pine, although somewhat less limiting than the three factors described in the preceding paragraphs.

An observational trip through north Arkansas revealed a wide expanse without shortleaf pine between Doniphan in Carter County, Mo., and Evening Shade in Sharp County, Ark. This entire area is underlain with Jefferson City dolomite which continues south from the Missouri-Arkansas boundary (Fig. 14). Thus, it constitutes a barrier even to the south where, presumably, climatic limitations are no longer a factor. In general, then, the area where Jefferson City dolomite is the surface rock is not, and probably never was, pine-bearing land.

Site Differences Within Natural Range

The foregoing sections describe sites along the natural boundary of shortleaf pine where the species is absent or rare. The ensuing sections describe sites where pine is more or less abundant, well within its natural range in Missouri.

1. Roubidoux Sandstone—Clarksville Stony Loam: The Roubidoux formation (Fig. 15), especially where it occurs in well-dissected terrain, is the major pine-bearing stratum of the Missouri Ozarks. The cherty, Clarksville stony loam soil which develops from this geologic formation generally supports extensive stands of pine and pine-oak. Here more than anywhere else, shortleaf pine is a prominent component of Missouri Ozark forests. In the summer of 1906 Record (1910) observed that shortleaf pine "is usually confined to the tops of ridges and upper slopes . . . the better soils of the hollows and creek bottoms being appropriated by hardwoods."

Stands of shortleaf pine are especially prominent where the topography is rolling to steep and the sandstone content of the residuum is high. Heller (1954), in describing the Roubidoux geologic formation, notes a wide variability in the proportion of sandstone and cherty dolomite. In general, he found more sandstone in the Roubidoux of southern Missouri, and less sandstone in the Roubidoux of the northern Missouri Ozarks.

Roubidoux residuum is detected by the presence of sandstone rocks in the soil mass, sandstone boulders on the land surface, smaller sandstone fragments mixed with chert, and the pale brownish yellow to orange color of the subsoil. Figure 19 shows a road-cut profile of the Clarksville stony loam soil developed from residuum of Roubidoux sandstone.

Shortleaf pine could occur, and may originally have occurred, anywhere in the southern part of the Missouri Ozarks where Roubidoux residuum appears on rolling to steep topography and narrow ridges. Locally, such areas may not support pine at present because of many past historical effects associated with the exact sequence of events during and after logging. However, past land-use history, including logging, burning, and grazing, does not seem to have changed the botanical range of shortleaf pine in Missouri. Although large volumes of pine were cut in the three major waves of high-grade logging between 1880 and 1920, second-growth pine still occurs essentially where it occurred before the coming of the white settler a century ago.

Braun (1950) called attention to the physiographic climax of pine in the mesophytic forest region of the Cumberland Mountains in Kentucky. There, shortleaf pine generally occurs where dipping (resistant) sandstone strata are exposed on ridge-tops. Working in the Ozark Province of Missouri, Steyermark (1940) observed that shortleaf pine was prominent on the sandy, very acid soils of ridges, whereas white oak and red maple were final dominants on the fine-textured, slightly acid soils of ravines.

Within the pine region of Missouri, pine may occur on all aspects when the residuum contains a large quantity of sandstone. When the sandstone bedrock occurs as a resistant cap on ridge-tops, making a sharp contact with a dolomitic bedrock below (Roubidoux over Gasconade), pine is commonly more or less restricted to the ridge-tops and south and west aspects, provided that sufficient soil is present. If insufficient soil is present, an xeric glade-like vegetation develops. If a deep soil develops on the lower slopes, however, hardwoods are present. This suggests that shortleaf pine is able to meet the competition of its associated hardwoods on freely to excessively well-drained sites, which may also be too low in soil nutrients for more exacting hardwood species. It also suggests that the hardwoods are better adapted to these lower slopes and eventually eliminate pine because of a more favorable soil moisture regime and higher nutrient levels, particularly of phosphorus.[15] Figure 20 depicts a geological profile across North Fork White River and Piney River showing the occurrence of shortleaf pine as related to the Roubidoux formation. This relationship is common throughout the central Ozarks where erosion has exposed the Jefferson City, Roubidoux, and Gasconade formations on upper, middle, and lower slopes, respectively.

2. "Eminence" Stony Loam: A soil series with this tentative name is presently being considered by soil surveyors. It occurs in the central and eastern Ozarks in positions which are down-slope and down-section from the Clarksville stony loam developed from the Roubidoux formation. The "Eminence" stony loam is associated with the Gasconade, Eminence, and

[15]Based on a very limited number of soil fertility tests.

Potosi geologic formations, the lowest and earliest cherty dolomites. The subsoil which develops from these rocks, *especially Eminence and Potosi,* is reddish brown, whereas the Clarksville stony loam subsoil is generally brownish-yellow. Sandstone boulders are usually absent, except where they have been "let down" from formerly overlying Roubidoux or where the Gunter sandstone (basal member of the Gasconade) occurs. The cream-colored chert from Gasconade rock is also distinctive.

Further study is needed before definite conclusions can be reached regarding relationships between these rocks, the soils formed from them, and the relative prominence and thrift of shortleaf pine and other species. It appears from general observations that the "Eminence" soil is dominated by hardwoods. Where pines are present, they occur as scattered individual trees and in occasional oak-pine stands. These exceptions apparently occur where (1) a sandstone influence is present, such as Gunter sandstone, let-down Roubidoux or a sand lens or facies in the dolomitic strata; (2) the equivalent effect of sandstone rock occurs through several combinations of thin soil, dry aspect, upper slope position, high chert content, and/or coarsely granular dolomitic bedrock; or (3) old-pasture succession to shortleaf pine is evident. These relationships suggest that shortleaf pine is best able to meet the competition of its associated hardwood species on moderately xeric sites.

3. Early Cambrian Geologic Formations: Except for the Hagerstown silt loam, derived from the chert-free Bonneterre dolomitic limestone, no series names have been assigned to the soils developed from the Derby-(Doerun) and Davis chert-free shaly-dolomites, and the Lamotte sandstone. Within the relatively small portion of the eastern Ozarks where these formations are present as surface rocks, shortleaf pine occurs as scattered individual trees or in oak-pine stands on the soils developed from Lamotte sandstone. In well dissected terrain, as in conjunction with a geologic fault (Weingarten, Mo.), the Lamotte supports good stands of pine.

As on the "Eminence" stony loam soils, minor local exceptions occur on residual soils developed from these three formations where a combination of site factors produces a drouthy site. Pure pine stands are rare, however, except where old-pasture succession or a past disturbance (fire, tornado, logging) has favored the early establishment and subsequent development of pine at the temporary expense of associated hardwoods. *Old-pasture succession to shortleaf pine* in Missouri, however, is far less pronounced than old-field succession to loblolly pine in the Piedmont region of southeastern United States, as described by Oosting (1942).

4. *Granite-Ashe Stony Loam:* The Ashe stony loam, which weathers from granite and porphyry, was originally covered with moderately extensive pine-oak stands, and still is. The soil mantle is often too thin and rocky, especially on the tops of granite or porphyry knobs, for good tree growth. With sufficient accumulation of soil on the lower slopes of the knobs—as at Silvermine—fairly thrifty stands of pine are present. Figure 21 is a highly generalized geologic and topographic section across southeastern Missouri, showing the location of pine-oak stands as related to the geologic strata. In general, pine is most abundant on the Roubidoux formation, less abundant on the granite, and scattered on the geologic strata between.

Pine Disjuncts

Outlying, disjunct stands of shortleaf pine adjacent to the major pine region in the Missouri Ozarks were examined in the expectation that the nature of their sites would shed further light on geologic and soil relationships. One such island of pine is in western Douglas County. Here, along Beaver Creek, Roubidoux sandstone is exposed where the drainage has cut through the overlying Jefferson City dolomite, as along Bryant Creek and near Gainesville, to the east.

A relatively small patch of pine in southern Christian County, near Chadwick, reveals a very interesting relationship. The underlying bedrock is the Burlington formation of middle Mississippian age. This is a very cherty limestone, the chert bearing typical crinoidal markings. This formation is characteristic of the western and southern topographic "breaks" of the White and James Rivers and underlies the small patches of pine in Taney and Stone Counties. Pine is characteristically associated with the very cherty Bodine soil (Scrivner and Frieze, 1953) which occurs on the eastern, narrow, ridge-top extremities of broad, rolling topography lying to the north and west toward Springfield. Figure 22 shows a generalized profile of this locality, with pine occurring only on the Bodine soil immediately above the Glades.

A narrow ridge-top outlier of Bodine soil derived from Burlington residuum occurs along the Hercules-Caney tower road in Taney County, capping the ridge directly above the glades (Kucera, 1957). This land could support pine but does not, presumably because it is an isolated island well within the surrounding glades.

Sandstone of unknown age was found in the subsoil at Saunders Tower near Chadwick. Geologists consulted have not yet determined whether this is Silurian or Devonian, or residuum from a slump or letdown of sandstone from up-section Mississippian strata. Sandstone was also found east of Cassville near Cato where another disjunct pine stand occurs. However, no sandstone was observed in the McDonald County pine area in extreme southwest Missouri. Bushberg (Sylamore) sandstone of Mississippian age and an unnamed sandstone of Devonian age are both possibilities[16] as these formations have been reported in this general area. Pine in McDonald County is restricted to the tops of narrow, chert-covered ridges and a short distance down south- and west-facing slopes.

Outlying pine stands in eastern Missouri on bluffs adjacent to the Mississippi River were also examined for possible geologic-soil relationships. Sandstones of Silurian and Devonian age were found in the soils supporting these stands. Furthermore, the soil surface of these ridge-top pine stands was covered with chert, in appearance much like that of the Bodine soil in southwest Missouri. A small patch of natural pine occurs in the Wolf Lake area[17] of the Shawnee National Forest in Illinois, northeast of Cape Girardeau, Mo. This pine appears to be associated with the St. Peter sandstone. On the Missouri side, however, the narrow band of St. Peter sandstone is more characteristically covered with eastern red-cedar than with shortleaf pine. Insomuch as this locality approaches the 17-inch winter precipitation limit, it appears likely that this thin soil is too drouthy for pine, but not for the more drouth resistant cedar and associated species. In fact, the vegetation on the adjoining Jefferson City formation in this part of the eastern Ozarks is strikingly similar to that of the southwestern Missouri glades. Schoolcraft (1821) noticed this when he walked toward Potosi from Herculaneum.

The upper Roubidoux formation with its associated Hanceville loam, near Salem in Dent County, Mo., did not support pine originally according to Schoolcraft (1821), nor does it now. This is the *undissected* upper Roubidoux upon which is preserved a remnant of a peneplane surface as the Central Ozark Plateau. Generally rock-free at the surface, this soil has, in places, a thin silt loam mantle like the Lebanon silt loam post oak flats. Also, like Lebanon silt loam, it has a pronounced subsoil pan formation which restricts the downward movement of water and definitely limits the depth of root development (Martinez, 1950). Dent County also lies near the 17-inch isohyet of winter precipitation (Figure 8), suggesting that this plateau is too dry for the best growth and development of shortleaf pine. Schoolcraft (1821) recorded plains grass and open stands of short-boled post oak trees in this vicinity.

From Evening Shade in Sharp County, Ark., westward along the

[16]Personal communication from A. G. Unklesbay, Professor of Geology, University of Missouri.

[17]Personal communication from R. E. Shake, graduate student, Department of Botany, University of Wisconsin.

"breaks" of the Arkansas River, shortleaf pine is a prominent component of the forest where sandstone and sandy dolomite outcrops of late Ordovician, Silurian, and Devonian age are encountered. St. Peter sandstone is a common bedrock in this locality. It is possible that the 22-24 inches of winter precipitation received here are enough to offset any drouthy tendencies of this soil, particularly since the parent material seems to possess more clay and more nutrients than the Missouri St. Peter rock.

Pyric and Biotic Factors

Turner (1935a) in commenting on the disjunct distributional nature of shortleaf pine in northern Arkansas, suggested that it was a waning species because of its relative ineffectiveness in competing with deciduous species. In Missouri, the shortleaf pine is a sub-climax species and can be considered a waning species only from the classical monoclimax standpoint. Fires of large extent appear to have been regular Indian activities for driving game and carrying on warfare (Fig. 5). Apparently, they were instrumental in stabilizing pine on many xeric sites. Fires also contributed toward the stabilization of grass on some forest-grass ectones, much as Turner (1935b) described for Arkansas. Steyermark (1940) reported that the intermingled climax plant associations in the Ozarks owe their diversity to the different rocks and soils on which they grow. He termed these plant communities "physiographic climaxes." Working in northern Arkansas, Read (1952) found striking relationships between tree species occurrence and immature soil types derived from several geologic formations. Like Steyermark, he considered that the immature soil derived from a single geologic formation might be chemically unbalanced or deficient in certain nutrients.

Early settlers used the grassy plains and park-like post oak stands for range pasture. Annual burning to "green-up" the open range, together with over-grazing, eventually reduced the amount and continuity of grassy and herbaceous fuels, so that fires burned "cooler" and oaks could get established and sprout repeatedly with each subsequent "light burning." This may well be the reason why aged local people continue to remark that such areas have "brushed up" during the past 50 years. An analogous situation is believed to exist in the grasslands of the southwestern states, where repeated burning and overgrazing are associated with the invasion of mesquite and juniper.

Migration of the Pine into Missouri

Accepting the hypothesis that shortleaf pine is a southern species that has slowly migrated northward following Pleistocene time, it seems plausible that pine first must have entered Missouri from Arkansas where pine-bearing lands of that state extend farthest north. If this is so, the first entry may have been in southwest Missouri, with a long time required for migration eastward across the glades before expanding into the east-central Ozarks (Fig. 2). The other possible migration route would be a long slow march across the wide expanse of Jefferson City dolomite in northern Arkansas into southern Missouri, with suspect localities in Ozark and Ripley Counties.

Regardless of the route of advance, the migration of shortleaf pine across wide biophysical barriers like the Jefferson City or Cotter geologic formation probably resulted in a highly selected racial sub-species with special adaptations for both winter hardiness and summer drouth resistance.

It is significant to note (Figures 2, 3, 18) that continuous pine stands cross the central Ozark Plateau at its two narrowest points, namely near Raymondville in northeastern Texas County, and near Willow Springs in northwestern Howell County. These two plateau crossings suggest that shortleaf pine actually advanced westward along the Roubidoux sandstone "breaks" from the upper Current River basin into the upper Piney River basin near Raymondville and from the upper Jacks Fork basin into the upper North Fork White River basin, near Willow Springs. This possibility seems all the more plausible when it is recognized that (1) there was slight chance of pine migration from northwest to southeast across the plateau divide near Raymondville (2) relatively continuous pine-oak stands extend farthest northward in Missouri to Franklin County along the Roubidoux breaks of the Meramec River, and (3) pine-oak stands appear to have advanced farther in the northeastern Missouri Ozarks along rough, stony land with Clarksville stony loam soils than they did on the Ashe soil from granite or the gently rolling Hagerstown soil from the Bonneterre formation.

Geology, Soil, and Pine

The broad relationships between parent material, soil series, and relative prominence[18] of shortleaf pine, as determined from the extensive field survey of this study, are shown in Figure 23. Within its natural range in the Missouri Ozarks, shortleaf pine is most prominent on the following

[18]Synonymous with the abstract phytosociological term "presence" as applied to stands and groups of stands.

parent materials and soil series:

Parent Material	*Soil Series*	*Relative Prominence*
Roubidoux (ss)	Clarksville (st. 1.)	10
Lamotte (ss)	(no name)	8
Granite-porphyry	Ashe	7
Burlington (limst.)	Bodine	5
Gasconade (dol.)	"Eminence"	5

In all other cases the relative prominence of shortleaf pine was judged to be less than 5, meaning that pine occurred as small, widely-scattered stands (4), scattered individual trees (3), widely scattered individual trees (2), rare (1), and absent (0).

INTERPRETATIONS AND MANAGEMENT IMPLICATIONS

Looking behind the local effects of past land-use on the relative presence or absence of shortleaf pine, a comprehension of the physical factors of site, coupled with the silvical characteristics of the species, is basic knowledge for the person who must decide where pine should and should not be favored in forest management. It seems abundantly evident that the Clarksville stony loam soils derived from Roubidoux sandstone, especially on well-dissected terrain, support the most extensive stands of shortleaf pine and pine-oak in the Ozark Province of Missouri. The question is, why is this so? The answer has been suggested in previous sections—because it is here that pine is best able to meet the competition of its associated hardwood species. Pine does not grow here because it prefers this site, or any of its site equivalents, but rather because it tolerates this site better than its hardwood associates.

A strong clue seems to lie in the commonly observed fact that pine stands, especially in disjunct and peripheral areas, are more prominent on south and west-facing slopes than on north and east-facing slopes. Again, it is not that pine prefers a warm, dry aspect, but rather, it tolerates such a site better than its associated hardwoods. This strongly suggests that the *soil moisture regime is the most important single factor* to influence the relative abundance of pine over large areas. The implication is that shortleaf pine is more drouth resistant than most of its associated hardwoods.

The relative drouth resistance of Ozark forest species was indicated by the effects of the 1952-54 drouth. The Poplar Bluff District of the

Shawnee National Forest suffered an estimated loss of 15 million board feet of standing saw timber on 145,000 acres of land.[19] This loss was equivalent to the district's cutting budget for three years. Farther west, on the 125,000-acre Pioneer Forest, an estimated 15 million board feet of standing timber died during the drouth, also three years of the cutting budget, or about two years of growth.[20]

The only known site where shortleaf pine suffered appreciable drouth mortality was on branch bottoms where the alluvium consisted of coarse gravel beds. The presence of subsoil gravel beds creates an extremely xeric situation. Black oak, southern red oak, and scarlet oak, especially the latter, were hard hit on "drouthy" sites throughout the Ozarks, including the Butler County flatwoods. At the other extreme, few eastern redcedars were drouth killed, even on the thin-soiled Taney County glades. Post oak also withstood the drouth with very little loss, but blackjack oak sustained moderate losses. Thus, it appears that shortleaf pine is less drouth resistant than eastern redcedar and post oak, equals the drouth resistance of white oak, and is more drouth resistant than black oak, southern red oak, and scarlet oak. Working with seedlings, Bourdeau (1954) found that post oak and blackjack oak were more drouth resistant than white oak, northern red oak, and scarlet oak.

Although a severe drouth like that of 1952-54 may not occur more than once in a hundred years, the Ozark Province has short drouth periods almost every summer, and prolonged drouths every 15 to 20 years. A drouth frequency such as this is sufficient to kill trees occasionally. Even more significant, perhaps, is the possibility that frequent drouths, especially on xeric sites, operate to the relative growth advantage of drouth resistant species.

In a broad way, this is how the rough Roubidoux sandstone sites may be visualized. Clarksville stony loam soil, containing much chert, with a variable sandstone content, and on rolling to steep terrain, is actually "drouthy." Pine did, and still does, occur simply because it is better able to grow here than its hardwood associates. Given full sunlight, as on a south- and west-facing slope, it is especially well qualified to grow under these relatively xeric conditions due to its high photosynthetic efficiency (Kozlowski, 1949). To be sure, shortleaf pine may grow faster and taller on sites which are richer in nutrients and more moist, (provided they are well drained). However, these "better" sites are proportionately better for the oaks and seedling pines cannot meet the competition of

[19]Personal communication from, Paul R. Larsson, Forest Ranger, U. S. Forest Service.

[20]Personal communication from Edward Woods, Forester, Pioneer Forest.

oak sprouts.

In general, forest land managers have to spend considerable time and money to maintain existing stands of pine on these more favorable hardwood sites. Even the high intrinsic value of pine at present may not justify such added costs, particularly if the future value of the oaks increases as current trends seem to indicate. Therefore, for economic reasons as well as basic silvical considerations, it may be unwise to attempt to maintain pine on these sites.

Pure pine could be the objective of management on Clarksville stony loam soils. Mixed oak-pine would be the reasonable silvical objective of forest management on the "Eminence" stony loam soils.

It has been suggested that the major pine bearing strata—sandstone and granite—can be too xeric and too sterile for shortleaf pine. Furthermore, if the slope is steep, faces south or west, and has a thin, rocky soil mantle, the site may be "glade-like" regardless of the bedrock, and support drouth resistant species like chinquapin oak and cedar.

At the other extreme of moisture, it has been suggested that shortleaf pine in Missouri requires 17 inches of winter precipitation, but does not seem to have a high degree of tolerance of poor internal drainage, as on the Lebanon silt loam post oak flats. Thus, shortleaf pine may tolerate summer drouths on such a site, but may not tolerate excessive winter wetness. Further research is needed to prove or disprove this hypothesis.

Figure 24 lists soil series of the Missouri Ozarks in the assumed order of their productivity for shortleaf pine, based on theoretical reasoning developed from this survey. The listing suggests that the well-drained Menfro, Hagerstown, and "Eminence" soils are capable of producing relatively tall pine trees, but are usually better adapted to cultivated crops or hardwoods. At the other extreme, the 10 soil series listed last are generally off-site for pine management, being either excessively well drained or having poor internal drainage due to a subsoil pan.

Between these two extremes are four soil series on which pine is indicated in the forest management type. Pure pine is suggested as the management objective on Clarksville stony loam, with pine-oak on the Lamotte and Ashe soils; and oak-pine on the Bodine soils which are too steep and rocky for sustained pasture use.

Although no conclusive evidence is available at present on site index for pine related to these soil series, the values in Figure 24, based only on observation, are presented as the best estimate available at this time. These estimates, of course, are subject to revision as further research data are developed.

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APPENDIX

Figures 1 to 25

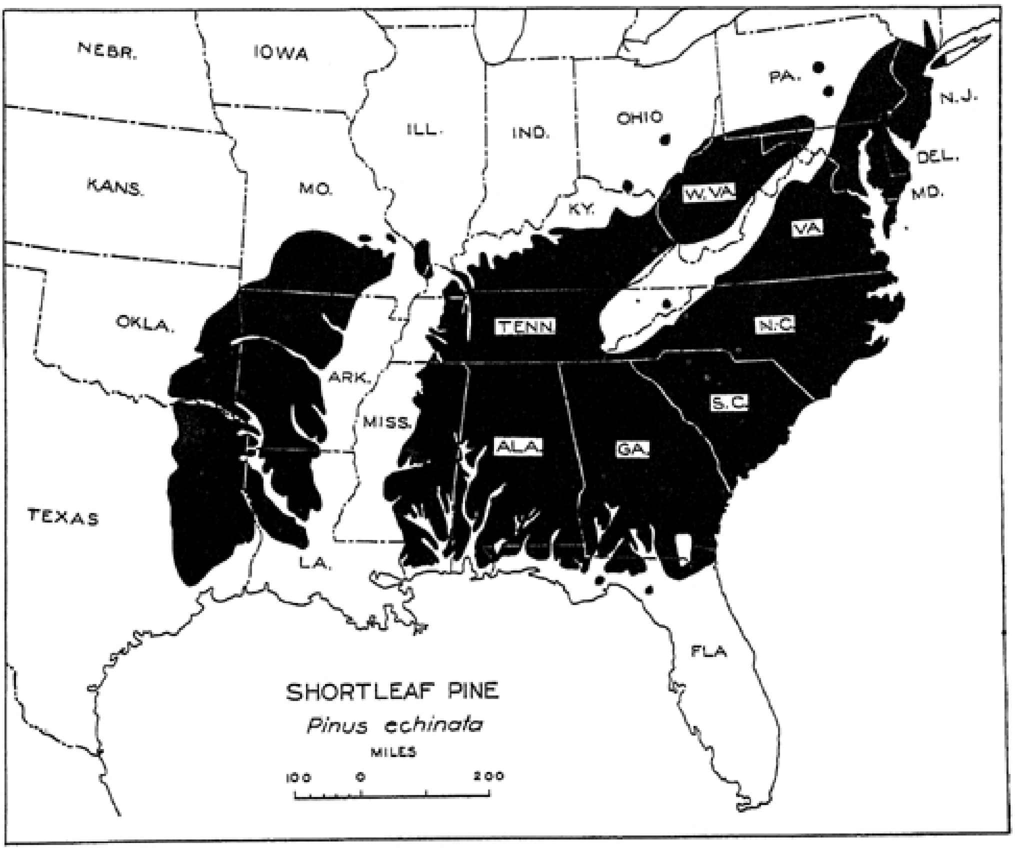


Fig. 1—The range of shortleaf pine in the United States, Munns (1938).

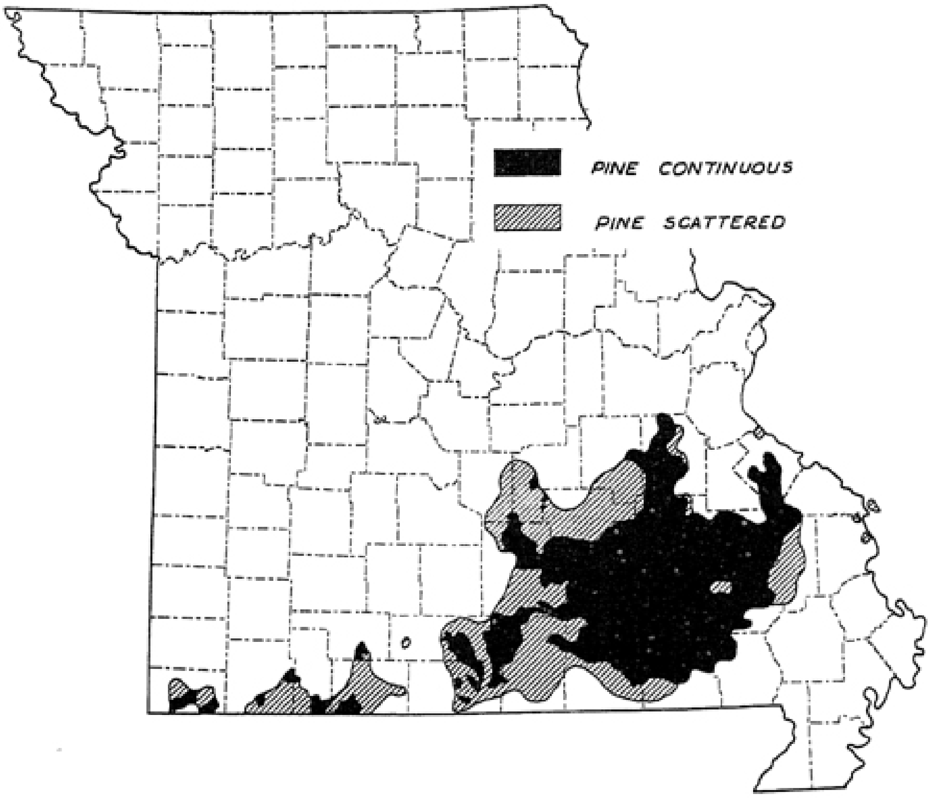


Fig. 2—The range of shortleaf pine in Missouri, Liming (1946).

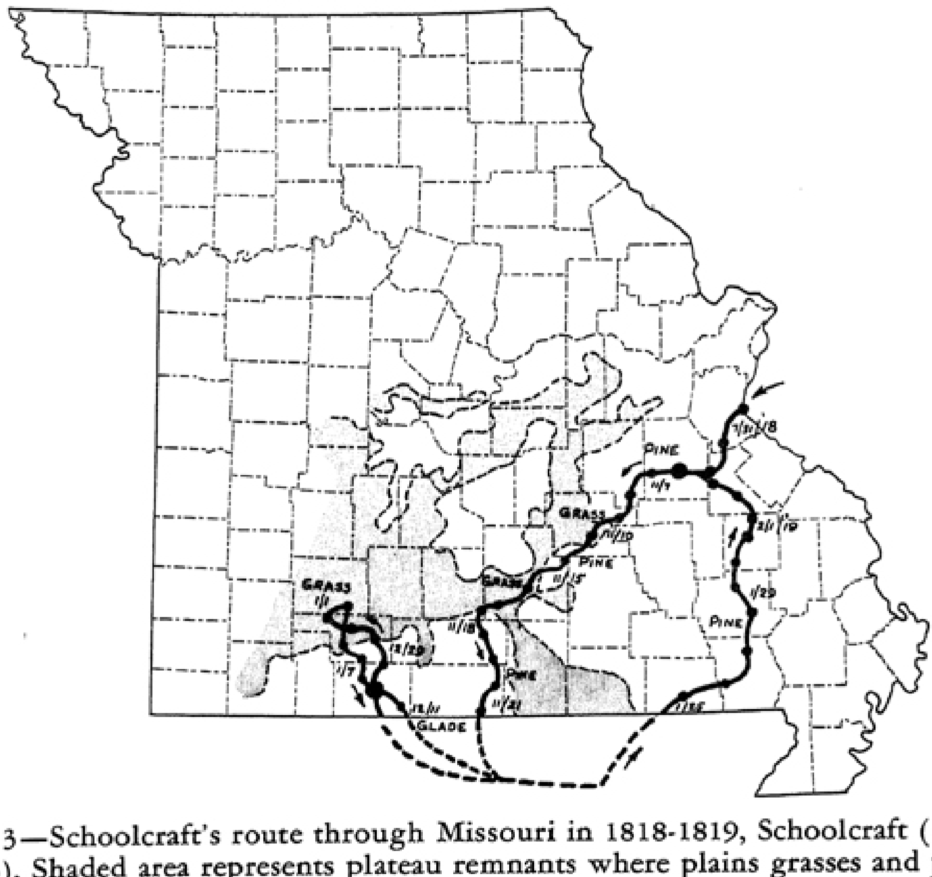


Fig. 3—Schoolcraft's route through Missouri in 1818-1819, Schoolcraft (1821; 1853). Shaded area represents plateau remnants where plains grasses and park-like stands of post oak were observed. Shortleaf pine was observed on rocky slopes in the areas shown.

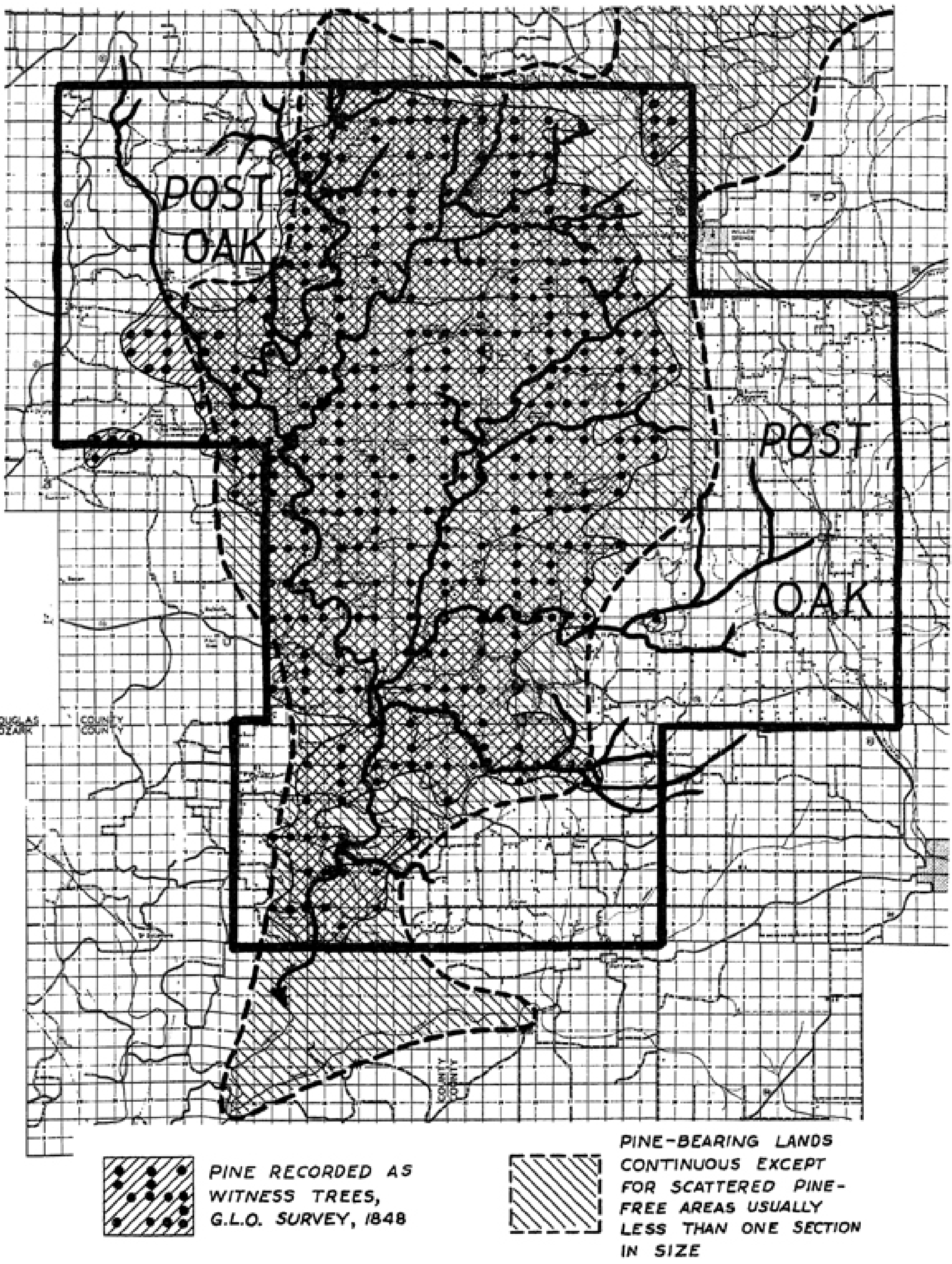


Fig. 4—Distribution of shortleaf pine on the Willow Springs District, Missouri National Forests, as indicated by witness tree records of the General Land Office survey (1848) and Liming (1946).

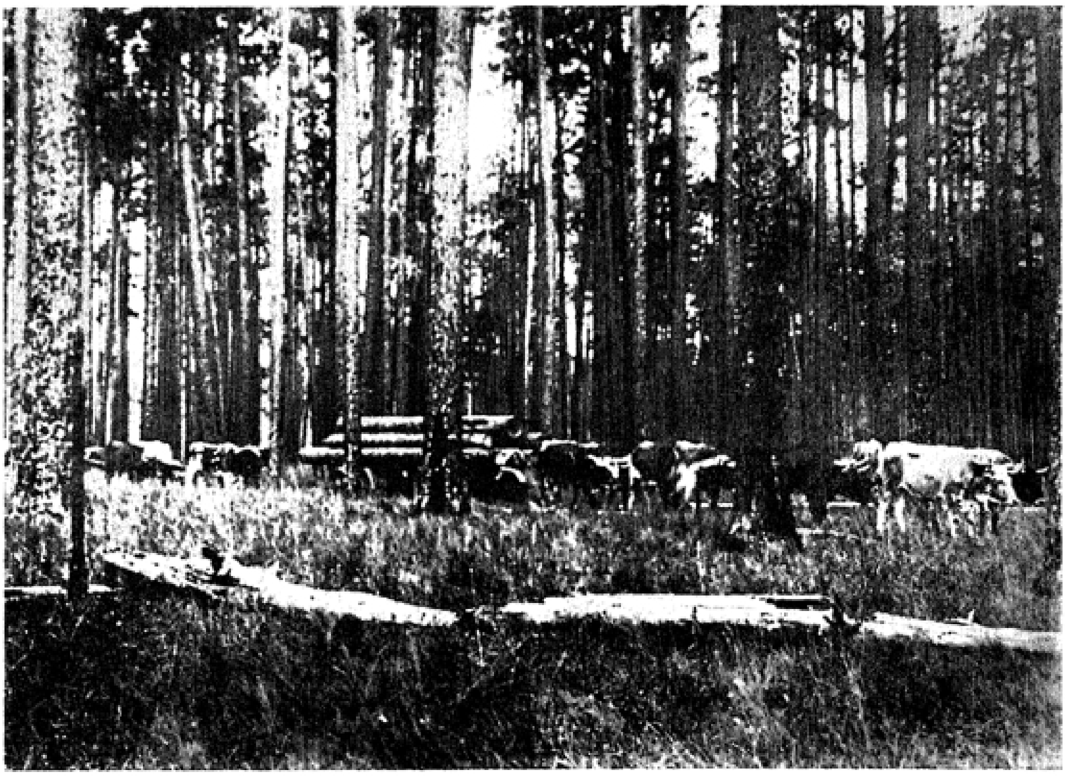


Fig. 5—Early logging (about 1880) with oxen in a stand of pine, Willow Springs District, Missouri National Forests. Note the absence of hardwood and pine undergrowth, and the presence of grass and fire-scarred trees. (Photo courtesy of C. G. Anderson, U. S. Forest Service).

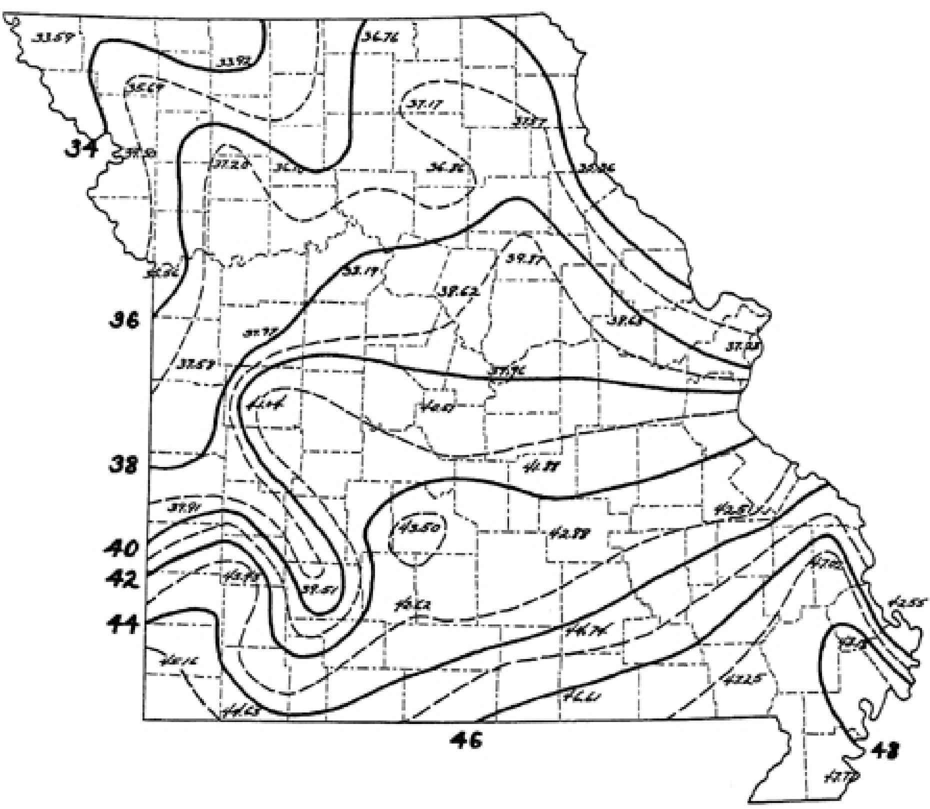


Fig. 6—Average annual precipitation in Missouri, inches, Decker (1955).

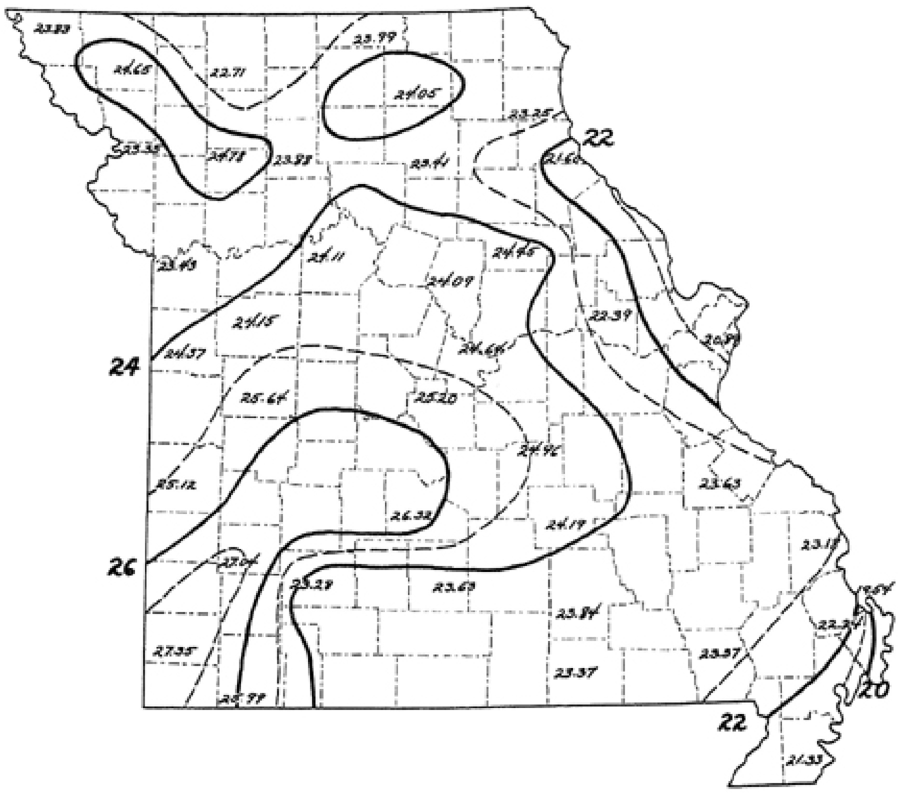


Fig. 7—Average summer (May-October) precipitation in Missouri, inches, Decker (1955).

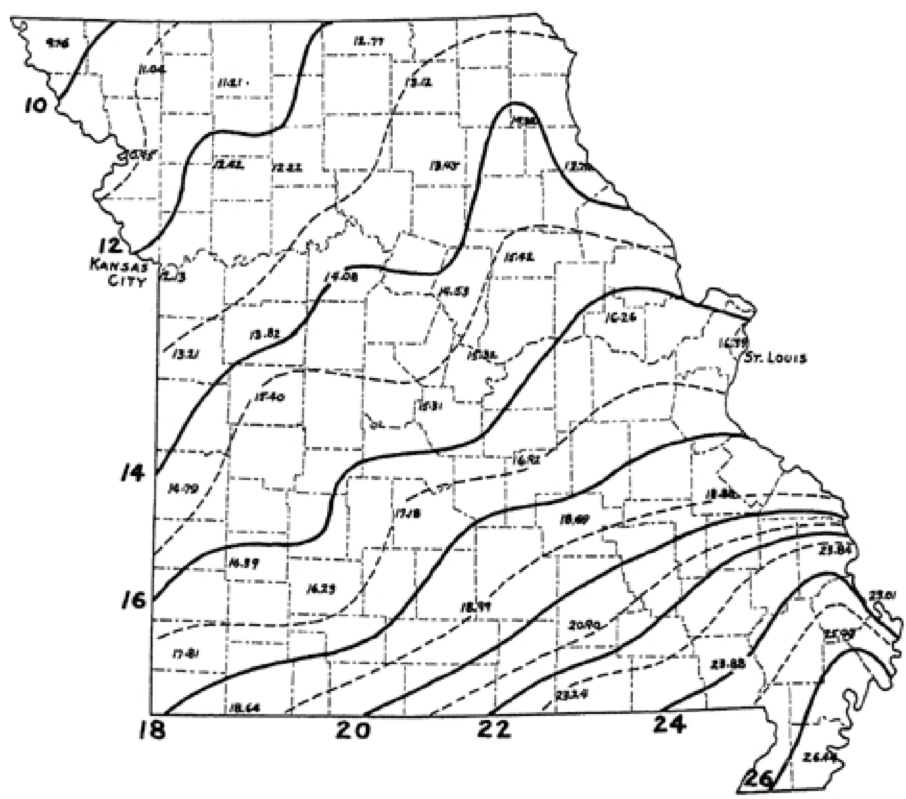


Fig. 8—Average winter (Nov.-April.) precipitation in Missouri, inches, Decker (1955).

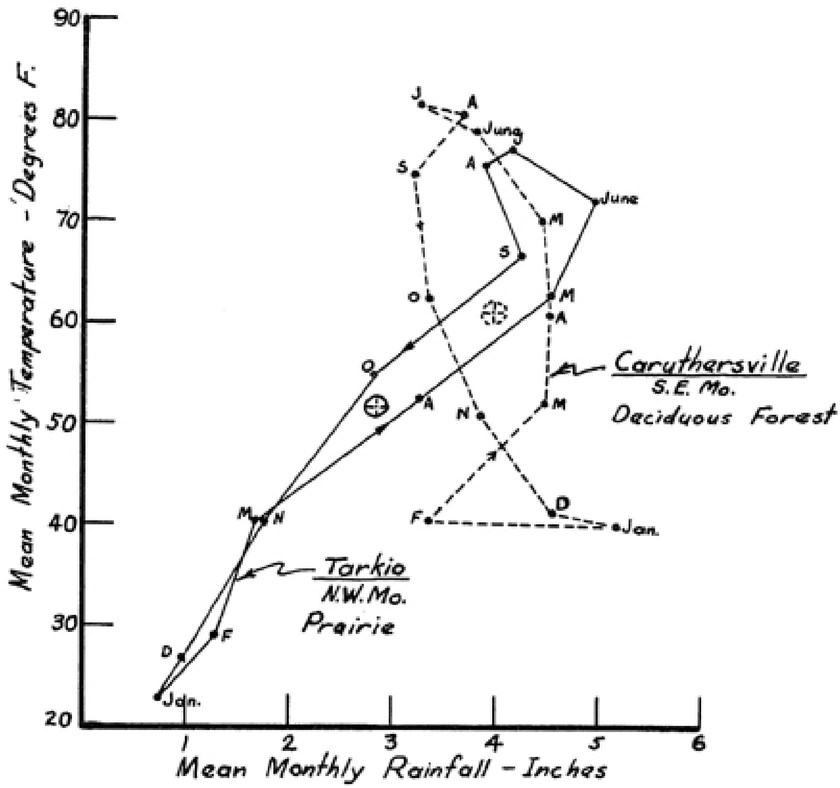


Fig. 9—Climographs for the deciduous forest of southeast Missouri and the tall grass prairie of northwest Missouri.

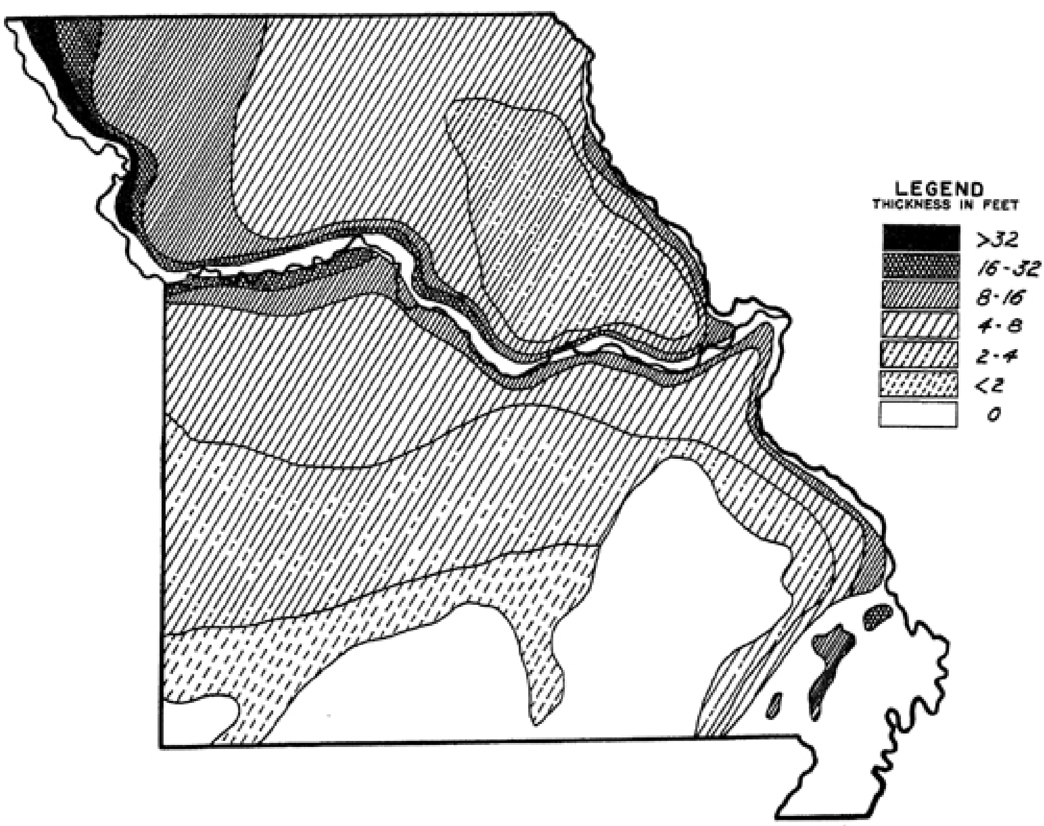


Fig. 10—Thickness of loess deposits in Missouri as they mantle broad, flat, undissected uplands, Thorp and Smith (1952).

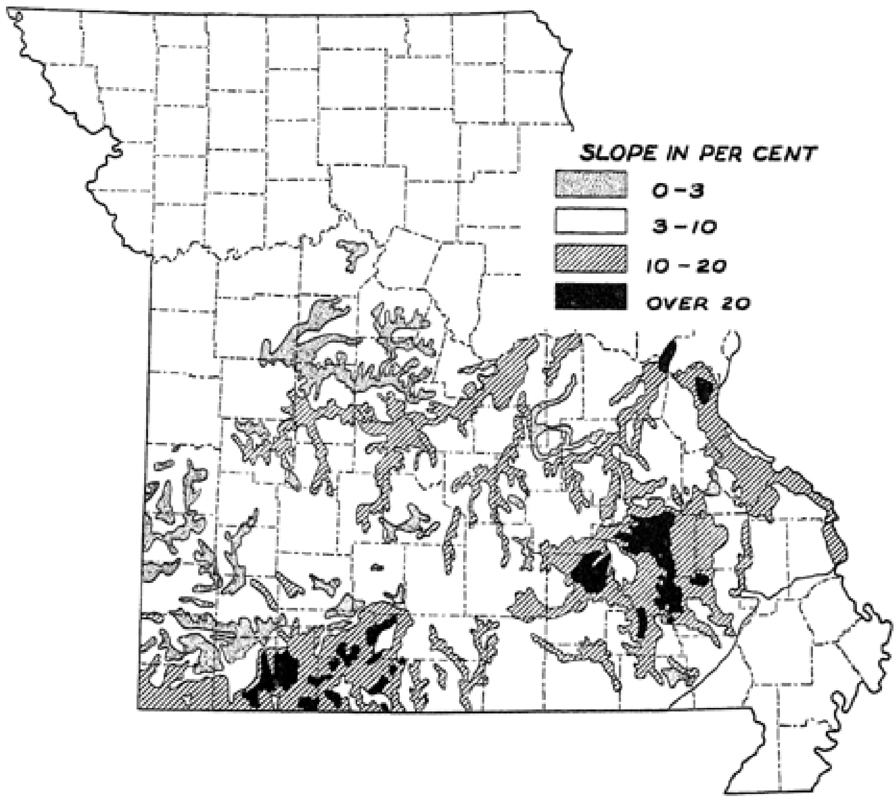


Fig. 11—Prevailing land slope in Missouri as determined from U. S. Geological Survey topographic maps, Collier (1955).

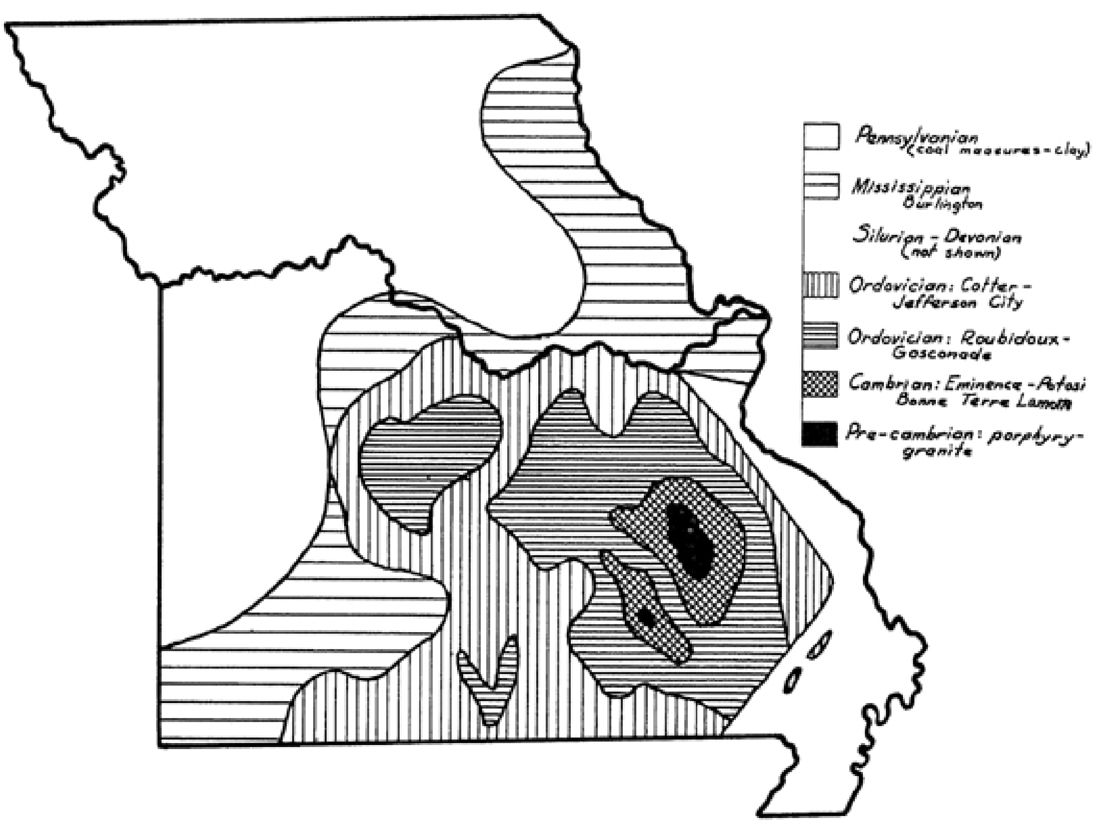


Fig. 12—Generalized geological map of Missouri, Clark (1939).

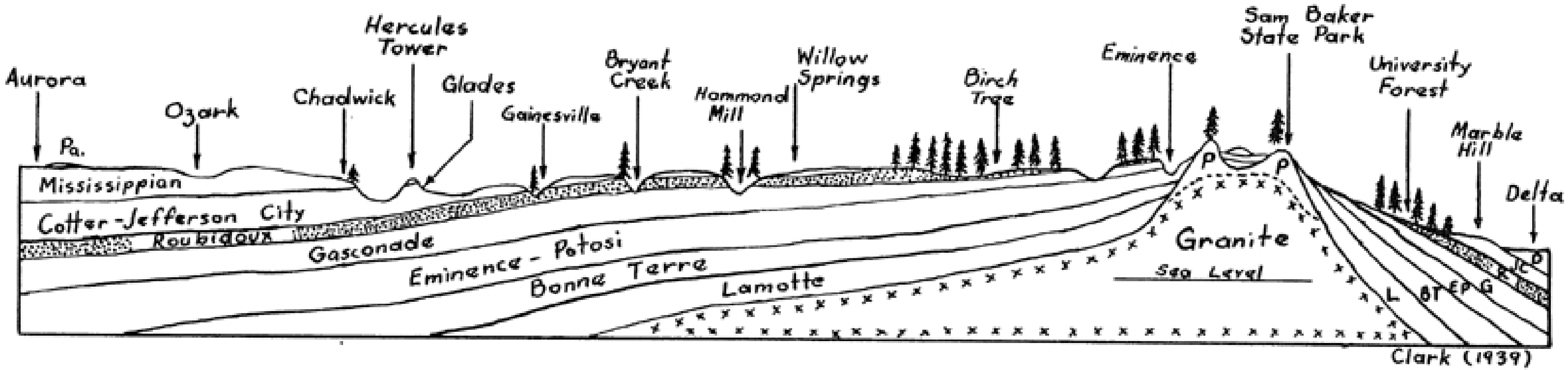


Fig. 13—Geological profile across south Missouri, Clark (1939).

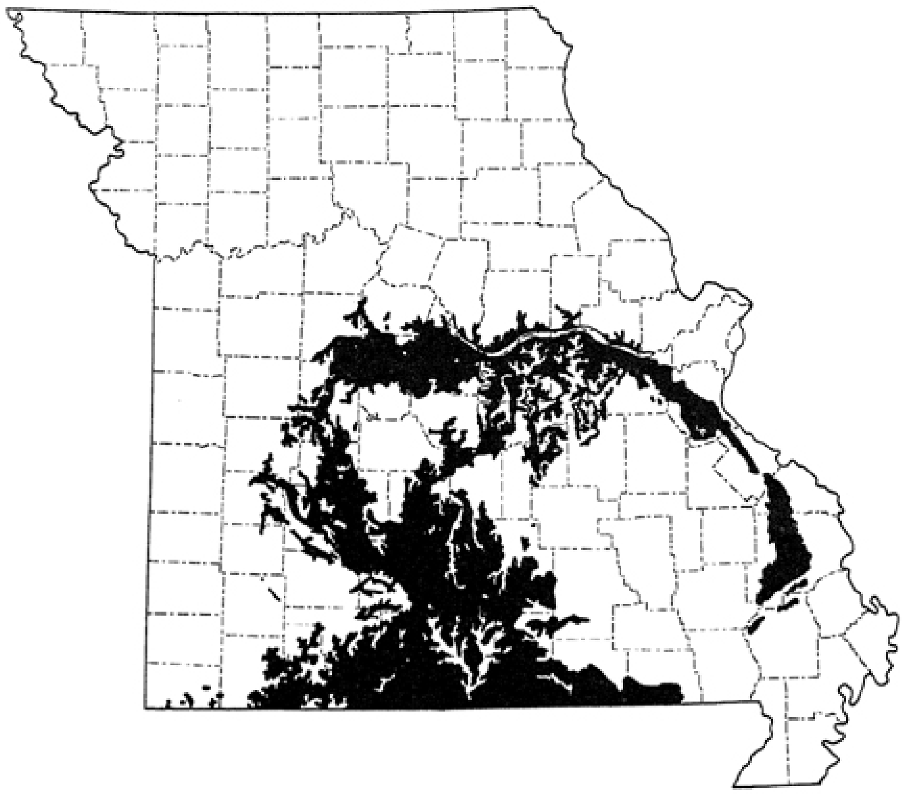


Fig. 14—Areal extent of surface exposures of the Jefferson City geologic formation (including the Cotter, Everton, and Powell) in Missouri, Clark (1939).

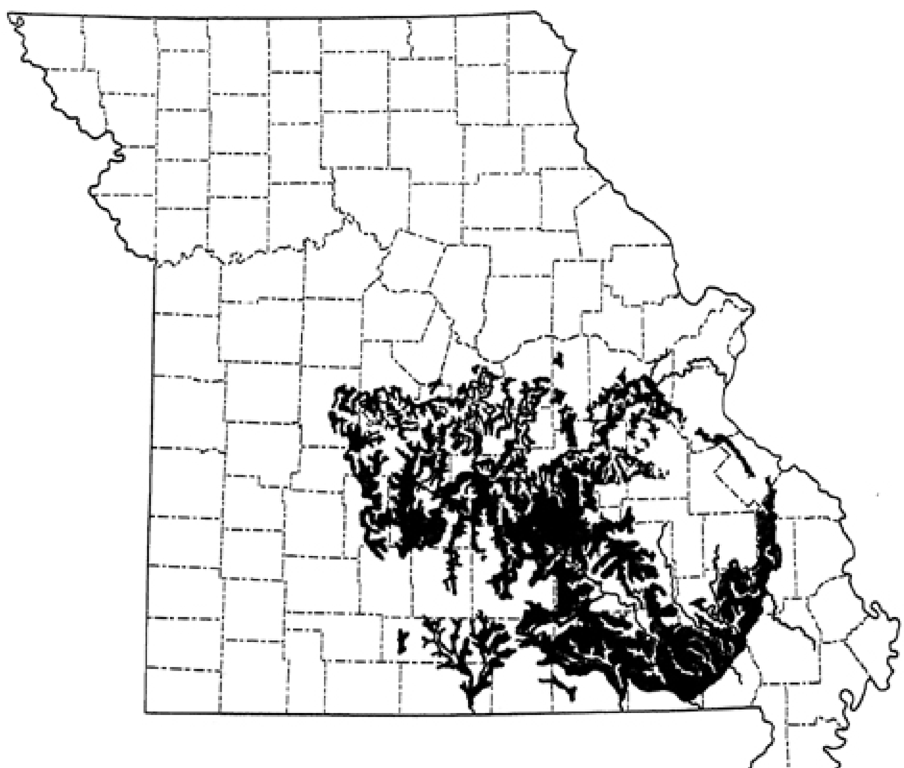


Fig. 15—Areal extent of surface exposures of the Roubidoux geologic formation in Missouri, Heller (1954).

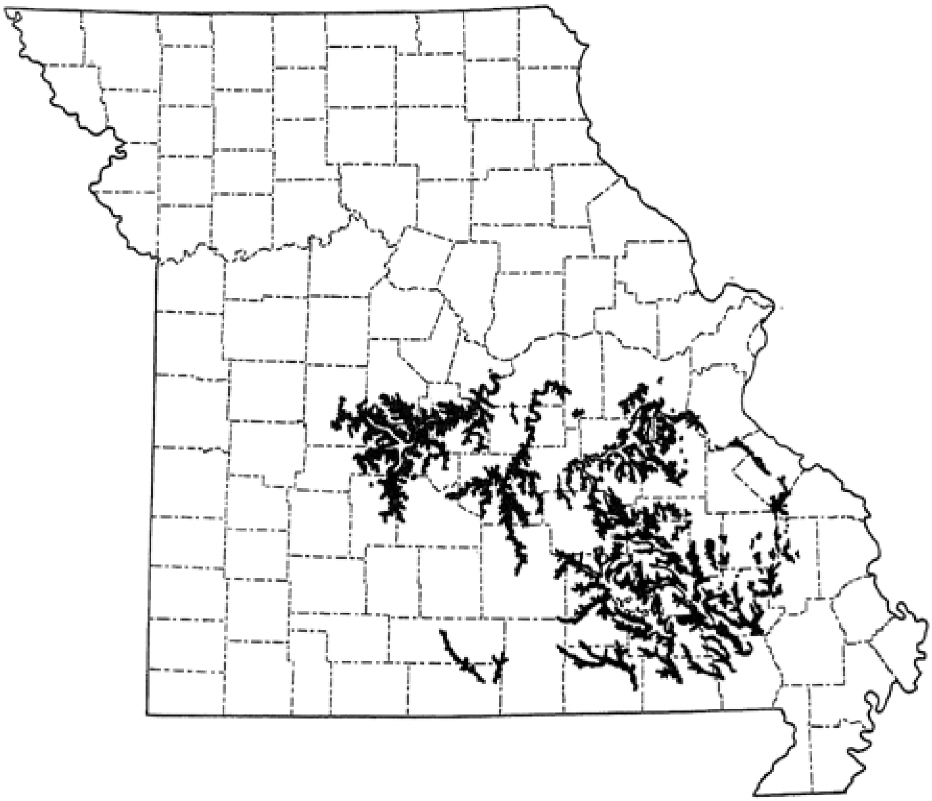


Fig. 16—Areal extent of surface exposures of the Gasconade geologic formation (including the Van Buren and Gunter) in Missouri, Clark (1939).

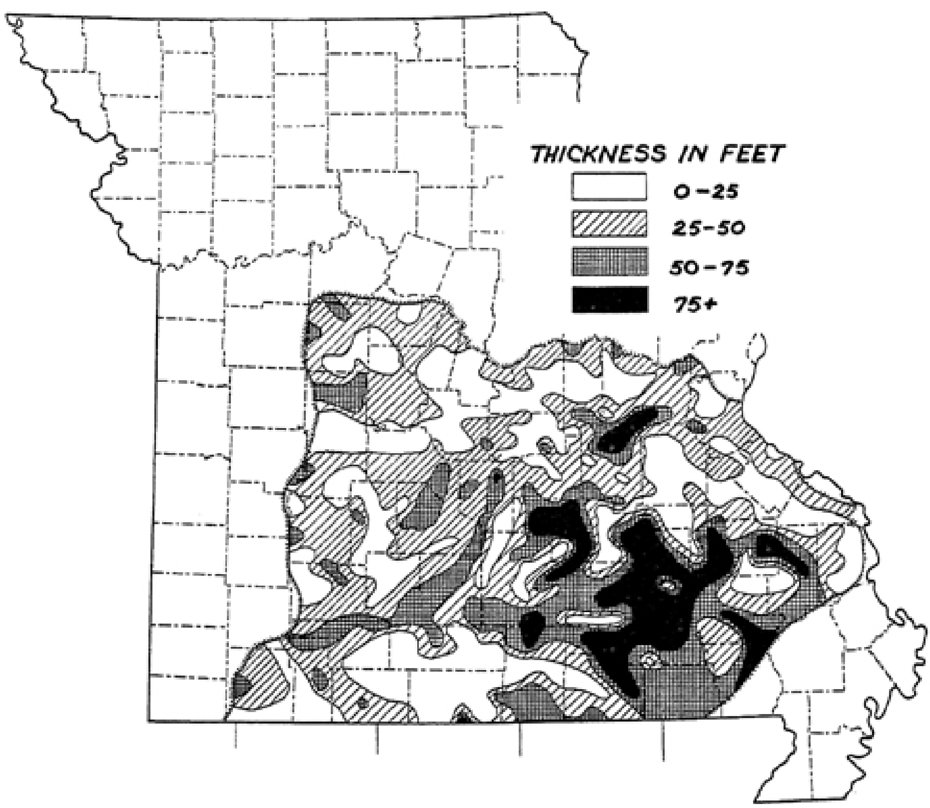


Fig. 17—Maximum thickness of residuum (unconsolidated geologic material) in the Missouri Ozarks, Mo. Geol. Surv. & Water Resources (1955).

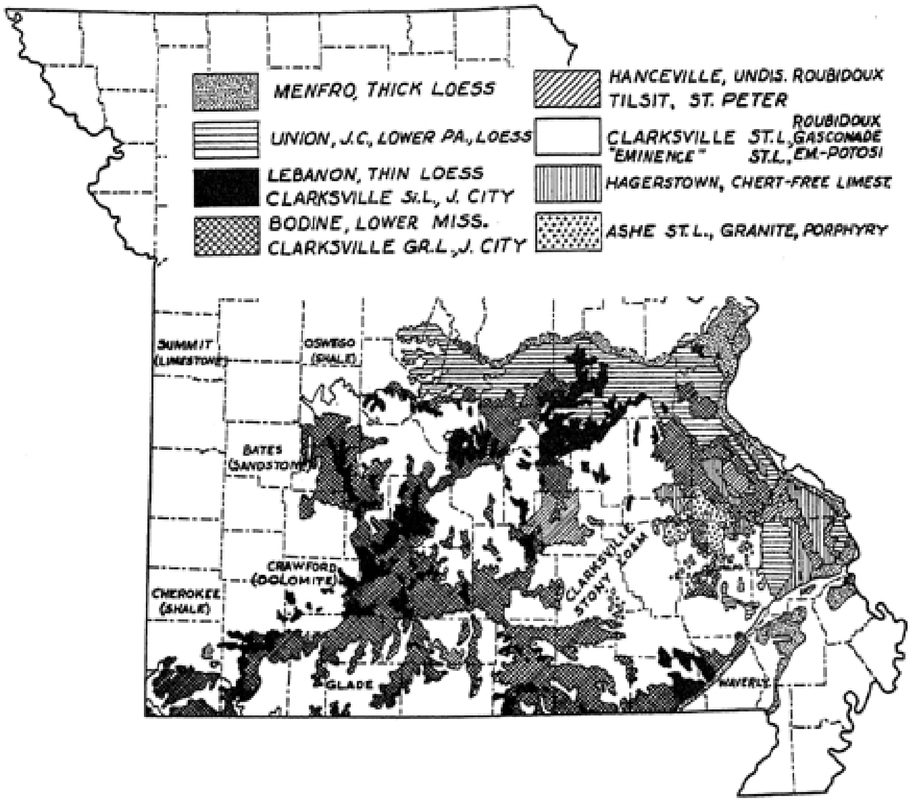


Fig. 18—Major soil areas of the Missouri Ozarks, Miller and Krusekopf (1929).

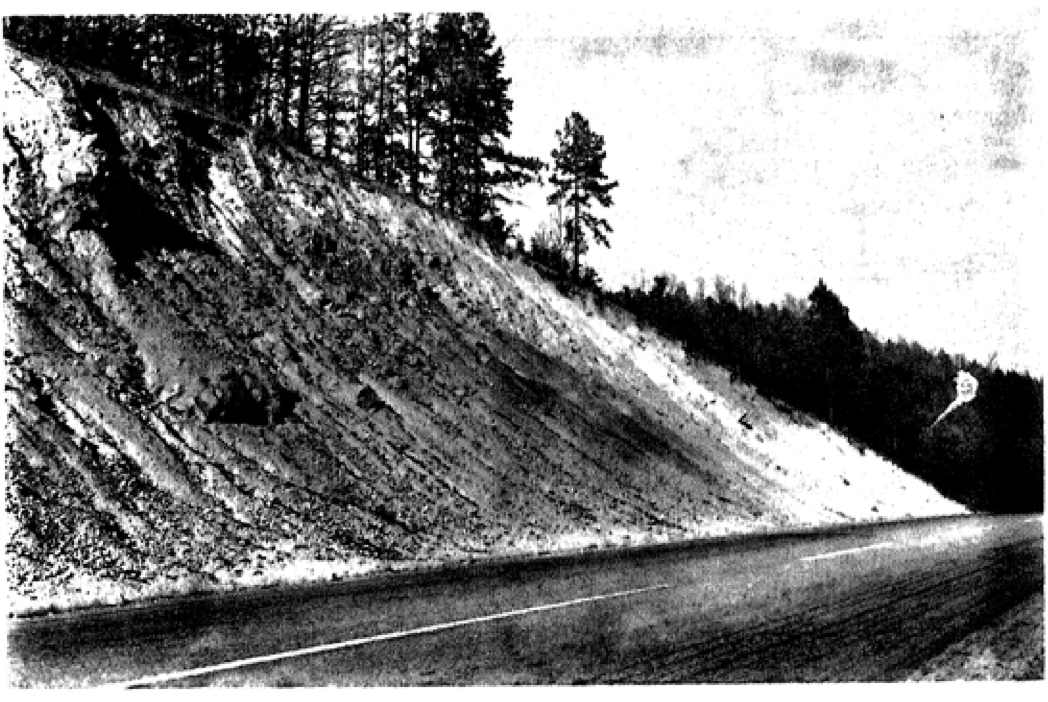


Fig. 19—Clarksville stony loam soil developed from residuum of the Roubidoux sandstone, a prime pine site.

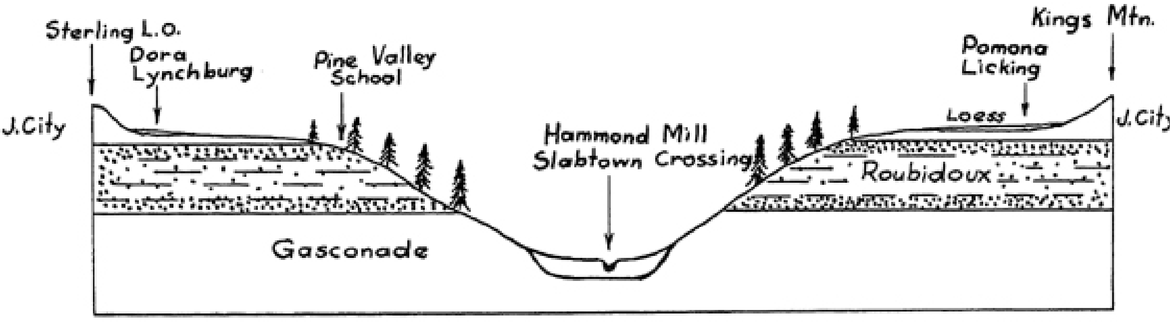


Fig. 20—Geological profile across North Fork White and Piney Rivers showing occurrence of shortleaf pine.

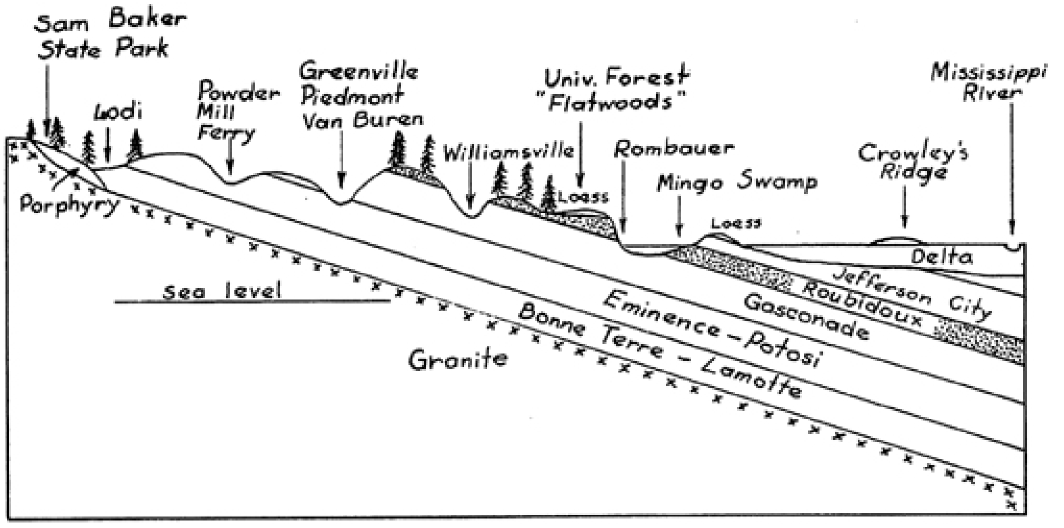


Fig. 21—Geological profile across southeastern Missouri showing occurrence of shortleaf pine.

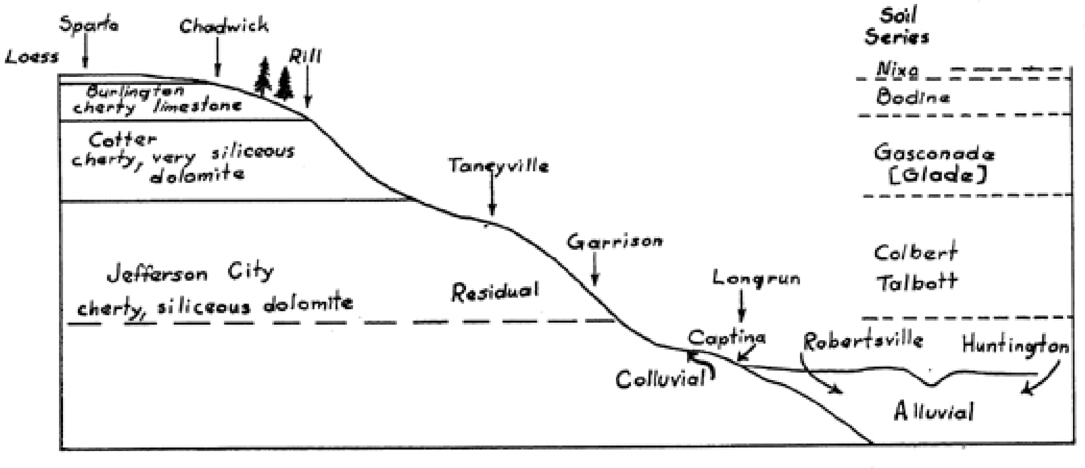


Fig. 22—Geological profile across the glade country of the southwestern Missouri Ozarks showing occurrence of shortleaf pine.

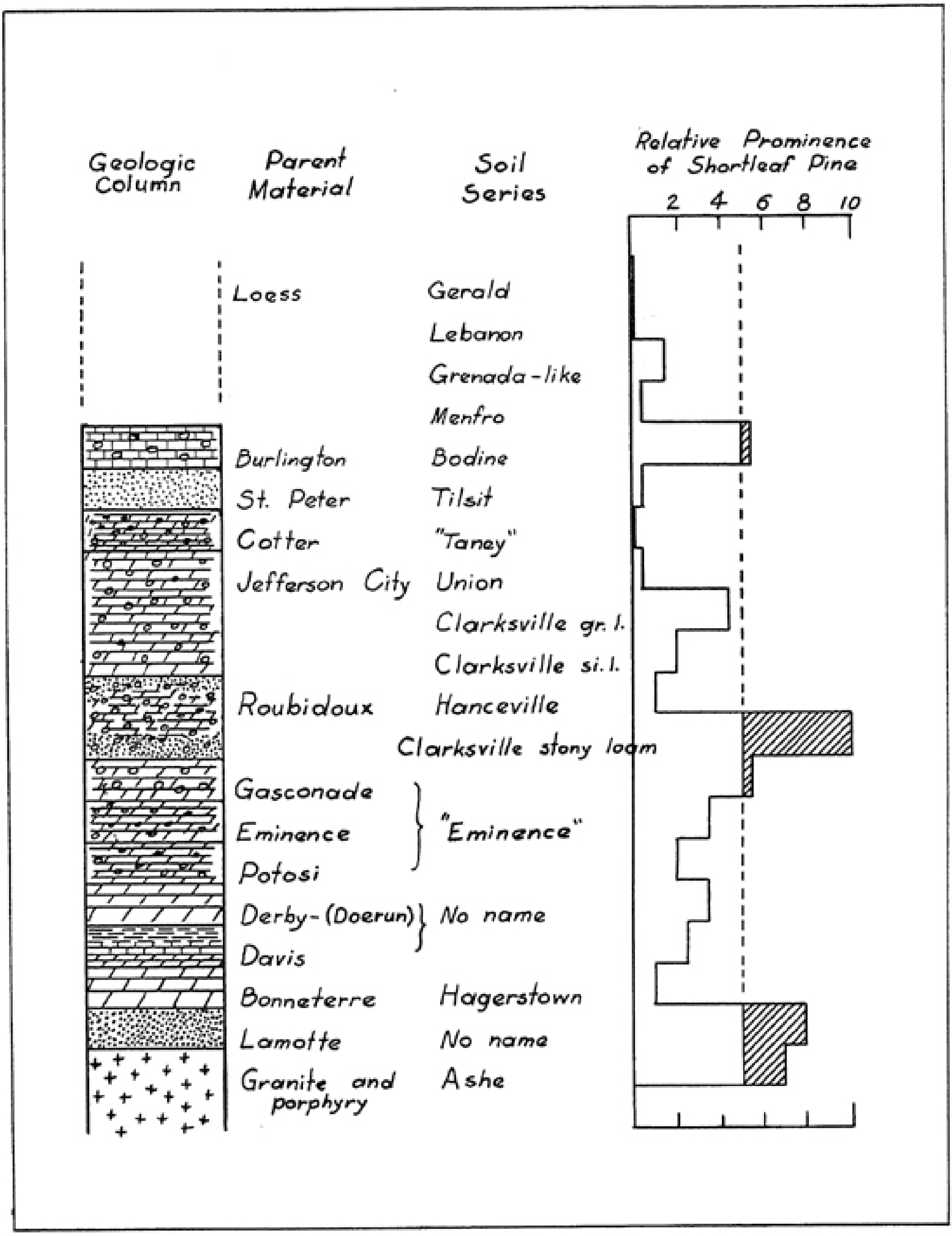
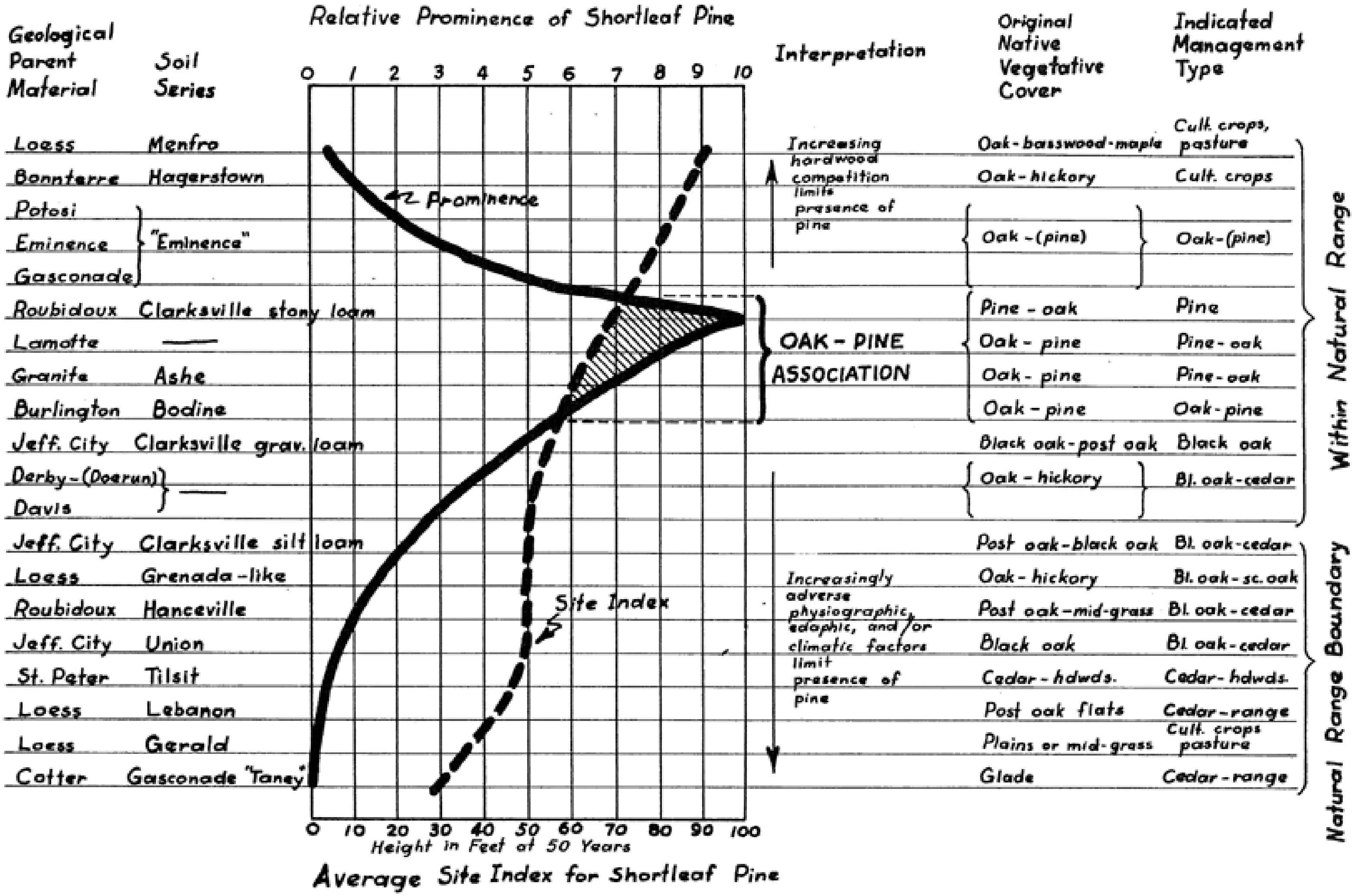


Fig. 23—Relationship between relative prominence of shortleaf pine, geologic parent material, and soil series.

Fig. 24—Relationship between relative prominence[21] of shortleaf pine and its **assumed average** site index[22] by soil series along the November-April 20-inch isohyet across the Missouri Ozarks.



[21]Implying sustained competitive ability (and relative basal area) of shortleaf pine relative to its hardwood associates.

[22]Conclusive information awaits completion of a comprehensive shortleaf pine site index research study.

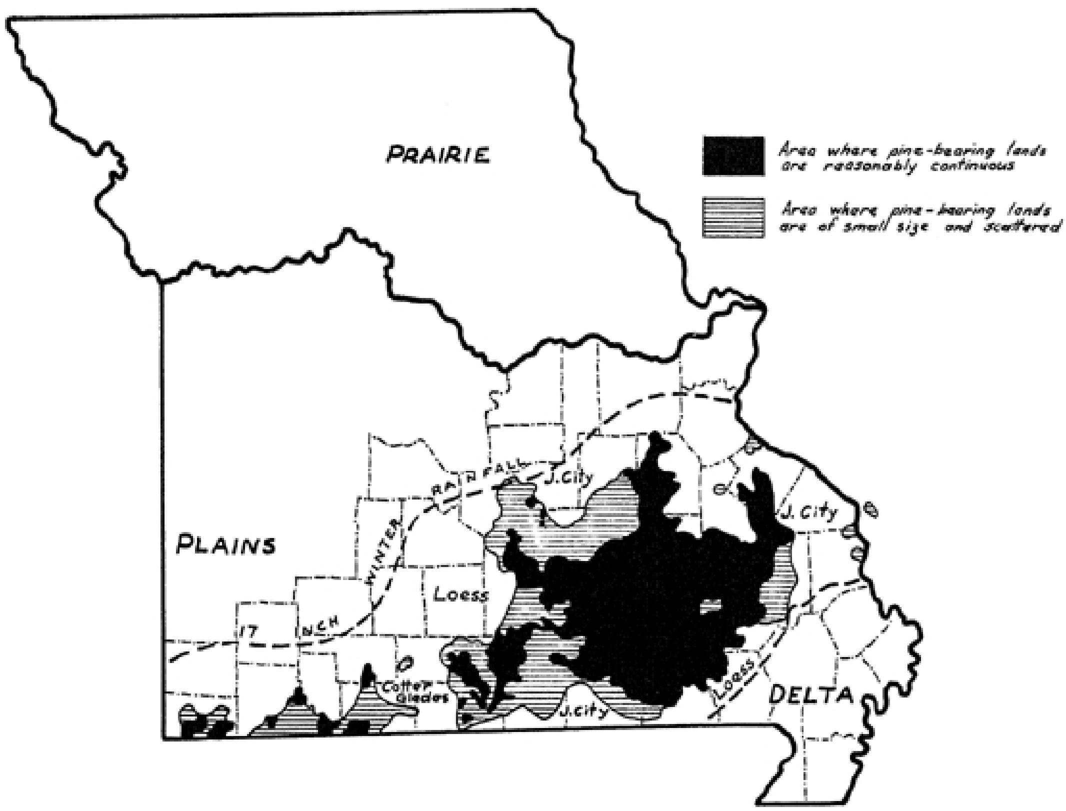


Fig. 25—The range of shortleaf pine in Missouri, indicating the general areas of limitations imposed by low winter rainfall, former Mississippi River flood plain, gentle relief and loess mantle of upland plateaus, and the Jefferson City geologic formation, including the Cotter glades.